

SEFE | STUDENT EDITION

# SOLAR ENERGY FOR EVERYONE

A Practical Guide from Basics to System Design

Learn, design, and practise step by step

● INCLUDES ANDROID APP



**DR. ISMAEL KHORSHED ABDULRAHMAN**

First Edition | 2026

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*Accompanied by a separate Teacher's Guide*

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## Solar Energy for Everyone:

### A Practical Guide from Basics to System Design

From energy and electricity basics to full solar system design — the companion book to the SEFE app

**Dr. Ismael Khorshed Abdulrahman**

PhD in Electrical and Computer Engineering

#### Free Electronic Edition

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Last updated: 31 August 2026 · AI model families and dated examples checked as of this date.

## How to Use This Book

This book is written in plain, simple English for students, technicians, teachers, and anyone who wants to learn solar energy from the beginning. Short sentences and common words are used on purpose. Every technical word is explained the first time it is used, and also collected in the Glossary at the end of the book.

Every chapter follows the same pattern: clear learning goals, plain explanations with figures and tables, important words with easy definitions, real math equations with worked examples, practical activities, a real-life case study, safety notes where needed, common mistakes to avoid, a short summary, and at least ten practice problems.

**This book is accompanied by a separate Teacher's Guide.** The Teacher's Guide contains every chapter's self-test (the questions together with their answers and explanations), the complete step-by-step solutions to all of this book's practice problems, and other teaching-support materials. Students: try every practice problem honestly, on paper, before checking your work against the Teacher's Guide. Teachers: use the self-tests in class, as homework, or as revision.

This book is one part of the Solar Energy for Everyone project. The same lessons, examples, problems, and self-tests are also available in the SEFE Android application and the SEFE Desktop application, with interactive calculators, simulations, and progress tracking.

A note on numbers: most prices, local market data, and city-by-city sun-hour figures in this book are clearly marked as example numbers for practice, not verified measurements. Where real, sourced data is available — such as the Kurdistan Region's Project Runaki electricity tariff, covered in Chapters 15 and 21 — it is clearly labeled as real data, with its source and date. Always confirm current numbers before a real design or purchase.

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PART ONE

# FOUNDATIONS OF ENERGY AND SUNLIGHT

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## CHAPTER ONE

# Energy and Power in Everyday Life

*What energy and power mean, using bills, appliances, and generators*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain what energy and power mean, with everyday examples.
- Use the units joule, watt, kilowatt, watt-hour, and kilowatt-hour correctly.
- Calculate energy use with the equation  $E = P \times t$ .
- Estimate the daily energy use of a home from its appliances.
- Convert a generator subscription in amperes into watts, and know what it can power.

## 1.1 Energy Around Us

Energy is everywhere. It moves cars, heats water, lights rooms, and charges phones. To understand solar power, we must first understand energy itself.

### WORD TO KNOW

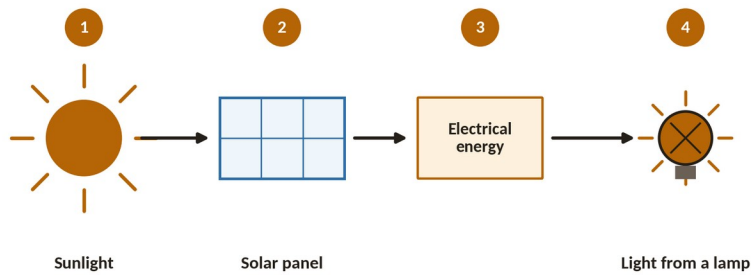
**Energy** — The ability to do work — to move, heat, light, or change things. Measured in joules (J) or kilowatt-hours (kWh).

Energy comes in different **forms**. The same energy can change from one form to another.

### Forms of energy

| Form       | Everyday example                      |
|------------|---------------------------------------|
| Light      | Sunlight, a lamp                      |
| Heat       | A stove, a water heater               |
| Motion     | A fan turning, a car moving           |
| Chemical   | Food, fuel, a battery                 |
| Electrical | Electricity in the wires of your home |

Energy is never created from nothing, and it never disappears. It only **changes form**. A solar panel does not create energy. It changes light energy from the sun into electrical energy.



*Sunlight → solar panel → electrical energy → light from a lamp. Energy changes form at every step.*

#### WORD TO KNOW

**Joule** — The basic scientific unit of energy. One joule is a very small amount — lifting a small apple by one meter takes about one joule.

The joule is small, so for home electricity we use bigger units: the watt-hour (Wh) and the kilowatt-hour (kWh). You will meet them in Lesson 3.

#### COMMON MISTAKE

**✗ Wrong:** Solar panels make energy from nothing.

**✓ Right:** Solar panels change sunlight energy into electrical energy. No sunlight, no electricity.

#### ACTIVITY (HOME) — BE AN ENERGY DETECTIVE

1. Walk through your home and find five things that change energy from one form to another.
2. For each one, write the form of energy going in and the form coming out.
3. Example: a fan changes electrical energy into motion (and a little heat).

*You need: Paper and pen*

## 1.2 Power: How Fast Energy Flows

Two kettles boil the same water. One takes 3 minutes. The other takes 6 minutes. They use about the same **energy**, but not at the same speed. The fast kettle has more **power**.

#### WORD TO KNOW

**Power** — How fast energy is used or produced. Measured in watts (W).

#### WORD TO KNOW

**Watt** — The unit of power. One watt means one joule of energy every second.

#### EQUATION: POWER FROM ENERGY AND TIME

$$P = \frac{E}{t}$$

In words: Power = Energy ÷ time

| Symbol | Meaning | Unit            |
|--------|---------|-----------------|
| P      | power   | watts (W)       |
| E      | energy  | watt-hours (Wh) |
| t      | time    | hours (h)       |

If energy is in watt-hours and time is in hours, power comes out in watts.

#### WORKED EXAMPLE — THE POWER OF A FAN

A fan uses 200 Wh of energy in 4 hours. What is its power?

1. Write the equation:  $P = E \div t$
2. Put in the numbers:  $P = 200 \text{ Wh} \div 4 \text{ h}$
3. Calculate:  $P = 50 \text{ W}$

**Answer: 50 W**

#### WORD TO KNOW

**Kilowatt** — 1000 watts. Written kW. Used for bigger appliances like water heaters and air conditioners.

#### Typical power of home appliances

| Appliance                    | Typical power |
|------------------------------|---------------|
| LED lamp                     | 10 W          |
| Phone charger                | 10 W          |
| Ceiling fan                  | 60–80 W       |
| Television                   | 100 W         |
| Refrigerator (when running)  | 150 W         |
| Washing machine              | 500 W         |
| Air conditioner (split unit) | 1500–2500 W   |
| Electric water heater        | 2000 W        |

Every appliance has a label or nameplate that shows its power in watts. Get the habit of reading it — designers of solar systems do this all the time.

#### ACTIVITY (HOME) — READ THE LABELS

1. Find five appliances at home.
2. Look for the label with the power in watts (W). It is often on the back or bottom.
3. Write down each appliance and its power. Keep this list — you will use it in Lesson 4.

You need: Paper and pen, A phone torch helps

#### COMMON MISTAKE

✗ **Wrong:** A big appliance always uses more energy.

✓ **Right:** Energy depends on power AND time. A 2000 W heater used for 10 minutes uses less energy than a 100 W television used all day.

### 1.3 Energy = Power × Time

This lesson has the most important equation of the chapter. You will use it in every solar design you ever make.

#### EQUATION: ENERGY FROM POWER AND TIME

$$E = P \times t$$

*In words: Energy = Power × time*

| Symbol | Meaning | Unit            |
|--------|---------|-----------------|
| E      | energy  | watt-hours (Wh) |
| P      | power   | watts (W)       |
| t      | time    | hours (h)       |

*To change Wh into kWh, divide by 1000. This is the same equation as Lesson 2, just turned around.*

#### WORD TO KNOW

**Watt-hour** — A unit of energy. The energy used when one watt works for one hour. Written Wh.

#### WORD TO KNOW

**Kilowatt-hour** — The energy of 1000 watts working for one hour. Written kWh. This is the unit on your electricity bill.

#### WORKED EXAMPLE — TELEVISION ENERGY USE

A television uses 100 W. It runs for 5 hours. How much energy does it use?

1. Write the equation:  $E = P \times t$
2. Put in the numbers:  $E = 100 \text{ W} \times 5 \text{ h}$
3. Calculate:  $E = 500 \text{ Wh}$
4. Convert to kWh:  $500 \div 1000 = 0.5 \text{ kWh}$

**Answer: 0.5 kWh**

#### WORKED EXAMPLE — AIR CONDITIONER ENERGY USE

An air conditioner uses 2000 W. It runs for 8 hours on a summer night. How much energy does it use?

1. Write the equation:  $E = P \times t$

2. Put in the numbers:  $E = 2000 \text{ W} \times 8 \text{ h}$
3. Calculate:  $E = 16000 \text{ Wh}$
4. Convert to kWh:  $16000 \div 1000 = 16 \text{ kWh}$

**Answer: 16 kWh — thirty-two times the television!**

Quick mental method: **watts  $\times$  hours  $\div$  1000 = kilowatt-hours**. Practise it until it is automatic.

#### WORD TO KNOW

**Electricity meter** — The device that counts how many kilowatt-hours (kWh) your home uses. Your bill is based on its reading.

Your electricity meter counts kWh, and your bill charges you for each kWh. When you buy electricity, you are buying energy — not power.

#### COMMON MISTAKE

**✗ Wrong:** Saying kW when you mean kWh, or kWh when you mean kW.

**✓ Right:** kW is power — how fast (like speed, km/h). kWh is energy — how much (like distance, km).

► *App tool: Try it: convert between W, kW, Wh, and kWh*

## 1.4 How Much Energy Does a Home Use?

Every solar design starts with one question: **how much energy do we need?** In this lesson you will estimate the daily energy of a whole home. Later, in Chapter 10, you will do it professionally.

#### WORD TO KNOW

**Appliance** — A machine at home that uses electricity, like a fridge, fan, or washing machine.

#### WORD TO KNOW

**Load** — Anything that uses electrical energy — a lamp, a fridge, a television. Also the total power all these things use together.

The method is simple. For each appliance: energy = power  $\times$  hours used per day. Then add everything up.

**Example home: one day of energy use**

| Appliance        | Power (W)          | Hours per day      | Energy (Wh) |
|------------------|--------------------|--------------------|-------------|
| 6 LED lamps      | $6 \times 10 = 60$ | 5                  | 300         |
| Television       | 100                | 6                  | 600         |
| Refrigerator     | 150                | 8 (see note below) | 1200        |
| Ceiling fan      | 60                 | 10                 | 600         |
| 2 phone chargers | $2 \times 10 = 20$ | 3                  | 60          |
| Washing machine  | 500                | 1                  | 500         |

| Appliance | Power (W) | Hours per day | Energy (Wh) |
|-----------|-----------|---------------|-------------|
| Total     | —         | —             | 3260        |

#### WORKED EXAMPLE — DAILY AND MONTHLY ENERGY OF THE EXAMPLE HOME

Using the table, find the home's daily and monthly energy use in kWh.

1. Add all the appliance energies:  $300 + 600 + 1200 + 600 + 60 + 500 = 3260$  Wh
2. Convert to kWh:  $3260 \div 1000 \approx 3.3$  kWh per day
3. Multiply by 30 days:  $3.3 \times 30 \approx 99$  kWh per month

**Answer: About 3.3 kWh per day, or about 99 kWh per month**

#### COMMON MISTAKE

**X Wrong:** Counting the fridge for 24 hours at full power.

**✓ Right:** A fridge switches on and off all day. Count its power for about 6–9 effective hours per day, not 24.

#### CASE STUDY — WHY THE SUMMER BILL JUMPS • ERBIL, KURDISTAN REGION

A family in Erbil measured their appliances and found about 3.3 kWh per day in winter. In summer they run one air conditioner for 8 hours a day. That single appliance adds  $2000 \text{ W} \times 8 \text{ h} = 16$  kWh per day — about **five times** everything else together. Their summer energy use is nearly six times their winter use. When they later asked for a solar system, the designer's first question was exactly this: *summer or winter, and how many hours of cooling?*

Notice the lesson of the case study: one or two big appliances usually control the whole energy picture. Find them first.

#### ACTIVITY (HOME) — HOME ENERGY AUDIT (FIRST VERSION)

1. Take your appliance list from Lesson 2.
2. For each appliance, write the hours it is used on a normal day.
3. Calculate each energy: watts  $\times$  hours = Wh.
4. Add them up and divide by 1000 to get kWh per day.
5. Multiply by 30 for the month. Compare with your electricity bill if you have one.

*You need: Your appliance list, Calculator or phone*

► *App tool: Check your audit with the Load Audit calculator*

## 1.5 Generators, Amperes, and Why Energy Matters

In Iraq and the Kurdistan Region, the public grid does not run all day. Many families buy extra electricity from a neighborhood generator. This lesson connects what you learned to that daily reality — and shows why solar energy is so interesting here.

#### WORD TO KNOW

**Generator subscription** — A monthly payment to a neighborhood generator for a fixed number of amperes during power cuts.

Generator subscriptions are sold in **amperes**: "5 amps", "10 amps". But appliances are rated in **watts**. One small equation connects them.

#### WORD TO KNOW

**Current** — The flow of electricity through a wire. Measured in amperes (A).

#### WORD TO KNOW

**Ampere** — The unit of electric current. Written A. Generator subscriptions are often sold by the ampere.

#### WORD TO KNOW

**Voltage** — The electrical pressure that pushes current through a wire. Measured in volts (V). Home electricity in Iraq is about 220 V.

#### EQUATION: ELECTRICAL POWER (PREVIEW — FULL STORY IN CHAPTER 2)

$$P = V \times I$$

*In words: Power = Voltage  $\times$  Current*

| Symbol | Meaning | Unit                            |
|--------|---------|---------------------------------|
| P      | power   | watts (W)                       |
| V      | voltage | volts (V) — about 220 V at home |
| I      | current | amperes (A)                     |

*Chapter 2 explains voltage and current properly. For now, use this to convert amperes into watts.*

#### WORKED EXAMPLE — WHAT CAN A 5-AMPERE SUBSCRIPTION POWER?

A family pays for 5 amperes from the neighborhood generator. The voltage is 220 V. How much power can they use?

1. Write the equation:  $P = V \times I$
2. Put in the numbers:  $P = 220 \text{ V} \times 5 \text{ A}$
3. Calculate:  $P = 1100 \text{ W}$

**Answer: 1100 W** — enough for lamps, TV, fan, and fridge together, but NOT enough for a 2000 W water heater.

#### Generator subscriptions: amperes $\rightarrow$ watts

| Subscription | Available power (at 220 V) | What it can run at the same time |
|--------------|----------------------------|----------------------------------|
| 3 A          | 660 W                      | Lamps, TV, fan, phone chargers   |



| Subscription | Available power (at 220 V) | What it can run at the same time                  |
|--------------|----------------------------|---------------------------------------------------|
| 5 A          | 1100 W                     | Lamps, TV, fan, fridge                            |
| 10 A         | 2200 W                     | The above plus a washing machine, or one small AC |

#### CASE STUDY — WHAT DOES GENERATOR ENERGY COST? • KURDISTAN REGION (EXAMPLE NUMBERS)

Suppose a subscription costs 10,000 IQD per ampere per month — so 5 A costs 50,000 IQD per month. *(These are example numbers for practice. Real local prices are collected in Chapter 21.)* The generator typically runs during outages, perhaps 8 hours a day. Even if the family used the full 1100 W for all 8 hours, that is  $1.1 \text{ kW} \times 8 \text{ h} \times 30 \text{ days} = 264 \text{ kWh}$ . So each kWh costs at least  $50,000 \div 264 \approx 190 \text{ IQD}$  — and in reality more, because no family uses the full power every minute. Generator energy is **expensive energy**. This is exactly why solar power is growing so fast in our region.

#### SAFETY

Generator safety: never connect a generator and the grid to your home at the same time without a proper changeover switch — this is dangerous for you and for the electricity workers. Keep generators outdoors: their exhaust gas is poisonous.

You can now speak both 'languages': amperes for subscriptions, watts and kilowatt-hours for appliances and bills. In the rest of this course you will learn to produce your own energy from the sun — and cut those generator hours.

#### CHAPTER SUMMARY

- Energy is the ability to do work. It changes form but is never created from nothing.
- Power is how fast energy is used, measured in watts (W).  $1 \text{ kW} = 1000 \text{ W}$ .
- Energy = Power  $\times$  time:  $E = P \times t$ . In units: watts  $\times$  hours  $\div 1000 = \text{kWh}$ .
- kW is speed (power); kWh is amount (energy). Your bill charges for kWh.
- A home's daily energy = the sum of (power  $\times$  hours) for every appliance.
- One or two big appliances (AC, water heater) usually control the whole energy picture.
- Generator subscriptions are sold in amperes.  $P = V \times I$  converts them to watts ( $V \approx 220 \text{ V}$ ).
- Generator energy costs much more per kWh than grid energy — a key reason to learn solar.

## Practice Problems

Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.

**Problem 1 [Basic]** A lamp uses 20 W. It is on for 5 hours. How much energy does it use, in Wh and in kWh?

**Problem 2 [Basic]** Convert: (a) 3500 Wh into kWh, and (b) 2.4 kWh into Wh.

**Problem 3 [Basic]** A television uses 120 W and runs 4 hours every day. How much energy does it use per day and per month (30 days), in kWh?

**Problem 4 [Basic]** An electric kettle uses 2000 W and runs for 6 minutes. How much energy does it use, in kWh? (Careful: convert minutes to hours first.)

**Problem 5 [Standard]** A room has: 4 lamps of 10 W used 5 hours, a 70 W fan used 8 hours, and a 110 W television used 3 hours. Find the total daily energy in kWh.

**Problem 6 [Standard]** A refrigerator is rated 160 W. Its compressor effectively runs 8 hours per day. Find its daily and monthly (30 days) energy in kWh.

**Problem 7 [Standard]** A family has a 3-ampere generator subscription at 220 V. During a power cut they want to run: a 100 W television, a 160 W refrigerator, three 10 W lamps, and a 500 W washing machine. Can they?

**Problem 8 [Standard]** A home uses 5 kWh per day. The example electricity price is 100 IQD per kWh. (Example numbers for practice — real prices are studied in Chapter 21.) What is the monthly bill for 30 days?

**Problem 9 [Standard]** Charging a phone uses about 10 W for 2 hours each day. An air conditioner uses 2000 W. For how many minutes would the AC need to run to use the same energy as a FULL MONTH of phone charging (30 days)?

**Problem 10 [Challenge]** A home has: 8 LED lamps (10 W, 5 h), one television (100 W, 6 h), one refrigerator (150 W, 8 h effective), two fans (70 W each, 10 h), one washing machine (500 W, 1 h), one water pump (370 W, 0.5 h). (a) Find the daily energy in kWh. (b) Find the monthly energy. (c) Which single appliance uses the most energy, and what would you check first to save energy?

**Problem 11 [Challenge]** A 5-ampere generator subscription costs 50,000 IQD per month (example numbers). The generator runs 8 hours per day. (a) What is the maximum energy the family could receive in a month (30 days)? (b) What is the minimum cost per kWh? (c) The real average use is about half the maximum — what is the real cost per kWh? Compare with the example grid price of 100 IQD/kWh.

**Problem 12 [Challenge]** A family runs their AC (1800 W) for 6 hours a day. They decide to run it only 4 hours and use a 70 W fan for the other 6 hours of the evening. (a) How much energy do they save per day? (b) Per month (30 days)? (c) How much money per month at the example price of 100 IQD/kWh?

## CHAPTER TWO

# Electricity Basics

*Current, voltage, resistance, circuits, and using a multimeter safely*

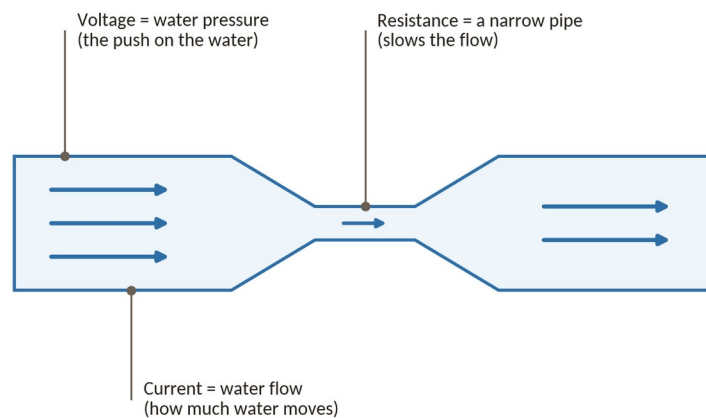
### IN THIS CHAPTER YOU WILL LEARN TO

- Explain current, voltage, and resistance, and how they work together in a circuit.
- Calculate current, voltage, and resistance using Ohm's law.
- Calculate electrical power using  $P = V \times I$  and  $P = I^2 \times R$ .
- Describe the difference between direct current (DC) and alternating current (AC), with examples of each.
- Calculate total resistance, current, and voltage in simple series and parallel circuits.
- Use a multimeter safely to measure voltage, current, and resistance, and follow basic electrical safety rules.

## 2.1 Current, Voltage, and Resistance

In Chapter 1 you met two important ideas: **current** (the flow of electricity, in amperes) and **voltage** (the electrical push, in volts). In this lesson you will meet their partner, **resistance**. Together, these three ideas explain every electrical circuit — including every solar power system you will ever design.

A simple way to picture electricity is to imagine water flowing in a pipe.



*Voltage is like water pressure. Current is like the flow of water. Resistance is like a narrow part of the pipe that slows the flow.*

### The water analogy for electricity

| Electrical quantity | Water analogy                 | Unit     |
|---------------------|-------------------------------|----------|
| Voltage (V)         | Water pressure — how hard the | Volt (V) |

| Electrical quantity | Water analogy                                       | Unit             |
|---------------------|-----------------------------------------------------|------------------|
|                     | water is pushed                                     |                  |
| Current (I)         | Water flow rate — how much water moves past a point | Ampere (A)       |
| Resistance (R)      | A narrow pipe or a valve that slows the flow        | Ohm ( $\Omega$ ) |

#### WORD TO KNOW

**Resistance** — The property of a material that opposes (pushes back against) the flow of electric current. Measured in ohms ( $\Omega$ ). More resistance means less current flows for the same voltage.

#### WORD TO KNOW

**Ohm** — The unit of electrical resistance. Written with the Greek letter  $\Omega$  (omega). A high number of ohms means the material blocks current strongly.

Different materials have very different resistance. This is why some materials are used for wires, and others are used to cover wires.

#### WORD TO KNOW

**Conductor** — A material with very low resistance that lets electric current flow easily. Copper and aluminium are common conductors, used to make wires.

#### WORD TO KNOW

**Insulator** — A material with very high resistance that blocks electric current. Plastic, rubber, and glass are common insulators, used to cover wires and protect people.

#### Typical resistance of common materials (approximate)

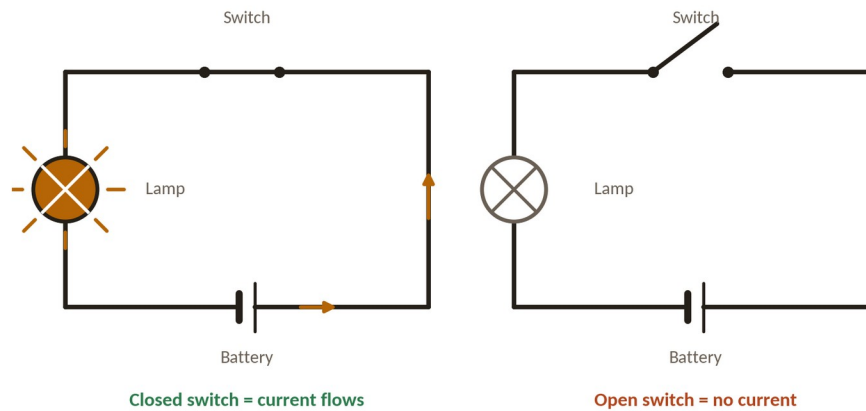
| Material or object           | Typical resistance                     |
|------------------------------|----------------------------------------|
| Copper wire, a few metres    | Very low — less than 1 $\Omega$        |
| A small light bulb filament  | Medium — tens to hundreds of $\Omega$  |
| Human skin, wet              | Low — around 1,000 $\Omega$ or less    |
| Human skin, dry              | High — around 100,000 $\Omega$ or more |
| Rubber or plastic insulation | Extremely high — millions of $\Omega$  |

Notice that wet skin has much lower resistance than dry skin. This is one reason water and electricity are such a dangerous mix — you will see this again in Lesson 5.

Current can only flow if it has a complete, unbroken path. This path is called a **circuit**.

#### WORD TO KNOW

**Circuit** — A complete, unbroken path that lets electric current flow, from the source, through the load, and back again. If the path breaks, current stops.



*A simple circuit: a battery, wires, a switch, and a lamp. Closed switch = closed circuit = current flows. Open switch = open circuit = no current.*

A switch is simply a device that opens or closes the path on purpose. Every circuit needs three things: a source of voltage (like a battery or a solar panel), a load that uses the current (like a lamp), and a conductor path connecting them.

#### COMMON MISTAKE

**✗ Wrong:** Resistance is always bad, and we should try to remove all resistance from every circuit.

**✓ Right:** Resistance is often useful and necessary. The resistance in a lamp filament or a heater element is exactly what produces light and heat. Only unwanted resistance — like a loose or corroded connection — is a problem.

#### ACTIVITY (CLASSROOM) — BUILD A SIMPLE CIRCUIT

1. Collect a battery, a small bulb (or an LED with a resistor), and two connecting wires.
2. Connect one wire from the battery's positive terminal to one side of the bulb.
3. Connect the second wire from the other side of the bulb back to the battery's negative terminal.
4. Check: the bulb should light up. This is a closed circuit.
5. Disconnect one wire. The bulb goes dark. This is an open circuit.

*You need: Battery (AA or 9 V), Small bulb or LED with resistor, Two connecting wires*

## 2.2 Ohm's Law and Electrical Power

You now know current, voltage, and resistance. This lesson connects them with one simple, powerful equation, and then uses it to calculate electrical power. You will use these equations in every chapter of this course.

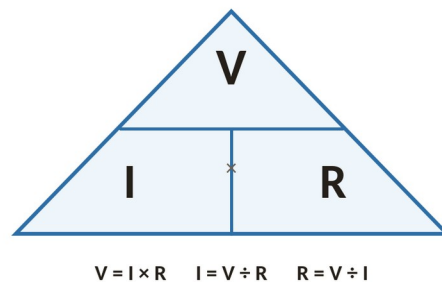
#### EQUATION: OHM'S LAW

$$V = I \times R$$

In words: Voltage = Current  $\times$  Resistance

| Symbol | Meaning    | Unit              |
|--------|------------|-------------------|
| V      | voltage    | volts (V)         |
| I      | current    | amperes (A)       |
| R      | resistance | ohms ( $\Omega$ ) |

This equation can be rearranged:  $I = V \div R$  (to find current), or  $R = V \div I$  (to find resistance).



The Ohm's law triangle. Cover the letter you want to find: V on top gives  $V = I \times R$ . Cover I to see  $I = V \div R$ . Cover R to see  $R = V \div I$ .

#### WORKED EXAMPLE — FIND THE CURRENT

A 12 V battery is connected across a 6  $\Omega$  resistor. Find the current.

1. Write the equation, rearranged for current:  $I = V \div R$
2. Put in the numbers:  $I = 12 \text{ V} \div 6 \Omega$
3. Calculate:  $I = 2 \text{ A}$

**Answer: 2 A**

#### WORKED EXAMPLE — FIND THE RESISTANCE

A 12 V battery lights a small bulb. A multimeter shows the current is 0.5 A. Find the bulb's resistance.

1. Write the equation, rearranged for resistance:  $R = V \div I$
2. Put in the numbers:  $R = 12 \text{ V} \div 0.5 \text{ A}$
3. Calculate:  $R = 24 \Omega$

**Answer: 24  $\Omega$**

Now let's connect electricity to something you already know from Chapter 1: power. Power is the rate of using energy, and in an electrical circuit it depends on voltage and current.

#### EQUATION: ELECTRICAL POWER FROM VOLTAGE AND CURRENT

$$P = V \times I$$

In words: Power = Voltage  $\times$  Current

| Symbol | Meaning | Unit        |
|--------|---------|-------------|
| P      | power   | watts (W)   |
| V      | voltage | volts (V)   |
| I      | current | amperes (A) |

This is the same equation you previewed in Chapter 1, Lesson 5. Now you know exactly what V and I mean.

#### WORKED EXAMPLE — POWER OF A BATTERY AND MOTOR

A 12 V battery pushes 2 A of current through a small motor. Find the power.

1. Write the equation:  $P = V \times I$
2. Put in the numbers:  $P = 12 \text{ V} \times 2 \text{ A}$
3. Calculate:  $P = 24 \text{ W}$

**Answer: 24 W**

There is a second way to calculate power, using only current and resistance. This is useful when you do not know the voltage directly.

#### EQUATION: ELECTRICAL POWER FROM CURRENT AND RESISTANCE

$$P = I^2 \times R$$

In words: Power = Current<sup>2</sup>  $\times$  Resistance

| Symbol | Meaning    | Unit              |
|--------|------------|-------------------|
| P      | power      | watts (W)         |
| I      | current    | amperes (A)       |
| R      | resistance | ohms ( $\Omega$ ) |

Found by combining Ohm's law ( $V = I \times R$ ) with  $P = V \times I$ . It shows that current has a very strong effect on power, because it is squared.

#### WORKED EXAMPLE — POWER OF A HEATER ELEMENT

A heater element has a resistance of 20  $\Omega$ . It carries a current of 5 A. Find the power.

1. Write the equation:  $P = I^2 \times R$
2. Put in the numbers:  $P = 5^2 \times 20 = 25 \times 20$
3. Calculate:  $P = 500 \text{ W}$
4. Check with Ohm's law:  $V = I \times R = 5 \times 20 = 100 \text{ V}$ , then  $P = V \times I = 100 \times 5 = 500 \text{ W}$ . It matches!

**Answer: 500 W**

#### Three ways to calculate power

| What you know                                        | Formula            | Example ( $I = 5 \text{ A}$ , $R = 20 \Omega$ , $V = 100 \text{ V}$ ) |
|------------------------------------------------------|--------------------|-----------------------------------------------------------------------|
| Voltage and current ( $V$ , $I$ )                    | $P = V \times I$   | $100 \times 5 = 500 \text{ W}$                                        |
| Current and resistance ( $I$ , $R$ )                 | $P = I^2 \times R$ | $5^2 \times 20 = 500 \text{ W}$                                       |
| Voltage and resistance ( $V$ , $R$ ) — bonus formula | $P = V^2 \div R$   | $100^2 \div 20 = 500 \text{ W}$                                       |

Why does this matter for solar systems? Power turns into heat wherever there is resistance. Too much current through a wire that is too thin makes it hot, wastes energy, and can even start a fire. This is exactly why cable size matters so much — you will study it fully in Chapter 9.

#### COMMON MISTAKE

**✗ Wrong:** If you double the voltage across a resistor, the power only doubles too.

**✓ Right:** If resistance stays the same, doubling the voltage also doubles the current (Ohm's law:  $I = V \div R$ ). Since power = voltage  $\times$  current, doubling both means the power becomes four times bigger, not two times bigger.

► *App tool: Try it: convert between V, A,  $\Omega$ , and W*

## 2.3 DC vs AC

Electric current comes in two kinds: direct current and alternating current. Solar systems use both, so it is important to know the difference.

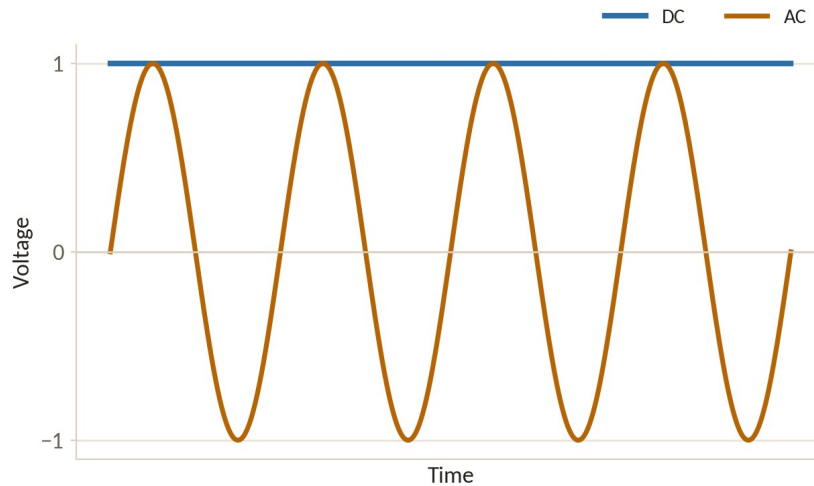
#### WORD TO KNOW

**Direct current** — Electric current that flows in only one direction and does not change. Short name: DC. Batteries and solar panels produce DC electricity.

#### WORD TO KNOW

**Alternating current** — Electric current that keeps changing direction, back and forth, many times every second. Short name: AC. The electricity grid and generators supply AC.





*DC stays constant in one direction (a flat line). AC swings back and forth above and below zero, many times each second (a wave shape).*

#### DC compared with AC

| Property                    | DC (direct current)                           | AC (alternating current)                   |
|-----------------------------|-----------------------------------------------|--------------------------------------------|
| Direction of flow           | Always the same direction                     | Keeps changing direction                   |
| Typical sources             | Batteries, solar panels                       | The grid, generators, wall sockets         |
| Symbol on a multimeter dial | A straight line (sometimes dashed)            | A wavy line, like this: ~                  |
| Used in solar systems for   | The panels and the battery side of the system | Normal home appliances, after the inverter |

Solar panels always produce DC. But most home appliances are built for AC. This is why a solar power system needs a device that changes DC into AC. That device is called an **inverter** — you will study it fully in Chapter 8. For now, just remember: DC in from the panels and battery, AC out to the appliances.

#### WORD TO KNOW

**Frequency** — How many times AC current completes a full back-and-forth cycle every second. Measured in hertz (Hz).

#### WORD TO KNOW

**Hertz** — The unit of frequency. One hertz (1 Hz) means one complete cycle every second. Iraq's grid frequency is 50 Hz.

#### EQUATION: PERIOD FROM FREQUENCY

$$T = \frac{1}{f}$$

*In words: Period = 1 ÷ Frequency*

| Symbol | Meaning                                  | Unit        |
|--------|------------------------------------------|-------------|
| T      | period — the time for one complete cycle | seconds (s) |
| f      | frequency                                | hertz (Hz)  |

*A higher frequency means a shorter period — each cycle happens faster.*

#### WORKED EXAMPLE — THE PERIOD OF IRAQ'S GRID AC

Iraq's electricity grid supplies AC at a frequency of 50 Hz. Find the period of one complete cycle.

1. Write the equation:  $T = 1 \div f$
2. Put in the numbers:  $T = 1 \div 50$
3. Calculate:  $T = 0.02 \text{ s}$
4. Convert to milliseconds:  $0.02 \times 1000 = 20 \text{ ms}$

**Answer: 0.02 s, which is 20 ms**

#### Mains voltage and frequency around the world

| Region                                    | Typical voltage | Frequency |
|-------------------------------------------|-----------------|-----------|
| Iraq and the Kurdistan Region             | 220 V           | 50 Hz     |
| Most of Europe, the Middle East, and Asia | 220–240 V       | 50 Hz     |
| United States and Canada                  | 120 V           | 60 Hz     |

In the Kurdistan Region, both the public grid and neighbourhood generators supply the same standard: about 220 V AC at 50 Hz. This is why your appliances work normally no matter which source is switched on — and a solar inverter must produce this same standard too.

#### COMMON MISTAKE

**X Wrong:** A solar panel produces the same kind of electricity as a wall socket.

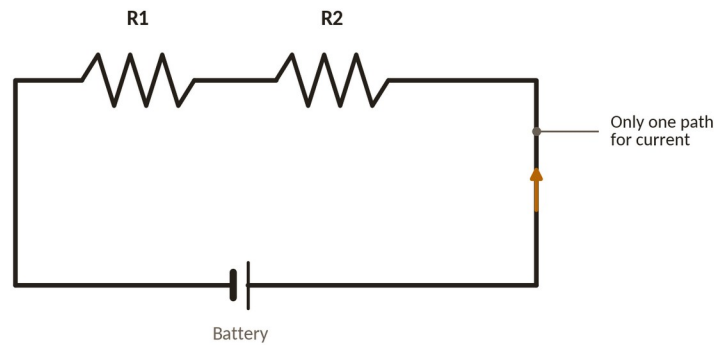
**✓ Right:** A solar panel produces DC electricity. A wall socket supplies AC electricity. An inverter changes DC into AC so a solar system can safely power normal home appliances.

## 2.4 Series and Parallel Circuits

There are two basic ways to connect components in a circuit: series and parallel. You will use these same two ideas again for connecting solar panels (Chapter 5) and batteries (Chapter 6) — so it is worth learning the rules well now, with simple circuits.

#### WORD TO KNOW

**Series circuit** — A circuit where components are connected one after another, in a single path. The same current flows through every component.



A series circuit: a battery and two resistors connected one after another in a single loop. Current has only one path to follow.

In a series circuit, there is only one path, so the current is the same everywhere in the loop. The supply voltage is shared out between the components — it adds up to equal the total.

#### EQUATION: TOTAL RESISTANCE IN SERIES

$$R_{\text{total}} = R_1 + R_2 + \dots$$

*In words: Total resistance =  $R_1 + R_2 + \dots$  (add every resistor)*

| Symbol  | Meaning                                | Unit              |
|---------|----------------------------------------|-------------------|
| R total | total resistance of the series circuit | ohms ( $\Omega$ ) |
| R1      | resistance of the first component      | ohms ( $\Omega$ ) |
| R2      | resistance of the second component     | ohms ( $\Omega$ ) |

Add as many resistors as are in the circuit. Total series resistance is always bigger than the biggest single resistor.

#### WORKED EXAMPLE — A SERIES CIRCUIT WITH TWO RESISTORS

A  $4\ \Omega$  resistor and a  $6\ \Omega$  resistor are connected in series to a 12 V battery. Find: (a) the total resistance, (b) the current, (c) the voltage across each resistor.

- (a) Total resistance:  $R_{\text{total}} = R_1 + R_2 = 4 + 6 = 10\ \Omega$
- (b) Current (same everywhere in series):  $I = V \div R_{\text{total}} = 12 \div 10 = 1.2\ \text{A}$
- (c) Voltage across each:  $V_1 = I \times R_1 = 1.2 \times 4 = 4.8\ \text{V}$ , and  $V_2 = I \times R_2 = 1.2 \times 6 = 7.2\ \text{V}$
- Check:  $4.8 + 7.2 = 12\ \text{V}$ , which matches the battery voltage

**Answer:  $R_{\text{total}} = 10\ \Omega$ ,  $I = 1.2\ \text{A}$ ,  $V_1 = 4.8\ \text{V}$ ,  $V_2 = 7.2\ \text{V}$**

Think of an old-style string of decorative lights, wired in series. If one lamp burns out, the path is broken, and the WHOLE string goes dark — not just the one lamp.

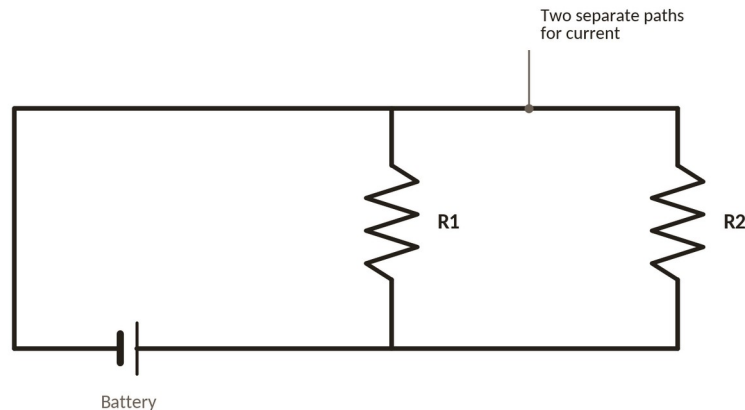
#### COMMON MISTAKE

**✗ Wrong:** Adding more lamps to a series circuit makes each lamp glow brighter.

**✓ Right:** Adding more lamps in series increases the total resistance. This makes the current smaller, so each lamp actually gets less voltage and glows dimmer, not brighter.

### WORD TO KNOW

**Parallel circuit** — A circuit where components are connected across the same two points, each on its own branch. Every branch gets the full supply voltage.



*A parallel circuit: a battery and two resistors, each connected directly across the battery on its own branch.*

In a parallel circuit, every branch is connected straight across the same two points, so every branch gets the full supply voltage. The total current from the source is the sum of the current in every branch.

### EQUATION: TOTAL RESISTANCE IN PARALLEL

$$\frac{1}{R_{\text{total}}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$$

*In words:  $1 \div \text{Total resistance} = (1 \div R_1) + (1 \div R_2) + \dots$*

| Symbol  | Meaning                                  | Unit              |
|---------|------------------------------------------|-------------------|
| R total | total resistance of the parallel circuit | ohms ( $\Omega$ ) |
| R1      | resistance of the first branch           | ohms ( $\Omega$ ) |
| R2      | resistance of the second branch          | ohms ( $\Omega$ ) |

*For exactly two resistors, a shortcut is  $R_{\text{total}} = (R_1 \times R_2) \div (R_1 + R_2)$ . Total parallel resistance is always smaller than the smallest single resistor.*

### WORKED EXAMPLE — THE SAME TWO RESISTORS, NOW IN PARALLEL

The same 4  $\Omega$  and 6  $\Omega$  resistors are now connected in parallel to the same 12 V battery. Find: (a) the total resistance, (b) the current in each resistor, (c) the total current from the battery.

1. (a)  $1 \div R_{\text{total}} = 1/4 + 1/6 = 3/12 + 2/12 = 5/12$ , so  $R_{\text{total}} = 12 \div 5 = 2.4 \Omega$
2. (b) Current in each branch (full 12 V across each):  $I_1 = V \div R_1 = 12 \div 4 = 3 \text{ A}$ , and  $I_2 = V \div R_2 = 12 \div 6 = 2 \text{ A}$
3. (c) Total current:  $I_{\text{total}} = I_1 + I_2 = 3 + 2 = 5 \text{ A}$
4. Check:  $I_{\text{total}} = V \div R_{\text{total}} = 12 \div 2.4 = 5 \text{ A}$ , which matches

**Answer: R total = 2.4  $\Omega$ , I1 = 3 A, I2 = 2 A, total current = 5 A**

Compare the two results: the exact same 4  $\Omega$  and 6  $\Omega$  resistors, on the exact same 12 V battery, draw only 1.2 A total in series but 5 A total in parallel — more than four times as much! Parallel branches give current more paths to flow through, which lowers the total resistance.

#### Series compared with parallel

| Property                             | Series circuit                                           | Parallel circuit                                        |
|--------------------------------------|----------------------------------------------------------|---------------------------------------------------------|
| Current                              | Same current everywhere                                  | Splits between branches; total = sum of branch currents |
| Voltage                              | Splits between components; adds up to the supply voltage | Same voltage across every branch                        |
| Total resistance                     | $R_1 + R_2 + \dots$ (bigger than any single resistor)    | Always smaller than the smallest single resistor        |
| If one component fails (breaks open) | The whole circuit stops                                  | Other branches keep working                             |
| Common example                       | Old-style decorative light strings                       | Household wiring                                        |

The wiring inside a home is parallel. Every lamp and socket is its own branch, connected across the same 220 V supply. This is exactly why one broken lamp does not switch off the rest of the house.

#### CASE STUDY — WHY THE WHOLE STRING OF LIGHTS WENT DARK • SULAYMANIYAH, KURDISTAN REGION

A shop owner in Sulaymaniyah put up a string of small solar-powered garden lights around his shop entrance, all wired in series, one after another. One evening a single LED failed — and instantly the whole string went dark, not just the one light. A technician explained why: in a series circuit, current has only one path. When one lamp breaks, the path is broken, and no current can reach any of the lamps. He rewired the lights in parallel groups instead. Now, if one LED fails, the rest stay lit — exactly like the wiring inside a house.

#### ACTIVITY (HOME) — SERIES OR PARALLEL? A HOME WALK

1. Walk around your home and look at how lamps and sockets are wired (ask an adult if you are not sure — do not open any switch or socket yourself).
2. Check: if one lamp is switched off or broken, do the others still work? This tells you it is parallel wiring.
3. Find any example at home wired in series — for example, some decorative light strings, or a switch and a fuse in the same path as a single appliance.
4. Write down what you found and explain why household wiring is parallel, not series.

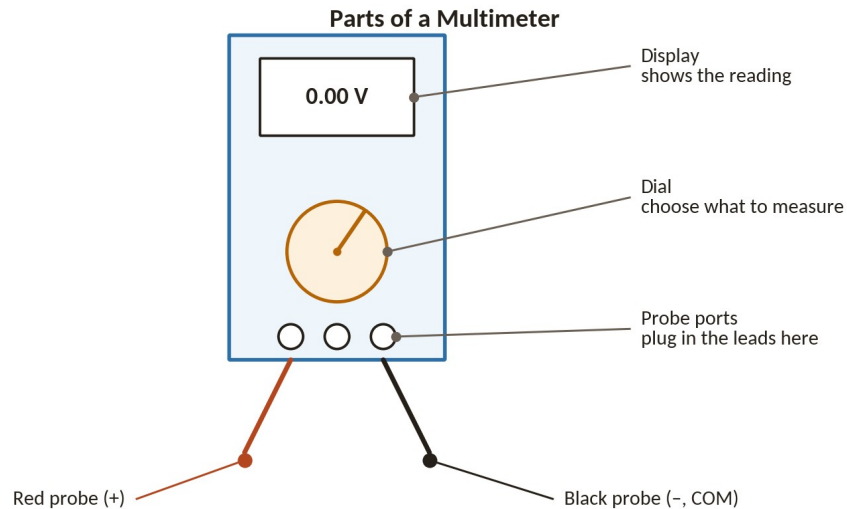
*You need: Paper and pen*

## 2.5 Using a Multimeter Safely

A multimeter is the most important tool for anyone who works with solar power. It lets you measure voltage, current, and resistance — everything you learned in this chapter — in real circuits. Used correctly, it is safe and simple. Used carelessly, it can damage the meter, the circuit, or you. This lesson teaches you to use it the right way.

#### WORD TO KNOW

**Multimeter** — A tool that measures electrical quantities — usually voltage, current, and resistance — in one device. It is the most important test tool for solar work.



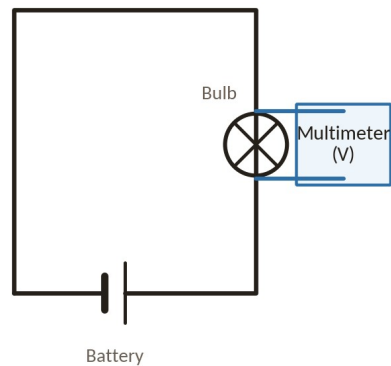
*The parts of a multimeter: the display, the function dial, the ports for the probes, and the red (positive) and black (negative/common) probes.*

The dial chooses what you measure. Look for: V with a straight or dashed line (DC voltage), V with a wavy line ~ (AC voltage), A (current), and  $\Omega$  (resistance). The wavy line ~ is the same AC symbol from Lesson 3.

#### Multimeter settings, quick guide

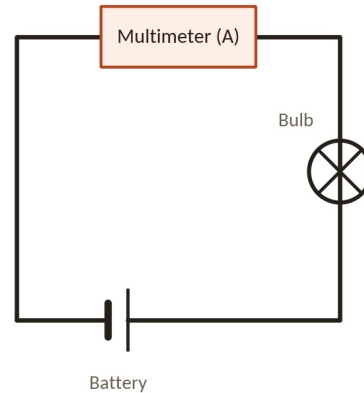
| To measure              | Dial setting                                 | How to connect the probes                                                              |
|-------------------------|----------------------------------------------|----------------------------------------------------------------------------------------|
| Voltage (V)             | V with a straight line (DC) or V with ~ (AC) | In parallel — touch the two points directly; no need to break the circuit              |
| Current (A)             | A (choose the mA or 10 A port as needed)     | In series — break the circuit and connect the meter into the path                      |
| Resistance ( $\Omega$ ) | $\Omega$                                     | Across the component only — remove it from the circuit and make sure there is no power |

### Measuring Voltage — Parallel



Voltage: connect IN PARALLEL (no break in the circuit)

### Measuring Current — Series



Current: connect IN SERIES (breaks the circuit)

Left: measuring voltage in parallel, across the battery and bulb, without breaking the circuit. Right: measuring current in series, with the circuit broken and the meter inserted into the path.

#### COMMON MISTAKE

**✗ Wrong:** Connecting the multimeter in current mode directly across a battery or wall socket, the same way you would connect it for a voltage reading.

**✓ Right:** Current mode must always be connected in series, breaking the circuit. Connecting current mode in parallel (across a voltage source) creates a short circuit through the meter — it can blow the meter's internal fuse instantly, or injure you.

#### COMMON MISTAKE

**✗ Wrong:** Measuring the resistance of a component while it is still connected and powered in a live circuit.

**✓ Right:** Resistance must be measured with the component isolated (usually removed from the circuit) and with no power applied. Measuring resistance on a live circuit gives wrong readings and can damage the meter.

#### WORD TO KNOW

**Continuity test** — A quick multimeter test that checks if a wire or connection is complete, with no break. The meter usually beeps if current can pass through.

#### WORKED EXAMPLE — USING A MEASUREMENT TO CALCULATE RESISTANCE

A multimeter measures 12 V across a bulb, and 2 A of current flowing through it. Use Ohm's law to find the bulb's resistance.

1. Write the equation:  $R = V \div I$
2. Put in the numbers:  $R = 12 \text{ V} \div 2 \text{ A}$
3. Calculate:  $R = 6 \Omega$

**Answer:** 6  $\Omega$

### SAFETY

Multimeter and test equipment safety: - Check the probes and leads for cracks or damage before every use. - Set the correct function and range BEFORE you connect the probes. Guessing can blow the meter's internal fuse. - If you are not sure of the value, start on a high range and move down. - Never change the dial while the probes are touching a live circuit. - Before touching any wire, turn off the breaker first, then use the multimeter to CONFIRM the power is really off — never trust a switch alone. - When testing near mains power, keep one hand in your pocket. This lowers the chance of current passing across your chest if something goes wrong.

### SAFETY

Home electrical safety: - Never touch switches, sockets, or bare wires with wet hands, or while standing on a wet floor. - Do not overload one socket with too many plugs at once. - Replace any cord or plug that is cracked, cut, or burnt — do not tape over damage. - Never bridge a blown fuse with a piece of wire. A fuse that blows often is a warning sign, not a problem to hide. - Keep children away from sockets and switches, and use socket covers where possible. - Only trained people should open a distribution box, breaker panel, or wall socket.

### SAFETY

Low voltage does not mean no danger. A 12 V battery feels 'safe' because the voltage is low, but batteries can push out very large currents — sometimes 100 A or more — if their terminals are short-circuited by a dropped tool or a stray wire. This huge current can make a metal tool red-hot in seconds, causing burns or fire. Never rest a metal tool across battery terminals, and remove rings and metal watches when working near batteries. Chapter 6 explains battery safety fully.

### CASE STUDY — FINDING A DANGEROUS FAULT BEFORE IT CAUSED A FIRE • DUHOK, KURDISTAN REGION

A technician was called to a home in Duhok where the circuit breaker kept tripping whenever the family used their washing machine and water heater together. Instead of guessing, he turned off the power and used a multimeter to run a continuity test on the connections inside the distribution box. He found one connection was loose, and the plastic around it had darkened from overheating — a warning sign of a wire that was close to starting a fire. He tightened the connection, and the tripping stopped. This is exactly why solar technicians are trained to test first and never guess: a multimeter finds hidden problems before they become dangerous.

### ACTIVITY (LABORATORY) — MULTIMETER MEASUREMENT LABORATORY

1. Set the multimeter to DC voltage and measure your battery's voltage (probes across the terminals, no circuit needed).
2. Build a simple circuit: battery, bulb (or LED with a resistor), and connecting wires.
3. With the circuit on, set the meter to DC voltage and measure across the bulb (parallel connection). Record the reading.
4. Turn off the circuit. Break it at one point, set the meter to DC current, and reconnect through the meter (series connection). Turn the circuit on and record the current.



5. Turn off the circuit, remove the bulb or resistor, and measure its resistance directly with the  $\Omega$  setting.
6. Use Ohm's law ( $V = I \times R$ ) to check: do your three measurements agree with each other?
7. Record all values in a small table and compare with a hand calculation.

*You need: Multimeter, Battery (AA or 9 V), Small bulb or LED with resistor, Connecting wires*

## CHAPTER SUMMARY

- Current (A) is the flow of electricity; voltage (V) is the push; resistance ( $\Omega$ ) opposes the flow. The water-pipe analogy: pressure, flow rate, and a narrow pipe.
- Ohm's law:  $V = I \times R$ . It can be rearranged to  $I = V \div R$  or  $R = V \div I$ .
- Electrical power:  $P = V \times I$ , and also  $P = I^2 \times R$ . Doubling the voltage on a fixed resistance makes the power four times bigger, not two.
- DC flows one way (batteries, solar panels); AC keeps changing direction (the grid, generators). Iraq and the Kurdistan Region use 220 V AC at 50 Hz.
- Solar panels produce DC; most appliances need AC; an inverter converts between them (full story in Chapter 8).
- Series circuits: same current everywhere, voltages add, resistances add, and one broken component stops everything.
- Parallel circuits: same voltage on every branch, currents add, total resistance is smaller than the smallest branch, and household wiring is parallel for exactly this reason.
- A multimeter measures voltage in parallel, current in series, and resistance only on an unpowered, isolated component.
- Safety rule: turn off power and prove it is off with the meter before touching a wire. Even low battery voltage can deliver dangerous short-circuit current.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A 9 V battery is connected across a 3  $\Omega$  resistor. Find the current.

**Problem 2 [Basic]** A resistor of 15  $\Omega$  carries a current of 2 A. Find the voltage across it.

**Problem 3 [Basic]** A small motor is connected to a 24 V supply and draws 1.5 A of current. Find the power it uses.

**Problem 4 [Basic]** Some countries use a mains frequency of 60 Hz (Iraq uses 50 Hz). Find the period of one complete cycle at 60 Hz, in milliseconds.

**Problem 5 [Standard]** Three resistors, 2  $\Omega$ , 3  $\Omega$ , and 5  $\Omega$ , are connected in series to a 20 V battery. Find (a) the total resistance, and (b) the current from the battery.

**Problem 6 [Standard]** Two resistors, 10  $\Omega$  and 40  $\Omega$ , are connected in parallel across a 16 V battery. Find (a) the total resistance, (b) the current in each resistor, and (c) the total current from the battery.

**Problem 7 [Standard]** A wire carries 4 A of current and has a resistance of 0.5  $\Omega$ . How much power is wasted as heat in the wire?

**Problem 8 [Standard]** A technician measures 18 V across a heater element and 3 A of current flowing through it. Find (a) the heater's resistance, and (b) the power it uses.

**Problem 9 [Standard]** A resistor of  $220\ \Omega$  is connected to Iraq's home electricity supply of 220 V. Find (a) the current through it, and (b) the power it uses.

**Problem 10 [Challenge]** A small 12 V solar lighting circuit has two LED lamps in parallel, each with an effective resistance of  $24\ \Omega$ . This parallel pair is connected in series with a  $4\ \Omega$  cable resistance (from a long wire run) to the 12 V battery. Find (a) the resistance of the parallel pair, (b) the total circuit resistance, (c) the total current from the battery, and (d) the voltage that actually reaches the parallel lamps.

**Problem 11 [Challenge]** A 220 V, 1000 W immersion water heater element is checked with a multimeter. Find (a) its resistance, (b) the current it draws, and (c) if it runs for 45 minutes a day, its daily energy in kWh (use  $E = P \times t$  from Chapter 1).

**Problem 12 [Challenge]** A small off-grid cabin has three lamps connected in PARALLEL to a 12 V battery. Each lamp has a resistance of  $60\ \Omega$ . Find (a) the total resistance of the three lamps, (b) the total current from the battery when all three are on, (c) what a multimeter would read at the battery terminals if one lamp burns out, and why, and (d) the new total current with only two lamps working.

## CHAPTER THREE

# The Sun and Solar Energy

*Measuring sunlight with irradiance, peak sun hours, the Sun's path, and solar maps*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain what solar radiation is, and how the atmosphere changes it before it reaches the ground.
- Calculate daily solar energy from peak sun hours, and explain the difference between irradiance ( $\text{W}/\text{m}^2$ ) and daily solar energy ( $\text{kWh}/\text{m}^2/\text{day}$ ).
- Describe the Sun's daily path across the sky, and explain why Earth has seasons.
- Explain how latitude, weather, and dust change the amount of sunlight a location receives.
- Compare solar maps and example peak sun hour data for the world, Iraq, and the Kurdistan Region.

## 3.1 What is Solar Radiation?

Almost every kind of energy on Earth starts with the Sun — it grows our food, drives the wind and rain, and, with the right equipment, makes electricity in a solar panel. In this chapter, you will learn to treat sunlight as something you can measure and calculate, just like you measured energy and power in Chapter 1.

### WORD TO KNOW

**Solar radiation** — Energy that travels from the Sun as light and heat. It is the source of almost all energy on Earth, including solar power.

The Sun is a star — a huge, hot ball of gas. Deep in its core, a process called nuclear fusion makes enormous amounts of energy. This energy travels outward and leaves the Sun as solar radiation, spreading out in every direction through space.

### Quick facts about the Sun

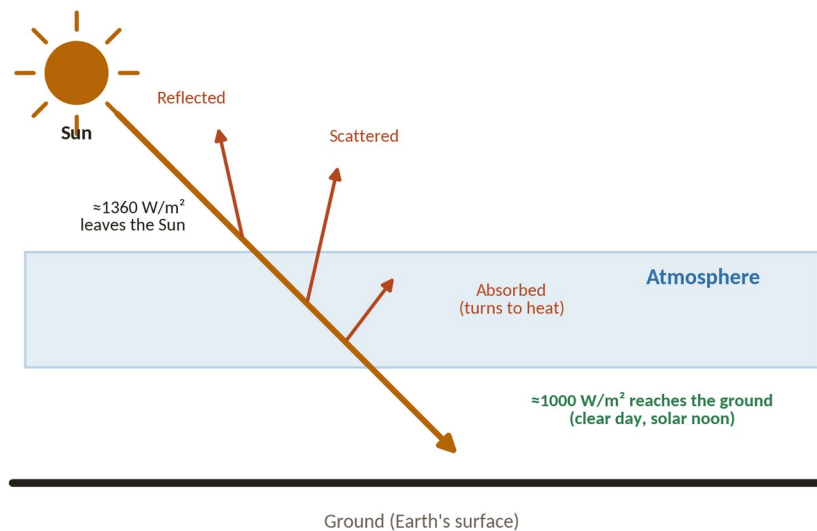
| Fact                          | Approximate value                                   |
|-------------------------------|-----------------------------------------------------|
| Distance from Earth           | About 150 million km                                |
| Diameter                      | About 1.4 million km (over 100 Earths side by side) |
| Surface temperature           | About 5,500 °C                                      |
| Main energy source            | Nuclear fusion in the Sun's core                    |
| Time for light to reach Earth | About 8 minutes                                     |

Light and heat leave the Sun and cross space at the speed of light — about 300,000 km per second. Even at this huge speed, sunlight takes about 8 minutes to reach Earth. When you feel warm sunlight on your skin, you are feeling energy that left the Sun about 8 minutes earlier.

### WORD TO KNOW

**Solar constant** — The power of sunlight on one square meter, measured just outside Earth's atmosphere, facing straight at the Sun. About 1360 watts per square meter ( $\text{W}/\text{m}^2$ ).

Because the solar constant is a power per square meter, you can find the total power on any flat area by multiplying: **power = irradiance  $\times$  area**. But not all of this energy reaches the ground. As sunlight passes through Earth's atmosphere, some is reflected back to space by clouds, some is absorbed by air and dust, and some is scattered in many directions. Ground-level sunlight is always less than the solar constant. On a clear day, close to solar noon, ground-level sunlight is about  $1000 \text{ W}/\text{m}^2$  — a number you will meet again when we study solar panels.



Sunlight leaves the Sun at about  $1360 \text{ W}/\text{m}^2$ . Passing through the atmosphere, some is reflected, some is absorbed, and some is scattered. About  $1000 \text{ W}/\text{m}^2$  can reach the ground on a clear day near solar noon.

#### WORD TO KNOW

**Direct radiation** — Sunlight that travels straight from the Sun to the ground without changing direction. It makes sharp, clear shadows.

#### WORD TO KNOW

**Diffuse radiation** — Sunlight that is scattered by clouds, dust, and air before it reaches the ground. It comes from all parts of the sky, not just from the Sun's direction.

#### COMMON MISTAKE

**✗ Wrong:** The full solar constant (about  $1360 \text{ W}/\text{m}^2$ ) reaches the ground everywhere, all the time.

**✓ Right:** The atmosphere reflects, absorbs, and scatters sunlight. Ground-level irradiance is usually lower — up to about  $1000 \text{ W}/\text{m}^2$  on a clear day at solar noon, and much less at other times or under clouds.

#### ACTIVITY (HOME) — SUN OR SHADE: DIRECT AND DIFFUSE LIGHT

1. On a sunny day, stand in an open space and look at your shadow. Is the edge of the shadow sharp or blurry?
2. Now find a shaded spot under a tree or a roof, out of direct sun. Is it completely dark, or can you still see clearly?
3. Write down why: the shade is not completely dark because diffuse light still reaches it from the rest of the sky.
4. If you can, compare a sunny day with a cloudy day. Notice that shadows almost disappear on a cloudy day — nearly all the light is now diffuse.

*You need: A sunny day, and a cloudy day if possible, Paper and pen*

### 3.2 Irradiance vs. Solar Energy (Peak Sun Hours)

In Chapter 1, you learned the difference between power (how fast) and energy (how much). Sunlight has exactly the same split. This lesson gives you the tools to turn changing sunlight into one simple number you can use for solar design.

#### WORD TO KNOW

**Irradiance** — The power of sunlight falling on one square meter of surface at a single moment. Measured in watts per square meter ( $\text{W}/\text{m}^2$ ).

Irradiance is never constant. It is zero before sunrise, rises through the morning, reaches its highest value near solar noon, then falls again to zero after sunset. Clouds and dust make it jump up and down even more. This table shows an example clear-sky pattern:

#### Example irradiance across a clear day (illustrative)

| Time of day             | Irradiance ( $\text{W}/\text{m}^2$ ) |
|-------------------------|--------------------------------------|
| 6:00 (near sunrise)     | 40                                   |
| 10:00                   | 700                                  |
| 12:00 (near solar noon) | 950                                  |
| 14:00                   | 700                                  |
| 18:00 (near sunset)     | 40                                   |

#### WORD TO KNOW

**Daily solar energy** — The total amount of sunlight energy that falls on one square meter of surface in one day. Measured in kilowatt-hours per square meter per day ( $\text{kWh}/\text{m}^2/\text{day}$ ).

To find the daily solar energy, you would need to add up the irradiance for every second of the day — like finding the area under the curve in the table above. That is hard to do by hand. Engineers use a simpler idea instead: **peak sun hours**.

#### WORD TO KNOW

**Peak sun hour** — The number of hours in a day when sunlight would need to shine at the standard strength of  $1000 \text{ W}/\text{m}^2$  to give the same total daily energy as the real sunlight. Written PSH.

#### EQUATION: DAILY SOLAR ENERGY AND PEAK SUN HOURS

$$H = G_{\text{STC}} \times \text{PSH}$$

In words: Daily solar energy = Standard irradiance  $\times$  Peak sun hours

| Symbol | Meaning                                                                                                     | Unit                                                              |
|--------|-------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| H      | daily solar energy (also called daily insolation)                                                           | kilowatt-hours per square meter per day (kWh/m <sup>2</sup> /day) |
| G_STC  | the standard irradiance used to define peak sun hours — always 1000 W/m <sup>2</sup> (1 kW/m <sup>2</sup> ) | kilowatts per square meter (kW/m <sup>2</sup> )                   |
| PSH    | peak sun hours                                                                                              | hours (h)                                                         |

This equation has the same shape as  $E = P \times t$  from Chapter 1 —  $G_{\text{STC}}$  (always 1 kW/m<sup>2</sup>) takes the place of power, and peak sun hours takes the place of time. Because  $G_{\text{STC}}$  is always exactly 1 kW/m<sup>2</sup>, the number of peak sun hours is always numerically equal to the daily solar energy in kWh/m<sup>2</sup>. To find peak sun hours from a known daily energy, rearrange:  $\text{PSH} = H \div G_{\text{STC}}$ .

#### WORKED EXAMPLE — FROM DAILY SOLAR ENERGY TO PEAK SUN HOURS

A location receives 6.0 kWh/m<sup>2</sup> of solar energy in one day. How many peak sun hours is this?

1. Write the equation:  $\text{PSH} = H \div G_{\text{STC}}$
2. Put in the numbers:  $\text{PSH} = 6.0 \text{ kWh/m}^2 \div 1 \text{ kW/m}^2$
3. Calculate:  $\text{PSH} = 6.0 \text{ hours}$

**Answer: 6.0 peak sun hours**

#### WORKED EXAMPLE — FROM PEAK SUN HOURS TO DAILY SOLAR ENERGY

A location has 4.5 peak sun hours on a winter day. What is the daily solar energy, in kWh/m<sup>2</sup>?

1. Write the equation:  $H = G_{\text{STC}} \times \text{PSH}$
2. Put in the numbers:  $H = 1 \text{ kW/m}^2 \times 4.5 \text{ h}$
3. Calculate:  $H = 4.5 \text{ kWh/m}^2$

**Answer: 4.5 kWh/m<sup>2</sup>**

Here is why peak sun hours matter so much: they let you make a quick estimate of what a real solar array could produce, before you study the full method in later chapters. The same equation works — just replace irradiance with array power.

#### WORKED EXAMPLE — A QUICK ESTIMATE OF ARRAY ENERGY

A 5 kW solar array is installed at a site with an example 5.5 peak sun hours per day. Estimate the array's daily energy production, ignoring losses.

1. Use the same idea: Energy  $\approx$  Array power  $\times$  Peak sun hours
2. Put in the numbers:  $E \approx 5 \text{ kW} \times 5.5 \text{ h}$
3. Calculate:  $E \approx 27.5 \text{ kWh per day}$

**Answer: About 27.5 kWh per day (a first estimate — Chapter 12 adds real-world losses).**

#### COMMON MISTAKE

**X Wrong:** Peak sun hours means the number of hours the Sun is in the sky (sunrise to sunset).

**✓ Right:** Peak sun hours is NOT the same as daylight hours. A place can have 12 hours of daylight but only about 5–6 peak sun hours, because irradiance is low near sunrise and sunset and high only around midday.

► *App tool: Try it: find peak sun hours from daily solar energy, or the other way around*

### 3.3 The Sun's Path and the Seasons

Earth spins once every 24 hours, and this spin makes the Sun appear to move across our sky. Earth also travels around the Sun once a year, tilted on its axis — and this tilt is the real reason we have seasons. This lesson explains both.

#### WORD TO KNOW

**Solar noon** — The moment during the day when the Sun is at its highest point in the sky. It is not always exactly 12:00 on the clock.

#### WORD TO KNOW

**Solar altitude** — The height of the Sun above the horizon, measured in degrees.  $0^\circ$  means the Sun is on the horizon;  $90^\circ$  means it is straight overhead.

Every day, the Sun rises in the east, climbs higher through the morning, reaches its highest point — its solar altitude — at solar noon, then descends and sets in the west. Its exact rising and setting direction, and how high it climbs, both change with the seasons.

#### WORD TO KNOW

**Axial tilt** — The tilt of Earth's spin axis, about  $23.5^\circ$  from straight up. This tilt is the real cause of the seasons.

Earth's axis stays pointed in the same direction as Earth travels around the Sun. Because of this, first the Northern Hemisphere leans toward the Sun, then later in the year it leans away. When your hemisphere leans toward the Sun, the Sun climbs higher in the sky, days grow longer, and you get more solar energy — summer. When it leans away, the Sun stays low, days grow shorter, and you get less solar energy — winter.

#### WORD TO KNOW

**Solstice** — One of the two days in the year when the Sun reaches its highest or lowest noon position in the sky, giving the longest or shortest day of the year.

#### WORD TO KNOW

**Equinox** — One of the two days in the year when day and night are about equal length everywhere on

Earth, and the Sun rises due east and sets due west.

#### EQUATION: SUN'S ALTITUDE AT SOLAR NOON (EQUINOX)

$$\alpha_{\text{noon}} = 90^\circ - \phi$$

*In words: Sun's altitude at solar noon (on the equinox) = 90° – your latitude*

| Symbol                 | Meaning                                                                     | Unit        |
|------------------------|-----------------------------------------------------------------------------|-------------|
| $\alpha_{\text{noon}}$ | the Sun's altitude (height above the horizon) at solar noon, on the equinox | degrees (°) |
| $\phi$                 | your location's latitude, in the Northern Hemisphere                        | degrees (°) |

*This simple rule is exact only on the two equinox days (about 20 March and 22–23 September). On other days the Sun is higher in summer and lower in winter. The sun-position simulation shows this for any date.*

#### WORKED EXAMPLE — SUN'S HEIGHT AT SOLAR NOON IN ERBIL, ON THE EQUINOX

Erbil's latitude is about 36°N. Find the Sun's approximate altitude above the horizon at solar noon on the equinox.

1. Write the equation: altitude = 90° –  $\phi$
2. Put in the number: altitude = 90° – 36°
3. Calculate: altitude = 54°

**Answer: About 54° above the horizon — quite high in the sky.**

#### Erbil's Sun through the year (example altitude and day length)

| Time of year                             | Sun's noon altitude | Approximate day length |
|------------------------------------------|---------------------|------------------------|
| Equinox (~20 March, ~22 September)       | About 54°           | About 12 hours         |
| June solstice (~21 June, summer)         | About 77°           | About 14.5 hours       |
| December solstice (~21 December, winter) | About 30°           | About 9.5 hours        |

#### COMMON MISTAKE

**X Wrong:** Seasons happen because Earth moves closer to the Sun in summer and farther away in winter.

**✓ Right:** Seasons are caused by Earth's 23.5° axial tilt, not by distance. In fact, Earth is slightly closer to the Sun in January (Northern Hemisphere winter) than in July (Northern Hemisphere summer).

#### SAFETY

Never look directly at the Sun, even briefly, and never look at it through a camera, phone screen, or unfiltered lens — it can permanently damage your eyes. Track the Sun's position using shadows and a compass, not by looking at the Sun itself. If you are outside around midday to observe shadows, wear a hat, use sunscreen, and drink water.



### ACTIVITY (FIELD) — TRACK THE SUN'S PATH AT SCHOOL, ACROSS A WEEK

1. Choose one fixed outdoor spot at school with a clear view of the sky, and a fixed pole, flagpole, or stick that makes a shadow.
2. At the same clock time every day for one week (for example, 10:00 and 14:00), mark the length and direction of the shadow on the ground, and note the approximate compass direction of the Sun (never look at the Sun itself).
3. After one week, compare your marks. Did the Sun's position change much? (It should barely change — big seasonal changes take months, not days.)
4. If your course continues into a different season, repeat the activity and compare the two sets of results.

*You need: A compass or phone compass app, A notebook, A fixed pole or stick for shadows*

► *App simulation: Explore the sun-position simulation: see the Sun's path for any date and city*

## 3.4 What Changes the Sunlight We Get (Latitude, Weather, Dust)

You now know what sunlight is and how it moves across the sky. But the amount of sunlight reaching a real place, on a real day, changes a lot. Three big factors control this: latitude, weather, and dust.

### WORD TO KNOW

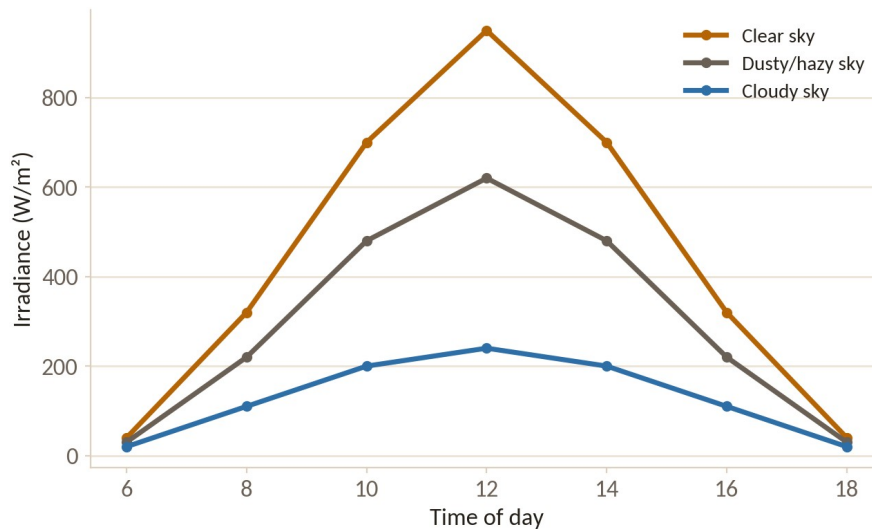
**Latitude** — A location's distance from the equator, measured in degrees, from 0° at the equator to 90° at the poles.

Latitude changes the Sun's average height in the sky, which you studied in Lesson 3. Think of a flashlight pointed straight down at a table — you get a small, bright circle of light. Now tilt the flashlight sideways — the same light spreads over a bigger, dimmer oval. This is what happens when the Sun is low in the sky: the same energy spreads over more ground, so each square meter receives less power. This is one reason why places near the equator often receive strong, direct sunlight all year, while places far from the equator get weaker, more spread-out sunlight, especially in winter.

Weather is the biggest day-to-day cause of change. Clouds reflect and absorb a large part of the sunlight before it reaches the ground. Even thin, hazy cloud can cut irradiance noticeably; thick, dark cloud can cut it by most of its clear-sky value.

### Example irradiance through a day: clear, dusty, and cloudy sky (illustrative)

| Time of day        | Clear sky (W/m <sup>2</sup> ) | Dusty/hazy sky (W/m <sup>2</sup> ) | Cloudy sky (W/m <sup>2</sup> ) |
|--------------------|-------------------------------|------------------------------------|--------------------------------|
| 6:00               | 40                            | 30                                 | 20                             |
| 8:00               | 320                           | 220                                | 110                            |
| 10:00              | 700                           | 480                                | 200                            |
| 12:00 (solar noon) | 950                           | 620                                | 240                            |
| 14:00              | 700                           | 480                                | 200                            |
| 16:00              | 320                           | 220                                | 110                            |
| 18:00              | 40                            | 30                                 | 20                             |



Example irradiance through the day for three conditions: clear sky (tall smooth curve, highest at solar noon), dusty/hazy sky (lower, similar shape), and cloudy sky (much lower and often uneven). Shapes shown are illustrative, not measured data for one specific day.

Dust affects sunlight in two different ways. Dust and sand floating in the air scatter and absorb sunlight before it reaches the ground, so everyone in the area gets less — a dust storm can cut irradiance by half or more for hours or days. Dust also settles on solar panels themselves, sitting on the glass and slowly blocking some of the light that reaches the cells, even on a clear day. You will measure this second effect, and learn cleaning schedules, in Chapter 5.

#### EQUATION: EFFECT OF CLOUDS OR DUST ON SOLAR ENERGY

$$H_{\text{actual}} = H_{\text{clear}} \times (1 - L)$$

In words: Actual solar energy = Clear-sky energy  $\times$  (1 – loss fraction)

| Symbol              | Meaning                                                                          | Unit                              |
|---------------------|----------------------------------------------------------------------------------|-----------------------------------|
| $H_{\text{actual}}$ | the solar energy actually received, with clouds or dust                          | kWh/m <sup>2</sup> /day           |
| $H_{\text{clear}}$  | the solar energy that would be received on a clear day, with no clouds or dust   | kWh/m <sup>2</sup> /day           |
| $L$                 | the fraction of energy lost to clouds or dust, written as a decimal (30% = 0.30) | none — a fraction between 0 and 1 |

This same idea works for irradiance ( $G$ , in W/m<sup>2</sup>, at one moment) or for daily solar energy ( $H$ , in kWh/m<sup>2</sup>/day, for a whole day) — just change which quantity you use.

#### WORKED EXAMPLE — SOLAR ENERGY LOST IN A DUST STORM

A clear-sky day would give 5.5 kWh/m<sup>2</sup> of solar energy. A dust storm reduces this by 40% for the whole day. How much solar energy is actually received?

1. Write the equation:  $H_{\text{actual}} = H_{\text{clear}} \times (1 - L)$
2. Put in the numbers:  $H_{\text{actual}} = 5.5 \times (1 - 0.40)$
3. Calculate:  $H_{\text{actual}} = 5.5 \times 0.60 = 3.3 \text{ kWh/m}^2$

**Answer: 3.3 kWh/m<sup>2</sup> — 2.2 kWh/m<sup>2</sup> less than the clear-sky value.**

#### COMMON MISTAKE

✗ **Wrong:** A place closer to the equator always gets more sunlight over a year than a place farther away.

✓ **Right:** Weather matters as much as latitude. Some places near the equator are cloudy rainforests with a weaker solar resource, while dry desert regions farther from the equator — like much of Iraq and the Kurdistan Region — often have a stronger solar resource because their skies stay clear so much of the year.

#### CASE STUDY — DUST STORMS AND SOLAR POWER · IRAQ AND THE KURDISTAN REGION

Iraq and the wider region are affected by dust storms, especially in spring. In severe events, visibility can fall to a few hundred meters, flights can be delayed or cancelled, and many people need medical care for breathing problems. During a storm like this, solar panel output can fall by half or more, and panels usually need extra cleaning once the storm passes. This is why real solar system designs in this region include a safety margin for dusty and hazy days, not just clear-sky performance.

#### SAFETY

During a dust storm: stay indoors when possible, and keep doors and windows closed. Never climb on a roof to inspect, clean, or repair solar panels during a dust storm or strong wind — wait until conditions are calm and safe, and always use proper fall-protection when working at height (Chapter 17 covers this fully).

### 3.5 Solar Maps of the World, Iraq, and Kurdistan

You now understand what changes sunlight at a location. In this lesson you will see that knowledge applied to real maps — starting with the whole world, then zooming in to Iraq and the Kurdistan Region.

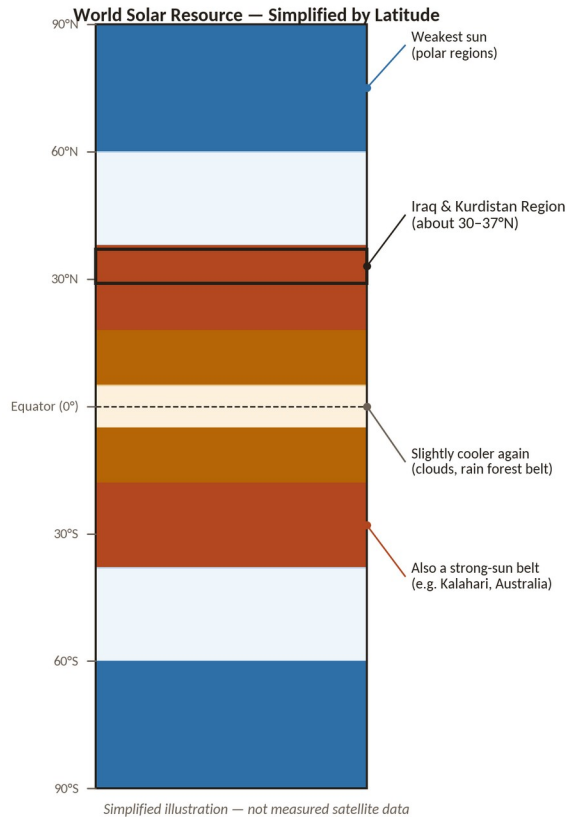
#### WORD TO KNOW

**Solar map** — A map that uses colors to show how much solar energy different places receive, usually averaged over a year.

#### WORD TO KNOW

**Solar resource** — The amount of useful sunlight energy available at a place. A 'strong' solar resource means a place is a good location for solar power.

World solar maps show a clear pattern. Dry, sunny regions with clear skies for most of the year — deserts and semi-desert areas such as the Sahara, the Arabian Peninsula and the wider Middle East, the Australian Outback, and parts of the south-western United States — usually show the strongest solar resource, often more than 2000 kWh/m<sup>2</sup> of solar energy per year. Cloudy equatorial regions, such as tropical rainforests, and high-latitude regions with long winters often show a weaker resource, even though some of them are much closer to the equator.



*A world solar resource map. Warmer colors (red, orange) mark the strongest solar resource — mostly dry, sunny latitudes including the Middle East. Cooler colors (blue, green) mark a weaker resource — cloudy or high-latitude regions.*

Iraq and the Kurdistan Region sit inside this strong band. Clear skies for most of the year, especially in summer, give the region one of the best solar resources in the world — a major reason solar power is growing quickly here, alongside the problems with grid electricity that you learned about in Chapter 1.

#### Example monthly peak sun hours for Erbil (illustrative)

| Month     | Example peak sun hours (h/day) |
|-----------|--------------------------------|
| January   | 3.2                            |
| February  | 3.9                            |
| March     | 5.0                            |
| April     | 5.9                            |
| May       | 6.9                            |
| June      | 7.8                            |
| July      | 7.9                            |
| August    | 7.6                            |
| September | 6.8                            |
| October   | 5.4                            |
| November  | 3.9                            |
| December  | 3.0                            |

### WORKED EXAMPLE — ERBIL'S EXAMPLE ANNUAL AVERAGE PEAK SUN HOURS

Using the monthly table above, find Erbil's example annual average peak sun hours.

1. Add all 12 monthly values:  $3.2+3.9+5.0+5.9+6.9+7.8+7.9+7.6+6.8+5.4+3.9+3.0 = 67.3$
2. Divide by 12 months:  $67.3 \div 12 \approx 5.61$
3. Round sensibly: about 5.6 peak sun hours per day, on average

**Answer: About 5.6 peak sun hours per day (example figure)**

### Example annual-average peak sun hours for five cities (illustrative)

| City         | Approximate latitude | Example annual average peak sun hours |
|--------------|----------------------|---------------------------------------|
| Duhok        | 36.9°N               | 5.5                                   |
| Erbil        | 36.2°N               | 5.6                                   |
| Sulaymaniyah | 35.6°N               | 5.4                                   |
| Baghdad      | 33.3°N               | 5.9                                   |
| Basra        | 30.5°N               | 6.0                                   |

*These monthly and city figures are example numbers for practice, built to show a realistic regional pattern. Real, verified data for these and other cities will be published after the regional data research task, in Chapter 21.*

### WORKED EXAMPLE — COMPARING TWO CITIES: ERBIL AND BASRA

Using the example annual averages above (Erbil 5.6 h, Basra 6.0 h), find the difference in yearly solar energy per square meter between the two cities.

1. Find each city's yearly solar energy per  $\text{m}^2$ : yearly energy = daily solar energy  $\times$  365 days.
2. Erbil:  $5.6 \text{ kWh/m}^2/\text{day} \times 365 = 2044 \text{ kWh/m}^2/\text{year}$
3. Basra:  $6.0 \text{ kWh/m}^2/\text{day} \times 365 = 2190 \text{ kWh/m}^2/\text{year}$
4. Find the difference:  $2190 - 2044 = 146 \text{ kWh/m}^2/\text{year}$  (about 7.1% more in Basra)

**Answer: Basra receives about 146 kWh/m<sup>2</sup>/year more than Erbil in this example — about 7.1% more.**

### CASE STUDY — IRAQ: A SOLAR HOTSPOT ON THE WORLD MAP • IRAQ AND THE KURDISTAN REGION

Global solar resource maps, produced by organizations that track sunlight and weather data worldwide, regularly place Iraq and its neighbors among the sunniest countries on Earth — in the same strong band as the Sahara and the Arabian Peninsula. For a country with a growing population, a hot climate that drives huge electricity demand for cooling, and a national grid that struggles to meet that demand, this is valuable news: the fuel for solar power — strong, reliable sunlight — is already here, essentially free, every clear day of the year.

### ACTIVITY (CLASSROOM) — COMPARE TWO CITIES' SOLAR DATA

1. Choose any two cities from the five-city table in this lesson.

2. Write down their example annual average peak sun hours.
3. Assume the same solar array size (for example, 3 kW) in both cities. Estimate each city's yearly energy production using:  $\text{yearly energy} \approx \text{array power} \times \text{peak sun hours} \times 365$ .
4. Compare your two results. Which city's array produces more energy, and by how much (in kWh and in %)?
5. Discuss: is the difference between these cities large enough to change how you would plan a solar project? Compare this to the difference caused by clouds or dust from Lesson 4.

*You need: The five-city table from this lesson, Calculator or the Peak Sun Hours calculator, Paper and pen*

► *App tool: Compare cities and estimate energy with the Peak Sun Hours calculator*

## CHAPTER SUMMARY

- Solar radiation is energy that travels from the Sun as light and heat. The solar constant is about  $1360 \text{ W/m}^2$ , measured just outside the atmosphere.
- The atmosphere reflects, absorbs, and scatters sunlight. Clear-sky, near-noon irradiance at ground level is about  $1000 \text{ W/m}^2$  — a mix of direct radiation and diffuse radiation.
- Irradiance ( $\text{W/m}^2$ ) is an instant power; daily solar energy ( $\text{kWh/m}^2/\text{day}$ ) is the total for a whole day — the same difference as power and energy in Chapter 1.
- A peak sun hour (PSH) is the equivalent number of hours of standard  $1000 \text{ W/m}^2$  sunlight that gives the same daily energy:  $\text{daily solar energy (kWh/m}^2) = 1 \text{ kW/m}^2 \times \text{peak sun hours}$ .
- Earth's daily spin causes the Sun's path across the sky. Earth's  $23.5^\circ$  axial tilt — not its distance from the Sun — causes the seasons.
- At the equinox, the Sun's noon altitude equals  $90^\circ$  minus your latitude. It is higher in summer and lower in winter, and days are longer in summer.
- Latitude, weather (especially clouds), and dust all change how much sunlight reaches a place — sometimes by 50% or more in a single dust storm.
- Solar maps use color to show the solar resource of different places. Iraq and the Kurdistan Region sit in a strong solar resource band on the world map.
- Example peak sun hour figures for Erbil, Sulaymaniyah, Duhok, Baghdad, and Basra all point to a strong regional solar resource — real, sourced numbers will replace these examples after the Chapter 21 data research.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** The solar energy at a location is  $4.8 \text{ kWh/m}^2$  in one day. How many peak sun hours is this?

**Problem 2 [Basic]** A location has 6.2 peak sun hours in one day in July. Find the daily solar energy, in  $\text{kWh/m}^2$ .

**Problem 3 [Basic]** The solar constant is about  $1360 \text{ W/m}^2$ . On a clear day at solar noon, ground-level irradiance is about  $1000 \text{ W/m}^2$ . About how many  $\text{W/m}^2$  are lost between space and the ground at that moment?

**Problem 4 [Basic]** A test panel measuring  $2 \text{ m}^2$  faces the Sun directly, just outside Earth's atmosphere. Using the solar constant (about  $1360 \text{ W/m}^2$ ), find the power falling on the panel.

**Problem 5 [Standard]** A solar site's latitude is about  $30.5^{\circ}\text{N}$  (close to Basra's latitude). Estimate the Sun's maximum altitude at solar noon on the equinox.

**Problem 6 [Standard]** Using the example annual-average peak sun hours from this chapter (Erbil 5.6 h, Baghdad 5.9 h), find the difference in daily solar energy between the two cities, and express Baghdad's advantage as a percentage of Erbil's value.

**Problem 7 [Standard]** Using the clear-sky and cloudy-sky noon irradiance values from the table in Lesson 4 ( $950 \text{ W/m}^2$  and  $240 \text{ W/m}^2$ ), find the percentage reduction caused by the clouds.

**Problem 8 [Standard]** A 3 kW solar array is installed at a site with an example 5.4 peak sun hours per day. Estimate its daily energy production (ignoring losses), and its energy production over 30 days.

**Problem 9 [Standard]** Using this chapter's example day-length figures for Erbil — about 14.5 hours in June and about 9.5 hours in December — find how many more hours of daylight June has than December, per day and per week (7 days).

**Problem 10 [Challenge]** Using Erbil's example peak sun hours for June (7.8 h), July (7.9 h), and August (7.6 h): (a) find the average peak sun hours for these three months, (b) find the average daily solar energy for the period in  $\text{kWh/m}^2$ , and (c) estimate the total energy a 2 kW array could produce over these three months (92 days), ignoring losses.

**Problem 11 [Challenge]** Using the example annual-average peak sun hours (Erbil 5.6 h, Basra 6.0 h) and an example electricity price of 100 IQD/kWh (as used in Chapter 1): (a) estimate the yearly energy a 5 kWp solar system would produce in each city (ignoring losses), (b) find the difference in kWh per year, and (c) find the value of that difference in IQD per year.

**Problem 12 [Challenge]** A solar water pump in Duhok (latitude about  $36.9^{\circ}\text{N}$ ) needs at least 8 hours of daylight to complete its full daily pumping cycle. Using this chapter's example day-length figures for the region (about 12 h at the equinox, about 14.5 h at the June solstice, about 9.5 h at the December solstice), decide whether the 8-hour requirement is met in each of these three example periods. Which period is the tightest (closest to failing)?

## CHAPTER FOUR

# How Solar Cells Work

*From sunlight to electricity — cells, modules, datasheets, and performance curves*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain the photovoltaic effect in simple words — how sunlight becomes electricity inside a solar cell.
- Describe how solar cells connect into modules, and modules connect into strings and arrays.
- Compare monocrystalline, polycrystalline, and thin-film cells, and calculate efficiency and fill factor.
- Read a solar panel datasheet and explain Voc, Isc, Vmp, Imp, STC, and NOCT.
- Calculate how temperature and sunlight level change a panel's power, using I-V and P-V curves.

## 4.1 The Photovoltaic Effect in Simple Words

In Chapter 3, you learned that sunlight carries energy — we measure it as irradiance, in watts per square meter ( $\text{W}/\text{m}^2$ ). In this lesson, you will learn exactly how a solar cell changes that sunlight into electricity. The idea is called the photovoltaic effect.

### WORD TO KNOW

**Photovoltaic effect** — The way certain materials make electricity directly when light shines on them. 'Photo' means light; 'voltaic' means electricity.

The word 'photovoltaic' comes from two parts: *photo*, from the Greek word for light, and *voltaic*, named after Alessandro Volta, who studied electricity long ago. So 'photovoltaic' simply means 'light-to-electricity'. We often shorten it to **PV**.

### WORD TO KNOW

**Solar cell** — The basic building block that changes sunlight into electricity. Most solar cells are made from a thin slice of silicon. Also called a photovoltaic (PV) cell.

A solar cell is a thin, flat slice of a special material — usually silicon. Silicon comes from sand and is the second most common element in the Earth's crust. Engineers purify it and shape it into thin wafers, only about as thick as a few sheets of paper.

### WORD TO KNOW

**Semiconductor** — A material that conducts electricity better than an insulator (like rubber) but worse than a metal (like copper). Silicon is the semiconductor used in most solar cells.

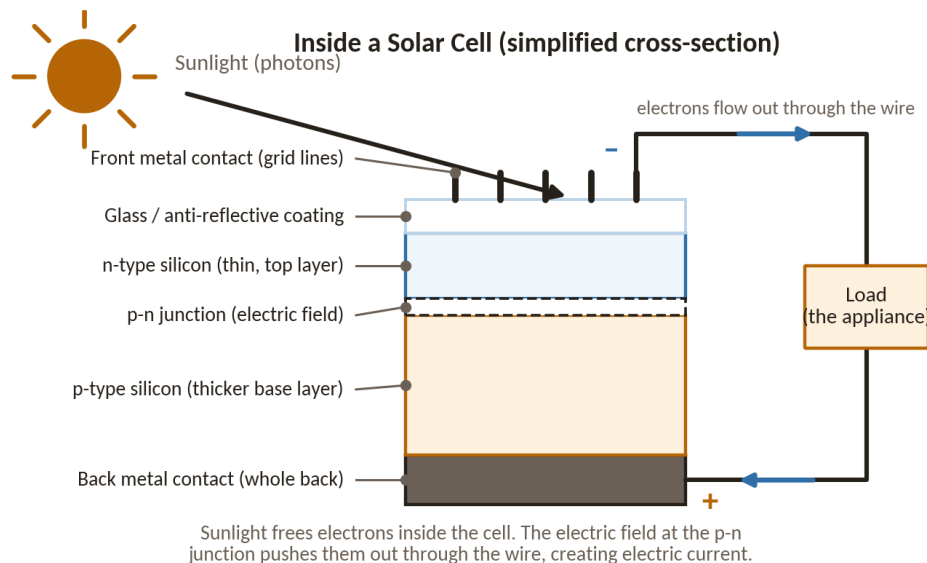
### WORD TO KNOW

**Photon** — A tiny packet of light energy from the sun. Photons hit a solar cell and knock electrons loose,



starting the flow of electricity.

Here is the simple story of what happens inside a solar cell: - Manufacturers treat the silicon so one side has extra free electrons and the other side has 'spaces' missing electrons. This creates a built-in electric field between the two sides. - Sunlight photons enter the cell and strike silicon atoms. - A photon with enough energy knocks an electron loose. - The built-in electric field pushes the loose electron toward one side of the cell. - If a wire connects one side of the cell to the other, the electrons flow through it. This flow of electrons is electric current.



*Sunlight photons enter the cell, free electrons, and the built-in electric field pushes them around an external circuit as current.*

This process makes **direct current (DC)** electricity — the same kind of electricity a battery makes. There are no moving parts, and nothing burns. As long as light keeps hitting the cell, the electrons keep flowing. Later, in Chapter 8, you will learn how an inverter changes this DC electricity into the AC electricity used by most home appliances.

#### **CASE STUDY — FROM A FRENCH LABORATORY TO YOUR ROOFTOP • FRANCE, 1839, AND NEW JERSEY, USA, 1954**

In 1839, a 19-year-old French scientist named Edmond Becquerel noticed something strange in his father's laboratory: shining light on a simple chemical device made a small electric current appear. He had discovered the photovoltaic effect, but nobody could use it yet. It took until 1954 for scientists at Bell Labs in the United States — Daryl Chapin, Calvin Fuller, and Gerald Pearson — to build the first practical silicon solar cell. It was only about 6% efficient, but it proved that sunlight could power real devices. Today's cells are three to four times more efficient, and solar power is one of the fastest-growing energy sources in the world — including here in Iraq and the Kurdistan Region.

#### **COMMON MISTAKE**

**✗ Wrong:** Solar (PV) cells work using the sun's heat, like a solar water heater.

**✓ Right:** Solar cells make electricity from LIGHT, not heat. In fact, too much heat actually reduces how

much electricity a cell produces — you will learn exactly why in Lesson 5.

#### ACTIVITY (HOME) — FIND THE PHOTOVOLTAIC EFFECT IN YOUR OWN LIFE

1. Find a small solar-powered device: a solar calculator, a solar garden light, or a solar phone charger.
2. Cover its solar cell completely with your hand or a book for a few seconds. Watch what happens (the display, light, or charging indicator).
3. Uncover it and let light reach the cell again. Watch what changes.
4. Write one sentence: what did you observe, and how does it show the photovoltaic effect at work?

*You need: A small solar-powered device, Paper and pen*

## 4.2 From Cell to Module to Array

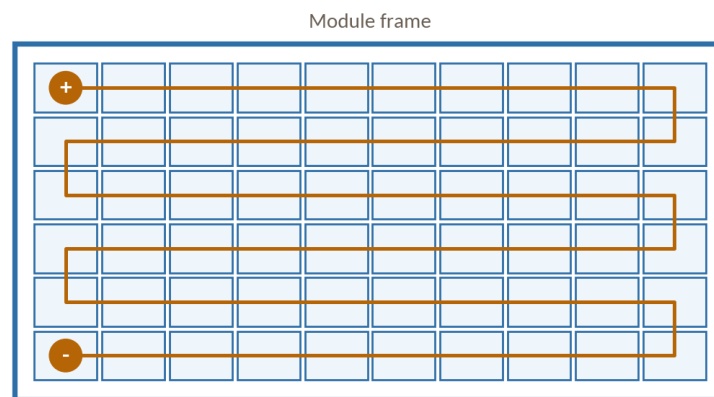
In Lesson 1, you learned that one solar cell produces electricity. But one cell alone is not very useful: its voltage is only about 0.5 to 0.6 volts — far too small to charge a phone or run a light. To get a useful voltage, manufacturers connect many cells together.

#### WORD TO KNOW

**Module** — A group of solar cells connected together, usually in series, and sealed in glass and a frame as one unit. Also called a solar panel.

Most modules made for homes have 60 or 72 cells, arranged in neat rows — for example, 6 rows  $\times$  10 columns = 60 cells. The cells are connected in series, like a row of small batteries joined end to end.

One Solar Module = 60 Cells Wired in Series



The chain's two ends (+ and -) become the module's output wires.

Series wiring adds up each cell's small voltage:  
 $60 \text{ cells} \times \text{about } 0.5\text{--}0.6 \text{ V per cell} \approx 30\text{--}36 \text{ V for the whole module.}$

*60 cells wired in series inside one module. Series wiring adds up the small voltage of each cell.*

When cells are connected in series, their voltages add together, while the current stays the same as one single cell. This is the same series rule you learned for electrical circuits — solar cells simply follow the same electrical rules as any other component.

### EQUATION: MODULE VOLTAGE FROM CELLS IN SERIES

$$V_{oc,m} \approx N \times V_{oc,c}$$

*In words: Module open-circuit voltage = number of cells in series × one cell's open-circuit voltage*

| Symbol            | Meaning                                  | Unit          |
|-------------------|------------------------------------------|---------------|
| N                 | number of cells connected in series      | cells (count) |
| V <sub>oc,c</sub> | open-circuit voltage of one cell         | volts (V)     |
| V <sub>oc,m</sub> | open-circuit voltage of the whole module | volts (V)     |

*This is a simple estimate. Real cells vary slightly, so always use the exact value from the datasheet for real design work.*

### WORKED EXAMPLE — ESTIMATING A MODULE'S VOLTAGE

A module has 60 cells connected in series. Each cell has an open-circuit voltage of about 0.63 V. Estimate the module's open-circuit voltage (V<sub>oc</sub>).

1. Write the equation:  $V_{oc,module} \approx N \times V_{oc,cell}$
2. Put in the numbers:  $V_{oc,module} \approx 60 \times 0.63 \text{ V}$
3. Calculate:  $V_{oc,module} \approx 37.8 \text{ V}$

**Answer: About 37.8 V. (A real datasheet for this module shows 38.0 V — very close. Small differences like this are normal.)**

One module is already useful — small ones can charge a phone or power an LED lamp. But a home or a farm usually needs much more power than one module can give. So installers connect several modules together, the same way cells are connected inside a module.

### WORD TO KNOW

**String** — A group of modules connected together in series (one after another) so their voltages add up.

### WORD TO KNOW

**Array** — Two or more modules — often connected in strings — working together as one power-producing unit.

The rule is the same at every level: **connecting in series adds voltage** (current stays the same); **connecting in parallel adds current** (voltage stays the same). Chapter 5 will teach the full rules for choosing series or parallel, including safety limits. For now, focus on understanding what each connection does.

### EQUATION: STRING VOLTAGE AND CURRENT

$$V_{string} = N_{series} \times V_{module}, \quad I_{string} = I_{module}$$

*In words: String voltage = number of modules in series × one module's voltage. String current = the same as one module's current.*

| Symbol              | Meaning                               | Unit            |
|---------------------|---------------------------------------|-----------------|
| N <sub>series</sub> | number of modules connected in series | modules (count) |

|          |                             |             |
|----------|-----------------------------|-------------|
| V_module | voltage of one module       | volts (V)   |
| I_module | current of one module       | amperes (A) |
| V_string | total voltage of the string | volts (V)   |
| I_string | current of the string       | amperes (A) |

The same idea applies to  $V_{mp}$  and  $I_{mp}$  at the maximum power point, which is what the next two examples use.

#### WORKED EXAMPLE — THREE MODULES IN SERIES

Three EcoRay 260 modules are connected in series. Each module has  $V_{mp} = 31.0\text{ V}$  and  $I_{mp} = 8.4\text{ A}$  at its maximum power point. Find the string's voltage and current.

1. Write the equation:  $V_{\text{string}} = N_{\text{series}} \times V_{\text{module}}$
2. Put in the numbers:  $V_{\text{string}} = 3 \times 31.0\text{ V} = 93.0\text{ V}$
3. Current in series stays the same:  $I_{\text{string}} = 8.4\text{ A}$

**Answer: 93.0 V and 8.4 A**

#### WORKED EXAMPLE — TWO STRINGS IN PARALLEL

Two of the series strings from the last example (each 93.0 V, 8.4 A) are connected in parallel to make one array. Find the array's total voltage, current, and power at maximum power.

1. Voltage stays the same in parallel:  $V_{\text{array}} = 93.0\text{ V}$
2. Current adds in parallel:  $I_{\text{array}} = 2 \times 8.4\text{ A} = 16.8\text{ A}$
3. Power:  $P_{\text{array}} = V_{\text{array}} \times I_{\text{array}} = 93.0 \times 16.8 = 1562.4\text{ W}$

**Answer: 93.0 V, 16.8 A, about 1562 W (six 260 W modules:  $6 \times 260 = 1560\text{ W}$  — matches closely, within normal rounding).**

#### From one cell to a full array (EcoRay 260 example)

| Level      | Example                           | Voltage ( $V_{mp}$ )    | Current ( $I_{mp}$ ) | Power                   |
|------------|-----------------------------------|-------------------------|----------------------|-------------------------|
| One cell   | Inside the module                 | $\approx 0.52\text{ V}$ | 8.4 A                | $\approx 4.4\text{ W}$  |
| One module | 60 cells in series                | 31.0 V                  | 8.4 A                | 260 W                   |
| One string | 3 modules in series               | 93.0 V                  | 8.4 A                | $\approx 780\text{ W}$  |
| One array  | 2 strings in parallel (6 modules) | 93.0 V                  | 16.8 A               | $\approx 1560\text{ W}$ |

#### COMMON MISTAKE

**✗ Wrong:** Connecting the same modules in parallel instead of series gives more total power.

**✓ Right:** Total power is the same either way — power depends on how many modules you have, not how you wire them. The wiring choice (series or parallel) changes the voltage and current, which must match your charge controller or inverter's limits. You will learn how to choose in Chapters 5, 7, and 8.

#### ACTIVITY (CLASSROOM) — COUNT THE CELLS IN A REAL MODULE

1. Find a real solar module, or a clear photo of one (ask your teacher, or search online).
2. Count the rows and columns of cells.
3. Multiply rows  $\times$  columns to find the total number of cells.
4. Check: is it 60, 72, or some other common number? Compare with a classmate's module if possible.

*You need: A real module or a clear photo, Paper and pen*

### 4.3 Types of Solar Cells and Efficiency

Not every solar cell is the same. Manufacturers make cells from different materials and in different ways. Each type has its own efficiency, look, and typical price. This lesson introduces the three main types you will meet in the market.

Remember from Chapter 3: irradiance (symbol  $G$ ) measures the power of sunlight falling on one square meter, in watts per square meter ( $\text{W/m}^2$ ). We will use this idea in every calculation in this lesson.

#### WORD TO KNOW

**Monocrystalline** — A solar cell made from one single, pure silicon crystal. It usually has the highest efficiency and a uniform dark blue or black color.

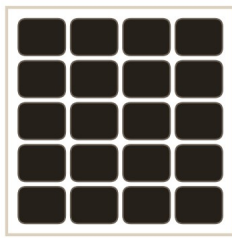
#### WORD TO KNOW

**Polycrystalline** — A solar cell made from many small silicon crystals melted together. It usually costs less than monocrystalline but has slightly lower efficiency.

#### WORD TO KNOW

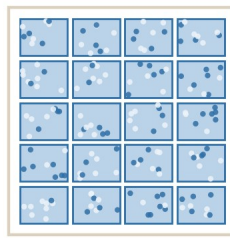
**Thin-film** — A solar cell made by putting a very thin layer of light-absorbing material on a backing, using much less material than crystalline cells. It has lower efficiency but can be light and flexible.

### Three Main Types of Solar Cells



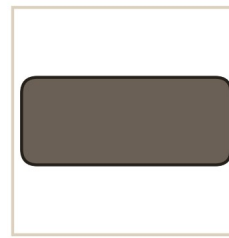
**Monocrystalline**

Highest efficiency



**Polycrystalline**

Mid efficiency,  
lower cost



**Thin-film**

Lowest efficiency —  
light and flexible

Three cell types side by side: monocrystalline (uniform dark, rounded corners), polycrystalline (blue, visible crystal grains), and thin-film (solid dark color, no visible cells).

#### Comparing the three main cell types

| Type            | Typical efficiency | Look                                             | Common use                                     |
|-----------------|--------------------|--------------------------------------------------|------------------------------------------------|
| Monocrystalline | 19–22%             | Uniform dark blue or black, rounded cell corners | Homes and businesses with limited roof space   |
| Polycrystalline | 15–17%             | Blue, visible crystal grain pattern              | Homes and farms with more available space      |
| Thin-film       | 10–13%             | Solid dark color, no visible individual cells    | Large open fields, curved or flexible surfaces |

Whichever type you choose, a cell never changes 100% of the sunlight hitting it into electricity. Some light reflects off the surface, some passes straight through, and some becomes heat. Only part of it becomes electricity — and that part is the cell's efficiency.

#### WORD TO KNOW

**Efficiency** — The percentage of sunlight energy that a solar cell or module changes into electrical energy. Efficiency = electrical power out ÷ sunlight power in, × 100%.

#### EQUATION: SOLAR CELL / MODULE EFFICIENCY

$$\eta = \frac{P_{\max}}{G \times A} \times 100\%$$

In words: Efficiency = maximum electrical power ÷ (irradiance × area) × 100%

| Symbol     | Meaning                                    | Unit                   |
|------------|--------------------------------------------|------------------------|
| $\eta$     | efficiency                                 | percent (%)            |
| $P_{\max}$ | maximum electrical power out               | watts (W)              |
| $G$        | irradiance (sunlight power on the surface) | watts per square meter |

|   |                            |                                 |
|---|----------------------------|---------------------------------|
|   |                            | (W/m <sup>2</sup> )             |
| A | area of the cell or module | square meters (m <sup>2</sup> ) |

For a fair rating, G is usually taken as 1000 W/m<sup>2</sup> — the Standard Test Conditions value you will meet in Lesson 4.

### WORKED EXAMPLE — EFFICIENCY OF A SINGLE CELL

A solar cell measures 0.15 m × 0.15 m. In full sun (1000 W/m<sup>2</sup>), it produces 4.0 W of electrical power. What is its efficiency?

1. Find the cell's area:  $A = 0.15 \text{ m} \times 0.15 \text{ m} = 0.0225 \text{ m}^2$
2. Find the sunlight power hitting it:  $G \times A = 1000 \text{ W/m}^2 \times 0.0225 \text{ m}^2 = 22.5 \text{ W}$
3. Efficiency:  $\eta = P_{\text{max}} \div (G \times A) \times 100 = 4.0 \div 22.5 \times 100$

**Answer: About 17.8%**

► *App tool: Try it: convert between cm<sup>2</sup> and m<sup>2</sup>, or check a percentage calculation*

Efficiency is not the only useful number. Two panels can have the same Voc and Isc but different real performance, because of something called the fill factor.

### WORD TO KNOW

**Fill factor** — A number (0 to 1, or a %) that shows how close a solar cell's real maximum power is to the largest possible value (Voc × Isc). A higher fill factor means a better-quality cell.

### EQUATION: FILL FACTOR

$$FF = \frac{P_{\text{max}}}{V_{\text{oc}} \times I_{\text{sc}}}$$

*In words: Fill factor = maximum power ÷ (open-circuit voltage × short-circuit current)*

| Symbol | Meaning               | Unit                             |
|--------|-----------------------|----------------------------------|
| FF     | fill factor           | ratio, 0 to 1 (often shown as %) |
| Pmax   | maximum power         | watts (W)                        |
| Voc    | open-circuit voltage  | volts (V)                        |
| Isc    | short-circuit current | amperes (A)                      |

Voc and Isc are explained fully in Lesson 4. For now, think of Voc × Isc as the 'largest possible' power if the cell were perfect.

### WORKED EXAMPLE — FINDING THE FILL FACTOR

A cell has Voc = 0.60 V, Isc = 8.0 A, and Pmax = 3.84 W. Find its fill factor.

1. Write the equation:  $FF = P_{\text{max}} \div (V_{\text{oc}} \times I_{\text{sc}})$
2. Multiply the bottom:  $V_{\text{oc}} \times I_{\text{sc}} = 0.60 \times 8.0 = 4.8$
3. Divide:  $FF = 3.84 \div 4.8 = 0.80$

**Answer: 0.80, or 80%**

Good crystalline silicon cells usually have a fill factor between about 0.75 and 0.85 (75–85%). A low fill factor can point to a damaged or poor-quality cell, or a cell that has become hot — another reason heat matters, as you will see in Lesson 5.

#### COMMON MISTAKE

**✗ Wrong:** The panel with the highest efficiency number is always the best choice.

**✓ Right:** Efficiency is only one factor. If roof space is limited, high efficiency matters a lot. If space is not a problem — many farms and flat roofs in Iraq and the Kurdistan Region have plenty of space — a cheaper, lower-efficiency polycrystalline panel can be a perfectly good, more economical choice.

#### ACTIVITY (HOME) — COMPARE PANEL TYPES

1. Search online, or ask a local solar equipment shop, for two or three real panel datasheets.
2. For each panel, write down its type (monocrystalline, polycrystalline, or thin-film) and its efficiency.
3. Compare the efficiencies with the typical ranges in this lesson's table.
4. Which type would you choose for a small city roof? Which for a large farm building? Explain why in one sentence for each.

*You need: Phone or computer with internet, or a paper datasheet, Paper and pen*

## 4.4 Reading a Datasheet (Voc, Isc, Vmp, Imp, STC, NOCT)

Every solar panel comes with a datasheet — a document from the manufacturer listing its exact numbers. Before you buy, design, or install any panel, you must be able to read one. This lesson teaches you the datasheet's vocabulary.

#### WORD TO KNOW

**Datasheet** — A document from the manufacturer that lists a product's technical numbers, such as a solar panel's power, voltage, and current ratings.

Let's look at an example datasheet for a panel we will call the 'EcoRay 260'. (This is an example panel for learning. Its numbers are typical of real 60-cell panels sold today, but always read the real datasheet of the panel you actually buy.)

#### EcoRay 260 — example datasheet (at STC)

| Parameter                                   | Symbol           | Value      |
|---------------------------------------------|------------------|------------|
| Maximum power                               | P <sub>max</sub> | 260 W      |
| Voltage at maximum power                    | V <sub>mp</sub>  | 31.0 V     |
| Current at maximum power                    | I <sub>mp</sub>  | 8.4 A      |
| Open-circuit voltage                        | V <sub>oc</sub>  | 38.0 V     |
| Short-circuit current                       | I <sub>sc</sub>  | 9.00 A     |
| Module efficiency                           | η                | 15.9%      |
| Temperature coefficient of P <sub>max</sub> | γ                | −0.40 %/°C |



| Parameter       | Symbol | Value           |
|-----------------|--------|-----------------|
| NOCT            | —      | 45°C            |
| Number of cells | —      | 60 (6 × 10)     |
| Dimensions      | —      | 1.65 m × 0.99 m |

Notice there are four electrical numbers close together: Voc, Isc, Vmp, and Imp. Let's take them one at a time, because mixing them up is one of the most common beginner mistakes.

#### WORD TO KNOW

**Open-circuit voltage** — The voltage of a solar panel measured when no current is flowing (the circuit is open). Written Voc. It is the panel's maximum possible voltage.

#### WORD TO KNOW

**Short-circuit current** — The current that flows when a solar panel's two terminals are connected directly together, so the voltage is zero. Written Isc. It is the panel's maximum possible current.

Here is the key idea: at Voc, current is zero, so power is zero. At Isc, voltage is zero, so power is also zero! A panel never actually operates at either of these two points. It produces its power somewhere in between, at one special point.

#### WORD TO KNOW

**Maximum power point** — The one point on a solar panel's I-V curve where it produces the most electrical power ( $V \times I$  is largest). Written MPP.

#### WORD TO KNOW

**Voltage at maximum power** — The panel's voltage exactly at the maximum power point. Written Vmp. Always a little less than Voc.

#### WORD TO KNOW

**Current at maximum power** — The panel's current exactly at the maximum power point. Written Imp. Always a little less than Isc.

#### EQUATION: MAXIMUM POWER FROM VMP AND IMP

$$P_{\max} = V_{\text{mp}} \times I_{\text{mp}}$$

*In words: Maximum power = voltage at maximum power × current at maximum power*

| Symbol | Meaning                                       | Unit        |
|--------|-----------------------------------------------|-------------|
| Pmax   | maximum power (also called peak power, or Wp) | watts (W)   |
| Vmp    | voltage at maximum power                      | volts (V)   |
| Imp    | current at maximum power                      | amperes (A) |

Manufacturers round  $P_{max}$  to a whole number for the panel's name (for example, '260 W'). The exact product  $V_{mp} \times I_{mp}$  from the datasheet may come out a little different, just from rounding.

#### WORKED EXAMPLE — CHECKING $P_{MAX}$ AGAINST THE NAMEPLATE

Using the EcoRay 260 datasheet,  $V_{mp} = 31.0$  V and  $I_{mp} = 8.4$  A. Calculate  $P_{max}$  and compare it to the nameplate rating.

1. Write the equation:  $P_{max} = V_{mp} \times I_{mp}$
2. Put in the numbers:  $P_{max} = 31.0 \text{ V} \times 8.4 \text{ A}$
3. Calculate:  $P_{max} = 260.4 \text{ W}$

**Answer: 260.4 W — matches the 260 W nameplate rating within normal rounding.**

#### COMMON MISTAKE

**✗ Wrong:** My panel's  $V_{oc}$  is 38.0 V, so during normal operation it makes 38.0 V.

**✓ Right:**  $V_{oc}$  is measured with NO current flowing — it is the maximum possible voltage, not the normal operating voltage. When the panel is connected and working, its voltage sits close to  $V_{mp}$  (about 31.0 V for the EcoRay 260), noticeably less than  $V_{oc}$ .

One more question: under what conditions are  $P_{max}$ ,  $V_{mp}$ ,  $I_{mp}$ ,  $V_{oc}$ , and  $I_{sc}$  measured? Every datasheet uses the same fixed testing rule, so panels from different manufacturers can be fairly compared.

#### WORD TO KNOW

**Standard test conditions** — The fixed conditions used to test and rate every solar panel: 1000 W/m<sup>2</sup> of sunlight, 25°C cell temperature, and a standard sunlight spectrum (AM1.5). Written STC.

STC uses a cell temperature of 25°C. But a real panel outdoors, in real sunlight, is almost never exactly 25°C — it is often much hotter. To estimate a more realistic operating temperature, manufacturers give a second rating: NOCT.

#### WORD TO KNOW

**Nominal operating cell temperature** — The cell temperature a panel reaches under a more realistic outdoor test: 800 W/m<sup>2</sup> sunlight, 20°C air temperature, and 1 m/s wind, with the panel at open circuit. Written NOCT. It helps estimate real operating temperature.

#### EQUATION: ESTIMATING CELL TEMPERATURE FROM NOCT

$$T_{\text{cell}} = T_{\text{ambient}} + \frac{\text{NOCT} - 20}{800} \times G$$

*In words: Cell temperature = air temperature + [(NOCT - 20) ÷ 800] × irradiance*

| Symbol               | Meaning                    | Unit                 |
|----------------------|----------------------------|----------------------|
| $T_{\text{cell}}$    | estimated cell temperature | degrees Celsius (°C) |
| $T_{\text{ambient}}$ | outdoor air temperature    | degrees Celsius (°C) |

|      |                                            |                                            |
|------|--------------------------------------------|--------------------------------------------|
| NOCT | the panel's NOCT rating from its datasheet | degrees Celsius (°C)                       |
| G    | actual irradiance at the time              | watts per square meter (W/m <sup>2</sup> ) |

The 20 and 800 in this formula come directly from the NOCT test conditions (20°C air, 800 W/m<sup>2</sup>). This formula gives a useful estimate, not an exact measurement.

#### WORKED EXAMPLE — CELL TEMPERATURE ON A HOT AFTERNOON

The EcoRay 260 has NOCT = 45°C. On a summer afternoon in Erbil, the air temperature is 45°C and the irradiance is 800 W/m<sup>2</sup>. Estimate the cell temperature.

1. Write the equation:  $T_{\text{cell}} = T_{\text{ambient}} + [(NOCT - 20) \div 800] \times G$
2. Find the bracket:  $(45 - 20) \div 800 = 25 \div 800 = 0.03125$
3. Multiply by G:  $0.03125 \times 800 = 25^\circ\text{C}$
4. Add the air temperature:  $45 + 25 = 70^\circ\text{C}$

**Answer: About 70°C — 45°C hotter than the 25°C STC rating condition.**

#### WORD TO KNOW

**Temperature coefficient** — A number, usually a small negative percentage per °C, that shows how much a solar panel's power drops for every 1°C rise in cell temperature above 25°C.

A cell temperature of 70°C is very common on a rooftop panel in an Iraqi or Kurdistan Region summer. What does that do to the power output? Lesson 5 answers this question exactly, using the temperature coefficient.

► *App simulation: Try it: change sunlight and temperature and watch Voc, Isc, Vmp, and Imp move on a live I-V curve*

#### SAFETY

Never touch both terminals of a panel, or short-circuit a panel or string, with bare hands or a metal tool — even a small panel in full sun can give a shock or spark, and a full-size panel or string can push enough current to cause burns or weld a tool to the terminals. To measure Isc safely, set a multimeter correctly to DC amps, and only test small, low-power educational panels this way. Never test a full-size array like this — use a clamp meter or proper PV test equipment instead.

#### ACTIVITY (HOME) — READ A REAL DATASHEET

1. Find a real solar panel datasheet (from a local shop, a manufacturer's website, or your teacher).
2. Find and write down these six values: Pmax, Vmp, Imp, Voc, Isc, and the temperature coefficient of Pmax.
3. Find the NOCT value if it is listed.
4. Calculate the panel's efficiency from its Pmax and its dimensions, using the equation from Lesson 3.

*You need: A real panel datasheet (paper or online), Calculator or phone, Paper and pen*

#### ACTIVITY (LABORATORY) — MEASURE VOC AND ISC OF A SMALL PANEL

1. Take a small, low-power solar panel (such as an educational or hobby panel) outdoors into direct

sunlight.

2. Set a multimeter to DC volts. Connect it across the panel's two terminals with nothing else connected. Read the voltage — this is your measured Voc.
3. Set the multimeter to DC amps (check its current rating first). Connect it directly across the terminals for a moment. Read the current — this is your measured Isc.
4. Compare your measured values with the panel's rated Voc and Isc. Are they the same? Explain any difference using what you learned about STC.

*You need: A small, low-power solar panel, A multimeter, Direct sunlight*

## 4.5 How Temperature and Sunlight Change Performance (I-V and P-V curves)

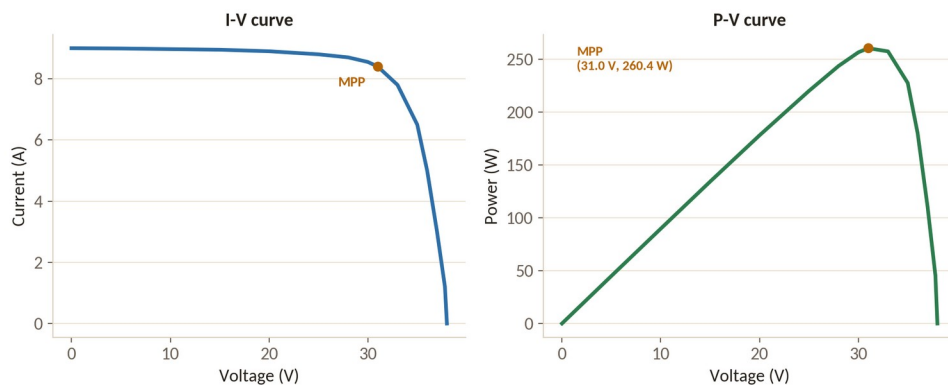
In Lesson 4, you learned four key points of a panel's behavior: Isc, Voc, and the maximum power point (Vmp, Imp). But a real panel does not just have four points — it has a whole curve of possible voltage and current pairs. This lesson shows you the full picture, and how weather changes it.

### WORD TO KNOW

**I-v curve** — A graph of a solar panel's current (I) against its voltage (V), from short circuit (Isc) to open circuit (Voc). It shows how the panel behaves at every possible operating point.

### WORD TO KNOW

**P-v curve** — A graph of a solar panel's power (P) against its voltage (V). It rises to one peak at the maximum power point, then falls.



*The I-V curve (left) stays almost flat near Isc, then bends and drops sharply to zero at Voc. The P-V curve (right) rises to one peak at the maximum power point (MPP), then falls to zero at Voc.*

### I-V and P-V data for the EcoRay 260 at STC (1000 W/m<sup>2</sup>, 25°C)

| Voltage V (volts) | Current I (amps) | Power P = V × I (watts) |
|-------------------|------------------|-------------------------|
| 0.0               | 9.00             | 0.00                    |
| 5.0               | 8.99             | 44.95                   |
| 10.0              | 8.97             | 89.70                   |
| 15.0              | 8.95             | 134.25                  |

| Voltage V (volts) | Current I (amps) | Power P = V × I (watts) |
|-------------------|------------------|-------------------------|
| 20.0              | 8.90             | 178.00                  |
| 25.0              | 8.80             | 220.00                  |
| 28.0              | 8.70             | 243.60                  |
| 30.0              | 8.55             | 256.50                  |
| 31.0 (Vmp)        | 8.40 (Imp)       | 260.40 (Pmax)           |
| 33.0              | 7.80             | 257.40                  |
| 35.0              | 6.50             | 227.50                  |
| 36.0              | 5.00             | 180.00                  |
| 37.0              | 3.00             | 111.00                  |
| 37.8              | 1.20             | 45.36                   |
| 38.0 (Voc)        | 0.00             | 0.00                    |

To plot the I-V curve, put voltage (V) on the horizontal axis and current (I) on the vertical axis, then mark each pair of numbers from the table and join them with a smooth line. To plot the P-V curve, use the same voltage values but put power (P) on the vertical axis. Notice the shape: current stays almost flat for a while, then drops fast near Voc; power climbs to a single peak at the MPP (31.0 V, 260.4 W), then falls back to zero.

#### ACTIVITY (CLASSROOM) — PLOT THE CURVES BY HAND

1. Draw two empty graphs on graph paper: one with V on the x-axis and I on the y-axis, and one with V on the x-axis and P on the y-axis.
2. Using the table in this lesson, plot every (V, I) point on the first graph and every (V, P) point on the second graph.
3. Join the points with a smooth curve on each graph.
4. Mark Isc and Voc on the I-V curve. Mark the maximum power point (MPP) on both curves.

*You need: Graph paper, Pencil and ruler, The data table from this lesson*

The curve you just plotted is only true for ONE set of conditions: 1000 W/m<sup>2</sup> of sunlight and 25°C cell temperature (STC). Change either one, and the curve moves. Let's see how.

#### How irradiance changes the curve (cell temperature held at 25°C)

| Irradiance G (W/m <sup>2</sup> ) | Isc (A) | Voc (V) | Pmax (W) | Pmax as % of STC |
|----------------------------------|---------|---------|----------|------------------|
| 1000 (full sun, STC)             | 9.00    | 38.0    | 260      | 100%             |
| 800                              | 7.20    | 37.6    | 206      | 79%              |
| 600                              | 5.40    | 37.0    | 152      | 58%              |
| 400                              | 3.60    | 36.2    | 99       | 38%              |
| 200                              | 1.80    | 34.8    | 48       | 18%              |

Look at the pattern: Isc changes A LOT with sunlight — it is almost exactly proportional to irradiance (drop the sunlight to 20%, and Isc drops to almost exactly 20%). Voc changes only a LITTLE — even at 200 W/m<sup>2</sup> (one-fifth

of full sun), Voc is still 34.8 V, not far below 38.0 V. Because power depends on both, Pmax drops roughly in proportion to sunlight, but a little faster, because Voc also falls a small amount.

Now for the second, and often more surprising, effect: temperature. This matters enormously in Iraq and the Kurdistan Region, where summer temperatures are extreme.

#### How cell temperature changes the curve (irradiance held at 1000 W/m²)

| Cell temperature (°C) | Voc (V) | Isc (A) | Pmax (W) | Pmax as % of STC |
|-----------------------|---------|---------|----------|------------------|
| 25 (STC)              | 38.0    | 9.00    | 260      | 100%             |
| 45                    | 35.6    | 9.02    | 239      | 92%              |
| 65                    | 33.1    | 9.04    | 218      | 84%              |
| 75                    | 31.9    | 9.05    | 208      | 80%              |

This time the pattern is almost the opposite: Isc barely changes with temperature — it even rises very slightly. But Voc falls a lot as the cell gets hotter. Since power depends on both, and the Voc drop is bigger, **Pmax falls as the cell gets hotter**. A hot solar cell is a weaker solar cell.

#### EQUATION: TEMPERATURE COEFFICIENT OF POWER

$$P_{\max}(T) = P_{\max}(\text{STC}) \times \left[ 1 + \frac{\gamma}{100} \times (T_{\text{cell}} - 25) \right]$$

*In words: Power at temperature T = Power at STC × [1 + (temperature coefficient ÷ 100) × (cell temperature – 25°C)]*

| Symbol    | Meaning                                                                                    | Unit                              |
|-----------|--------------------------------------------------------------------------------------------|-----------------------------------|
| Pmax(T)   | maximum power at the actual cell temperature                                               | watts (W)                         |
| Pmax(STC) | maximum power rated at STC (25°C)                                                          | watts (W)                         |
| γ         | temperature coefficient of power, from the datasheet (a negative number for silicon cells) | percent per degree Celsius (°/°C) |
| Tcell     | actual cell temperature                                                                    | degrees Celsius (°C)              |

*Because γ is negative, the bracket becomes smaller than 1 whenever the cell is hotter than 25°C, so Pmax(T) comes out lower than Pmax(STC).*

#### WORKED EXAMPLE — POWER LOSS ON A HOT ERBIL AFTERNOON

In Lesson 4, we estimated the EcoRay 260's cell temperature at 70°C on a hot Erbil afternoon (NOCT = 45°C, air temperature 45°C, irradiance 800 W/m²). Its temperature coefficient of Pmax is –0.40%/°C. Assuming full 1000 W/m² sun for this comparison, find the power output at 70°C.

1. Find the temperature difference:  $T_{\text{cell}} - 25 = 70 - 25 = 45^\circ\text{C}$
2. Find the percentage change:  $\gamma \times 45 = -0.40\% \times 45 = -18\%$
3. Apply the formula:  $P_{\max}(70^\circ\text{C}) = 260 \text{ W} \times (1 - 0.18) = 260 \times 0.82$

**Answer: 213.2 W — an 18% loss compared to the 260 W STC rating, from heat alone.**

#### CASE STUDY — WHY PANELS RARELY REACH THEIR 'RATED' POWER ON A SUMMER AFTERNOON · IRAQ AND THE KURDISTAN REGION

Cities like Erbil, Duhok, Sulaimani, Baghdad, and Basra enjoy outstanding sunshine — often more than 3000

hours of sunshine a year, with summer irradiance regularly reaching or exceeding  $1000 \text{ W/m}^2$  around midday. This is excellent news for solar energy. But it comes with a challenge: summer air temperatures often reach  $45\text{--}50^\circ\text{C}$ , and a panel mounted flat on a hot roof, with poor airflow behind it, can reach a cell temperature of  $65\text{--}75^\circ\text{C}$  or more. As you calculated above, that kind of heat can cost a panel 15–20% of its rated power, even while the sun is shining at full strength. The good news: the region's very high total annual irradiance more than makes up for this summer heat penalty over the whole year — which is exactly why solar energy performs so well here overall. Two practical lessons follow: (1) mount panels with an air gap underneath, so wind can cool the back of the panel, instead of fixing them flat against a hot roof; and (2) when comparing two similar panels, the one with the smaller (less negative) temperature coefficient will lose less power on hot days — a genuinely useful number to check on the datasheet, not just  $P_{\text{max}}$ .

### SAFETY

On a summer afternoon, a dark panel surface can reach  $70\text{--}80^\circ\text{C}$  or more — hot enough to burn skin on contact. Avoid touching panel surfaces, frames, or mounting hardware with bare hands during the hottest part of the day. If you must work on a hot array, do it early morning or evening, wear gloves, and let equipment cool before touching metal parts.

### COMMON MISTAKE

**✗ Wrong:** Strong sunshine always means strong panel output.

**✓ Right:** Strong sunshine (high irradiance) increases current, which raises power — but strong sunshine also usually means high heat, which lowers voltage and reduces power. The two effects pull in opposite directions. This is why a panel's single highest-output moment of the year is often a bright, cool day in spring, not the hottest day of summer.

► *App simulation: Try it: move the sunlight and temperature sliders and watch the I-V and P-V curves stretch and shrink*

You can now do more than just describe a solar cell — you can read its datasheet, estimate its output under real conditions, and explain why performance changes hour by hour and season by season. Chapter 5 builds directly on this: choosing panels, aiming them at the sun, and connecting them into a working array.

### CHAPTER SUMMARY

- The photovoltaic effect changes sunlight (photons) directly into DC electricity inside a semiconductor, usually silicon — no moving parts, no burning fuel.
- One solar cell makes only a small voltage (about  $0.5\text{--}0.6 \text{ V}$ ), so cells are connected in series inside a module to add up to a useful voltage.
- Connecting modules in series adds voltage; connecting modules in parallel adds current. Strings and arrays are built this way.
- The three common cell types are monocrystalline (highest efficiency), polycrystalline (mid efficiency, often lower cost), and thin-film (lowest efficiency, light and sometimes flexible).
- Efficiency = electrical power out  $\div$  sunlight power in ( $\eta = P_{\text{max}} \div (G \times A)$ ). Fill factor compares the real  $P_{\text{max}}$  to the 'ideal'  $V_{\text{oc}} \times I_{\text{sc}}$ .
- A datasheet's key numbers are  $V_{\text{oc}}$  and  $I_{\text{sc}}$  (the two extreme points, where power is actually zero) and  $V_{\text{mp}}$  and  $I_{\text{mp}}$  (the maximum power point, where the panel really operates).
- STC ( $1000 \text{ W/m}^2$ ,  $25^\circ\text{C}$  cell, AM1.5) is the standard every panel is rated by. NOCT estimates a more

realistic outdoor cell temperature.

- The I-V curve stays nearly flat until close to  $V_{oc}$ , then drops sharply. The P-V curve rises to one peak at the maximum power point, then falls.
- Higher irradiance increases current a lot, and power roughly with it. Higher temperature reduces voltage, and therefore power — heat is the enemy of solar cell output.
- In Iraq and the Kurdistan Region, strong sun is a big advantage, but summer heat can cut panel output by 15–20% — good system design plans for both.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A solar cell measures  $0.15\text{ m} \times 0.15\text{ m}$ . In full sun ( $1000\text{ W/m}^2$ ), it produces  $3.6\text{ W}$  of electrical power. What is its efficiency, in %?

**Problem 2 [Basic]** A small module has 36 cells connected in series. Each cell has an open-circuit voltage of about  $0.60\text{ V}$ . Estimate the module's open-circuit voltage ( $V_{oc}$ ).

**Problem 3 [Basic]** You need a small array with about  $500\text{ W}$  of power. If you use modules rated  $100\text{ Wp}$  each, how many modules do you need?

**Problem 4 [Basic]** A panel is rated  $100\text{ W}$  at STC. Its temperature coefficient of  $P_{max}$  is  $-0.45\%/^{\circ}\text{C}$ . If the cell temperature rises to  $35^{\circ}\text{C}$  ( $10^{\circ}\text{C}$  above the  $25^{\circ}\text{C}$  STC reference), by how many watts does the power drop?

**Problem 5 [Standard]** A module's datasheet shows:  $V_{oc} = 36.0\text{ V}$ ,  $I_{sc} = 8.80\text{ A}$ ,  $P_{max} = 245\text{ W}$ . Find the fill factor (FF), as a percentage.

**Problem 6 [Standard]** A module is rated  $250\text{ W}$  ( $P_{max}$ ) at STC and measures  $1.64\text{ m} \times 0.99\text{ m}$ . What is its efficiency?

**Problem 7 [Standard]** A designer wants a string voltage as close as possible to  $150\text{ V}$ , but NOT more than  $150\text{ V}$ , using modules with  $V_{mp} = 32.0\text{ V}$ . How many modules should be connected in series? What is the exact string voltage?

**Problem 8 [Standard]** An 'EcoRay 300' panel is rated  $300\text{ W}$  at STC. Its temperature coefficient of  $P_{max}$  is  $-0.38\%/^{\circ}\text{C}$ . On a hot day in Basra, the cell temperature reaches  $68^{\circ}\text{C}$ . Assuming full  $1000\text{ W/m}^2$  sunshine, what is the panel's power output?

**Problem 9 [Standard]** For a panel with  $\text{NOCT} = 44^{\circ}\text{C}$ , estimate the cell temperature when the ambient air temperature is  $38^{\circ}\text{C}$  and the irradiance is  $700\text{ W/m}^2$ .

**Problem 10 [Standard]** A designer connects 4 modules in series to form one string (each module:  $V_{mp} = 30.5\text{ V}$ ,  $I_{mp} = 8.2\text{ A}$ ). Two identical strings are connected in parallel. Find: (a) the string voltage, (b) the array's total current, (c) the array's total power at maximum power point.

**Problem 11 [Challenge]** An 'EcoRay 400' module is rated  $P_{max} = 400\text{ W}$  at STC, measures  $1.90\text{ m} \times 1.05\text{ m}$ , and has a temperature coefficient of  $P_{max}$  of  $-0.35\%/^{\circ}\text{C}$ . (a) Find its efficiency at STC. (b) On a summer afternoon, the irradiance is  $850\text{ W/m}^2$  and the cell temperature reaches  $63^{\circ}\text{C}$ . Estimate the actual power output. (Assume power scales directly with irradiance, then apply the temperature correction.)



**Problem 12 [Challenge]** A manufacturer states a cell has  $V_{oc} = 0.65 \text{ V}$  and  $I_{sc} = 9.50 \text{ A}$ , with a fill factor of 0.80. The cell's area is  $243 \text{ cm}^2$  ( $0.0243 \text{ m}^2$ ). (a) Estimate the cell's maximum power ( $P_{max}$ ). (b) Estimate its efficiency at STC ( $1000 \text{ W/m}^2$ ).

**Problem 13 [Challenge]** A family in Duhok needs a  $3000 \text{ W}$  ( $3 \text{ kW}$ ) array. Option A: monocrystalline modules rated  $400 \text{ W}$  each,  $1.95 \text{ m}^2$  per module. Option B: polycrystalline modules rated  $330 \text{ W}$  each,  $1.94 \text{ m}^2$  per module. (a) How many modules of each type are needed (round up to a whole module)? (b) What total roof area does each option need? (c) Which option needs less roof area, and by how much?

## CHAPTER FIVE

# Solar Panels in Practice

*Choosing, aiming, connecting, and mounting real panels*

### IN THIS CHAPTER YOU WILL LEARN TO

- Compare solar panel datasheets and choose panels using efficiency, electrical ratings, and cost per watt.
- Recommend a panel orientation and tilt angle for a site, using its latitude.
- Explain how shading and dust reduce panel output, and estimate power loss from soiling.
- Calculate the voltage, current, and power of panels connected in series and parallel.
- Describe the main ways solar panels are mounted, and the safety points to check first.

## 5.1 Choosing and Comparing Panels

Chapter 4 explained how a solar cell works and what its key numbers mean. Now it is time to use that knowledge. Shops and suppliers sell many brands and types of panels. This lesson shows you how to read a real datasheet and compare panels fairly, instead of choosing by brand name or price alone.

### WORD TO KNOW

**Datasheet** — A document from the panel's manufacturer that lists its electrical, mechanical, and warranty specifications, so buyers can compare panels fairly.

Most panels sold today use one of three cell technologies. Each one looks different and performs a little differently.

### WORD TO KNOW

**Monocrystalline** — A solar cell type cut from a single silicon crystal. It has a uniform dark blue-black or black color, and it usually has the highest efficiency of the common cell types.

### WORD TO KNOW

**Polycrystalline** — A solar cell type made from many small silicon crystals melted together. It looks blue with a speckled pattern, and it is usually a little less efficient than monocrystalline, but often cheaper.

### WORD TO KNOW

**Thin-film** — A solar panel made by putting a very thin layer of light-absorbing material onto a backing, instead of using thick silicon wafers. It is light and sometimes flexible, but usually less efficient, so it needs more area for the same power.

Comparing the three main cell types

| Cell type       | Typical efficiency (example range) | Look                                                     | Common use                                                              |
|-----------------|------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------|
| Monocrystalline | 19–22%                             | Uniform dark black or blue; rounded corners on each cell | Roofs with limited space; the most common choice today                  |
| Polycrystalline | 15–18%                             | Blue with a speckled pattern; square cells               | Larger roofs and ground mounts with more space; often lower cost        |
| Thin-film       | 10–13%                             | Dark and smooth; sometimes flexible                      | Special cases: curved surfaces, very light structures, large open areas |

Before comparing two real datasheets, you need to know what their key numbers mean. Every datasheet reports its main numbers at one fixed test condition, so that any two panels can be compared fairly.

#### WORD TO KNOW

**Standard test conditions** — The fixed conditions used in a factory to measure and compare every panel: sunlight of  $1000 \text{ W/m}^2$ , cell temperature of  $25^\circ\text{C}$ , and a standard light spectrum. Written STC. All the main numbers on a datasheet are measured at STC.

#### WORD TO KNOW

**Rated power** — The panel's power output at standard test conditions, in watts (W) or watt-peak (Wp). Written Pmax. This is the number used in a panel's name, like a '450 W panel'.

#### WORD TO KNOW

**Open-circuit voltage** — The voltage a panel produces when it is not connected to any load, so no current flows. Written Voc. It is the highest voltage the panel can produce.

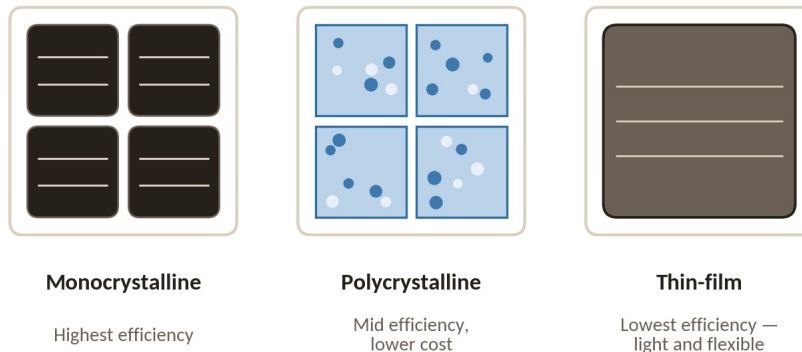
#### WORD TO KNOW

**Short-circuit current** — The current a panel produces when its two terminals are connected directly together, so the voltage is zero. Written Isc. It is the highest current the panel can produce.

#### WORD TO KNOW

**Maximum power point** — The exact combination of voltage and current where a panel produces its highest power. Written MPP. The voltage there is called Vmp and the current is called Imp.

### A Closer Look: Cell Surface Textures



Close-up look of the three main cell types side by side: monocrystalline (uniform dark), polycrystalline (speckled blue), and thin-film (smooth dark layer).

### Two example datasheets, used for practice in this chapter

| Specification                   | Panel A — Monocrystalline  | Panel B — Polycrystalline  |
|---------------------------------|----------------------------|----------------------------|
| Rated power (Pmax)              | 450 W                      | 330 W                      |
| Efficiency                      | ≈20.7%                     | ≈17.0%                     |
| Open-circuit voltage (Voc)      | 49.5 V                     | 46.0 V                     |
| Short-circuit current (Isc)     | 11.58 A                    | 9.35 A                     |
| Voltage at max power (Vmp)      | 41.5 V                     | 37.6 V                     |
| Current at max power (Imp)      | 10.85 A                    | 8.78 A                     |
| Temperature coefficient of Pmax | −0.35 %/°C                 | −0.41 %/°C                 |
| Size (length × width)           | 2.094 m × 1.038 m          | 1.960 m × 0.992 m          |
| Weight                          | 22.5 kg                    | 21.5 kg                    |
| Product warranty                | 12 years                   | 10 years                   |
| Performance warranty            | 25 years (≥ 84.8% of Pmax) | 25 years (≥ 80.7% of Pmax) |

Two more rows deserve a quick note. The **temperature coefficient** tells us how much power drops for every 1°C above 25°C — a smaller (less negative) number is better in a hot climate like Iraq's. Chapter 4 explains this fully. A **product warranty** covers build defects; a **performance warranty** promises the panel will still make most of its rated power after many years (here, at least 84.8% or 80.7% after 25 years).

### EQUATION: PANEL EFFICIENCY

$$\eta = \frac{P_{\max}}{A \times 1000} \times 100$$

In words: Efficiency (%) = Rated power ÷ (Panel area × 1000 W/m<sup>2</sup>) × 100

| Symbol | Meaning | Unit |
|--------|---------|------|
|--------|---------|------|

|            |             |                                 |
|------------|-------------|---------------------------------|
| $\eta$     | efficiency  | % (percent)                     |
| $P_{\max}$ | rated power | watts (W)                       |
| A          | panel area  | square meters (m <sup>2</sup> ) |

1000 W/m<sup>2</sup> is the standard test sunlight level. This equation just checks how much of that sunlight energy the panel turns into electricity.

#### WORKED EXAMPLE — CHECKING PANEL B'S EFFICIENCY

Panel B measures 1.960 m × 0.992 m and is rated 330 W. Use the efficiency equation to check the 17.0% value on its datasheet.

1. Find the area:  $A = 1.960 \times 0.992 \approx 1.94 \text{ m}^2$
2. Write the equation:  $\eta = P_{\max} \div (A \times 1000) \times 100$
3. Put in the numbers:  $\eta = 330 \div (1.94 \times 1000) \times 100$
4. Calculate:  $\eta = 330 \div 1940 \times 100 \approx 17.0\%$

**Answer:  $\approx 17.0\%$  — matches the datasheet.**

#### WORD TO KNOW

**Cost per watt** — The price of a panel divided by its rated power. It helps compare the value of different panels, in money per watt (for example, \$/W).

#### EQUATION: COST PER WATT

$$C_w = \frac{\text{Price}}{P_{\max}}$$

*In words: Cost per watt = Price ÷ Rated power*

| Symbol     | Meaning           | Unit                                  |
|------------|-------------------|---------------------------------------|
| CW         | cost per watt     | currency per watt (for example, \$/W) |
| Price      | the panel's price | currency (for example, \$)            |
| $P_{\max}$ | rated power       | watts (W)                             |

*Use this only to compare panels sold in the same currency, at the same time and place.*

#### WORKED EXAMPLE — COST PER WATT: PANEL A VS. PANEL B

A shop sells Panel A for \$148.50 and Panel B for \$92.40 (example prices, for practice). Find the cost per watt of each, and say which one is the better deal by this measure alone.

1. Panel A:  $CW = \text{Price} \div P_{\max} = \$148.50 \div 450 \text{ W} = \$0.33/\text{W}$
2. Panel B:  $CW = \$92.40 \div 330 \text{ W} = \$0.28/\text{W}$
3. Compare: \$0.28/W is lower than \$0.33/W

**Answer: Panel B costs less per watt (\$0.28/W vs. \$0.33/W).**

But cost per watt is not the whole story. Panel A is more efficient, so it makes more power from the same roof area. If your roof space is limited, the more expensive, more efficient panel can still be the better choice — Chapter 4's efficiency idea and this lesson's cost idea must be weighed together, not used alone.

#### CASE STUDY — EFFICIENCY VS. SPACE ON A SMALL ROOF • ERBIL, KURDISTAN REGION (EXAMPLE FIGURES)

A shop owner in Erbil has only 20 m<sup>2</sup> of usable flat roof space, after leaving room for the water tank and a walkway. Using Panel B (330 W, ≈1.94 m<sup>2</sup> each), about 10 panels fit — a system of roughly 3.3 kW. Using Panel A (450 W, ≈2.17 m<sup>2</sup> each), only 9 panels fit in the same space — but that is roughly 4.05 kW, noticeably more power from the same roof. *(These are example figures for practice.)* Because his roof is the real limit, not his budget, the higher-efficiency panel is the better choice here, even though it costs more per watt.

Some simple buying tips for the local market: - Ask for the datasheet, not just a price. - Check that the glass is not cracked and the frame is not bent. - Ask for the performance warranty document, not only a spoken promise. - Compare at least two or three sellers — prices and quality both vary. - Be careful with unlabeled or inconsistently labeled panels. The P<sub>max</sub> printed on the panel should match its datasheet.

#### COMMON MISTAKE

**✗ Wrong:** Choosing the panel with the lowest price, or the highest power number, without checking anything else.

**✓ Right:** Compare efficiency, the full electrical ratings, cost per watt, and the warranty together. The 'best' panel depends on your roof space and your budget, not on one number alone.

#### ACTIVITY (HOME) — COMPARE TWO REAL DATASHEETS

1. Find two real solar panel datasheets — from a local shop, a supplier's website, or a manufacturer's website.
2. Make a table like the one in this lesson: P<sub>max</sub>, efficiency, Voc, Isc, Vmp, Imp, temperature coefficient, size, and warranty.
3. If you can find a price for each, calculate the cost per watt.
4. Write one sentence saying which panel you would choose for a small roof with limited space, and why.

*You need: Two real panel datasheets (paper or online), Calculator or phone*

## 5.2 Orientation and Tilt Angle

Chapter 3 showed how the sun moves across the sky and changes height with the seasons. A panel only works at its best if it is aimed to catch that sunlight well. Aiming a panel means setting two things: its orientation and its tilt angle.

#### WORD TO KNOW

**Orientation** — The compass direction that a solar panel faces.

#### WORD TO KNOW

**Azimuth** — The compass direction of something, measured in degrees. Due north is 0°, east is 90°, south is 180°, and west is 270°.

Iraq and the Kurdistan Region are well north of the equator, at roughly 30° to 37°N. In the Northern Hemisphere, the sun spends most of the day in the southern part of the sky. So, as a simple rule: **point panels toward true south** (azimuth 180°) for the most sunlight across the whole day. (In the Southern Hemisphere, the rule flips — panels there should face true north.)

#### WORD TO KNOW

**Tilt angle** — The angle between a solar panel's surface and the flat, horizontal ground. A panel lying flat has a tilt angle of 0°; a panel standing straight up has a tilt angle of 90°.

#### WORD TO KNOW

**Magnetic declination** — The small difference between the direction a compass needle points (magnetic north) and true north. It must be corrected for when using a simple compass to find true south for solar panels.

A simple compass points to magnetic north, not true north — the two are a few degrees apart, and the exact difference changes slowly over time and by location. Many phone compass apps can show true north directly, or you can look up the current declination for your city online. For most home systems, being a little off true south is not a big problem — see the mistake box at the end of this lesson.

#### EQUATION: YEAR-ROUND TILT GUIDELINE

$$\beta \approx \varphi$$

*In words: Recommended tilt angle ≈ site latitude*

| Symbol    | Meaning                | Unit        |
|-----------|------------------------|-------------|
| $\beta$   | recommended tilt angle | degrees (°) |
| $\varphi$ | site latitude          | degrees (°) |

*This is a simple starting guideline for the best AVERAGE energy across the whole year, not an exact rule. Installers often round to a convenient rack angle.*

#### EQUATION: TILT FOR THE BEST SUMMER ENERGY

$$\beta_{\text{summer}} \approx \varphi - 15$$

*In words: Summer tilt ≈ latitude - 15°*

| Symbol                  | Meaning                               | Unit        |
|-------------------------|---------------------------------------|-------------|
| $\beta_{\text{summer}}$ | tilt angle for the best summer energy | degrees (°) |
| $\varphi$               | site latitude                         | degrees (°) |

*The summer sun is higher in the sky, so a flatter panel catches it better.*

#### EQUATION: TILT FOR THE BEST WINTER ENERGY

$$\beta_{\text{winter}} \approx \varphi + 15$$

In words: Winter tilt  $\approx$  latitude +  $15^\circ$

| Symbol                  | Meaning                               | Unit                 |
|-------------------------|---------------------------------------|----------------------|
| $\beta_{\text{winter}}$ | tilt angle for the best winter energy | degrees ( $^\circ$ ) |
| $\varphi$               | site latitude                         | degrees ( $^\circ$ ) |

The winter sun is lower in the sky, so a steeper panel catches it better.

#### WORKED EXAMPLE — TILT ANGLES FOR ERBIL

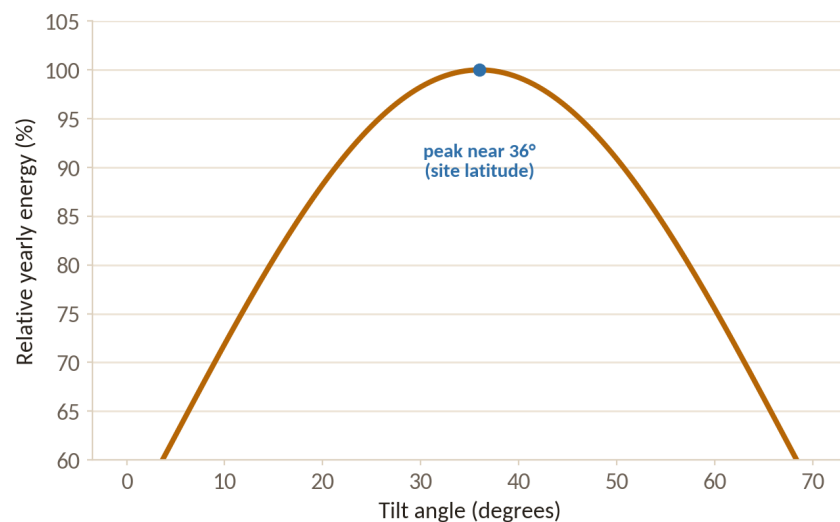
Erbil is at latitude  $36.2^\circ\text{N}$ . Find the recommended year-round, summer, and winter tilt angles using the guidelines above.

1. Year-round:  $\beta \approx \varphi = 36.2^\circ \approx 36^\circ$
2. Summer:  $\beta_{\text{summer}} \approx \varphi - 15 = 36.2 - 15 = 21.2^\circ \approx 21^\circ$
3. Winter:  $\beta_{\text{winter}} \approx \varphi + 15 = 36.2 + 15 = 51.2^\circ \approx 51^\circ$

**Answer:** Year-round  $\approx 36^\circ$ , summer  $\approx 21^\circ$ , winter  $\approx 51^\circ$ .

#### Approximate year-round tilt for some regional cities

| City         | Latitude             | Recommended year-round tilt |
|--------------|----------------------|-----------------------------|
| Duhok        | $36.9^\circ\text{N}$ | $\approx 37^\circ$          |
| Erbil        | $36.2^\circ\text{N}$ | $\approx 36^\circ$          |
| Sulaymaniyah | $35.6^\circ\text{N}$ | $\approx 36^\circ$          |
| Baghdad      | $33.3^\circ\text{N}$ | $\approx 33^\circ$          |
| Basra        | $30.5^\circ\text{N}$ | $\approx 30^\circ$          |



Yearly solar energy collected at a fixed south-facing orientation, as tilt angle changes, for a location near  $36^\circ\text{N}$ . The curve peaks close to the latitude angle and falls off gently on either side — both a flat  $0^\circ$  panel and a very steep  $70^\circ$  panel collect clearly less energy over the full year.



Most home systems use one FIXED tilt all year, close to the latitude value, because it is simple and works reasonably well every month. Adjusting the tilt twice a year (steeper in winter, flatter in summer) gains some extra energy, but it means someone must physically reset the rack — more common for off-grid systems with a caretaker nearby than for a simple rooftop home system.

One more local detail: almost every roof in Iraq and the Kurdistan Region is flat concrete, not sloped. A flat roof gives 0° tilt on its own, so reaching the target angle always needs a mounting frame — Lesson 5 covers this fully.

#### COMMON MISTAKE

**✗ Wrong:** A completely flat panel (0° tilt) is fine — it still faces the sun.

**✓ Right:** A flat panel collects noticeably less energy over a full year than one tilted near the latitude angle, especially in winter when the sun is low. A flat panel also collects dust faster, because rain and gravity cannot help wash it off (more on this in Lesson 3).

#### ACTIVITY (FIELD) — ORIENTATION SURVEY WITH A PHONE COMPASS

1. Go to a roof or open space where panels might be installed (school roof, home roof, or yard).
2. Open a compass app on a phone. If possible, set it to show true north, not just magnetic north.
3. Face the direction the available panel space would point, and read the compass bearing.
4. Calculate how many degrees this is away from true south (180°). This is the orientation error.
5. Estimate the roof or ground's slope, or confirm it is flat.
6. Check your result with the tilt & orientation calculator or Simulation 2.

*You need: Smartphone with a compass app, Paper and pen*

► *App tool: Try it: find the recommended tilt and orientation for your city*

► *App simulation: Explore: move the tilt and orientation sliders and watch yearly energy change*

## 5.3 Shading, Dust, and Soiling

A panel can be the best model, correctly aimed, and still make far less power than expected. Two everyday problems cause this: something blocking the sunlight, and dirt sitting on the glass. They are different problems with different fixes.

#### WORD TO KNOW

**Shading** — Something blocking direct sunlight from reaching part or all of a solar panel, such as a building, a tree, or a water tank.

Common shading sources on rooftops include a neighboring building, a water tank, a satellite dish, a tree branch, a chimney, or even another row of panels. Shadows also change through the day and through the year, because the sun's position keeps changing — exactly what Lesson 2 and Chapter 3 described. A spot that is clear at midday might be shaded in the early morning or late afternoon.

#### WORD TO KNOW

**Bypass diode** — A small electronic part inside a panel's junction box that lets current skip around a shaded or faulty group of cells, instead of that group blocking the whole panel's current.

Shading loss is NOT simply proportional to the shaded area — it is often much worse. Here is why: the cells inside a panel are wired in series, so the same current must flow through every cell, like people walking through a narrow doorway one at a time. A heavily shaded cell can only pass a small current, so it holds back the current for the whole chain — unless a bypass diode is there to help. Most 60-cell panels have 3 bypass diodes, each one protecting a group of about 20 cells. If a shadow fully covers even just one cell in a group, that whole group — roughly one-third of the panel's power — is lost until the shadow moves, even though the shadow itself covers less than 2% of the panel's surface.

#### WORD TO KNOW

**Hot spot** — A dangerously hot area on a solar cell, caused when a shaded or damaged cell is forced to absorb power as heat instead of producing it. Bypass diodes exist mainly to prevent hot spots.

#### SAFETY

Repeated or severe partial shading (like a fixed shadow from a chimney that falls on the same spot every day) can create hot spots over time, which may damage a panel or, rarely, start a fire. Avoid designing an array with permanent, unavoidable shading on part of it — redesign the layout or the row spacing instead.

The second problem is dirt on the glass. Even with zero shading, a dusty panel simply receives less sunlight.

#### WORD TO KNOW

**Soiling** — A loss of solar panel performance caused by dust, sand, dirt, or other material settling on the panel's surface and blocking some sunlight.

Dust storms are common across Iraq and the Kurdistan Region, especially in the warmer, drier months from roughly spring through summer, often driven by strong, dry winds sometimes called shamal winds. Between storms, ordinary dust still settles on every outdoor surface, including solar panels.

#### EQUATION: POWER LOSS FROM SOILING

$$P_{\text{actual}} = P_{\text{STC}} \times (1 - L_{\text{soil}})$$

*In words: Actual power = Rated (clean, STC) power × (1 – soiling loss)*

| Symbol              | Meaning                                                      | Unit                                                     |
|---------------------|--------------------------------------------------------------|----------------------------------------------------------|
| P <sub>actual</sub> | actual power output in full sunlight with the panel as it is | watts (W)                                                |
| P <sub>STC</sub>    | rated power at standard test conditions (clean panel)        | watts (W)                                                |
| L <sub>soil</sub>   | soiling loss                                                 | fraction (write a percent as a decimal, e.g., 8% = 0.08) |

*This simple model assumes even dust across the whole panel. Chapter 12 covers soiling as one part of a full system loss calculation.*

#### WORKED EXAMPLE — A DUSTY PANEL A

Panel A (450 W, from Lesson 1) has been collecting dust for a few weeks. Its output has dropped by an example 8%. Find its actual power output in strong, direct sunlight.

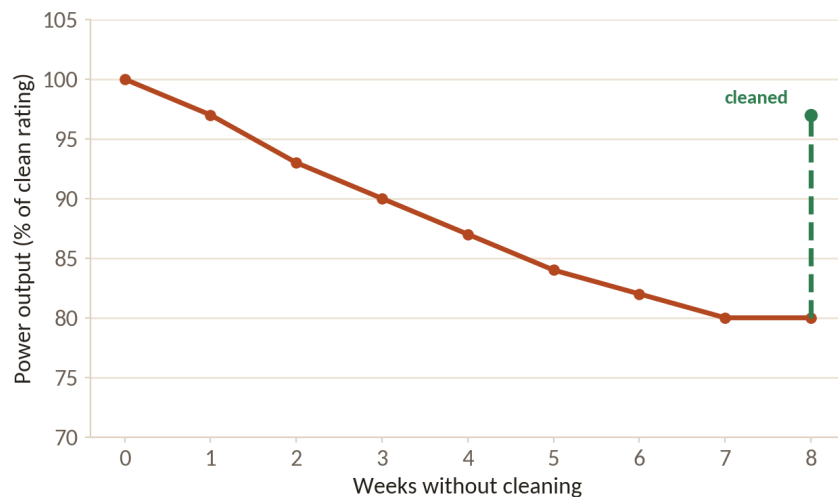
1. Write the equation:  $P_{\text{actual}} = P_{\text{STC}} \times (1 - L_{\text{soil}})$

2. Change the percent to a fraction:  $8\% = 0.08$
  3. Put in the numbers:  $P_{\text{actual}} = 450 \times (1 - 0.08) = 450 \times 0.92$
  4. Calculate:  $P_{\text{actual}} = 414 \text{ W}$
- Answer: 414 W (a loss of 36 W).**

#### Example soiling loss ranges (for practice)

| Condition                                  | Typical time without cleaning | Example power loss |
|--------------------------------------------|-------------------------------|--------------------|
| Light dust                                 | 1–2 weeks, dry season         | 2–5%               |
| Moderate dust                              | 3–6 weeks, dry season         | 5–12%              |
| Heavy dust, or soon after a dust storm     | Several weeks uncleaned       | 15–25%             |
| Very heavy — thick caked dust or mud spots | Months uncleaned              | 25% or more        |

These numbers are example ranges for practice, based on general soiling patterns seen in dusty regions. Real loss depends on the site, the tilt angle, how high the panel sits above the ground, and the local weather — every installation is a little different. A steeper tilt (Lesson 2) usually helps dust slide off more easily, especially after light rain.



*Example chart: panel power output falling gradually as dust builds up over several weeks without cleaning, then jumping back up close to full power right after cleaning.*

#### CASE STUDY — DUST STORMS AND A SHOP'S SOLAR SYSTEM • KURDISTAN REGION (EXAMPLE FIGURES)

A small shop installed a 3 kW rooftop system in spring. Over the next eight weeks, without any cleaning — including one strong dust storm — the owner noticed the system's daily production had fallen by about a fifth. (*This is an example figure for practice; real loss depends on the storm, the tilt angle, and how long the dust sits.*) A neighbor with a similar system, but mounted nearly flat at only  $5^\circ$ , needed to clean much more often than the shop, which used a steeper  $30^\circ$  tilt frame — dust simply slid off more easily there after light rain. After cleaning, both systems returned close to normal output within a day.

Good cleaning habits for the region: clean more often in the dusty months, and less often the rest of the year. Work in the early morning or evening, when the panels and the roof are cooler and the sun is gentler — not at midday in summer heat. Use plenty of clean water and a soft cloth or sponge if water is available; a soft, dry brush works when water is scarce. Never use abrasive materials (sand, steel wool, hard brushes) — they can scratch the glass coating and reduce output permanently.

#### SAFETY

When cleaning: never clean panels that are part of a live, connected system while they are wet, without first checking it is safe to do so — water and electricity together are dangerous. Avoid the hottest part of the day, both for your own safety in the heat and to reduce thermal shock to the glass. Use a stable ladder, do not stand on the panels themselves, and never work alone on a roof.

#### COMMON MISTAKE

**X Wrong:** Rain keeps panels clean, so manual cleaning is not necessary.

**✓ Right:** Light rain often is not enough to remove settled dust, and can even leave streaky, patchy residue that blocks light unevenly. Manual cleaning is usually still needed, especially since the region's dry season can bring many weeks without meaningful rain.

#### ACTIVITY (FIELD) — THE DUST EXPERIMENT

1. Find a small solar panel that has been sitting outside, undisturbed, for at least two weeks (a garden light panel or a small demonstration panel works well).
2. On a sunny day, around midday, measure its open-circuit voltage (Voc) and short-circuit current (Isc) with a multimeter, **WITHOUT** cleaning it. Record both values.
3. Gently clean the panel with a soft cloth and water (or a dry, soft brush).
4. Immediately measure Voc and Isc again, in the same sunlight.
5. Calculate the percent change in Voc and the percent change in Isc. Which one changed more? (Dust mostly blocks light, which mainly affects current — Voc usually changes only a little.)

*You need: A dusty small solar panel, A multimeter, Soft cloth or brush and water*

► [App simulation: Explore: change shading and months since cleaning, and watch the power loss](#)

## 5.4 Connecting Panels: Series and Parallel

A single panel's voltage and current — Panel A gives 41.5 V and 10.85 A at its maximum power point (Lesson 1) — is rarely enough on its own for a whole home system. Real systems connect many panels together, using exactly the series and parallel ideas from Chapter 2. The difference now is that each 'component' in the circuit is a whole panel.

#### WORD TO KNOW

**Series connection** — Connecting panels one after another, the positive terminal of one to the negative terminal of the next. In series, voltage adds up and current stays the same.

#### WORD TO KNOW

**Parallel connection** — Connecting panels side by side, positive to positive and negative to negative. In

parallel, current adds up and voltage stays the same.

#### WORD TO KNOW

**String** — A group of solar panels connected together in series.

#### WORD TO KNOW

**Array** — All the solar panels in a system, connected together — usually made of one or more strings.

#### EQUATION: STRING VOLTAGE (PANELS IN SERIES)

$$V_{\text{string}} = n_s \times V_{\text{panel}}$$

*In words: String voltage = number of panels in series × one panel's voltage*

| Symbol   | Meaning                                                                             | Unit            |
|----------|-------------------------------------------------------------------------------------|-----------------|
| V_string | total string voltage                                                                | volts (V)       |
| ns       | number of panels connected in series                                                | count (no unit) |
| V_panel  | one panel's voltage (use Voc for the maximum possible, or Vmp for normal operation) | volts (V)       |

*Current does NOT change in series — it stays the same as a single panel, because there is only one path for it to flow.*

#### WORKED EXAMPLE — FOUR PANEL A MODULES IN SERIES

Four Panel A modules (Voc = 49.5 V, Isc = 11.58 A) are connected in series to form one string. Find the string's open-circuit voltage and short-circuit current.

1. Write the equation:  $V_{\text{string}} = n_s \times V_{\text{panel}}$
2. Put in the numbers:  $V_{\text{string}} = 4 \times 49.5 \text{ V}$
3. Calculate:  $V_{\text{string}} = 198 \text{ V}$
4. Current stays the same as one panel:  $I_{\text{string}} = I_{\text{sc}} = 11.58 \text{ A}$

**Answer: 198 V, 11.58 A.**

#### EQUATION: ARRAY CURRENT (STRINGS IN PARALLEL)

$$I_{\text{array}} = n_p \times I_{\text{string}}$$

*In words: Array current = number of strings in parallel × one string's current*

| Symbol   | Meaning                                                | Unit            |
|----------|--------------------------------------------------------|-----------------|
| I_array  | total array current                                    | amperes (A)     |
| np       | number of strings connected in parallel                | count (no unit) |
| I_string | one string's current (the same as one panel's current) | amperes (A)     |

*Voltage does NOT change in parallel. Every parallel string should be identical — same number and type of panels — so they all share the same voltage.*

#### WORKED EXAMPLE — THREE STRINGS IN PARALLEL

Three identical strings, each like the one above (198 V, 11.58 A), are connected in parallel to form the full array. Find the array's open-circuit voltage and short-circuit current.

1. Voltage stays the same, because the strings are identical:  $V_{\text{array}} = 198 \text{ V}$
2. Write the current equation:  $I_{\text{array}} = n_p \times I_{\text{string}}$
3. Put in the numbers:  $I_{\text{array}} = 3 \times 11.58 \text{ A}$
4. Calculate:  $I_{\text{array}} = 34.74 \text{ A}$

**Answer: 198 V, 34.74 A.**

Remember Power = Voltage  $\times$  Current from Chapter 1. It works for a whole array too — and it gives a second way to check the array's total power.

#### WORKED EXAMPLE — THE ARRAY'S TOTAL POWER, TWO WAYS

The array above has 4 series  $\times$  3 parallel = 12 Panel A modules, each rated 450 W ( $V_{\text{mp}} = 41.5 \text{ V}$ ,  $I_{\text{mp}} = 10.85 \text{ A}$ ). Find the total array power at STC, using two different methods.

1. Method 1 — add up the panels: Total  $P_{\text{max}} = 12 \times 450 \text{ W} = 5400 \text{ W} = 5.4 \text{ kW}$
2. Method 2 — use  $P = V \times I$  at the maximum power point:  $V_{\text{array}}(\text{mp}) = 4 \times 41.5 = 166 \text{ V}$ , and  $I_{\text{array}}(\text{mp}) = 3 \times 10.85 = 32.55 \text{ A}$
3.  $P = 166 \text{ V} \times 32.55 \text{ A} \approx 5403 \text{ W} \approx 5.4 \text{ kW}$

**Answer:  $\approx 5.4 \text{ kW}$  (5400 W), confirmed two ways. The small difference (5400 vs. 5403) is just normal rounding on the datasheet.**

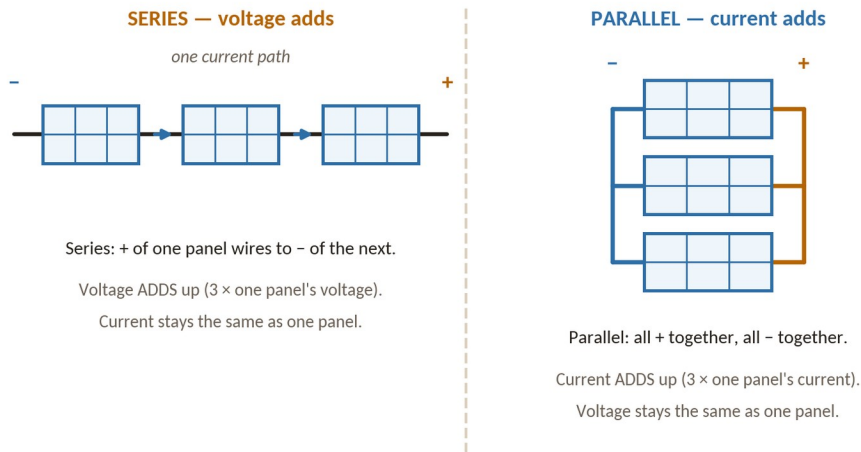
Always match panels within one string — the same model, with the same current rating. If you connect a weaker or older panel into a string of stronger ones, it limits the current for the WHOLE string, exactly like the shaded cell in Lesson 3. One mismatched panel can quietly reduce the output of every panel around it.

#### COMMON MISTAKE

**✗ Wrong:** Mixing different panel models, wattages, or a partly worn panel into the same series string, because 'a panel is a panel.'

**✓ Right:** Match panels within a string: same model, same current rating. A weaker panel in a string limits the current for every panel in that string, just like one shaded cell limits a whole panel.

## Connecting Panels: Series vs. Parallel



Two wiring diagrams side by side: panels connected in series (voltage adds, one path for current) and panels connected in parallel (current adds, voltage stays the same).

### SAFETY

A string of panels in full sun is 'live' the moment light hits it — it does not need to be switched on. Even a small string can reach a dangerous DC voltage, and DC arcs do not switch themselves off the way AC arcs often do. Cover panels with an opaque sheet while wiring them, or work early or late in the day when sunlight is weak. Use insulated tools and gloves, and use proper connectors (Chapter 9 covers these) instead of twisting bare wires together.

In a real installation, panels connect through weatherproof plug connectors (commonly called MC4 connectors), and the array usually passes through fuses or breakers before reaching the charge controller or inverter. Chapter 9 covers connectors, fuses, and protection in full.

### ACTIVITY (LABORATORY) — SERIES AND PARALLEL WITH SMALL SOLAR CELLS

1. Get two or more identical small solar cells or mini panels (from a kit, a solar garden light, or a solar calculator) and a multimeter.
2. In good sunlight, measure and record the voltage and current of ONE cell alone.
3. Connect two cells in series (+ to -). Measure the total voltage and current, and compare with your prediction from the equations.
4. Reconnect the same two cells in parallel (+ to +, - to -). Measure the total voltage and current, and compare with your prediction.
5. Discuss: which arrangement would charge a 12 V battery better? Which would better run a small 3 V motor?

You need: Two or more identical small solar cells or mini panels, A multimeter, Connecting wires, Sunlight

► App tool: Try it: enter your panel specs and string layout to check the numbers

► App simulation: Explore: change the number of panels and see voltage, current, and power update live

## 5.5 Mounting Basics

Choosing the right panel (Lesson 1), aiming it well (Lesson 2), keeping it clean (Lesson 3), and wiring it correctly (Lesson 4) all depend on one more thing: the panel must be held firmly, at the right angle, for twenty years or more, through wind, rain, and summer heat. This is the job of mounting.

### WORD TO KNOW

**Rack** — The metal frame that holds solar panels in place at the chosen tilt angle and orientation.

### WORD TO KNOW

**Tilt frame** — A rack built to lift the back edge of a panel on a flat roof, so the panel sits at a chosen tilt angle instead of lying flat.

### Common mounting types

| Mounting type        | Where it is used                                                   | Key point                                                                                             |
|----------------------|--------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Pitched roof mount   | Sloped roofs (tile, metal sheet)                                   | Rails follow the roof slope; short angled brackets set the final tilt                                 |
| Flat roof tilt frame | Flat concrete roofs — very common in Iraq and the Kurdistan Region | A triangular frame sets tilt and orientation freely; often held down with ballast instead of drilling |
| Ground mount         | Open land, farms, larger systems                                   | Posts set in concrete or driven into the ground; easy access for cleaning and repair                  |
| Pole mount           | Single or few panels — water pumps, streetlights, remote sites     | One strong pole; the panel can sometimes be tilted by hand for the season                             |

### CASE STUDY — WHY (ALMOST) EVERY ROOF NEEDS A FRAME HERE • IRAQ AND THE KURDISTAN REGION

Most homes, shops, and schools in Iraq and the Kurdistan Region have flat concrete roofs. This is very different from places where sloped, tiled roofs are common and already sit at a useful angle. On a flat roof, a panel laid flat would face straight up — losing a large part of its yearly energy, as Lesson 2 showed, and collecting dust faster, as Lesson 3 showed. This is why almost every home system in the region uses a tilt frame: a simple metal rack that lifts the back edge of the panel to a chosen angle, usually close to the site's latitude. Many installers avoid drilling into the concrete, since a flat roof must still keep out winter rain, and instead use a non-penetrating rack held down with ballast.

### WORD TO KNOW

**Ballast** — Heavy weight, such as concrete blocks, placed on a mounting rack to hold it down without drilling into the roof.

Drilling into a roof to bolt down a rack (a penetrating mount) is stronger, but every hole must be carefully sealed, or it can leak for years afterward. A ballasted, non-penetrating rack avoids this risk, but it must be heavy



enough and low enough to resist strong wind — a specialist can calculate the ballast needed for a given rack height, tilt, and local wind conditions.

#### COMMON MISTAKE

**✗ Wrong:** Drilling into a flat concrete roof anywhere convenient, without proper waterproofing.

**✓ Right:** Every roof penetration needs careful sealing, or it can cause leaks for years. Many installers on flat roofs prefer a ballasted, non-penetrating rack specifically to avoid this risk.

#### WORD TO KNOW

**Clamp** — A metal bracket that fixes a panel's edge to a mounting rail. A mid clamp holds two panels where they meet; an end clamp holds the outer edge of a row.

Panels are not screwed directly onto a rack through their glass. They sit on rails and are held down by clamps at their frame edges — mid clamps between two neighboring panels, and end clamps at the ends of each row. This spreads the load evenly and leaves a small air gap under the panel, which helps it run a little cooler — useful, since Lesson 1's temperature coefficient means a hot panel makes less power.

#### WORD TO KNOW

**Wind load** — The force that wind puts on a mounted panel and its rack. Racks and roofs must be strong enough to handle the local wind load safely.

#### WORD TO KNOW

**Inter-row shading** — One row of panels casting a shadow onto the row behind it, usually when the sun is low in the sky. Rows need enough space between them to avoid this.

If a roof or field fits more than one row of tilted panels, leave enough space between rows so that the front row does not shade the row behind it — especially in winter, when the sun is lowest (Lesson 2). A simple rule of thumb for steep tilt angles is to leave a gap of at least two to two-and-a-half times the panel's vertical rise between the back of one row and the front of the next. A site survey (Chapter 16) checks this properly for a real project.

#### WORKED EXAMPLE — ROOF AREA FOR THE ARRAY

The array from Lesson 4 has 12 Panel A modules (each  $2.094 \text{ m} \times 1.038 \text{ m}$ ). Planning for a 20% extra allowance for row spacing, walkways, and frame edges, how much roof area should be planned for?

1. One panel's area:  $2.094 \times 1.038 \approx 2.17 \text{ m}^2$
2. 12 panels:  $12 \times 2.17 \approx 26.1 \text{ m}^2$
3. Add 20% for spacing and edges:  $26.1 \times 1.2 \approx 31.3 \text{ m}^2$

**Answer: About  $31 \text{ m}^2$  of roof space.**

#### SAFETY

Mounting work happens on roofs or at height — treat it seriously. Use a stable ladder and, where possible, proper fall-protection equipment, and never work alone on a roof. Roofs and panel glass get very hot in the

Iraqi and Kurdish summer sun — work in the early morning or late afternoon when possible, and wear gloves. Before loading any roof with panels, racks, and ballast, check that the roof structure can safely carry the extra weight and the local wind load — for anything beyond a small system, ask a qualified engineer, especially on older buildings. Always secure loose tools and materials so nothing falls on someone below.

#### ACTIVITY (HOME) — MOUNTING ANGLE AND LAYOUT SKETCH

1. Choose a real or imagined flat roof (home or school) and estimate its usable area, avoiding water tanks, satellite dishes, or shaded corners.
2. Pick a tilt angle for your location, using Lesson 2's guideline (tilt  $\approx$  latitude).
3. Sketch the roof from above. Draw rows of panels, leaving a gap between rows so the row behind is not shaded (see the rule of thumb above).
4. Count how many panels fit in your sketch, and compare with the array size from Lesson 4's worked examples.

*You need: Tape measure or estimated steps, Paper and pen*

#### CHAPTER SUMMARY

- Compare panels using more than price: check  $P_{max}$ , efficiency,  $V_{oc}$ ,  $I_{sc}$ ,  $V_{mp}$ ,  $I_{mp}$ , and warranty on the datasheet, and use cost per watt to compare value.
- A more efficient panel needs less roof space for the same power — important when roof area, not budget, is the limit.
- In the Northern Hemisphere, face panels true south and tilt them close to the site's latitude for the best year-round energy.
- A flat or badly aimed panel loses a large share of its possible yearly energy, and collects dust faster.
- Shading is not proportional to shadow size — a small shadow can block a large share of a panel's power, because cells are wired in series and grouped by bypass diodes.
- Dust and soiling reduce output steadily; regular cleaning restores it — dust storms make this an important, recurring task in Iraq and the Kurdistan Region.
- In series, voltage adds and current stays the same. In parallel, current adds and voltage stays the same.
- Always match panels within a string, and respect DC safety — even a small string can reach a dangerous voltage in full sun.
- Most roofs in the region are flat, so panels usually need a tilt frame; ballasted racks avoid the leak risk of drilling into concrete.
- Mounting must survive local wind and match the roof's real carrying capacity, not just hold the panel's own weight.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A panel is rated 320 W. It measures  $1.65\text{ m} \times 1.00\text{ m}$ . What is its efficiency, in %?

**Problem 2 [Basic]** Panel X costs \$114 (example price) and is rated 380 W. Panel Y costs \$160 (example price) and is rated 500 W. Find the cost per watt of each. Which one is cheaper per watt?

**Problem 3 [Basic]** Three identical panels, each with  $V_{oc} = 45\text{ V}$ , are connected in series. Find the string's open-circuit voltage.

**Problem 4 [Basic]** Four identical panels, each with  $I_{sc} = 9\text{ A}$ , are connected in parallel. Find the array's short-circuit current.

**Problem 5 [Standard]** A 350 W panel loses an example 12% of its power to dust after five weeks without cleaning. Find its actual power output in strong sunlight.

**Problem 6 [Standard]** Duhok is at latitude  $36.9^\circ\text{N}$ . Find the recommended year-round tilt, and the recommended summer and winter tilt angles, using the simple guidelines from Lesson 2.

**Problem 7 [Standard]** A designer connects 5 identical panels in series to form one string. Each panel:  $V_{oc} = 41\text{ V}$ ,  $I_{sc} = 10.5\text{ A}$ ,  $P_{max} = 340\text{ W}$ . Two such strings are connected in parallel. Find: (a) the string voltage, (b) the array current, (c) the total array power.

**Problem 8 [Standard]** A shop wants 6 panels rated 400 W each, priced at an example \$0.32 per watt. Find (a) the total power of the array, and (b) the total cost.

**Problem 9 [Standard]** A panel has 60 cells and 3 bypass diodes, each protecting a group of 20 cells. A satellite dish fully shades 1 cell in one group, all day. (a) What fraction of the panel's area does that one shaded cell cover? (b) Roughly what fraction of the panel's rated power is still available while the shadow is there, and what percent loss is that?

**Problem 10 [Challenge]** A family wants about 3.2 kW of solar panels for their roof. They choose a panel rated 400 W,  $V_{oc} = 45\text{ V}$ ,  $I_{sc} = 11.5\text{ A}$ , priced at an example \$0.29/W. (a) How many panels do they need? (b) If they arrange them as 2 equal strings in parallel, how many panels are in each string? (c) Find the string's  $V_{oc}$ . (d) Find the total example cost.

**Problem 11 [Challenge]** You plan a 10-panel array. Each panel measures  $2.0\text{ m} \times 1.0\text{ m}$  ( $2.0\text{ m}^2$  each). The installer says to plan for 55% extra area beyond the panels' own area, for tilt frames and row spacing. How much total roof area should you plan for?

**Problem 12 [Challenge]** A 3 kW array normally produces energy as if the sun shone at full strength for an average of 4.5 hours every day (you will study this 'sun-hours' idea fully in Chapter 3). During a dusty month, soiling cuts output by an example 15% for the whole month (30 days). (a) Find the normal expected daily energy, in kWh. (b) Find the actual daily energy during the dusty month. (c) Find the total energy lost over the 30 days because of dust, in kWh.

PART TWO

# SYSTEM COMPONENTS

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## CHAPTER SIX

# Batteries and Energy Storage

*Battery types, sizing the bank, and safe local buying and handling*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain why solar systems need energy storage, and describe the main battery types used (flooded, AGM, gel, and LiFePO4).
- Calculate a battery's total and usable energy from its voltage, capacity, and depth of discharge.
- Explain cycle life, and describe how depth of discharge and temperature affect a battery's lifetime.
- Describe the three main charging stages and connect batteries safely in series and parallel.
- Calculate the size of a battery bank from daily energy use, autonomy days, depth of discharge, and system voltage.
- Judge battery quality in the local market, and follow safe battery-handling practices.

## 6.1 Why We Need Storage, and Battery Types

A solar panel only makes electricity when the sun is shining. But people need power at night, on cloudy days, and during grid cuts. This is the problem that a battery solves.

### WORD TO KNOW

**Energy storage** — Keeping energy now so it can be used later, at a different time. A battery is the main way solar systems store energy.

Off-grid and hybrid solar systems need batteries so the home has power after sunset. Even simple backup systems use a battery to bridge a power cut. (Chapter 11 explains the different system types in detail.)

### WORD TO KNOW

**Battery** — A device that stores electrical energy using a chemical reaction, and releases it later as electric current.

Not every battery is right for solar work. A car battery is built to give one short, huge burst of current to start an engine, then it is recharged almost immediately. A solar battery must do something very different: give a smaller, steady current for many hours, get deeply used, and be recharged slowly the next day — over and over, for years.

### WORD TO KNOW

**Deep-cycle battery** — A battery built to be discharged deeply and recharged many hundreds or thousands of times, unlike a car battery which is built for short bursts.

#### COMMON MISTAKE

✗ **Wrong:** Any 12 V battery, including a car (starting) battery, is fine for a solar system.

✓ **Right:** Car batteries are damaged quickly by deep, repeated discharge. Always use a deep-cycle battery, made for solar and backup-power use.

Solar systems today mainly use four battery types. The first three are all **lead-acid** batteries — they use the same basic chemistry but package it differently. The fourth is a **lithium** battery, a newer and different chemistry.

#### WORD TO KNOW

**Electrolyte** — The liquid, mat, or gel inside a battery that carries the chemical reaction. In lead-acid batteries, the electrolyte is a mix of sulfuric acid and water.

#### WORD TO KNOW

**Flooded battery** — A lead-acid battery with a free liquid electrolyte. The cheapest and most common type, but it needs regular water top-up and good ventilation.

#### WORD TO KNOW

**AGM battery** — AGM stands for Absorbed Glass Mat. The acid is soaked into a fiberglass mat, so the battery is sealed and needs no water top-up.

#### WORD TO KNOW

**Gel battery** — A lead-acid battery where the acid is mixed with silica to form a thick gel. Sealed, and handles heat and deep cycling better than a flooded battery.

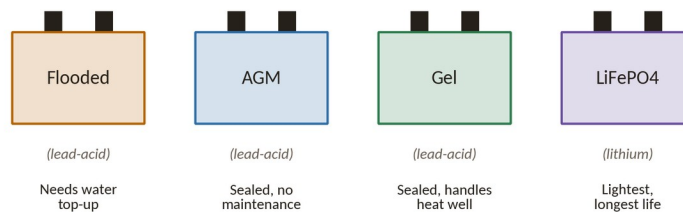
#### WORD TO KNOW

**Lifepo4 battery** — A lithium battery using lithium iron phosphate chemistry. Written LiFePO<sub>4</sub>. It costs more today, but lasts far more cycles than lead-acid and can be discharged much deeper.

#### The four main battery types

| Type                    | How it works                                  | Good points                                                          | Watch out for                                                                   |
|-------------------------|-----------------------------------------------|----------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Flooded (wet) lead-acid | Lead plates sit in a liquid acid electrolyte  | Lowest price; parts easy to find; can be serviced                    | Needs regular water top-up; must stay upright; needs good ventilation           |
| AGM (sealed lead-acid)  | Acid is soaked into a fiberglass mat          | Sealed and maintenance-free; no water top-up; handles vibration well | Costs more than flooded; damaged by deep over-discharge or wrong charge voltage |
| Gel (sealed lead-acid)  | Acid is mixed with silica to form a thick gel | Sealed; handles heat and deep, repeated cycling well                 | Needs the correct, lower charge voltage, or it can be damaged permanently       |

| Type              | How it works                                                           | Good points                                                 | Watch out for                                                                           |
|-------------------|------------------------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| LiFePO4 (lithium) | Lithium iron phosphate chemistry with an electronic protection circuit | Longest cycle life; deepest safe discharge; lightest weight | Highest price today; needs its matching charge settings; most will not charge below 0°C |



Four battery types used in solar systems: flooded, AGM, gel, and LiFePO4 (lithium).

So which type should a project use? It depends on budget, how the battery will be used, and how it will be looked after. Lesson 4 goes deeper into choosing wisely in the local market.

#### Which battery type fits which use? (general guide)

| Use                                                      | Common choice     | Why                                                                            |
|----------------------------------------------------------|-------------------|--------------------------------------------------------------------------------|
| Budget home system, easy local service                   | Flooded lead-acid | Lowest price and widely available, but needs water top-up and good ventilation |
| Sealed system, less maintenance, moderate budget         | AGM               | No water top-up; handles some vibration; moderate price                        |
| Hot climate, deep daily cycling, moderate budget         | Gel               | Handles heat and deep cycling well, but needs the correct charge settings      |
| Long life, light weight, frequent cycling, higher budget | LiFePO4 (lithium) | Longest cycle life and deepest safe discharge, but highest upfront cost        |

#### ACTIVITY (HOME) — BATTERY DETECTIVE

1. Find a battery at home, school, or a nearby shop — for example, inside a UPS (backup power box), an inverter system, or a car.
2. Read the label. Write down its voltage, its capacity if shown (in Ah), and any type name you can see (flooded, AGM, gel, or lithium/LiFePO4).
3. Decide which of the four types in this lesson it is, and explain how you decided.

You need: Paper and pen, A phone torch helps to read small labels

## 6.2 Capacity, Depth of Discharge, and Cycle Life

Now that you know the battery types, this lesson answers the most practical question of all: **how big a battery does a project need?** This lesson ends with the most important equation in this chapter.

#### WORD TO KNOW

**Capacity** — How much electric charge a battery can store, measured in ampere-hours (Ah). A 100 Ah battery can, in theory, give 100 A for 1 hour, or 10 A for 10 hours, or 5 A for 20 hours.

#### WORD TO KNOW

**Ampere-hour** — The unit used to measure battery capacity. Written Ah. 1 Ah means the battery can supply 1 ampere of current for 1 hour.

#### EQUATION: BATTERY ENERGY FROM VOLTAGE AND CAPACITY

$$E = V \times C$$

*In words: Energy = Voltage  $\times$  Capacity*

| Symbol | Meaning                      | Unit              |
|--------|------------------------------|-------------------|
| E      | energy stored in the battery | watt-hours (Wh)   |
| V      | battery voltage              | volts (V)         |
| C      | battery capacity             | ampere-hours (Ah) |

*Volts  $\times$  ampere-hours = watt-hours. This is the same idea as Chapter 1's  $E = P \times t$ , now applied to a battery.*

#### WORKED EXAMPLE — ENERGY STORED IN ONE BATTERY

A battery is rated 12 V, 100 Ah. How much energy can it store, in Wh and kWh?

1. Write the equation:  $E = V \times C$
2. Put in the numbers:  $E = 12 \text{ V} \times 100 \text{ Ah}$
3. Calculate:  $E = 1200 \text{ Wh}$
4. Convert:  $1200 \div 1000 = 1.2 \text{ kWh}$

**Answer: 1200 Wh = 1.2 kWh**

But a battery is almost never used down to completely empty. Going too low damages most batteries and shortens their life. This is where two new ideas come in: **state of charge** and **depth of discharge**.

#### WORD TO KNOW

**State of charge** — How full a battery is right now, shown as a percentage. Written SoC. 100% SoC means full; 0% SoC means empty.

#### WORD TO KNOW

**Depth of discharge** — How much of a battery's capacity has already been used, shown as a percentage. Written DoD.  $\text{DoD} = 100\% - \text{SoC}$ . A deeper discharge puts more stress on the battery.

#### EQUATION: USABLE ENERGY FROM VOLTAGE, CAPACITY, AND DEPTH OF DISCHARGE



$$E_{\text{usable}} = V \times C \times \text{DoD}$$

In words: Usable energy = Voltage × Capacity × Depth of discharge

| Symbol   | Meaning                                              | Unit                             |
|----------|------------------------------------------------------|----------------------------------|
| E_usable | the energy that can safely be taken from the battery | watt-hours (Wh)                  |
| V        | battery voltage                                      | volts (V)                        |
| C        | battery capacity                                     | ampere-hours (Ah)                |
| DoD      | maximum allowed depth of discharge                   | fraction from 0 to 1 (0.5 = 50%) |

Always write DoD as a decimal (50% = 0.5, 80% = 0.8) before you calculate, or the answer will be far too big.

#### WORKED EXAMPLE — USABLE ENERGY OF THE SAME BATTERY

The same 12 V, 100 Ah battery is a lead-acid type with a maximum safe DoD of 50%. How much usable energy does it really give?

1. Write the equation:  $E_{\text{usable}} = V \times C \times \text{DoD}$
2. Change the percent to a decimal: 50% = 0.5
3. Put in the numbers:  $E_{\text{usable}} = 12 \text{ V} \times 100 \text{ Ah} \times 0.5$
4. Calculate:  $E_{\text{usable}} = 600 \text{ Wh}$

**Answer: 600 Wh — only half of the total 1200 Wh, because of the 50% DoD limit**

#### COMMON MISTAKE

**✗ Wrong:** Discharge a lead-acid battery all the way to 0% to get every last Wh out of it.

**✓ Right:** Going past the safe DoD limit damages lead-acid batteries fast and shortens their life a lot. Stop at the DoD the maker recommends — often 50%.

#### Typical maximum safe depth of discharge (DoD) by battery type

| Battery type      | Typical maximum DoD | Notes                                         |
|-------------------|---------------------|-----------------------------------------------|
| Flooded lead-acid | 40–50%              | Deeper discharge greatly shortens life        |
| AGM               | 50–60%              | A little deeper than flooded is usually safe  |
| Gel               | 50–70%              | Depends on the brand and model                |
| LiFePO4 (lithium) | 80–100%             | Always check the maker's exact recommendation |

#### WORD TO KNOW

**Cycle life** — The number of full charge-and-discharge cycles a battery can complete before its capacity drops too low to be useful. A deeper DoD each cycle gives a shorter cycle life.

Approximate cycle life vs. depth of discharge (typical example values — always check the datasheet)

| Depth of discharge each cycle | Lead-acid (flooded / AGM / gel) | LiFePO4 (lithium)     |
|-------------------------------|---------------------------------|-----------------------|
| 100% (full discharge)         | ≈ 200–300 cycles                | ≈ 2000–3000 cycles    |
| 50%                           | ≈ 1000–1200 cycles              | ≈ 4000–6000 cycles    |
| 20%                           | ≈ 2500–3000 cycles              | ≈ 8000 cycles or more |

Look at the pattern: a shallower DoD gives many more cycles, for **any** battery type. This is a real design choice — a bigger, more expensive battery bank used gently will often outlast a smaller bank used hard. Lesson 4 shows how to compare this in cost terms.

Now we can put capacity, voltage, days of autonomy, and DoD together into one equation — the equation used to size almost every battery bank in this course.

#### EQUATION: BATTERY BANK SIZING

$$C_{\text{bank}} = \frac{E_{\text{daily}} \times N_{\text{auto}}}{V_{\text{sys}} \times \text{DoD}}$$

*In words: Battery bank capacity = (Daily energy need × Days of autonomy) ÷ (System voltage × Depth of discharge)*

| Symbol  | Meaning                                                                    | Unit                             |
|---------|----------------------------------------------------------------------------|----------------------------------|
| C_bank  | required battery bank capacity                                             | ampere-hours (Ah)                |
| E_daily | energy the battery bank must supply each day                               | watt-hours (Wh)                  |
| N_auto  | days of autonomy — days with little or no sun the battery must cover alone | days                             |
| V_sys   | system (battery bank) voltage                                              | volts (V)                        |
| DoD     | maximum allowed depth of discharge                                         | fraction from 0 to 1 (0.5 = 50%) |

*Always round the answer UP to the next available battery size. Rounding down leaves the bank undersized on cloudy days.*

#### WORKED EXAMPLE — SIZING A BATTERY BANK FOR A SMALL HOME (LEAD-ACID)

A small home needs 3000 Wh (3 kWh) of energy from its battery bank each day. The system is designed for 2 days of autonomy. The system voltage is 12 V. The batteries are flooded lead-acid, with a maximum DoD of 50% (0.5). Find the required bank capacity, and the number of 12 V, 200 Ah batteries needed.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (3000 \text{ Wh} \times 2) \div (12 \text{ V} \times 0.5)$
3. Calculate the top:  $3000 \times 2 = 6000 \text{ Wh}$
4. Calculate the bottom:  $12 \times 0.5 = 6$
5. Divide:  $C_{\text{bank}} = 6000 \div 6 = 1000 \text{ Ah}$
6. Number of batteries:  $1000 \text{ Ah} \div 200 \text{ Ah (each battery)} = 5 \text{ batteries}$

**Answer: 1000 Ah at 12 V — five 12 V, 200 Ah batteries connected in parallel**

#### WORKED EXAMPLE — THE SAME HOME WITH LIFEPO4 BATTERIES

Same home: 3000 Wh/day, 2 days of autonomy, 12 V system. This time the batteries are LiFePO4, with a

maximum DoD of 80% (0.8). Find the required bank capacity.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (3000 \text{ Wh} \times 2) \div (12 \text{ V} \times 0.8)$
3. Calculate the top:  $3000 \times 2 = 6000 \text{ Wh}$
4. Calculate the bottom:  $12 \times 0.8 = 9.6$
5. Divide:  $C_{\text{bank}} = 6000 \div 9.6 = 625 \text{ Ah}$

**Answer: 625 Ah — about 37% smaller than the 1000 Ah lead-acid bank, because LiFePO<sub>4</sub> allows a much deeper discharge**

► *App tool: Check your battery bank sizing with the calculator*

#### ACTIVITY (CLASSROOM) — SIZE YOUR OWN BATTERY BANK

1. Take a daily energy value from a home energy audit (your own, or the example from Chapter 1).
2. Choose a system voltage (12 V or 24 V), a number of autonomy days (1 or 2), and a battery type with its typical DoD from the table above.
3. Use the battery bank sizing equation to calculate the required capacity in Ah.
4. Compare your answer with a classmate who chose a different battery type. Whose bank is bigger, and why?

*You need: Calculator or phone, Paper and pen*

## 6.3 Charging Stages, Temperature Effects, and Connecting Batteries

Charging a battery is not just "connect it and wait." A good charger — or a solar charge controller — moves through stages, so the battery fills up quickly but safely. Lead-acid batteries normally use three stages.

### WORD TO KNOW

**Bulk stage** — The first charging stage. The charger sends as much safe current as it can. The battery voltage slowly rises while it fills up.

### WORD TO KNOW

**Absorption stage** — The second charging stage. The charger holds the voltage steady at a set maximum, while the current slowly falls as the battery finishes filling.

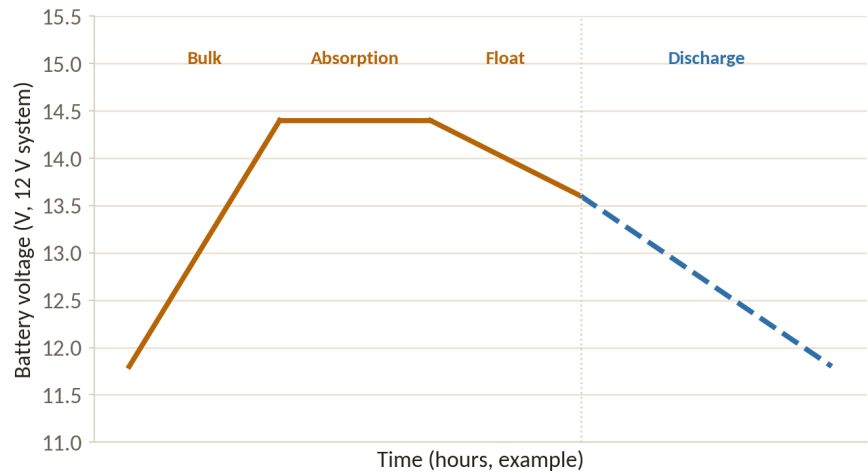
### WORD TO KNOW

**Float stage** — The third charging stage. The charger holds a lower, gentle voltage to keep a full battery topped up, without overcharging it.

#### The three main charging stages

| Stage | What the charger does                             | What happens to voltage and current                 |
|-------|---------------------------------------------------|-----------------------------------------------------|
| Bulk  | Sends as much safe current as the source can give | Current stays high and steady; voltage slowly rises |

| Stage      | What the charger does                                    | What happens to voltage and current                |
|------------|----------------------------------------------------------|----------------------------------------------------|
| Absorption | Holds the voltage steady at a set maximum                | Voltage stays constant; current slowly falls       |
| Float      | Holds a lower, gentle voltage to maintain a full battery | Voltage is lower and steady; current is very small |



A charge and discharge cycle: battery voltage rises through the bulk, absorption, and float stages while charging, then falls again while the battery is discharged (used).

#### COMMON MISTAKE

**✗ Wrong:** Use the same charging voltages and stages for every battery type.

**✓ Right:** Lead-acid and lithium batteries need different charging voltages. Always set the charger or charge controller for the exact battery type in use (Chapter 7 explains controller settings).

How can you tell how full a battery is without opening it? For a lead-acid battery, resting voltage (measured after some hours with no charging and no load) is a reasonable guide. LiFePO4 is different, as the table below shows.

#### Resting voltage vs. state of charge (12 V systems, no load — for reference only)

| State of charge | Lead-acid (12 V nominal) | LiFePO4 (12.8 V nominal) |
|-----------------|--------------------------|--------------------------|
| 100%            | 12.7 V                   | 13.3 V                   |
| 75%             | 12.4 V                   | 13.2 V                   |
| 50%             | 12.2 V                   | 13.1 V                   |
| 25%             | 11.9 V                   | 12.9 V                   |
| 0% (empty)      | ≤ 11.8 V                 | ≤ 10.0 V                 |

Notice the difference: lead-acid voltage changes steadily as it empties, so it is a fair fuel gauge. LiFePO4 voltage stays almost flat until it is nearly empty, then drops fast — voltage alone is a poor fuel gauge for lithium. Good lithium systems use a proper battery monitor instead.

### ACTIVITY (LABORATORY) — MEASURE BATTERY VOLTAGE AT DIFFERENT CHARGE LEVELS

1. Use a multimeter set to DC volts. Measure the resting voltage of a 12 V battery first thing in the morning, after it has rested with no charging or load overnight.
2. Measure again at midday, and again in the evening after a day of use.
3. Compare each reading with the table above to estimate the state of charge at each time.
4. Record your three readings and your estimated state of charge for each.

*You need: A 12 V battery, A multimeter, Notebook*

Temperature also changes how a battery behaves — and how long it lives. This matters a great deal in a hot climate like Iraq and the Kurdistan Region.

### WORD TO KNOW

**Temperature compensation** — Automatically adjusting the charging voltage based on the battery's temperature, so it is not overcharged when hot or undercharged when cold. Many charge controllers do this with a temperature sensor.

### How heat shortens lead-acid battery life (typical rule of thumb)

| Average battery temperature                   | Expected life (relative to the 25°C rating) |
|-----------------------------------------------|---------------------------------------------|
| 25°C (77°F) — the standard rating temperature | 100% (full rated life)                      |
| 35°C (95°F)                                   | ≈ 50%                                       |
| 45°C (113°F)                                  | ≈ 25%                                       |

### CASE STUDY — BEATING THE HEAT: BATTERIES IN A KURDISTAN SUMMER • KURDISTAN REGION

Summer air temperatures in Erbil and other Kurdistan Region cities regularly pass 40°C, and a poorly ventilated rooftop room or metal cabinet can get much hotter inside. A lead-acid battery bank kept there might sit at an average of 40–45°C for months every year. Using the rule of thumb above, that can cut its working life to a quarter of what the datasheet promises — a battery rated for 5 years might last only about 1–2 years. The fix costs little: place the battery bank in the coolest, most shaded, well-ventilated space available (an inside room or shaded cabinet with airflow, not a sealed box in direct sun), and consider LiFePO<sub>4</sub> for hot installations, since it tolerates heat somewhat better and never needs water top-up, which evaporates faster in heat.

### COMMON MISTAKE

**X Wrong:** Install the battery bank on the rooftop in direct sun, because there is space there.

**✓ Right:** Direct sun and high heat can cut a lead-acid battery's life to a quarter or less. Always place batteries in a shaded, ventilated space.

Cold matters too, but differently. Cold does not damage a lead-acid battery the way heat does, but it temporarily lowers the capacity available. LiFePO<sub>4</sub> batteries are more sensitive: most will not accept charging current at all below 0°C (32°F) — their built-in protection circuit stops it automatically to protect the cells.

### WORD TO KNOW

**Battery management system (bms)** — An electronic circuit built into a lithium battery that protects it — for example, by stopping charging if the battery is too cold, too hot, too full, or too empty.

Now to a very practical skill: one battery is rarely enough. Real systems connect several batteries together to reach the voltage and capacity a design needs.

#### WORD TO KNOW

**Nominal voltage** — The standard "name" voltage of a battery or cell, such as 2 V, 6 V, 12 V, or 24 V. The real voltage moves a little above and below this as the battery charges and discharges.

A lead-acid "12 V" battery is really six 2 V cells connected in series inside its case. A LiFePO<sub>4</sub> "12 V" battery is really four 3.2 V cells in series (about 12.8 V nominal). To build a bigger bank, we connect whole batteries together the same way, outside the case.

#### WORD TO KNOW

**Battery series connection** — Connecting the positive terminal of one battery to the negative terminal of the next. This adds up the voltage, while the capacity (Ah) stays the same as one battery.

#### EQUATION: BATTERIES IN SERIES

$$V_{\text{bank}} = n_s \times V_{\text{battery}}$$

*In words: Bank voltage = number of batteries in series × one battery's voltage*

| Symbol               | Meaning                                           | Unit            |
|----------------------|---------------------------------------------------|-----------------|
| V <sub>bank</sub>    | total voltage of the series string                | volts (V)       |
| n <sub>s</sub>       | number of identical batteries connected in series | count (no unit) |
| V <sub>battery</sub> | voltage of one battery                            | volts (V)       |

*Capacity (Ah) does NOT increase in series — the bank capacity stays equal to one battery's capacity.*

#### WORKED EXAMPLE — FOUR BATTERIES IN SERIES

Four 12 V, 100 Ah batteries are connected in series. Find the bank's total voltage, capacity, and energy.

1. Voltage:  $V_{\text{bank}} = n_s \times V_{\text{battery}} = 4 \times 12 \text{ V} = 48 \text{ V}$
2. Capacity stays the same as one battery: 100 Ah
3. Energy:  $E = V \times C = 48 \text{ V} \times 100 \text{ Ah} = 4800 \text{ Wh} = 4.8 \text{ kWh}$

**Answer: 48 V, 100 Ah, 4.8 kWh**

#### WORD TO KNOW

**Battery parallel connection** — Connecting all the positive terminals together, and all the negative terminals together. This adds up the capacity (Ah), while the voltage stays the same as one battery.

### EQUATION: BATTERIES IN PARALLEL

$$C_{\text{bank}} = n_p \times C_{\text{battery}}$$

In words: Bank capacity = number of batteries in parallel  $\times$  one battery's capacity

| Symbol    | Meaning                                             | Unit              |
|-----------|-----------------------------------------------------|-------------------|
| C_bank    | total capacity of the parallel group                | ampere-hours (Ah) |
| n_p       | number of identical batteries connected in parallel | count (no unit)   |
| C_battery | capacity of one battery                             | ampere-hours (Ah) |

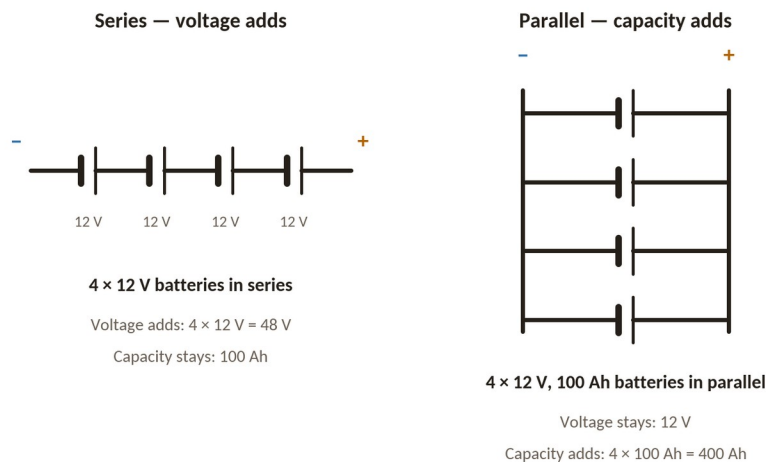
Voltage does NOT increase in parallel — the bank voltage stays equal to one battery's voltage.

### WORKED EXAMPLE — FIVE BATTERIES IN PARALLEL

Five 12 V, 200 Ah batteries are connected in parallel. Find the bank's total voltage and capacity.

1. Voltage stays the same as one battery: 12 V
2. Capacity:  $C_{\text{bank}} = n_p \times C_{\text{battery}} = 5 \times 200 \text{ Ah} = 1000 \text{ Ah}$

**Answer: 12 V, 1000 Ah — this is exactly the battery bank sized in Lesson 2!**



Left: four batteries in series raise the voltage. Right: four batteries in parallel raise the capacity (Ah).

### WORKED EXAMPLE — COMBINING SERIES AND PARALLEL

A design needs a 48 V, 400 Ah bank, built from 12 V, 100 Ah batteries. How many batteries are needed, and how are they connected?

1. Batteries in series for the voltage:  $48 \text{ V} \div 12 \text{ V} = 4$  batteries in series (one "string")
2. Capacity of one string stays at 100 Ah
3. Strings needed in parallel for the capacity:  $400 \text{ Ah} \div 100 \text{ Ah} = 4$  strings
4. Total batteries: 4 in series  $\times$  4 strings = 16 batteries

**Answer: 16 batteries: 4 in series per string, 4 strings in parallel (a "4S4P" bank)**

### COMMON MISTAKE

✗ **Wrong:** Save money by mixing an old battery, a new battery, and a different brand in the same bank.

✓ **Right:** Always use identical batteries — same type, brand, model, age, and capacity — in a series or parallel bank. Mixing causes uneven charging, shortens the whole bank's life, and can be a safety risk.

### SAFETY

When connecting or disconnecting a battery bank: remove rings, watches, and metal jewelry first. Use insulated tools. A metal tool touching both terminals of a battery — or the wrong two terminals in a bank — causes a short circuit, with very high current, hot sparks, and fire risk. Connect one battery at a time, and double-check polarity (+ to –, or + to +) before making the final connection.

► *App simulation: Try it: watch a battery's state of charge change through a full day*

You now understand how batteries charge, how heat and cold affect them, and how to wire a bank for the right voltage and capacity. Lesson 4 puts this to work: buying good batteries in a real shop, and staying safe around them.

## 6.4 Choosing Batteries in the Local Market

You now understand battery types, sizing, and wiring. This last lesson helps you buy wisely in a real shop, and stay safe while working with real batteries.

### WORD TO KNOW

**C-rate** — The speed of charging or discharging, compared to a battery's capacity. C20 means fully discharging over 20 hours; C100 means over 100 hours. The same battery shows a bigger Ah number at a slower rate.

This matters when shopping: a seller may print the biggest, most attractive Ah number on the label — often the slow C100 rating — even though your system will use the battery much faster than that. Always check which C-rate the Ah number is measured at, and compare batteries at the same rate.

**Example: how discharge rate changes usable capacity (one 100 Ah, C20-rated battery)**

| Discharge rate (time to empty)   | Approximate usable capacity |
|----------------------------------|-----------------------------|
| C100 (100 hours)                 | ≈ 110 Ah                    |
| C20 (20 hours) — the rated value | 100 Ah                      |
| C10 (10 hours)                   | ≈ 90 Ah                     |
| C5 (5 hours)                     | ≈ 80 Ah                     |

Before buying a battery, check: - **Weight** — for the same size and Ah rating, a heavier lead-acid battery usually has more real lead inside. - **Brand and warranty** — a known brand with a written warranty (often 1–3 years) is safer than an unknown brand with none. - **Manufacture date** — batteries lose some capacity sitting in a shop. Choose the newest stock you can find. - **The C-rate on the label** — compare batteries at the same discharge rate. - **Physical condition** — no cracks, no leaking, no swelling, and clean, uncorroded terminals. - **Price compared to reputation** — a price far below similar batteries is a warning sign, not a bargain.



### COMMON MISTAKE

**X Wrong:** Always choose the cheapest battery to save money.

**✓ Right:** A cheap battery that fails in one year often costs more per year than a quality battery that lasts five years. Compare the cost per year of service, not just today's price.

### WORKED EXAMPLE — COMPARING TWO BATTERIES BY COST PER YEAR

A shop sells Battery A for 150,000 IQD, expected to last about 2 years. Battery B costs 280,000 IQD, expected to last about 5 years. (Example prices for practice.) Which battery costs less per year?

1. Battery A cost per year:  $150,000 \div 2 = 75,000$  IQD/year
2. Battery B cost per year:  $280,000 \div 5 = 56,000$  IQD/year
3. Compare:  $56,000 < 75,000$

**Answer: Battery B costs less per year (56,000 IQD/year) even though it costs more to buy today — it is the better long-term value**

In Iraq and the Kurdistan Region, flooded and AGM lead-acid batteries are the most common and easiest to find, often imported through regional distributors. LiFePO<sub>4</sub> batteries are becoming more available, especially from shops that specialize in solar equipment, but they usually cost more to buy today than a lead-acid battery of similar usable energy.

### CASE STUDY — TWO NEIGHBORS, TWO BATTERIES • KURDISTAN REGION (EXAMPLE SCENARIO)

Two neighbors each bought a 12 V, 100 Ah battery for their home solar backup. The first chose the cheapest unbranded battery in the market, with no warranty. It failed after 14 months — light, thin plates inside, and no real deep-cycle design. The second paid about 40% more for a known brand with a 2-year written warranty. That battery was still working well after 4 years. Bought again and again over those 4 years, the "cheap" battery actually cost the first neighbor more money in total than the quality battery cost the second — and left him without backup power more than once, during real power cuts.

### SAFETY

**Acid:** flooded lead-acid batteries contain sulfuric acid, which burns skin, eyes, and clothing. If acid touches skin or eyes, rinse immediately with plenty of clean water for at least 15 minutes and get medical help. Wear gloves and eye protection when working near flooded batteries, and never tip a battery on its side.

### WORD TO KNOW

**Hydrogen gas** — An invisible, explosive gas released by lead-acid batteries while they charge. It has no smell, and can explode if it collects in a closed space and meets a spark or flame.

### SAFETY

**Hydrogen gas:** all lead-acid batteries release some hydrogen gas while charging. Always charge batteries in a well-ventilated room. Never smoke, use an open flame, or allow sparks near charging batteries.

## WORD TO KNOW

**Short circuit** — An unwanted direct connection between a battery's positive and negative terminals, letting a very large, dangerous current flow suddenly.

## SAFETY

Short circuits: a battery bank can release very high current in a short circuit — enough to melt metal, throw sparks, and start a fire, in a fraction of a second. Never place tools or metal objects across battery terminals. Remove rings, watches, and metal jewelry before working on a bank. Always fit a fuse or breaker close to the battery, sized correctly for the wiring (Chapter 9 explains this in detail).

## SAFETY

General handling: batteries are heavy — lift with your legs, not your back, or use two people. Store and charge batteries in a dry, ventilated space, away from direct sun and open flame. Keep a suitable fire extinguisher nearby. Keep children away from the battery area, and switch off the battery bank's main disconnect before any maintenance work.

## COMMON MISTAKE

**✗ Wrong:** Charge a battery inside a closed cupboard with the door shut, to keep it out of sight.

**✓ Right:** Hydrogen gas needs airflow to escape safely. Always charge batteries where air can move freely, or in a properly vented enclosure.

## ACTIVITY (LABORATORY) — BATTERY SAFETY INSPECTION

1. With your teacher, inspect a real battery or battery storage area at school or home.
2. Check: is the area ventilated? Are the terminals covered and free of corrosion? Is there a fuse or breaker near the battery? Any cracks, leaks, or swelling? Any warning signs posted?
3. Write down what is good, and what should be fixed.
4. Discuss your list with the class or your teacher.

*You need: Notebook, Torch (flashlight), Teacher supervision*

► *App tool: Plan your bank before you shop: try the [Battery Bank Sizing calculator](#)*

## CHAPTER SUMMARY

- Batteries store energy so solar systems can supply power at night, on cloudy days, and during grid cuts.
- The main types are flooded, AGM, and gel (all lead-acid), and LiFePO<sub>4</sub> (lithium). Always use a deep-cycle battery, never a car battery.
- Energy stored:  $E = V \times C$ . Usable energy:  $E_{\text{usable}} = V \times C \times \text{DoD}$  (write DoD as a decimal).
- Depth of discharge (DoD) and cycle life trade off — a shallower DoD gives many more charge-discharge cycles.
- Battery bank sizing:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$  — always round up to the next available battery size.
- Charging has three stages: bulk (fast fill), absorption (steady voltage), and float (gentle top-up). Lead-acid

and lithium need different settings.

- Heat is a major enemy of lead-acid battery life — keep battery banks shaded and ventilated, especially in a hot Kurdistan Region summer.
- Series connection adds voltage (Ah stays the same); parallel connection adds capacity (V stays the same). Always use identical batteries.
- When buying, compare batteries at the same C-rate, and compare cost per year of service, not just the price today.
- Battery safety: acid burns, hydrogen gas can explode near a spark, and short circuits can cause fire — work carefully, ventilated, and with insulated tools.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A battery is rated 12 V, 80 Ah. How much energy can it store, in Wh and in kWh?

**Problem 2 [Basic]** A battery has a capacity of 200 Ah and a maximum depth of discharge (DoD) of 50%. How many Ah can be safely used?

**Problem 3 [Basic]** Four 12 V, 100 Ah batteries are connected in series. What is the bank's total voltage and capacity?

**Problem 4 [Basic]** Six 12 V, 150 Ah batteries are connected in parallel. What is the bank's total voltage and capacity?

**Problem 5 [Standard]** A 12 V, 150 Ah battery has a maximum DoD of 50%. Find its usable energy, in Wh and kWh.

**Problem 6 [Standard]** A home needs 2000 Wh of energy from its battery bank each day, with 3 days of autonomy. The system voltage is 24 V and the batteries are lead-acid with a maximum DoD of 50%. Find the required battery bank capacity, in Ah.

**Problem 7 [Standard]** A battery is labeled '100 Ah, C20 rate'. At the faster C10 rate, it delivers only about 90% of that rating. How many Ah can it deliver at the C10 rate?

**Problem 8 [Standard]** A battery bank must supply 1500 Wh per day of usable energy, with 2 days of autonomy, at 12 V, using LiFePO<sub>4</sub> batteries with a maximum DoD of 0.8. Find the required bank capacity, in Ah.

**Problem 9 [Standard]** Battery C costs 120,000 IQD and lasts about 2 years. Battery D costs 250,000 IQD and lasts about 5 years. (Example prices for practice.) Which battery costs less per year of service, and by how much?

**Problem 10 [Challenge]** A health center needs 4800 Wh of energy from its battery bank each night, with 2 days of autonomy in case of bad weather. The system voltage is 24 V, using AGM batteries (12 V, 200 Ah each) with a maximum DoD of 50%. (a) Find the required bank capacity in Ah. (b) How many batteries are needed, and how should they be connected? (c) Find the total usable energy of the bank you designed, and check it meets the need.

**Problem 11 [Challenge]** A lead-acid bank gives 2400 Wh of usable energy per cycle (at its 50% DoD limit) and is rated for about 1000 cycles at that DoD. A LiFePO<sub>4</sub> bank with the same 2400 Wh usable energy per cycle (at its 80% DoD limit) is rated for about 4000 cycles. (Typical example ratings — always check the datasheet.) The lead-acid bank costs 1,500,000 IQD and the LiFePO<sub>4</sub> bank costs 4,000,000 IQD (example prices). (a) Find the

total lifetime energy each bank can deliver, in kWh. (b) Find the cost per kWh of lifetime energy for each bank. Which is the better long-term value?

**Problem 12 [Challenge]** A technician connects three batteries in parallel to save money: a 12 V, 100 Ah flooded battery (2 years old), a 12 V, 100 Ah AGM battery (brand new), and a 12 V, 100 Ah battery from a different brand (age unknown). (a) Name two problems with this design. (b) Suggest a correct design that still gives about 12 V and 300 Ah.

**Problem 13 [Challenge]** A mountain cabin runs these loads from its battery bank each evening: 6 LED lamps (10 W each, 5 hours), lights and a router (60 W, 5 hours), and a small fridge (75 W, effectively 8 hours). (a) Find the total daily energy needed from the battery, in Wh. (b) The owner wants 1.5 days of autonomy, a 12 V system, and LiFePO<sub>4</sub> batteries (DoD = 0.8). Find the required bank capacity, in Ah. (c) Available battery sizes are 100 Ah, 150 Ah, and 200 Ah (all 12 V). Using only ONE battery size in a single parallel group, which size and how many batteries meet the need with the least excess capacity?

## CHAPTER SEVEN

# Charge Controllers

*How a small device protects the battery and gets the most energy from the sun*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain what a charge controller does, and why a solar array should never connect directly to a battery.
- Describe how PWM controllers work, and explain the nominal-voltage-matching rule.
- Describe how MPPT controllers track the maximum power point, and estimate the extra energy they can harvest compared to PWM.
- Calculate a charge controller's minimum current rating from the array's short-circuit current and a safety factor.
- Compare PWM and MPPT controllers, and choose the right settings for different battery types.

## 7.1 What a Charge Controller Does

A solar panel does not know when to stop. On a sunny day, it will keep pushing current into a battery long after the battery is full. At night, a battery can push its own current backward into the panel and slowly lose its charge. A small device solves both problems, and many more. It sits between the solar array and the battery, and it is the subject of this chapter.

### WORD TO KNOW

**Array** — All the solar panels in a system, wired together and working as one unit. Chapter 5 explains array wiring in full.

### WORD TO KNOW

**Charge controller** — The device between the solar array and the battery. It controls how the battery is charged, and protects it from overcharge, over-discharge, and reverse current. Also called a charge regulator.

Think of a charge controller as a careful gatekeeper. It watches the battery all day and decides exactly how much current should flow, and when.

### What a charge controller does

| Job                   | Why it matters                                                |
|-----------------------|---------------------------------------------------------------|
| Regulate charging     | Controls how fast and how much the battery charges, in stages |
| Stop overcharge       | Protects the battery from damage once it is full              |
| Block reverse current | Stops the battery from draining back into the panels at night |

| Job                                       | Why it matters                                                  |
|-------------------------------------------|-----------------------------------------------------------------|
| Protect from over-discharge (some models) | Disconnects small DC loads if the battery voltage drops too low |

#### WORD TO KNOW

**Overcharge** — Charging a battery past its safe voltage. It can boil away the water in a flooded battery, damage its plates, and in a lithium battery it can cause serious, even dangerous, damage.

Without a controller, a panel in strong sun would keep charging a full battery. The controller watches the battery voltage and reduces or stops the charging current at the right moment, so the battery never reaches an unsafe voltage.

#### WORD TO KNOW

**Reverse current** — Current that flows backward, from the battery into the solar panel, when there is no sunlight. Without a charge controller, this slowly drains the battery every single night.

This happens because a solar panel behaves a little like a one-way gate only while it makes its own current. At night, with no light, the battery's own voltage can push current the wrong way through the panel. The charge controller has a switch that opens at night, so no current can flow backward.

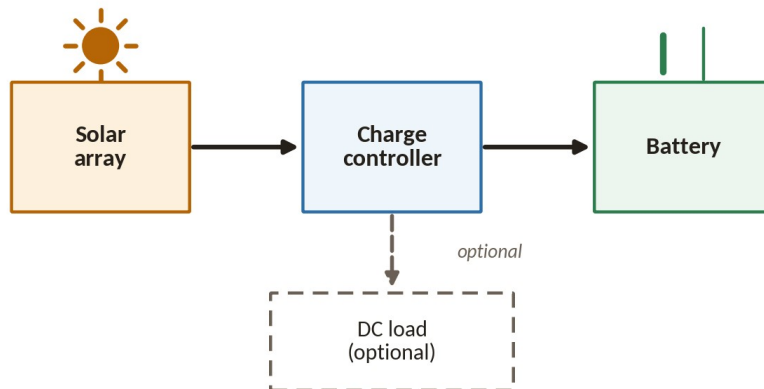
#### WORD TO KNOW

**Battery** — A device that stores electrical energy using a chemical reaction, and releases it later as electricity. Chapter 6 explains battery types in full.

#### WORD TO KNOW

**Low-voltage disconnect** — A safety feature on many controllers. It disconnects small DC loads (like lights) from the battery if the battery voltage drops too low, to stop over-discharge. Short form: LVD.

A controller usually has three sets of connection points: one for the array, one for the battery, and sometimes a small **load output** for direct DC devices like lights. If the battery gets too low, the controller can disconnect this load output automatically — this is the low-voltage disconnect at work. Most inverters, however, connect straight to the battery terminals, not to this small load output, because they usually need more current than it is built for.



Where the charge controller sits: solar array → charge controller → battery, with an optional small load output.

#### WORD TO KNOW

**Charging stage** — A step in the charging process. Controllers use different stages, one after another, to charge a battery quickly and safely, then keep it topped up without stress.

#### The three main charging stages

| Stage      | What happens                                                                                             | Goal                                         |
|------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------|
| Bulk       | The controller sends as much current as the array and controller allow. Battery voltage climbs steadily. | Charge the battery quickly while it is empty |
| Absorption | The controller holds the voltage steady at a set point. Current slowly drops as the battery fills.       | Finish charging fully, without overcharging  |
| Float      | The controller lowers the voltage to a gentle maintenance level.                                         | Keep a full battery topped up without stress |

Lesson 4 gives the exact voltage numbers for each stage, and shows how they change for different battery types.

#### SAFETY

Always connect the wires in the right order: **battery first, then array**. When you disconnect, do it in reverse: array first, then battery. Breaking a live DC connection under load can cause a spark — unlike AC, a DC arc does not go out by itself, so this order matters for your safety and the equipment's.

#### COMMON MISTAKE

**X Wrong:** Connecting a solar panel straight to a battery is fine, just for a short time.

**✓ Right:** Never connect a panel directly to a battery, even briefly. In strong sun, a small battery can be overcharged in minutes, and without a controller it will also lose charge through reverse current every

night.

#### ACTIVITY (LABORATORY) — FIND THE CONTROLLER'S CONNECTIONS

1. Look at a real charge controller, or a clear picture of one.
2. Find the terminals for the array (PV input), the battery, and the load output, if there is one.
3. Look for any LED lights or a screen. Check the manual, if you have it, to see what they show.
4. Write down the numbers printed on the controller, such as its rated current and voltage. You will need this skill in Lesson 4.

*You need: A charge controller (real or a picture), its instruction manual, if available*

## 7.2 PWM Controllers

There are two main kinds of charge controller: PWM and MPPT. This lesson explains PWM — the simpler, older, and cheaper kind. It is still a good, honest choice for many small systems.

#### WORD TO KNOW

**PWM** — Pulse width modulation. A way of switching a connection on and off very fast to control the average current. PWM controllers use this trick to control battery charging.

#### WORD TO KNOW

**Duty cycle** — The share of time a fast switch spends 'on' during each on/off cycle. A high duty cycle means more current flows on average; a low duty cycle means less.

A PWM controller works like a very fast, very smart light switch. During the bulk stage, it stays on almost 100% of the time, so the battery gets full current. As the battery voltage nears the absorption set point, the controller switches on and off many times a second, lowering the duty cycle bit by bit. This holds the voltage steady while the current gently tapers off — without ever letting the voltage go too high.

Here is the catch. A PWM controller does not convert anything — it simply connects the array to the battery through its fast switch. This means the array is forced to operate at almost exactly the battery's voltage, not at its own best voltage.

#### WORD TO KNOW

**Nominal voltage** — A simple, rounded name for a battery or panel's voltage class, like '12 V'. The real voltage is usually different. A '12 V' battery is really about 11.8–14.4 V depending on its charge. A '12 V' panel's real operating voltage is often about 17–18 V.

#### WORD TO KNOW

**String** — A group of solar panels wired one after another (in series), so their voltages add up. An array can be one string, or several strings wired in parallel.



This gives the golden rule for PWM: **the array's nominal voltage should match the battery's nominal voltage.** A '12 V' panel, or a string that adds up to 12 V, suits a 12 V battery. A '24 V' panel or string suits a 24 V battery. Anything higher just wastes the extra voltage — a PWM controller cannot use it.

#### WORKED EXAMPLE — HOW MUCH POWER DOES PWM ACTUALLY DELIVER?

A 165 W solar panel has  $V_{mp} = 18.0\text{ V}$  and  $I_{mp} = 9.2\text{ A}$  at standard test conditions. It charges a 12 V lead-acid battery through a PWM controller. The battery is charging at 14.4 V. Estimate the power the panel actually delivers, and compare it with its rated power. (This is a simple estimate that assumes the current stays close to  $I_{mp}$ . The real shape of a panel's voltage-current curve is covered in Chapter 4.)

1. Rated power at the maximum power point:  $P = V_{mp} \times I_{mp} = 18.0\text{ V} \times 9.2\text{ A} = 165.6\text{ W}$
2. With PWM, the panel is forced to operate at close to the battery voltage, not  $V_{mp}$ : about 14.4 V
3. Estimated delivered power:  $P \approx 14.4\text{ V} \times 9.2\text{ A} = 132.5\text{ W}$
4. Compare with rated power:  $132.5 \div 165.6 \approx 0.80$ , so about 80% of the rated power is used

**Answer: About 132.5 W delivered — about 20% less than the panel's rated 165.6 W, because PWM cannot use the panel's full voltage.**

#### CASE STUDY — A SIMPLE LIGHTING KIT FOR A VILLAGE HOME • KURDISTAN REGION

A small home outside a village has no grid connection. The family installs one 100 W, 12 V nominal panel, a small 12 V battery, a PWM controller, and three LED lights. Because the panel's nominal voltage matches the battery's nominal voltage, the PWM controller wastes very little power — a perfect, low-cost match. For a system this small and simple, MPPT would add cost without adding much benefit. This is exactly the kind of job PWM was made for.

#### COMMON MISTAKE

**✗ Wrong:** Any 12 V panel works well with a PWM controller, as long as the total wattage is enough.

**✓ Right:** For PWM, the array's nominal voltage must stay close to the battery's nominal voltage. Wiring two 12 V panels in series (making a 24 V string) into a PWM controller on a 12 V battery can waste half or more of the second panel's power, because PWM only uses the string's current, not its extra voltage. For a 12 V battery and PWM, wire extra panels in parallel instead.

#### ACTIVITY (HOME) — CHECK A SMALL SOLAR PRODUCT

1. Find a small solar product at home or in a local shop — a garden light, a phone-charging panel, or a small lighting kit.
2. Look at the panel for its printed power (W) and voltage (V).
3. Think about the battery it charges. Is the panel's voltage close to the battery's nominal voltage?
4. Decide: does this product most likely use a PWM controller? Explain your reasoning in one sentence.

*You need: A small solar product, or a picture/advertisement of one*

## 7.3 MPPT Controllers

Lesson 2 showed a problem: a PWM controller cannot use a panel's extra voltage, only its current. What if a controller could capture that extra voltage too, and turn it into extra current instead of wasting it? That is exactly what an MPPT controller does.

### WORD TO KNOW

**MPPT** — Maximum power point tracking. A smart charging method that constantly finds the array's best operating point, and converts extra voltage into extra current, so more of the panel's power reaches the battery.

### WORD TO KNOW

**Maximum power point** — The exact spot on a solar panel's voltage-current curve where it produces the most power. Its voltage is called  $V_{mp}$  and its current is called  $I_{mp}$ .

A panel's maximum power point is not fixed. It shifts a little through the day as sunlight and temperature change. An MPPT controller checks the array many times a second and always adjusts to stay at the best point — a little like a car automatically shifting gears to get the best power at any speed.

Once the MPPT controller finds  $V_{mp}$  and  $I_{mp}$ , its DC-DC converter changes that power to match the battery's voltage. Power is roughly conserved: if the array's voltage is higher than the battery's voltage, the converter delivers a **higher current** to the battery than the array itself produces. This is exactly the extra power that a PWM controller would have wasted.

### EQUATION: ESTIMATING THE MPPT ENERGY GAIN

$$\text{Gain} \approx \frac{V_{mp} - V_{\text{battery}}}{V_{\text{battery}}} \times 100\%$$

In words: Estimated MPPT gain (%) = (Array  $V_{mp}$  – Battery charging voltage) ÷ Battery charging voltage × 100

| Symbol               | Meaning                                                                                                   | Unit        |
|----------------------|-----------------------------------------------------------------------------------------------------------|-------------|
| Gain                 | the estimated extra energy an MPPT controller can harvest, compared to PWM, on the same array and battery | percent (%) |
| $V_{mp}$             | the array's voltage at its maximum power point, at that moment                                            | volts (V)   |
| $V_{\text{battery}}$ | the battery's actual charging voltage at that moment                                                      | volts (V)   |

*This is a simple estimate, not an exact figure. It assumes the array's current stays about the same with either controller type — only the voltage changes. Real results also depend on temperature, weather, and the MPPT converter's own small losses (about 2–5%). As a rule of thumb, MPPT controllers usually harvest about 10% to 30% more energy than PWM controllers, and the gain is largest when  $V_{mp}$  is much higher than the battery voltage — for example, on cold mornings, or when panels are wired with extra series voltage.*

### WORKED EXAMPLE — ESTIMATING THE MPPT ADVANTAGE FOR A 12 V SYSTEM

An array's maximum power point voltage is 18.0 V. A 12 V lead-acid battery is charging at 14.4 V (absorption stage). Estimate how much more energy an MPPT controller could harvest compared to a PWM controller, on this same array and battery.

1. Write the equation:  $\text{Gain} \approx (V_{mp} - V_{\text{battery}}) \div V_{\text{battery}} \times 100\%$

2. Put in the numbers:  $\text{Gain} \approx (18.0 - 14.4) \div 14.4 \times 100\%$

3. Calculate:  $\text{Gain} \approx 3.6 \div 14.4 \times 100\% = 25\%$

**Answer: About 25% more energy — a typical result for a 12 V nominal array charging a 12 V battery.**

#### WORD TO KNOW

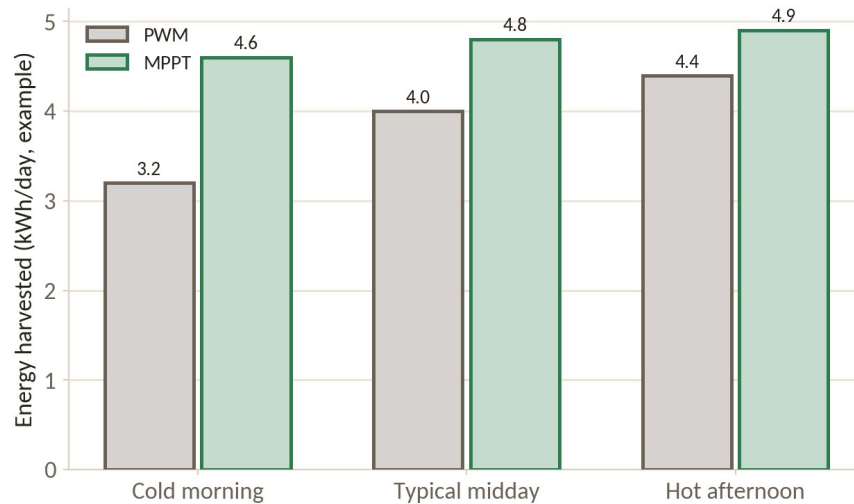
**Open-circuit voltage** — The voltage of a solar panel or array when no current is flowing — its highest possible voltage. Written Voc. It is higher than Vmp, and it rises further in cold weather.

#### SAFETY

Every MPPT controller has a maximum PV input voltage, often 100 V or 150 V. The array's open-circuit voltage (Voc) must always stay below this limit — remember, Voc rises on cold mornings. Wiring too many panels in series can push Voc above the limit and permanently damage the controller. Always check the controller's datasheet before wiring long series strings.

#### PWM vs. MPPT: quick comparison

| Feature                  | PWM controller                                                         | MPPT controller                                                                             |
|--------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| How it works             | A fast on/off switch connects the array almost directly to the battery | A DC-DC converter tracks the maximum power point and turns extra voltage into extra current |
| Best array voltage       | Should stay close to the battery's nominal voltage                     | Can be much higher than the battery voltage                                                 |
| Typical energy harvested | Baseline                                                               | About 10–30% more than PWM, depending on conditions                                         |
| Cost                     | Lower                                                                  | Higher                                                                                      |
| Wiring flexibility       | Panels usually wired to match battery voltage                          | Panels can be wired in longer series strings, allowing thinner, cheaper cable               |
| Good fit for             | Small systems, tight budgets, matched voltages                         | Larger systems, long cable runs, cold climates, mismatched voltages                         |



Example daily energy harvested by a PWM controller compared with an MPPT controller, for the same array and battery.

#### CASE STUDY — A MOUNTAIN TELECOM SITE CHOOSES MPPT • KURDISTAN REGION

A telecommunications relay sits on a mountainside, far from the grid. The equipment shelter is 40 meters from the best place to mount the panels. The engineers wire the panels into two long series strings, which keeps the current low and lets them use much thinner, cheaper cable over that distance. An MPPT controller then converts the strings' high voltage down to the battery bank's voltage safely and efficiently. A PWM controller could not have used this wiring plan at all — the voltage mismatch would have wasted a large share of the array's power, defeating the purpose of the long cable run.

#### COMMON MISTAKE

**✗ Wrong:** MPPT is always better, so always buy an MPPT controller, no matter what.

**✓ Right:** For a small, well-matched 12 V system on a tight budget, a good PWM controller is often the smarter choice. Choose the controller type by looking at the whole system — array voltage, battery voltage, cable runs, and budget — not just by the label PWM or MPPT.

► [App simulation: Try it: compare PWM and MPPT harvested energy in the simulation](#)

## 7.4 Sizing and Configuring a Controller

Choosing a real charge controller means two jobs. First, pick the right **size**, so it can safely carry the array's current. Second, pick the right **settings**, so it charges the battery correctly. This lesson covers both.

#### WORD TO KNOW

**Short-circuit current** — The highest current a solar panel or array can produce — measured with its two wires connected directly together, with no load. Written  $I_{sc}$ . It is higher than  $I_{mp}$ .

Why size a controller using  $I_{sc}$ , and not the more familiar  $I_{mp}$ ? Because the controller must survive the worst realistic moment, not just a typical one. Very bright, cool, clear days — and bright light reflecting off clouds or a light-colored wall — can push the array's current briefly above its normal rated value. The controller must handle that safely, every time, for twenty years.

## EQUATION: CHARGE CONTROLLER CURRENT RATING

$$I_{\text{controller}} \geq I_{\text{SC}} \times 1.25$$

*In words: Controller current rating  $\geq$  Array short-circuit current  $\times 1.25$*

| Symbol                  | Meaning                                                                                                                                                   | Unit        |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| $I_{\text{controller}}$ | the minimum current rating the charge controller must have                                                                                                | amperes (A) |
| $I_{\text{SC}}$         | the total short-circuit current of the whole array, as wired (add $I_{\text{sc}}$ for every string wired in parallel; series wiring does not add current) | amperes (A) |

1.25 is a safety factor. It allows for sunlight brighter than standard test conditions, and it keeps the controller from working at its very limit all day. Charge controllers come in standard sizes — commonly 10, 20, 30, 40, 50, 60, 80, and 100 A. Always round your answer UP to the next standard size. Never round down.

### WORKED EXAMPLE — SIZING A CONTROLLER FOR A SMALL HOME ARRAY

A home array has four 165 W panels. Each panel:  $V_{\text{oc}} = 22.0 \text{ V}$ ,  $I_{\text{sc}} = 9.5 \text{ A}$ . The panels are wired as two strings of two panels in series, with the two strings wired in parallel, feeding a 24 V battery bank. Find the minimum controller current rating, and choose a standard controller size.

1. Find each string's short-circuit current. Panels in series do NOT add current, so each string's  $I_{\text{sc}} = 9.5 \text{ A}$ , the same as one panel.
2. Find the array's total  $I_{\text{sc}}$ . The two strings are in parallel, and parallel wiring DOES add current:  $I_{\text{SC}}(\text{array}) = 2 \times 9.5 \text{ A} = 19.0 \text{ A}$
3. Apply the safety factor:  $I_{\text{controller}}(\text{min}) = 19.0 \text{ A} \times 1.25 = 23.75 \text{ A}$
4. Choose a standard size at or above 23.75 A. A 20 A controller is too small, so choose a 30 A controller.

**Answer: The controller must be rated at least 23.75 A. Choose a standard 30 A controller.**

Always check the voltage side too. This array's total open-circuit voltage is  $2 \times 22.0 \text{ V} = 44.0 \text{ V}$  (series wiring adds voltage). As Lesson 3 explained, this  $V_{\text{oc}}$  — and its higher, cold-weather value — must stay below the chosen controller's maximum PV input voltage rating.

### COMMON MISTAKE

**✗ Wrong:** 23.75 A is close enough to 20 A, so buying the cheaper 20 A controller is fine.

**✓ Right:** Always round UP to the next standard size, never down. A controller running at or above its rated current overheats, and can fail or even catch fire. Rounding down removes your entire safety margin.

► *App tool: Check your sizing with the Charge Controller Sizing calculator*

Sizing gets the current right. Configuring gets the voltage right for your specific battery. Most controllers let you choose a battery type setting, sometimes called a profile — for example flooded lead-acid, sealed (AGM or gel), or lithium ( $\text{LiFePO}_4$ ). Choosing the correct one matters as much as choosing the right size.

### WORD TO KNOW

**Temperature compensation** — A controller feature that automatically adjusts the charging voltage for a lead-acid battery's temperature. Hot batteries need a lower voltage; cold batteries need a higher voltage. It usually needs a small temperature sensor clipped to the battery.

## WORD TO KNOW

**Equalization** — A controlled overcharge, done on purpose sometimes for flooded lead-acid batteries. It mixes the acid and helps prevent a problem called sulfation. It must never be done to sealed (AGM, gel) or lithium batteries.

## Typical charging settings by battery type (12 V system, example values)

| Battery type                   | Absorption voltage | Float voltage         | Equalization      | Temperature compensation |
|--------------------------------|--------------------|-----------------------|-------------------|--------------------------|
| Flooded lead-acid              | about 14.4–14.8 V  | about 13.2–13.8 V     | Yes, occasionally | Yes, recommended         |
| Sealed (AGM / gel)             | about 14.2–14.6 V  | about 13.5–13.8 V     | Never             | Small amount, if any     |
| Lithium (LiFePO <sub>4</sub> ) | about 14.2–14.6 V  | little or none needed | Never             | Not usually needed       |

These numbers are typical examples for a 12 V nominal system. For a 24 V system, multiply by two; for a 48 V system, multiply by four. Always check the battery manufacturer's own datasheet for the exact numbers — this table is a guide, not a rulebook.

## SAFETY

Never run an equalization charge on a sealed (AGM or gel) or lithium battery. It can dry out a sealed battery or seriously damage a lithium battery. A lithium battery pack should also have its own battery management system (BMS) for cell protection — the charge controller's lithium setting works together with the BMS, it does not replace it.

## CASE STUDY — PLANNING AHEAD IN SULAYMANIYAH · SULAYMANIYAH, KURDISTAN REGION

A family buys 2 panels now and sizes their controller for exactly that — no more. A year later, with a little more money saved, they add 2 more panels in parallel. The array's current nearly doubles, but their controller cannot handle it, so they must buy a second, bigger controller and rewire everything. A neighbor, planning the same way, bought one controller sized for the **full array** they intended to reach in a year, even though only half the panels were installed at first. It cost a little more up front, but it saved a second purchase and a day of rework later. When you expect to grow a system, size the controller for the future array, not just today's.

## ACTIVITY (LABORATORY) — CONFIGURE A CONTROLLER FOR TWO BATTERY TYPES

1. Using a real charge controller (with DIP switches, buttons, or a Bluetooth app) or the app's simulated controller, find the battery type setting.
2. Set it to flooded lead-acid. Write down the bulk/absorption, float, and equalization settings shown.
3. Change the setting to lithium (LiFePO<sub>4</sub>). Write down how the settings change.
4. Discuss: what could happen if a lithium battery were charged using the flooded lead-acid profile, or a lead-acid battery were charged using the lithium profile?

*You need: A real or simulated charge controller with adjustable battery type settings, Paper and pen*

## CHAPTER SUMMARY

- A charge controller sits between the solar array and the battery. It regulates charging, stops overcharge, and blocks reverse current at night.
- Controllers charge in stages: bulk (full current), absorption (steady voltage, tapering current), and float (gentle top-up).
- PWM controllers connect the array to the battery through a fast on/off switch. The array's nominal voltage should match the battery's nominal voltage.
- MPPT controllers use a DC-DC converter to track the array's maximum power point and turn extra voltage into extra current.
- MPPT usually harvests about 10% to 30% more energy than PWM. The gain is biggest when the array's  $V_{mp}$  is much higher than the battery voltage.
- Size a controller with: minimum current = array short-circuit current ( $I_{sc}$ )  $\times$  1.25. Always round UP to the next standard size.
- Always check that the array's open-circuit voltage ( $V_{oc}$ ) stays below the controller's maximum input voltage rating — remember,  $V_{oc}$  rises in cold weather.
- Set the correct battery type (profile) on the controller — flooded, sealed (AGM/gel), or lithium — because each needs different charging voltages.
- Never equalize a sealed or lithium battery. Only flooded lead-acid batteries can be safely equalized, and only occasionally.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A small array has one string of panels. Its short-circuit current is 8.0 A. Using the standard safety factor of 1.25, find the minimum controller current rating.

**Problem 2 [Basic]** A panel's  $V_{mp} = 17.0$  V and  $I_{mp} = 8.0$  A, so its rated power is 136 W. A PWM controller forces it to operate at the battery's charging voltage of 13.0 V. Assuming the current stays close to  $I_{mp}$ , estimate the delivered power, and the percent of rated power delivered.

**Problem 3 [Basic]** Three panels, each with  $V_{oc} = 21.0$  V, are wired in series to form one string. What is the string's total open-circuit voltage?

**Problem 4 [Basic]** Three panels, each with  $I_{sc} = 8.5$  A, are wired in parallel. What is the total short-circuit current?

**Problem 5 [Standard]** An array has 3 strings wired in parallel. Each string has 2 panels wired in series. Each panel:  $I_{sc} = 8.8$  A,  $V_{oc} = 20.5$  V. Find (a) the array's total  $I_{sc}$ , (b) the array's total  $V_{oc}$ , and (c) the minimum controller current rating using the 1.25 safety factor, with a standard size chosen from 10, 20, 30, 40, 50, 60, 80, 100 A.

**Problem 6 [Standard]** A high-voltage MPPT array has  $V_{mp} = 72.0$  V. A 48 V nominal battery bank is charging at 56.0 V. Estimate the MPPT energy gain over PWM, in percent.

**Problem 7 [Standard]** A technician checks a controller charging a 12 V flooded battery through the day. In the morning, the voltage climbs steadily while the current stays at its maximum. By late morning, the voltage reaches 14.4 V and holds there while the current slowly drops. In the afternoon, the voltage drops to 13.5 V and stays there with only a small current flowing. Name the three stages, in the order they happened.

**Problem 8 [Standard]** A family installs 2 identical panels wired in parallel ( $I_{sc} = 9.0$  A each). They plan to add 2 more identical panels in parallel next year, making 4 panels total in parallel. (a) Find today's minimum controller current rating (safety factor 1.25). (b) Find next year's minimum controller current rating after the panels are added. Choose standard sizes from 10, 20, 30, 40, 50, 60, 80, 100 A for both.

**Problem 9 [Standard]** A 24 V nominal battery bank is charged by an array with  $V_{mp} = 36$  V, through a PWM controller. The battery charges at 28.0 V. (a) Estimate the percent of rated power the PWM controller can actually deliver (assume current stays about the same). (b) Would MPPT be a clearly better choice here? Estimate the MPPT gain to support your answer.

**Problem 10 [Challenge]** A small business in Duhok installs an array of six panels, each rated:  $V_{oc} = 21.6$  V,  $I_{sc} = 9.8$  A. They are wired as 3 strings of 2 panels in series, all 3 strings in parallel, charging a 24 V battery bank through an MPPT controller. The controller's datasheet lists a maximum PV input voltage of 100 V. On a cold morning, assume the array's  $V_{oc}$  rises by 8% above its rated value. (a) Find the array's total  $I_{sc}$ . (b) Find the minimum controller current rating (safety factor 1.25), and choose a standard size from 10, 20, 30, 40, 50, 60, 80, 100 A. (c) Find the array's  $V_{oc}$  at standard conditions, and on the cold morning. (d) Is the controller's 100 V maximum input voltage safe in both cases? Explain.

**Problem 11 [Challenge]** A 24 V nominal array has  $V_{mp} = 34.0$  V on a hot afternoon, but  $V_{mp} = 38.5$  V on a cool winter morning, because heat lowers a panel's voltage. The battery charges at 27.0 V in both cases. (a) Estimate the MPPT gain over PWM on the hot afternoon. (b) Estimate the MPPT gain on the cool morning. (c) In which condition does MPPT help more, and why does that make sense?

**Problem 12 [Challenge]** A rural clinic needs a 12 V battery bank charged by 4 panels ( $V_{oc} = 22.0$  V,  $I_{sc} = 9.5$  A,  $V_{mp} = 18.0$  V each). Two wiring plans are possible. Plan A: all 4 panels wired in parallel. Plan B: 2 strings of 2 panels in series, with the 2 strings wired in parallel. (a) For Plan A, find the array's  $I_{sc}$ ,  $V_{oc}$ , and  $V_{mp}$ . (b) For Plan B, find the array's  $I_{sc}$ ,  $V_{oc}$ , and  $V_{mp}$ . (c) Which plan suits a PWM controller, and which needs MPPT? Explain using the nominal-voltage-matching rule. (d) For the plan that suits PWM, find the minimum controller current rating (safety factor 1.25), and choose a standard size from 10, 20, 30, 40, 50, 60, 80, 100 A.



## CHAPTER EIGHT

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# Inverters

*How DC becomes AC, and how to choose the right inverter*

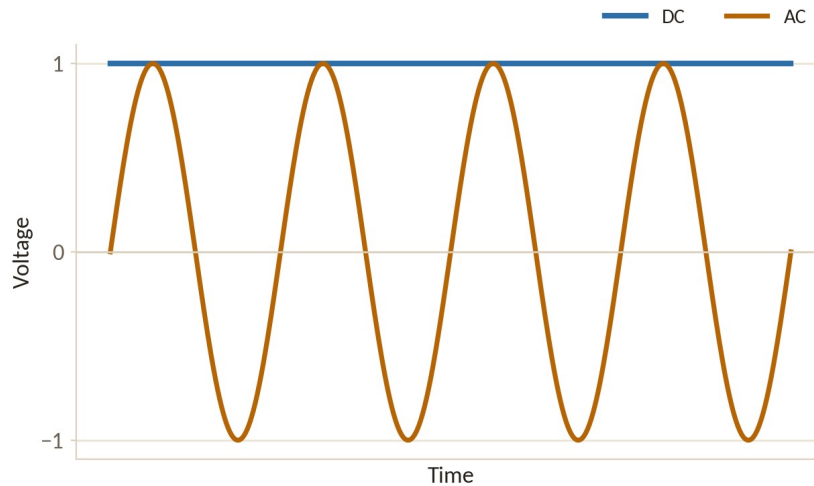
### IN THIS CHAPTER YOU WILL LEARN TO

- Explain why solar systems need an inverter, and describe the difference between DC and AC electricity.
- Compare square wave, modified sine wave, and pure sine wave inverters, and identify which loads need which.
- Describe off-grid, grid-tie, hybrid, and inverter-charger types, and explain how hybrid inverter-chargers combine grid, generator, and solar or battery power.
- Calculate inverter efficiency, and explain why efficiency changes with the size of the load.
- Distinguish continuous power rating from surge (peak) power rating, and calculate the surge power needed by a motor.
- Size an inverter for a real set of loads, using a safety margin and a surge check.

### 8.1 From DC to AC: Waveforms

Solar panels and batteries produce **DC** electricity. But almost every home, shop, and appliance in Iraq and the Kurdistan Region runs on **AC** electricity from the wall socket. Something must change one into the other. That something is the **inverter** — the subject of this whole chapter.

As you learned in Chapter 2, picture DC as a flat, steady push in one direction — like water flowing one way through a pipe. AC is different: it pushes one way, then the other way, then back again, over and over. If you drew a graph of the voltage over time, DC would be a flat line and AC would be a smooth wave that goes up and down.



Direct current (DC) stays flat and always flows the same way. Alternating current (AC) rises and falls, changing direction many times each second.

#### WORD TO KNOW

**Inverter** — A device that changes DC electricity into AC electricity, so that solar panels and batteries can power normal AC appliances.

AC does not just switch back and forth randomly — it repeats in a steady pattern, called a **cycle**. How many cycles happen every second is the **frequency** — a term you also met in Chapter 2 — measured in hertz (Hz). The public grid in Iraq and the Kurdistan Region supplies AC at about 220 V and 50 cycles per second, or 50 Hz. A good inverter must copy this same standard, or sensitive appliances will not run correctly.

#### EQUATION: PERIOD FROM FREQUENCY

$$T = \frac{1}{f}$$

In words: Period = 1 ÷ frequency

| Symbol | Meaning                                  | Unit        |
|--------|------------------------------------------|-------------|
| T      | period — the time for one complete cycle | seconds (s) |
| f      | frequency                                | hertz (Hz)  |

A higher frequency means a shorter period — more cycles packed into every second. Iraq's grid uses 50 Hz, the same standard used across most of the Middle East and Europe (some countries, such as the USA, use 60 Hz instead).

#### WORKED EXAMPLE — THE PERIOD OF IRAQ'S GRID FREQUENCY

Iraq's public grid supplies AC at 50 Hz. What is the period — the time for one complete cycle?

1. Write the equation:  $T = 1 \div f$
2. Put in the numbers:  $T = 1 \div 50 \text{ Hz}$
3. Calculate:  $T = 0.02 \text{ s}$
4. Convert to milliseconds:  $0.02 \times 1000 = 20 \text{ ms}$

**Answer: 0.02 seconds, or 20 milliseconds, per cycle**

#### WORD TO KNOW

**Waveform** — The shape you get when you draw a graph of AC voltage over time. Different inverters produce different waveform shapes.

An inverter builds its AC output by switching the DC current on and off very fast, thousands of times each second, and shaping the result. How well it copies a smooth, natural sine wave decides the waveform **quality**. There are three common types.

#### WORD TO KNOW

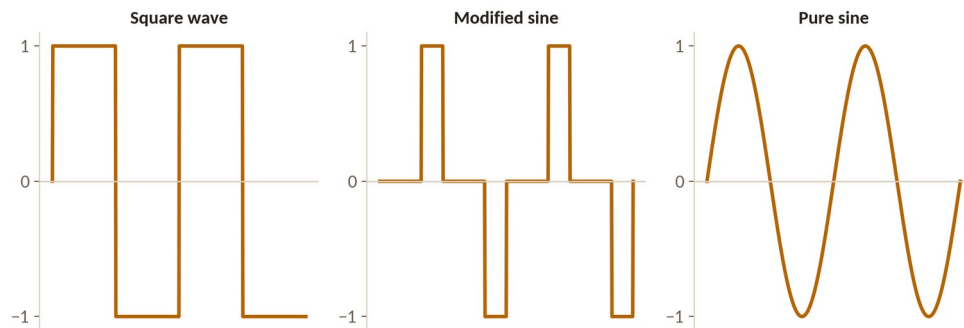
**Square wave** — The simplest and lowest-quality inverter waveform. It jumps sharply between two fixed levels, with no smooth curve at all.

#### WORD TO KNOW

**Modified sine wave** — A middle-quality inverter waveform. It moves in rough, flat-topped steps that only roughly copy the smooth shape of a true sine wave.

#### WORD TO KNOW

**Pure sine wave** — The highest-quality inverter waveform. It is a smooth curve that closely matches the AC power from the public grid.



*Three inverter output waveforms: square wave (sharp steps), modified sine wave (rounded steps), and pure sine wave (smooth curve, like the public grid).*

#### Comparing the three waveforms

| Waveform           | Quality | Good for                                      | Watch out for                                            |
|--------------------|---------|-----------------------------------------------|----------------------------------------------------------|
| Square wave        | Lowest  | Very simple resistive tools only (rare today) | Can damage motors and most electronics — mostly obsolete |
| Modified sine wave | Medium  | Lamps, simple heaters, basic power tools      | Motors run hotter and noisier; can harm or               |

| Waveform       | Quality | Good for                                                    | Watch out for                                |
|----------------|---------|-------------------------------------------------------------|----------------------------------------------|
|                |         |                                                             | confuse sensitive electronics                |
| Pure sine wave | Highest | Everything — motors, computers, medical and audio equipment | Costs more than modified sine wave inverters |

In practice: **resistive loads** (lamps, simple heating elements, an iron) barely notice the difference, because they just need the right voltage. **Motors** (a refrigerator compressor, a fan, a water pump) run hotter, noisier, and less efficiently on a modified sine wave, and may fail sooner. **Sensitive electronics** (computers, some TVs and chargers, medical devices, audio equipment) can buzz, behave strangely, or even be damaged on a poor waveform. When in doubt, or when a motor runs for many hours a day, choose pure sine wave.

#### SAFETY

A motor — such as a refrigerator compressor or a water pump — that runs for a long time on a poor-quality waveform can run hot. Over weeks or months, this heat can damage the motor's wire insulation and become a fire risk. Always use a pure sine wave inverter for loads with motors that run for many hours a day.

#### COMMON MISTAKE

**✗ Wrong:** A cheap modified sine wave inverter is fine for everything, because it powers a lamp with no problem.

**✓ Right:** A lamp is a simple, forgiving load. Motors and many electronics need a cleaner waveform. Test the real appliances you plan to use, or choose pure sine wave to be safe.

#### ACTIVITY (HOME) — FIND THE MOTORS IN YOUR HOME

1. Walk through your home and list ten electrical items.
2. Sort each one into a group: (a) simple resistive loads like lamps and heaters, (b) items with a motor like a fan, fridge, or washing machine, (c) sensitive electronics like a computer, TV, or charger.
3. For each group, write down which waveform (square, modified sine, or pure sine) you would choose, and why.

*You need: Paper and pen*

## 8.2 Types of Inverters

Every inverter changes DC into AC, as you learned in Lesson 1. But inverters also have different **jobs**, depending on what the solar system connects to: a battery only, the public grid only, or several sources at once. This lesson looks at the four types you will meet most often.

#### WORD TO KNOW

**Off-grid inverter** — An inverter that is not connected to the public grid at all. It takes DC power from a battery bank and supplies AC power to the loads.

An off-grid inverter works completely alone. Solar panels charge the battery bank through a charge controller (Chapter 7), and the inverter draws DC from the battery to make AC for the home. It is the right choice where there is no public grid — a remote village, a farm, a mountain site — or as a stand-alone backup system.

#### WORD TO KNOW

**Grid-tie inverter** — An inverter designed to connect to the public grid. It synchronizes with the grid's voltage and frequency and feeds solar power directly to the home or the grid.

A grid-tie inverter (also called a grid-tied or on-grid inverter) does not normally need a battery. In the simplest systems, any solar power made during the day is used in the home or sent out to the grid, and the home simply pulls from the grid at night or on cloudy days. This is the cheapest way to save on electricity bills where the grid is reliable — but it has one important safety rule.

#### WORD TO KNOW

**Anti-islanding** — A safety feature that makes a grid-tie inverter switch off automatically as soon as it senses that the public grid has gone down.

#### SAFETY

Anti-islanding exists to protect people. Repair crews work on 'dead' power lines assuming there is no electricity in them. If a grid-tie inverter kept sending power into a line during an outage, it could badly injure or kill a worker. This is exactly the same idea as Chapter 1's generator safety rule — never let two power sources feed the same wires unless the equipment is designed and certified to switch between them safely.

#### COMMON MISTAKE

**X Wrong:** "I have solar panels, so my lights will stay on during a power cut."

**✓ Right:** A simple grid-tie inverter switches off during a grid power cut, by law and by design. Only an off-grid or hybrid system with a battery can keep your lights on during an outage.

Many homes here want both things at once: savings from solar and the grid, AND backup power when the grid or the neighborhood generator both fail. That is the job of the third type.

#### WORD TO KNOW

**Hybrid inverter** — An inverter that can work with solar panels, a battery, AND the grid or a generator, all in the same system. It can send power between sources automatically.

A hybrid inverter usually follows a priority order that you can set yourself: for example, use solar power first, then stored battery power, and only pull from the grid or generator last, when the battery is running low. Some owners prefer the opposite order, to save the battery for outages. Either way, this order is a **setting**, not something fixed forever.

#### COMMON MISTAKE

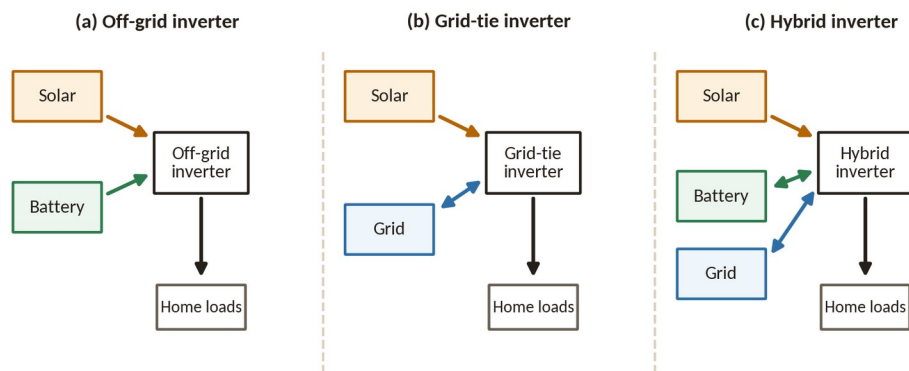
**X Wrong:** A hybrid inverter always uses solar power first automatically, with nothing to set up.

✓ **Right:** Most hybrid inverters let you choose the source priority yourself — solar, battery, or grid/generator first. Check and set this for the lowest bills and the longest battery life.

#### WORD TO KNOW

**Inverter-charger** — A device that both changes DC to AC for the loads AND changes AC from the grid or a generator back into DC to recharge the battery, automatically.

The charging half of an inverter-charger is what keeps the battery full even during a run of cloudy days — it simply borrows some grid or generator power to top up the battery, then switches back to solar and battery once they are ready again. Most hybrid inverters sold today are also inverter-chargers: one box does both jobs.



*Block diagrams: an off-grid inverter connects only to solar and battery; a grid-tie inverter connects only to solar and the grid; a hybrid inverter connects to solar, battery, AND the grid or generator together.*

#### Comparing the three inverter types

| Type                               | Needs a battery? | Connects to the grid?       | Typical use                                                                        |
|------------------------------------|------------------|-----------------------------|------------------------------------------------------------------------------------|
| Off-grid inverter                  | Yes, always      | No                          | Sites with no grid, or stand-alone backup systems                                  |
| Grid-tie inverter                  | No, usually      | Yes, required to operate    | Homes with reliable grid power, to cut the electricity bill                        |
| Hybrid inverter (inverter-charger) | Yes              | Yes, optional and automatic | Homes wanting backup power AND lower bills — the most common choice in this region |

This last row explains why hybrid inverter-chargers are so popular in local markets. Most families here deal with **three** possible power sources on any given day: the public grid (limited hours), a neighborhood generator subscription (Chapter 1), and now solar with a battery. A hybrid inverter-charger is built to manage exactly this mix — automatically.

#### CASE STUDY — ONE BOX, THREE POWER SOURCES • ERBIL, KURDISTAN REGION — EXAMPLE FIGURES FOR PRACTICE

A small grocery shop in Erbil used to run two separate systems: city grid power when it was on, and a manual switch over to a diesel generator during outages. The owner installed one hybrid inverter-charger with a battery bank and a small solar array on the roof. Now the system runs itself: **solar first** during the day, **battery next** using stored solar energy, and **grid or generator last**, only when the battery drops below a set level. The owner set the inverter to start the generator automatically if the battery falls below 30%, and to stop it once the battery is full again. *(These figures are for practice — real local costs are studied in Chapter 21.)* In the first month, the family estimated their generator ran about 3 hours a day instead of the old 8 hours a day — less fuel, less noise, and no more manually flipping switches during business hours. One hybrid inverter-charger replaced a separate inverter, a separate battery charger, and a manual changeover switch.

### 8.3 Efficiency, Continuous vs Surge Power

No machine is perfect. Every time an inverter changes DC into AC, a little energy turns into heat and is lost. This lesson shows how to measure that loss, and how to read the two most important numbers on an inverter's label: continuous power and surge power.

#### WORD TO KNOW

**Inverter efficiency** — The percentage of DC input energy that comes out as usable AC output energy. The rest is lost as heat inside the inverter.

#### EQUATION: INVERTER EFFICIENCY

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$$

*In words: Efficiency (%) = (AC output power ÷ DC input power) × 100*

| Symbol           | Meaning                                         | Unit        |
|------------------|-------------------------------------------------|-------------|
| $\eta$           | efficiency                                      | percent (%) |
| $P_{\text{out}}$ | AC output power delivered to the loads          | watts (W)   |
| $P_{\text{in}}$  | DC input power drawn from the battery or panels | watts (W)   |

*$\eta$  is the Greek letter 'eta', commonly used for efficiency. No inverter is 100% efficient — some energy always becomes heat. A better inverter simply wastes less.*

#### WORKED EXAMPLE — FINDING AN INVERTER'S EFFICIENCY

An inverter takes in 1200 W of DC power from the battery and delivers 1080 W of AC power to the loads. What is its efficiency?

1. Write the equation:  $\eta = (P_{\text{out}} \div P_{\text{in}}) \times 100$
2. Put in the numbers:  $\eta = (1080 \div 1200) \times 100$
3. Calculate:  $\eta = 90\%$

**Answer: 90%**

#### WORKED EXAMPLE — WORKING BACKWARD: HOW MUCH DC POWER IS REALLY NEEDED?

A fridge and some lights need 300 W of AC power. The inverter is 90% efficient. How much DC power must the battery actually supply?

1. Rearrange the equation:  $P_{in} = P_{out} \div \eta$
2. Change 90% to a decimal: 0.9
3. Put in the numbers:  $P_{in} = 300 \text{ W} \div 0.9$
4. Calculate:  $P_{in} \approx 333 \text{ W}$

**Answer: About 333 W of DC power — 33 W more than the 300 W actually used, lost as heat inside the inverter.**

Efficiency also changes with how hard the inverter is working. Every inverter uses a small amount of power just to stay switched on, even with nothing connected. When the load is very small, this fixed loss is a big share of the total, so efficiency looks poor. As the load grows, that fixed loss becomes a smaller share, and efficiency rises — until the load gets close to the inverter's maximum, when extra heat brings efficiency down slightly again.

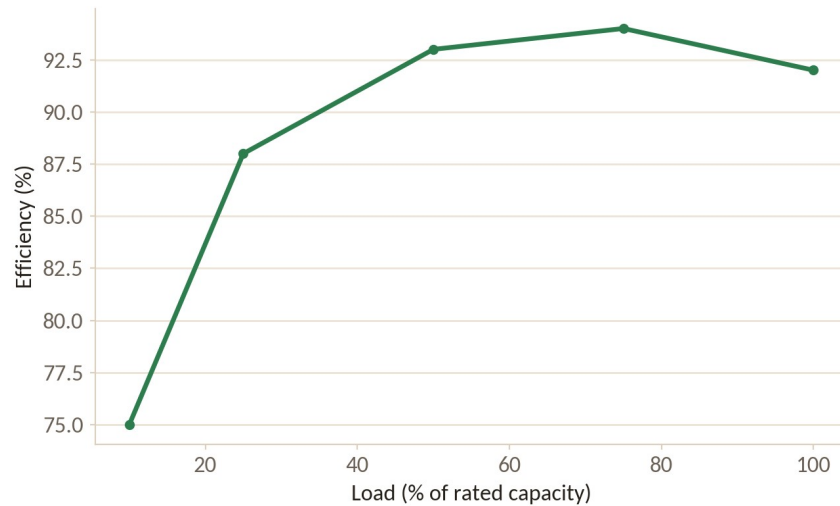
#### WORD TO KNOW

**Standby consumption** — The small amount of power an inverter uses just to stay switched on, even when no appliance is drawing power from it. Also called idle consumption.

**A typical inverter efficiency curve (example values — always check the datasheet)**

| Load (% of rated capacity) | Typical efficiency |
|----------------------------|--------------------|
| 10%                        | ≈ 75%              |
| 25%                        | ≈ 88%              |
| 50%                        | ≈ 93%              |
| 75%                        | ≈ 94%              |
| 100%                       | ≈ 92%              |





*A typical inverter efficiency curve. Efficiency is low at very small loads, rises quickly, stays high across a wide middle range, and may dip slightly at full load due to heat. (Example curve — check the exact datasheet for your model.)*

#### COMMON MISTAKE

**✗ Wrong:** An inverter's efficiency is the same number no matter how small or large the load is.

**✓ Right:** Efficiency changes with load. It is usually lowest when the load is very small (a phone charger on a large inverter, for example) and highest somewhere in the middle of the inverter's range.

One more label to know: some inverters and UPS units are rated in **VA** instead of, or as well as, watts.

#### WORD TO KNOW

**Volt-ampere** — A unit sometimes used on inverter and UPS nameplates instead of watts. Written VA. For simple loads like lamps, VA and W are about the same number. For loads with motors, VA is usually higher than W.

#### COMMON MISTAKE

**✗ Wrong:** Thinking a '2000 VA' inverter and a '2000 W' inverter always supply exactly the same real power.

**✓ Right:** W is the real, usable power. VA is a little higher whenever the load includes motors. When comparing two inverters, check whether the rating on each one is in W or in VA.

Now to the two ratings that matter most for choosing the right size, which you will use in Lesson 4.

#### WORD TO KNOW

**Continuous power rating** — The steady AC power an inverter can supply non-stop, for as long as needed, without overheating or shutting down.

#### WORD TO KNOW

**Surge power** — The higher power an inverter can supply for a few seconds only. Also called peak power.

Mainly used to start motors.

Why do motors need a surge? When a motor first switches on, it is not yet spinning — this is called the **locked-rotor** moment. For a fraction of a second to a few seconds, the motor pulls far more current than it needs once it is running smoothly. A refrigerator compressor, a fan motor, and a water pump motor all do this every single time they start.

**Typical starting surge, by load type (example ranges — check the motor's nameplate when possible)**

| Load type                            | Typical starting surge (× running power) |
|--------------------------------------|------------------------------------------|
| Resistive load (lamp, simple heater) | 1× (no real surge)                       |
| Fan                                  | 1.5–2×                                   |
| Refrigerator or freezer compressor   | 3–5×                                     |
| Water pump motor                     | 3–6×                                     |
| Air conditioner compressor           | 3–5×                                     |

#### WORKED EXAMPLE — SURGE POWER OF A WATER PUMP

A water pump motor runs at 750 W. Its datasheet says the starting surge is about 5 times the running power. What surge power must the inverter supply?

1. Write the relationship: surge power = running power × surge factor
2. Put in the numbers: surge power = 750 W × 5
3. Calculate: surge power = 3750 W

**Answer: 3750 W, for a few seconds while the pump starts**

#### SAFETY

If an inverter shuts down and shows an overload warning, do not just keep restarting it. Turn off some loads first, let it cool down if it feels hot, then try again. Restarting again and again into the same overload can damage the inverter and is also a fire risk.

#### ACTIVITY (HOME) — WATCH THE LIGHTS DIM

1. Turn on a lamp or two in the same room as a fridge, fan, or water pump.
2. Watch the lamps closely at the moment the motor switches on.
3. If the lamps dim or flicker for a moment, that is the motor's starting surge pulling extra current.
4. Write down which appliances in your home cause this, and which do not.

*You need: A lamp and a motor-driven appliance nearby*

► [App simulation: See how efficiency changes with load in the Inverter Performance simulation](#)

## 8.4 Sizing an Inverter

Now put Lessons 1–3 to work. This lesson gives you a simple, four-step method to choose an inverter that will run all your loads, every day, without shutting down.

**The four-step method:** - **Step 1 — Continuous load.** Add the running (steady) watts of every load that could be switched on at the same time. Include a motor's own running watts here too, along with everything else. - **Step 2 — Safety margin.** Add a safety margin, usually 20–25%, to Step 1's total. This gives the minimum CONTINUOUS rating the inverter must have. - **Step 3 — Surge load.** Find your single largest motor. Multiply its running watts by its starting surge factor (Lesson 3) to get its surge power. Add this to the running watts of every OTHER load that could already be on at that same moment — not the motor's own running watts, because while it is starting, it draws surge power, not running power. This gives the minimum SURGE rating the inverter must have. - **Step 4 — Choose.** Pick an inverter whose continuous rating is at least Step 2's number, AND whose surge rating is at least Step 3's number. Also match its DC input voltage to your battery bank, and prefer pure sine wave for motors and sensitive electronics (Lesson 1).

#### EQUATION: MINIMUM CONTINUOUS INVERTER RATING

$$P_{\text{cont}} \geq P_{\text{total}} \times (1 + m)$$

*In words: Minimum continuous rating ≥ Total running watts × (1 + margin)*

| Symbol  | Meaning                                                | Unit                                         |
|---------|--------------------------------------------------------|----------------------------------------------|
| P_cont  | minimum continuous inverter rating                     | watts (W)                                    |
| P_total | total running watts of all loads used at the same time | watts (W)                                    |
| m       | safety margin                                          | decimal fraction (for example, 0.25 for 25%) |

*A margin of 20–25% is a common rule of thumb. It leaves room for the inverter to age, for a few extra devices later, and keeps it from running at maximum stress all the time.*

#### EQUATION: MINIMUM SURGE INVERTER RATING

$$P_{\text{surge}} \geq P_{\text{other}} + (P_{\text{motor}} \times k)$$

*In words: Minimum surge rating ≥ Other running watts + (largest motor's running watts × surge factor)*

| Symbol  | Meaning                                                       | Unit                                          |
|---------|---------------------------------------------------------------|-----------------------------------------------|
| P_surge | minimum surge (peak) inverter rating                          | watts (W)                                     |
| P_other | running watts of other loads already on when the motor starts | watts (W)                                     |
| P_motor | running (rated) watts of the largest motor                    | watts (W)                                     |
| k       | starting surge factor for that motor                          | multiplier, no unit (for example, 4 means 4×) |

*Use the motor's own datasheet if you have one. If not, use the typical ranges from Lesson 3's table. Always check BOTH numbers — many 'the inverter keeps tripping' problems are a surge problem, not a continuous-power problem.*

#### WORKED EXAMPLE — SIZING FOR AN EVENING WITH A REFRIGERATOR

A home runs these loads together in the evening: 6 LED lamps (10 W each), a television (100 W), a refrigerator (150 W running, starting surge 4×), and 2 fans (70 W each). Size the inverter.

1. Continuous loads: lamps  $6 \times 10 = 60$  W; TV 100 W; fridge 150 W; fans  $2 \times 70 = 140$  W
2. Total continuous:  $60 + 100 + 150 + 140 = 450$  W
3. Add a 25% margin:  $450 \times 1.25 = 562.5$  W → round up to 563 W minimum continuous rating
4. Fridge surge:  $150 \text{ W} \times 4 = 600$  W

5. Other loads already running when the fridge starts:  $60+100+140 = 300 \text{ W}$

6. Minimum surge rating:  $300 + 600 = 900 \text{ W}$

**Answer: Minimum continuous  $\approx 563 \text{ W}$ ; minimum surge  $\approx 900 \text{ W}$ . A common commercial size such as 1000 W continuous / 2000 W surge covers both with room to spare.**

Notice that the fridge's surge requirement (900 W) is well above the continuous minimum (563 W) — this is completely normal. Always check both numbers, never just one.

#### WORKED EXAMPLE — SIZING FOR A WATER PUMP — WHY SURGE CAN DOMINATE

The same home also runs a 750 W borehole water pump for evening irrigation, together with 2 LED lamps (10 W each) near the pump controls, while the TV, fridge, and fans are switched off at that time. The pump's starting surge is about 5 times its running power. Size the inverter for this situation.

1. Continuous loads: pump 750 W + 2 lamps  $\times 10 \text{ W} = 770 \text{ W}$

2. Add a 25% margin:  $770 \times 1.25 = 962.5 \text{ W} \rightarrow$  round up to 963 W minimum continuous rating

3. Pump surge:  $750 \text{ W} \times 5 = 3750 \text{ W}$

4. Other loads already running when the pump starts:  $2 \times 10 = 20 \text{ W}$

5. Minimum surge rating:  $20 + 3750 = 3770 \text{ W}$

**Answer: Minimum continuous  $\approx 963 \text{ W}$ ; minimum surge  $\approx 3770 \text{ W}$ . Neither a 1000 W/2000 W nor a 1500 W/3000 W inverter is big enough — the surge requirement forces at least a 2000 W continuous / 4000 W surge inverter.**

Compare the two examples. In the first, the continuous number (563 W) was the number that mattered most. In the second, the continuous number (963 W) looks modest, but the pump's large starting surge (3770 W) forces a much bigger inverter. A single large motor can completely change the size you need — exactly why Lesson 3 asked you to always check both numbers.

#### Typical commercial inverter sizes (continuous / surge)

| Continuous rating | Typical surge rating (about 2 $\times$ continuous) |
|-------------------|----------------------------------------------------|
| 300 W             | 600 W                                              |
| 500 W             | 1000 W                                             |
| 1000 W            | 2000 W                                             |
| 1500 W            | 3000 W                                             |
| 2000 W            | 4000 W                                             |
| 3000 W            | 6000 W                                             |
| 5000 W            | 10000 W                                            |

These are typical example sizes only — real shops also sell in-between sizes, such as 600 W or 800 W, and the surge ratio can vary from about 1.5 $\times$  to 2 $\times$  continuous depending on the brand and model. Always read the actual datasheet or nameplate before buying.

One more check before you buy: the inverter's DC input voltage must match your battery bank's voltage — usually 12 V, 24 V, or 48 V. Bigger systems normally use 48 V, because the same power then moves with less

current, allowing thinner and cheaper cables. Chapters 6 and 12 explain how to choose the battery bank voltage in detail.

#### SAFETY

Connecting an inverter to the wrong battery voltage — for example, a 24 V inverter to a 12 V battery bank, or the other way around — can destroy the inverter instantly, damage the batteries, and may even cause a fire. Always check and match the voltages carefully before connecting.

#### COMMON MISTAKE

**✗ Wrong:** Sizing an inverter using only the sum of the appliance watts.

**✓ Right:** Also add a safety margin, and check the surge power needed by the largest motor. Many 'the inverter trips every time the pump starts' problems come from skipping this step.

#### ACTIVITY (HOME) — SIZE AN INVERTER FOR YOUR OWN HOME

1. Take your appliance list from Chapter 1 (or make a new one).
2. Decide which loads could realistically run together, and add their running watts.
3. Add a 20–25% safety margin to find the minimum continuous rating.
4. Find your home's largest motor. Estimate its surge power using Lesson 3's table, or its nameplate/datasheet if you have one.
5. Add that surge power to the other loads running at the same moment to find the minimum surge rating.
6. Compare your two numbers with real inverters you can find in a local shop or online. Which ones would work?

*You need: Your appliance list, Calculator or phone*

► *App tool: Check your sizing with the Inverter Sizing calculator*

#### CHAPTER SUMMARY

- An inverter changes DC electricity (from panels and batteries) into AC electricity for normal appliances.
- AC in Iraq and the Kurdistan Region is about 220 V at 50 Hz; a good inverter must match this standard.
- There are three inverter waveforms: square wave (lowest quality), modified sine wave (medium), and pure sine wave (best — safe for motors and electronics).
- Off-grid inverters work with a battery only; grid-tie inverters work with the public grid only and shut off automatically during a power cut (anti-islanding); hybrid inverters and inverter-chargers combine solar, battery, and grid or generator power.
- Hybrid inverter-chargers are very common in Iraq and the Kurdistan Region because they manage grid, generator, and solar/battery power together, automatically.
- Inverter efficiency =  $(\text{AC output power} \div \text{DC input power}) \times 100\%$ . A few percent is always lost as heat, and efficiency is lowest at very small loads.
- Continuous power rating is what the inverter supplies non-stop; surge (peak) power is the short burst needed to start a motor, often 3–6 times its running power.
- To size an inverter: add the running watts of loads used together, add a 20–25% safety margin, then check that the surge rating covers the largest motor's starting surge plus the other loads running at that moment.

- Sizing by continuous watts alone is a common mistake — a pump or compressor can trip the inverter even when the continuous total looked fine.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A trader imports a batch of inverters originally made for a 60 Hz market, but Iraq's grid standard is 50 Hz. What is the period of one AC cycle at 60 Hz, and how does it compare with the period at Iraq's 50 Hz (0.02 s)?

**Problem 2 [Basic]** A homeowner has a modified sine wave inverter left over from an old UPS. They want to power: (a) three LED lamps, and (b) a small refrigerator whose compressor motor runs for many hours a day. For each load, say whether the modified sine wave inverter is a safe long-term choice, and give one reason.

**Problem 3 [Basic]** An inverter takes in 500 W of DC power from the battery and delivers 450 W of AC power to the loads. What is its efficiency, in percent?

**Problem 4 [Basic]** A fan motor runs at 80 W. Lesson 3's table gives a typical starting surge of about 2 times the running power for a fan. What surge power should the inverter be able to supply the moment this fan starts?

**Problem 5 [Standard]** A small shop runs these loads together during the day: 8 LED lamps (10 W each), 2 ceiling fans (70 W each), and a laptop charger (60 W). (a) Find the total continuous load. (b) Find the minimum continuous inverter rating, using a 25% safety margin.

**Problem 6 [Standard]** A small clinic room runs a split air conditioner (compressor running power 900 W, starting surge about 4× its running power) together with 3 LED lamps (10 W each) and a small vaccine fridge (100 W, already running steadily before the AC starts). (a) Find the total continuous load. (b) Find the minimum continuous inverter rating with a 25% margin. (c) Find the minimum surge rating needed when the AC compressor starts.

**Problem 7 [Standard]** A family currently has grid power for about 10 hours a day and a diesel generator for the rest. They want to add solar panels and a battery, and they want their lights, refrigerator, and Wi-Fi router to keep working even during the hours when BOTH the grid and the generator are off. Which inverter type should they choose — off-grid, grid-tie, or hybrid? Give two reasons.

**Problem 8 [Standard]** A UPS nameplate shows '1000 VA / 600 W'. A technician wants to connect six devices rated 150 W each (900 W total) at the same time, reasoning that 900 is less than the 1000 VA rating. Is the technician correct? What is the real maximum power, in watts, this UPS can safely deliver?

**Problem 9 [Standard]** A hybrid inverter is 92% efficient. It needs to deliver 600 W of AC power to a home's essential loads during a power cut. How much DC power must it draw from the battery?

**Problem 10 [Challenge]** An off-grid inverter is 88% efficient. In the evening it delivers 250 W of AC power to the loads for 4 hours. (a) How much DC power must the battery supply? (b) How much DC energy (in Wh) does the battery supply over the 4 hours? (c) How much AC energy (in Wh) do the loads actually receive? (d) How much energy is lost as heat inside the inverter, in Wh, over the 4 hours?

**Problem 11 [Challenge]** A home wants to run, at the same time in the evening: 10 LED lamps (10 W each), a television (120 W), a refrigerator (140 W running, starting surge about 4×), a washing machine (500 W running, starting surge about 3×), and 2 ceiling fans (70 W each). The fridge and the washing machine do not start at exactly the same moment as each other. (a) Find the total continuous load. (b) Find the minimum continuous inverter rating with a 25% margin. (c) Find the minimum surge rating, checking BOTH the fridge and the

washing machine as the motor that is starting, and using the larger result. (d) Using Lesson 4's table of commercial sizes, what is the smallest suitable inverter (continuous / surge)?

**Problem 12 [Challenge]** A poultry farm shed uses a 1500 W water pump motor (starting surge about 5× its running power) to fill a header tank each evening, together with 4 LED lamps (10 W each) for lighting the shed at the same time. (a) Find the minimum continuous inverter rating, using a 25% margin. (b) Find the minimum surge rating. (c) The farm owner already has a spare inverter rated 2000 W continuous / 3000 W surge. Is it big enough for this pump? If not, which rating — continuous or surge — is the problem, and by how much is it short?

## CHAPTER NINE

# Wiring, Protection, and Safety Equipment

*The parts that make a system safe and reliable*

### IN THIS CHAPTER YOU WILL LEARN TO

- Describe the difference between DC (PV) cable and AC cable, and choose a cable size using a current-rating table.
- Calculate the voltage drop in a cable, and calculate the minimum cable cross-section needed to stay within a voltage-drop limit.
- Explain why DC circuits need DC-rated fuses, breakers, and disconnect switches, and size a protection device correctly for a given cable.
- Explain how earthing, bonding, and an RCD protect people from electric shock, and how a surge protection device protects equipment from lightning and voltage spikes.
- Apply safe wiring practices, including correct MC4 connector use, suitably rated enclosures, and clear system labelling.

## 9.1 Cable Types and Sizing

Every part of a solar system — panels, batteries, charge controllers, and inverters — is connected by cable. Chapter 2 warned that a wire which is too thin gets hot. Chapter 5 promised that Chapter 9 would explain cables, connectors, and protection devices in full. That chapter has arrived. This lesson teaches you to choose the right cable, every time.

### WORD TO KNOW

**Cable** — An insulated conductor, or a group of conductors together, made to carry electric current safely from one point to another. People often just say 'wire' for the same thing.

A solar system uses two very different electrical 'worlds': DC cable, carrying direct current between panels, batteries, and controllers; and AC cable, carrying alternating current from the inverter to normal appliances and the grid. They are not interchangeable — each is built for its own job.

### WORD TO KNOW

**PV cable** — A special cable made for solar panel and array wiring. It has extra-strong insulation that resists sunlight (UV), rain, and heat for years outdoors — ordinary indoor cable cannot survive on a roof.

### Comparing PV (DC) cable and standard AC cable

| Feature          | PV (DC) cable                                                 | Standard AC building cable                            |
|------------------|---------------------------------------------------------------|-------------------------------------------------------|
| Where it is used | Array wiring: panels to combiner box, controller, or inverter | Inverter output to loads, distribution board, sockets |



| Feature                  | PV (DC) cable                                                                       | Standard AC building cable                                                                                |
|--------------------------|-------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------|
| Sunlight (UV) resistance | Built for many years outdoors in direct sun                                         | Usually NOT UV-resistant — must be protected inside conduit or a wall if used outdoors                    |
| Insulation               | Double-insulated, often rated up to 1000 V DC or more                               | Rated for the local AC voltage, commonly 300/500 V or similar                                             |
| Typical colour code      | Red = positive (+), black = negative (–) — always confirm, never trust colour alone | Brown = live, blue = neutral, green/yellow = earth (a common international code) — always confirm locally |

### SAFETY

Never use ordinary indoor cable for outdoor array wiring, even 'to save money for now.' Sunlight breaks down normal insulation within a year or two. Cracked insulation exposes bare conductor to rain and touch — a shock and fire risk that is easy to avoid by using proper PV-rated cable from the start.

### WORD TO KNOW

**Cross-sectional area** — The area of the metal conductor's cut face, seen if you sliced straight through the cable. Measured in square millimetres (mm<sup>2</sup>). A bigger number means a thicker, more capable conductor.

Cables come in standard sizes, in mm<sup>2</sup>: 1.5, 2.5, 4, 6, 10, 16, 25, 35, 50, and larger. Always choose one of these standard sizes — never a size in between. Some imported cable, especially from the USA or China, is marked in AWG (American Wire Gauge) instead. In AWG, a SMALLER number means a THICKER wire — the opposite of mm<sup>2</sup>. For example, 10 AWG is about 5.3 mm<sup>2</sup>, and 8 AWG is about 8.4 mm<sup>2</sup>. If you are not sure, ask the seller for the mm<sup>2</sup> size, or measure the bare conductor with a calliper.

### WORD TO KNOW

**Current rating** — The maximum current a cable can carry continuously without getting too hot. Also called ampacity. A bigger cross-sectional area gives a higher current rating.

A cable's current rating is not fixed by its size alone. It also depends on: the conductor material (copper carries more current than aluminium of the same size); the insulation's maximum temperature; how the cable is installed (in free air, bundled tightly with other cables, in conduit, or buried); and the surrounding (ambient) temperature. A hotter surrounding and tighter bundling both LOWER the safe current rating.

**Typical current rating for copper cable (example reference values — single cable, free air, moderate ambient temperature)**

| Cross-sectional area | Typical current rating |
|----------------------|------------------------|
| 1.5 mm <sup>2</sup>  | 18 A                   |
| 2.5 mm <sup>2</sup>  | 25 A                   |
| 4 mm <sup>2</sup>    | 32 A                   |
| 6 mm <sup>2</sup>    | 41 A                   |
| 10 mm <sup>2</sup>   | 57 A                   |

| Cross-sectional area | Typical current rating |
|----------------------|------------------------|
| 16 mm <sup>2</sup>   | 76 A                   |
| 25 mm <sup>2</sup>   | 100 A                  |
| 35 mm <sup>2</sup>   | 125 A                  |
| 50 mm <sup>2</sup>   | 150 A                  |

### WORD TO KNOW

**Derating** — Reducing a cable's safe current rating below its normal table value, to allow for tough conditions such as high ambient temperature or several cables bundled together.

In Iraq and the Kurdistan Region, summer roof and attic temperatures can be much higher than the 'moderate' temperature used in typical reference tables — a cable lying on a hot roof in direct sun can get even hotter than the surrounding air. In high heat, derate: choose the next larger cable size, or use the manufacturer's own temperature-correction table. Also be careful in the local market: some cheap cable sold as 'pure copper' is actually copper-clad aluminium — a thin copper coating over an aluminium core. It carries less current and corrodes faster than real copper, but looks the same from outside. A same-size sample of real copper cable is noticeably heavier than copper-clad aluminium — weight is a simple, practical check. When in doubt, buy from a seller who can show a proper datasheet.

### SAFETY

An undersized cable is a serious fire risk. Current flowing through resistance always makes heat (Chapter 2). Too much current in too thin a cable can melt insulation and ignite nearby material, often with no obvious warning until it is too late. Never guess a cable size. Always check the expected current against the cable's rating, with a safety margin.

### EQUATION: DESIGN CURRENT WITH A SAFETY MARGIN

$$I_{\text{design}} = I_{\text{expected}} \times (1 + m)$$

*In words: Design current = expected current × (1 + safety margin)*

| Symbol                | Meaning                                                                                                                               | Unit                                         |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| $I_{\text{design}}$   | the current used to choose the cable size, and later the protection device                                                            | amperes (A)                                  |
| $I_{\text{expected}}$ | the circuit's normal or maximum expected current — for a PV array circuit, this is usually its short-circuit current, $I_{\text{sc}}$ | amperes (A)                                  |
| $m$                   | safety margin                                                                                                                         | decimal fraction (for example, 0.25 for 25%) |

*This chapter uses a simple 25% margin ( $m = 0.25$ ) throughout, for both cable sizing (this lesson) and protection-device sizing (Lesson 3). It allows for the small extra current a panel can give in strong, cool sunlight, and lets the system age safely.*

### WORKED EXAMPLE — CHOOSING A CABLE BY CURRENT RATING

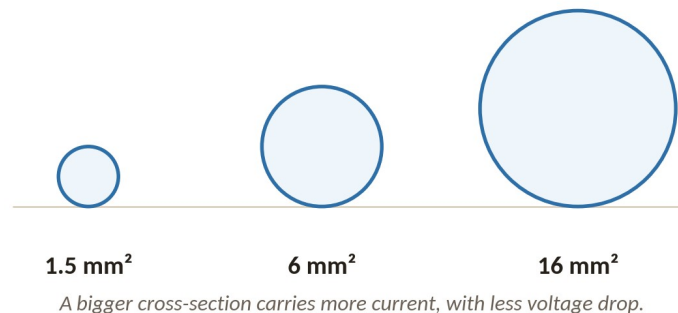
A solar array's datasheet gives a short-circuit current ( $I_{\text{sc}}$ ) of 13 A. Using a 25% safety margin, find the design current. Then use the current-rating table to find the smallest cable size that is safe for this current.

1. Write the equation:  $I_{\text{design}} = I_{\text{expected}} \times (1 + m)$
  2. Put in the numbers:  $I_{\text{design}} = 13 \text{ A} \times 1.25$
  3. Calculate:  $I_{\text{design}} = 16.25 \text{ A}$
  4. Check the table:  $1.5 \text{ mm}^2$  is rated 18 A, and  $18 \text{ A} \geq 16.25 \text{ A}$  — this size passes the current-rating check
- Answer: 16.25 A design current; a  $1.5 \text{ mm}^2$  cable already meets the current-rating check. But this is only half the story — Lesson 2 checks this same cable for voltage drop, over a real distance.**

#### COMMON MISTAKE

- ✗ Wrong:** Choosing a cable only because it physically fits the connector, or because 'it looks about right.'
- ✓ Right:** Always calculate the design current and compare it with the cable's current-rating table. A cable that fits the connector can still be dangerously undersized.

Cable cross-sections, drawn to scale



*Cable cross-sections compared, drawn to scale:  $1.5 \text{ mm}^2$ ,  $6 \text{ mm}^2$ , and  $16 \text{ mm}^2$ . A bigger cross-sectional area means a thicker conductor, less resistance, and a higher current rating.*

#### ACTIVITY (HOME) — CABLE DETECTIVE

1. Find three different cables at home or in a local electrical shop — for example, a phone charger cable, a lamp cord, and a thicker appliance cable.
2. For each one, look for a printed size (in  $\text{mm}^2$ ) on the cable jacket, or ask the shop for it.
3. Guess which one has the biggest cross-sectional area just by feeling its thickness, then check if you were right.
4. Write down which cable you think is a PV cable, an AC cable, or neither, and why.

*You need: A few different cables or cords, Paper and pen*

► *App tool: Check a real cable's current rating with the Cable Sizing calculator*

## 9.2 Voltage Drop

A cable is never a perfect conductor. Chapter 2 showed that every real conductor has some resistance, and that power turns into heat wherever current meets resistance ( $P = I^2 \times R$ ). In a long or thin cable, this small

resistance quietly steals some of your system's voltage before it ever reaches the battery, the controller, or the load. This lesson teaches you to calculate that loss, and to size a cable that keeps it small.

#### WORD TO KNOW

**Voltage drop** — The loss of voltage along a cable, caused by the cable's own resistance. The voltage arriving at the load is always a little lower than the voltage that left the source.

#### WORD TO KNOW

**Resistivity** — A property of a material that shows how strongly it resists current flow, for a standard size and length. Its symbol is  $\rho$  (the Greek letter rho). Copper has low resistivity, so it is a good conductor. This is different from resistance (Chapter 2), which depends on a specific object's size and shape as well as its material.

#### EQUATION: VOLTAGE DROP IN A CABLE

$$V_{\text{drop}} = \frac{2 \times \rho \times L \times I}{A}$$

*In words: Voltage drop = (2 × resistivity × length × current) ÷ cross-sectional area*

| Symbol | Meaning                                                          | Unit                                                                      |
|--------|------------------------------------------------------------------|---------------------------------------------------------------------------|
| V_drop | the voltage lost along the cable                                 | volts (V)                                                                 |
| $\rho$ | resistivity of the conductor material (copper $\approx 0.0175$ ) | ohm-millimetres-squared per metre ( $\Omega \cdot \text{mm}^2/\text{m}$ ) |
| L      | one-way cable length, from source to load                        | metres (m)                                                                |
| I      | current flowing in the cable                                     | amperes (A)                                                               |
| A      | cross-sectional area of one conductor                            | square millimetres ( $\text{mm}^2$ )                                      |

*The '2' appears because current must travel out to the load AND back again, through two conductor lengths. Copper's resistivity is about  $0.0175 \Omega \cdot \text{mm}^2/\text{m}$ . Aluminium's is about  $0.028 \Omega \cdot \text{mm}^2/\text{m}$  — roughly 1.6 times higher — so an aluminium cable must be thicker than a copper cable for the same job.*

#### WORKED EXAMPLE — FINDING THE VOLTAGE DROP OF A CHOSEN CABLE

A  $6 \text{ mm}^2$  copper cable runs 10 m (one-way) from a solar array to a charge controller, carrying 15 A. Using  $\rho = 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ , find the voltage drop. Then express it as a percentage for both a 12 V system and a 24 V system.

1. Write the equation:  $V_{\text{drop}} = (2 \times \rho \times L \times I) \div A$
2. Put in the numbers:  $V_{\text{drop}} = (2 \times 0.0175 \times 10 \times 15) \div 6$
3. Calculate the top:  $2 \times 0.0175 \times 10 \times 15 = 5.25$
4. Divide:  $V_{\text{drop}} = 5.25 \div 6 = 0.875 \text{ V}$
5. As a percentage of 12 V:  $(0.875 \div 12) \times 100 \approx 7.3\%$
6. As a percentage of 24 V:  $(0.875 \div 24) \times 100 \approx 3.6\%$

**Answer: 0.875 V is lost in the cable — about 7.3% on a 12 V system, but only about 3.6% on a 24 V system. The SAME cable and the SAME loss in volts is a much bigger problem at a lower system voltage.**

## WORD TO KNOW

**Voltage drop percentage** — The voltage drop written as a percentage of the system's voltage, instead of in volts. This is the number designers compare against a recommended limit, because the same voltage loss matters more on a lower-voltage system.

## Recommended maximum voltage drop (typical design guidelines)

| Circuit segment                                             | Recommended maximum voltage drop |
|-------------------------------------------------------------|----------------------------------|
| Array to charge controller or inverter (DC)                 | 1–3%                             |
| Battery to inverter (DC, often high current at low voltage) | 1–2%                             |
| Inverter or controller to AC loads                          | 2–3%                             |
| Whole system, source to farthest load, all segments added   | 5% or less                       |

These are common design guidelines used across the solar industry — manufacturers and local codes may give slightly different exact numbers, so always check the equipment manual when one is available. Unless a problem tells you otherwise, this course uses a 3% limit for a single cable run. Also note: to keep the method simple, this course uses the SAME design current (Lesson 1, already including its safety margin) for both the current-rating check and the voltage-drop check. This is a small simplification that always leaves you a little on the safe side.

## EQUATION: MINIMUM CABLE CROSS-SECTION FOR A VOLTAGE-DROP LIMIT

$$A_{\min} = \frac{2 \times \rho \times L \times I}{V_{\text{allow}}}$$

*In words: Minimum cross-section = (2 × resistivity × length × current) ÷ allowed voltage drop*

| Symbol             | Meaning                                                                     | Unit                                  |
|--------------------|-----------------------------------------------------------------------------|---------------------------------------|
| A <sub>min</sub>   | the smallest safe cross-sectional area for the chosen voltage-drop limit    | square millimetres (mm <sup>2</sup> ) |
| ρ                  | resistivity of the conductor material                                       | Ω·mm <sup>2</sup> /m                  |
| L                  | one-way cable length                                                        | metres (m)                            |
| I                  | current flowing in the cable                                                | amperes (A)                           |
| V <sub>allow</sub> | the maximum voltage drop you will allow — percentage limit × system voltage | volts (V)                             |

*This equation is the voltage-drop equation, rearranged to solve for area. Always round the answer UP to the next standard cable size (1.5, 2.5, 4, 6, 10, 16, 25, 35, 50 mm<sup>2</sup>, and so on) — never round down.*

## WORKED EXAMPLE — THE MINIMUM CABLE CROSS-SECTION — A FULL WORKED EXAMPLE

Continue Lesson 1's array: design current 16.25 A, system voltage 12 V, maximum allowed voltage drop 3%. The array is 8 m (one-way) from the charge controller. (a) Check the 1.5 mm<sup>2</sup> cable that passed Lesson 1's current-rating test. (b) Find the minimum cross-section for the 3% limit, and choose the standard size to use.

1. (a) Check 1.5 mm<sup>2</sup>: V<sub>drop</sub> = (2 × 0.0175 × 8 × 16.25) ÷ 1.5 = 4.55 ÷ 1.5 ≈ 3.03 V
2. (a) As a percentage: (3.03 ÷ 12) × 100 ≈ 25.3% — far above the 3% limit, so 1.5 mm<sup>2</sup> FAILS

3. (b) Find the allowed voltage drop in volts:  $3\% \times 12 \text{ V} = 0.36 \text{ V}$
4. (b) Apply the minimum cross-section equation:  $A_{\text{min}} = (2 \times 0.0175 \times 8 \times 16.25) \div 0.36 = 4.55 \div 0.36 \approx 12.64 \text{ mm}^2$
5. (b) Round UP to the next standard size: choose  $16 \text{ mm}^2$

**Answer:  $1.5 \text{ mm}^2$  easily passes the current-rating check but badly fails the voltage-drop check (about 25% loss). The minimum size for the 3% voltage-drop limit is about  $12.64 \text{ mm}^2$ , so the standard size to use is  $16 \text{ mm}^2$  — more than ten times the cross-sectional area that the current-rating check alone suggested.**

This is the single most important idea in cable sizing: ALWAYS check both the current rating (Lesson 1) and the voltage drop (this lesson), and choose the LARGER of the two resulting cable sizes. A cable that is big enough for voltage drop is always big enough for current too — but a cable that is only big enough for current can still waste a dangerous share of your energy, especially on a 12 V system with any real distance. This is also exactly why Chapter 8 recommended 24 V or 48 V battery banks for bigger systems — a higher system voltage makes the same percentage limit far easier to reach.

#### COMMON MISTAKE

**X Wrong:** "The cable passed the current-rating table, so it is definitely the right size."

**✓ Right:** Current rating and voltage drop are two SEPARATE checks. A cable can easily pass one and badly fail the other — always do both, and use the bigger result.

#### SAFETY

A large voltage drop is not just wasted energy. Motors and pumps running on low voltage draw MORE current to do the same work, which makes both the cable and the motor run hotter than expected — a hidden fire and equipment-damage risk. Never ignore a voltage-drop warning from a hand calculation or from the app's cable sizing calculator.

#### ACTIVITY (HOME) — MEASURE A REAL VOLTAGE DROP

1. Find a long, thin extension cord and a higher-power appliance such as a kettle, iron, or heater.
2. With an adult's help, plug the appliance in through the extension cord and switch it on.
3. Using a multimeter (Chapter 2), measure the voltage at the wall socket, then measure it again at the appliance's plug, both while the appliance is running.
4. Compare the two readings. Even a small difference shows real voltage drop happening in the cord.

*You need: Multimeter, A long, thin extension cord, A higher-power appliance (kettle, iron, or heater), Adult supervision*

► *App tool: Check current rating AND voltage drop together with the Cable Sizing calculator*

## 9.3 Fuses, Breakers, and Disconnect Switches (DC vs AC)

A correctly sized cable (Lessons 1–2) can still overheat if something goes wrong — a fault, a mistake, or damaged insulation. This lesson covers the devices that watch for danger and react automatically: fuses and breakers. It also covers disconnect switches, which let YOU safely turn a circuit off on purpose.

#### WORD TO KNOW

**Overcurrent** — Any current higher than a circuit or cable is designed to carry safely. It covers two situations: an overload and a short circuit.

#### WORD TO KNOW

**Overload** — Too much current flowing for too long, usually because too many loads are switched on together, or a motor is struggling. Gentler than a short circuit, but still dangerous over time because it slowly overheats a cable.

Chapter 6 introduced the short circuit — a sudden, direct connection between positive and negative that lets a very large current flow. A short circuit can happen anywhere in a system, not only at a battery — for example, if damaged insulation lets two bare conductors touch. Overload and short circuit are the two dangers that a fuse or breaker is built to catch.

#### WORD TO KNOW

**Fuse** — A simple protection device with a thin metal strip inside. If too much current flows, the strip heats up, melts, and breaks the circuit. A fuse must be replaced after it operates — people say it has 'blown.'

#### WORD TO KNOW

**Circuit breaker** — A protection device with a mechanical switch inside that trips (switches off) automatically when too much current flows. Unlike a fuse, a breaker can simply be reset and used again.

Chapter 5 warned that 'DC arcs do not switch themselves off the way AC arcs often do.' Here is why that matters for fuses and breakers too. AC current crosses zero volts about 100–120 times every second, which helps any arc inside a switching device die out naturally the moment it forms. DC current never crosses zero — it just keeps pushing in one direction. An arc inside a device built only for AC can keep burning, growing hotter, instead of stopping. This is why a device's DC rating is usually LOWER than its AC rating, even on the exact same physical product.

#### SAFETY

NEVER use an AC-only fuse, breaker, or switch on a DC circuit, even if the current number on the label looks high enough. Always choose a device clearly marked for DC use, rated at or above your system's DC voltage. A device that cannot stop a DC arc can keep burning inside its own housing — a serious fire risk.

#### DC-rated versus AC-rated protection devices

| Feature                                    | DC-rated device                                                                           | AC-rated device                                                                         |
|--------------------------------------------|-------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|
| Arc behaviour                              | Must fully extinguish a continuous arc by itself — needs a bigger gap or a special design | AC current crosses zero about 100–120 times a second, helping the arc extinguish itself |
| Voltage rating for a similar physical size | Often LOWER than the AC rating of a similar-looking product                               | Usually higher, because AC self-extinguishes more easily                                |
| Marking                                    | Clearly marked with a maximum DC voltage, for example 'DC 600 V'                          | Clearly marked with a maximum AC voltage, for example 'AC 400 V'                        |

| Feature          | DC-rated device                  | AC-rated device                            |
|------------------|----------------------------------|--------------------------------------------|
| Common solar use | Array circuits, battery circuits | Inverter output, AC loads, grid connection |

#### EQUATION: CHOOSING A PROTECTION DEVICE RATING

$$I_{\text{design}} \leq I_{\text{device}} \leq I_{\text{cable}}$$

*In words: Design current ≤ protection device rating ≤ cable's current rating*

| Symbol              | Meaning                                                                          | Unit        |
|---------------------|----------------------------------------------------------------------------------|-------------|
| $I_{\text{design}}$ | the circuit's design current, from Lesson 1 (already includes the safety margin) | amperes (A) |
| $I_{\text{device}}$ | the rated current of the chosen fuse or breaker                                  | amperes (A) |
| $I_{\text{cable}}$  | the current rating (ampacity) of the cable being protected, from Lesson 1        | amperes (A) |

*Choose the smallest standard device size that still satisfies both sides of this rule. Too small, and it trips during normal operation. Too big, and it can no longer protect the cable from overheating.*

#### WORKED EXAMPLE — SIZING A DC BREAKER FOR AN ARRAY CIRCUIT

Lesson 1's array has a design current of 16.25 A. Lesson 2 showed this circuit needs a 16 mm<sup>2</sup> cable, rated for about 76 A. Choose a DC breaker from these standard sizes: 6, 10, 13, 16, 20, 25, 32, 40 A.

1. Apply the rule:  $I_{\text{design}} \leq I_{\text{device}} \leq I_{\text{cable}}$ , so  $16.25 \text{ A} \leq I_{\text{device}} \leq 76 \text{ A}$
2. Check 16 A: is  $16 \geq 16.25$ ? No — 16 A is slightly BELOW the design current, so it could nuisance-trip
3. Check 20 A: is  $20 \geq 16.25$ ? Yes. Is  $20 \leq 76$ ? Yes — both conditions are satisfied

**Answer: A 20 A DC breaker — the smallest standard size that is not less than the design current, and not more than the cable's rating.**

#### WORKED EXAMPLE — SIZING A DC FUSE FOR A BATTERY-TO-INVERTER CIRCUIT

An inverter draws 2000 W continuously from a 24 V battery bank. Using  $I = P \div V$  (Chapter 2), find the current, add a 25% safety margin, and choose a fuse from these standard sizes: 60, 80, 100, 125, 150 A.

1. Find the current:  $I = P \div V = 2000 \text{ W} \div 24 \text{ V} \approx 83.3 \text{ A}$
2. Add the safety margin:  $I_{\text{design}} = 83.3 \times 1.25 \approx 104.2 \text{ A}$
3. Check the standard sizes: 100 A is less than 104.2 A, so it fails; 125 A  $\geq$  104.2 A, so it passes

**Answer: A 125 A DC fuse. Notice how much current flows at only 24 V — this circuit also needs a thick, short cable (at least 35 mm<sup>2</sup>, from Lesson 1's table), which is exactly why battery-to-inverter cables are always kept as short as possible.**

#### WORD TO KNOW

**Disconnect switch** — A manual switch used to safely turn off part of a solar system on purpose, for testing, maintenance, or in an emergency. Also called an isolator.



Unlike a fuse or breaker, a disconnect switch does not react automatically — a person operates it. But it still must be rated correctly: switching off a heavily loaded DC circuit with a switch that is not built for DC can create the same dangerous, sustained arc described earlier. Never disconnect a loaded PV circuit by simply pulling an MC4 connector apart by hand in full sun — use a proper DC-rated disconnect, or de-energize the circuit first by covering the panels.

#### Where disconnect switches belong in a typical system

| Location                                                    | Type          | Purpose                                              |
|-------------------------------------------------------------|---------------|------------------------------------------------------|
| Between array and charge controller or inverter             | DC disconnect | Isolate the array for testing or maintenance         |
| Between battery and inverter                                | DC disconnect | Isolate the battery bank safely                      |
| Between inverter and AC loads                               | AC disconnect | Isolate the inverter's AC output                     |
| Between the system and the public grid (grid-tie or hybrid) | AC disconnect | Lets utility workers safely isolate the whole system |

#### SAFETY

Before touching any conductor: switch off and isolate every relevant disconnect and breaker, then PROVE it is de-energized with a multimeter (Chapter 2) before you touch anything. Never trust a switch position alone — a label can be wrong, or someone else may re-energize the circuit without knowing you are working on it.

#### COMMON MISTAKE

**X Wrong:** Pressing an inverter's or charge controller's own on/off button, and treating the circuit as fully isolated.

**✓ Right:** An electronic on/off button usually just changes an internal setting — dangerous voltage and current can still be present on the wiring. Always use a proper disconnect switch or breaker to fully isolate a circuit before working on it.

#### CASE STUDY — THE WRONG SWITCH IN THE WRONG PLACE • KURDISTAN REGION (A COMMON, REALISTIC SCENARIO)

A small workshop added a solar array to help run its tools. To save a little money, the installer used a leftover AC isolator switch as the array's DC disconnect, because the current rating on the label looked high enough. Everything worked fine for months. One afternoon, a worker switched off the array disconnect during full sunlight to test a connection — and the switch could not fully extinguish the DC arc that formed inside it. The switch's contacts were badly burned, and the workshop lost the use of that circuit until a proper DC-rated disconnect was fitted. No one was hurt, but the damage — and the lost work time — could have been avoided completely by matching the device to DC from the very beginning.

#### ACTIVITY (HOME) — FIND THE PROTECTION DEVICES IN YOUR HOME

1. With an adult, find your home's distribution board (the box with the fuses or breakers).
2. Count the breakers or fuses. Read their current ratings (in A) if you can see them.
3. Find the main switch — the one that turns off everything at once.

4. If your home has an RCD (Lesson 4 explains this), find it too — it often has a 'TEST' button.
5. Write down what you found. Do not open, touch, or reset anything without an adult who knows the system.

*You need: Notebook and pen, Adult supervision*

## 9.4 Earthing/Grounding, Surge Protection, and Safe Wiring Practice

This final lesson protects PEOPLE, not just equipment. You will learn how earthing and a safety switch called an RCD protect a person from electric shock, how a surge protection device protects equipment from lightning, and the everyday good habits that keep a solar system safe for its entire life.

### WORD TO KNOW

**Earthing** — Connecting the metal parts of a system — panel frames, racks, enclosures — to the ground with a wire, so that if a fault happens, dangerous voltage flows safely into the earth instead of staying on metal that a person could touch. Also called grounding.

### WORD TO KNOW

**Earth electrode** — A metal rod or plate driven or buried in the ground, connected to a system's earthing wire, giving fault current a safe path into the earth. Also called an earth rod.

Picture a damaged wire touching a metal panel frame. Without earthing, the whole frame becomes 'live' at a dangerous voltage, silently, with no warning. If a person then touches the frame while also touching the ground, their body can complete the circuit — a severe or fatal shock. With proper earthing, the fault current flows through the LOW-resistance earth wire instead, usually tripping a breaker or RCD immediately, long before a person is ever at risk. Solar equipment frames, rails, and enclosures should always be earthed, no matter the system type. Some inverters or controllers also need a specific conductor connected to earth in a particular way — always follow the manufacturer's own earthing instructions exactly, because wiring this incorrectly can create a hidden hazard or damage the equipment.

### WORD TO KNOW

**Bonding** — Connecting all the metal parts of a system together with a conductor, so they are all at the same electrical potential (voltage). Bonding is usually done together with earthing, so nothing metal is ever left 'floating' at a different voltage from everything around it.

### WORD TO KNOW

**Residual current device (rCD)** — A safety switch that constantly compares the current going out on the live wire with the current coming back on the neutral wire. If even a small amount is missing — for example, leaking to earth through a person's body — it switches the circuit off in a fraction of a second. Also called an ELCB (earth leakage circuit breaker), or in some countries a GFCI.

### SAFETY

An RCD is one of the most life-saving devices in this whole course. A standard RCD for personal protection trips at about 30 mA — small enough, and fast enough, to stop a dangerous shock before it causes serious

harm. Fit an RCD on the AC output of every solar system, and on any socket a person might touch, especially outdoors, in a wet location, or near a water pump.

#### WORD TO KNOW

**Voltage surge** — A short, sudden increase in voltage, far above the normal level, usually lasting a tiny fraction of a second. Common causes are lightning and the switching of heavy equipment nearby. Do not confuse this with an inverter's surge power rating (Chapter 8) — a different idea that just happens to share the word 'surge.'

#### WORD TO KNOW

**Surge protection device** — A device that senses a dangerous voltage surge and instantly diverts the extra energy safely to earth, protecting the equipment connected after it. Also called an SPD or a surge arrester.

An SPD is normally fitted close to the equipment it protects: one on the DC side, between the array and the charge controller or inverter, and one on the AC side, between the inverter and the loads or the grid. A rooftop solar array is tall, metal, and directly exposed to the sky, and long outdoor cable runs can pick up a damaging voltage even from a nearby lightning strike that never touches the array directly. In Iraq and the Kurdistan Region, spring and early-summer thunderstorms, unstable grid voltage, and frequent switching between grid, generator, and solar power all make surge protection a genuinely worthwhile investment, not an optional extra.

#### SAFETY

Never work on a solar system's wiring, disconnects, or earthing during a lightning storm, or when one is clearly approaching. Lightning can strike a rooftop array or a nearby structure and send a dangerous surge through the system's cables even without a direct hit.

#### WORD TO KNOW

**Mc4 connector** — A weatherproof, locking plug-and-socket connector used to join solar panel cables safely. The name comes from 'Multi-Contact,' the original maker, and its 4 mm pin size. Once clicked together, it should only be unplugged with a proper tool, not pulled apart by hand.

#### SAFETY

Never unplug a loaded MC4 connector by hand in full sunlight. A string of panels in the sun is 'live' even with no switch turned on, and pulling connectors apart under load can cause a dangerous arc at your fingertips. Use a rated DC disconnect, or cover the panels to stop current first.

#### ACTIVITY (LABORATORY) — CRIMP AND TEST AN MC4 CONNECTION

1. Strip the end of a piece of PV cable to the length shown in the connector's instructions — not too short, not too long.
2. Insert the bare conductor into the correct metal pin (male or female) and crimp it firmly with the proper MC4 crimping tool.

3. Give the crimped wire a gentle pull to check it is fully secure before continuing.
4. Push the crimped pin into its connector housing until you hear or feel it click into place.
5. Before connecting to a live panel, use a multimeter to check polarity and continuity, and check the housing is fully locked by trying a gentle pull.

You need: MC4 connector kit (male and female), A length of PV cable, MC4 crimping tool, Wire strippers, Multimeter

#### WORD TO KNOW

**Polarity** — Which terminal or wire is positive (+) and which is negative (-) in a DC circuit. Getting this wrong is called reverse polarity, and it can damage equipment instantly.

#### COMMON MISTAKE

✗ **Wrong:** Connecting a DC cable without checking positive and negative first, because 'it still makes a connection either way.'

✓ **Right:** Always check polarity with a multimeter, or by checking wire colour and connector shape, BEFORE connecting any DC cable. Reverse polarity can instantly destroy a charge controller, inverter, or battery.

#### WORD TO KNOW

**Enclosure** — A protective box or cabinet that holds electrical parts — such as breakers, fuses, or connectors — safely away from weather, dust, and accidental touch.

#### WORD TO KNOW

**Ip rating** — A code, such as IP65, that shows how well an enclosure protects against dust and water. A higher number means better protection.

#### Common IP ratings in solar work

| IP rating | Meaning                                                               | Typical solar use                                               |
|-----------|-----------------------------------------------------------------------|-----------------------------------------------------------------|
| IP54      | Protected against dust and against splashing water from any direction | Indoor or sheltered equipment                                   |
| IP65      | Fully dust-tight; protected against water jets from any direction     | Outdoor combiner boxes, junction boxes, most outdoor enclosures |
| IP67      | Fully dust-tight; protected against temporary immersion in water      | Ground-level boxes, or equipment at risk of flooding            |

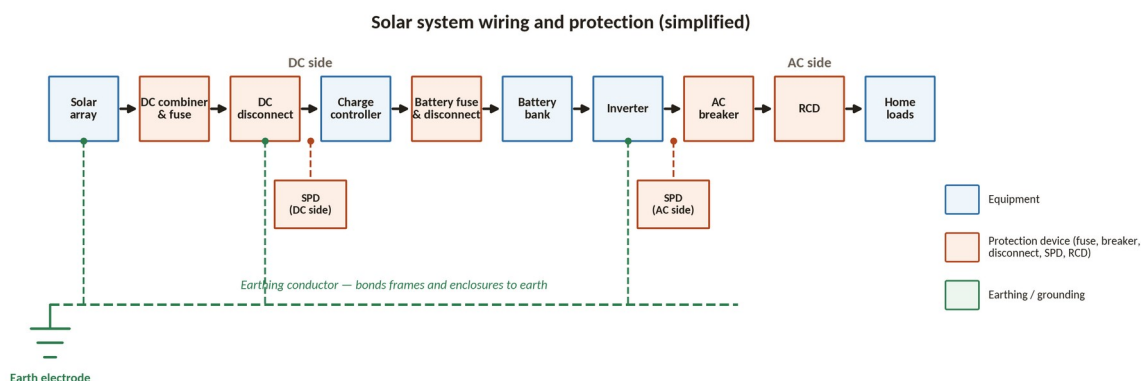
#### Good wiring practice checklist

| Good practice                                     | Why it matters                                                  |
|---------------------------------------------------|-----------------------------------------------------------------|
| Support and clip cables neatly; avoid sharp bends | Loose or sharply bent cable wears through its insulation faster |
| Leave a drip loop before any outdoor enclosure    | Stops rainwater running down the cable straight into the box    |

| Good practice                                                                                 | Why it matters                                                                                        |
|-----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
| Use PV-rated cable outdoors, never ordinary indoor cable                                      | Ordinary cable cracks and fails within a year or two in direct sunlight                               |
| Keep DC and AC cables separate, and clearly label both                                        | Prevents dangerous mix-ups during testing or repair                                                   |
| Label the main disconnect and distribution board clearly, showing that solar power is present | Warns any electrician or emergency worker that the system may still be live even when the grid is off |
| Tighten connections to the correct torque, and re-check after a few weeks                     | Loose connections overheat and can start fires; cables can settle after installation                  |
| Protect cable from rodents and mechanical damage near ground level                            | Chewed or crushed cable is a common, avoidable fault                                                  |

### CASE STUDY — A STORM, A SURGE, AND A LESSON LEARNED • KURDISTAN REGION (A COMMON, REALISTIC SCENARIO)

A shop owner installed a small hybrid solar system on his flat roof, with the array, cables, and inverter all correctly sized and fused. To save a little money, he skipped the surge protection devices, thinking the fuses and breakers already covered his system's safety. During a spring thunderstorm, lightning struck near the building — not the array itself, but close enough. A voltage surge travelled up the array's cable and destroyed the charge controller's electronics in an instant, even though every fuse and breaker stayed perfectly normal, because a voltage surge is far too fast for them to react to. Replacing the controller cost far more than a pair of surge protection devices would have. He fitted SPDs on both the DC and AC sides when he rebuilt the system, and now reminds every customer: fuses and breakers stop overcurrent; only an SPD stops a surge.



A complete system wiring diagram with every protection device labelled: array, DC combiner and fuse, DC disconnect, surge protection device (DC side), charge controller, battery fuse and disconnect, inverter, surge protection device (AC side), AC breaker, RCD, and the earthing conductor connecting frames, enclosures, and the earth electrode.

### CHAPTER SUMMARY

- A cable is an insulated conductor. PV (DC) cable must resist UV, weather, and years outdoors; standard AC cable usually must not be used outside without protection.
- A cable's current rating (ampacity) depends on its size, material, insulation, installation method, and ambient temperature — derate for Iraq's hot summers.
- Voltage drop:  $V_{\text{drop}} = (2 \times \rho \times L \times I) \div A$ . Minimum cross-section:  $A_{\text{min}} = (2 \times \rho \times L \times I) \div V_{\text{allow}}$ , then

round UP to the next standard size.

- Always check BOTH current rating and voltage drop, and choose the larger resulting cable size — voltage drop often dominates on low-voltage (12 V) systems.
- Fuses and breakers stop overcurrent (overload or short circuit). A device's rating must satisfy  $I_{\text{design}} \leq I_{\text{device}} \leq I_{\text{cable}}$ .
- DC needs its own DC-rated fuses, breakers, and disconnect switches — DC arcs do not self-extinguish the way AC arcs do, so never substitute an AC-rated device.
- Disconnect switches let a person safely isolate part of a system; always prove a circuit is de-energized with a multimeter before touching it.
- Earthing and bonding protect people by giving fault current a safe path to the ground; an RCD (about 30 mA) detects current leaking to earth and switches off in a fraction of a second.
- A surge protection device (SPD) protects equipment from lightning and switching surges — a completely different job from a fuse, breaker, or RCD.
- Good practice: PV-rated outdoor cable, correct MC4 crimping (never unplug a loaded connector by hand), checked polarity, suitably rated (IP) enclosures, and clear labelling of every disconnect and panel.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** Using the current-rating table from Lesson 1 ( $1.5 \text{ mm}^2 = 18 \text{ A}$ ,  $2.5 \text{ mm}^2 = 25 \text{ A}$ ,  $4 \text{ mm}^2 = 32 \text{ A}$ ,  $6 \text{ mm}^2 = 41 \text{ A}$ ,  $10 \text{ mm}^2 = 57 \text{ A}$ ), what is the smallest standard cable size that can safely carry 30 A?

**Problem 2 [Basic]** A DC circuit's design current (safety margin already included) is 12 A. Choose the smallest standard breaker size from this list that is not less than the design current: 6, 10, 13, 16, 20, 25 A.

**Problem 3 [Basic]** A cable is rated for 32 A. A fuse protecting this cable is rated 40 A. Is this a safe combination? Explain why or why not.

**Problem 4 [Basic]** A cable's voltage drop is measured as 0.6 V in a 12 V system. What is the voltage drop as a percentage of the system voltage?

**Problem 5 [Standard]** A  $6 \text{ mm}^2$  copper cable runs 12 m (one-way) from an array to a charge controller, carrying 18 A. Using  $\rho = 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ , find the voltage drop in volts.

**Problem 6 [Standard]** A 24 V DC circuit carries a design current of 10 A over a one-way distance of 20 m. The maximum allowed voltage drop is 3%. Using  $\rho = 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ , find the minimum cross-sectional area (before rounding), and state the standard cable size you would choose.

**Problem 7 [Standard]** A solar array has a short-circuit current ( $I_{\text{sc}}$ ) of 9 A. Using a 25% safety margin, find the design current. Then, using the current-rating table ( $1.5 \text{ mm}^2 = 18 \text{ A}$ ,  $2.5 \text{ mm}^2 = 25 \text{ A}$ ,  $4 \text{ mm}^2 = 32 \text{ A}$ ), find the smallest cable size that meets the CURRENT rating alone.

**Problem 8 [Standard]** An inverter draws 2500 W continuously from a 24 V battery bank. Find the DC current ( $I = P \div V$ ), add a 25% safety margin to find the design current, and choose the smallest suitable fuse from this list: 100, 125, 150, 175 A.

**Problem 9 [Standard]** A home's distribution board has a 32 A main breaker and a 30 mA RCD. During a fault, 45 mA of current flows to earth through a person's body. Will the RCD detect this and trip? Explain your answer.

**Problem 10 [Challenge]** A solar array has  $I_{sc} = 12$  A. The one-way cable distance from the array to the charge controller is 18 m, and the system voltage is 24 V. Use a 25% safety margin for the design current,  $\rho = 0.0175 \Omega \cdot \text{mm}^2/\text{m}$  for copper, and a maximum allowed voltage drop of 3%. (a) Find the design current. (b) Using the current-rating table ( $1.5 \text{ mm}^2 = 18$  A,  $2.5 \text{ mm}^2 = 25$  A,  $4 \text{ mm}^2 = 32$  A), find the smallest cable that meets the CURRENT rating. (c) Check the voltage drop for that cable size in volts and as a percentage — does it meet the 3% limit? (d) If not, find the minimum cross-section for the voltage-drop limit, and state the standard cable size to use.

**Problem 11 [Challenge]** A hybrid inverter's AC output circuit has a continuous design current of 18 A. The AC cable chosen for this circuit is rated for 25 A. (a) Choose a suitable AC breaker from these standard sizes: 10, 13, 16, 20, 25, 32 A. (b) The circuit also needs an RCD for shock protection. What standard RCD trip current would you choose? (c) Give ONE reason this system also needs a surge protection device (SPD), even though it already has a breaker and an RCD.

**Problem 12 [Challenge]** A small solar water pump's array has  $I_{sc} = 10$  A. The one-way DC cable run from the array to the controller is 25 m, and the system voltage is 12 V. Use a 25% design margin,  $\rho = 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ , and a tighter maximum allowed voltage drop of 2% (this circuit is critical for the pump to work reliably). (a) Find the design current. (b) Find the minimum cross-section required by the voltage-drop limit. (c) State the standard cable size to use. (d) Using that final cable size and the current-rating table ( $35 \text{ mm}^2 = 125$  A,  $50 \text{ mm}^2 = 150$  A), confirm the cable is also safe for current.

PART THREE

# DESIGNING SOLAR SYSTEMS

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## CHAPTER TEN

# Understanding Electrical Loads

*Audit, profile, and prioritize the loads a solar system must power*

### IN THIS CHAPTER YOU WILL LEARN TO

- Build a professional load audit using nameplate power, duty cycle, and weekly use patterns.
- Construct a daily load profile and find a home's peak load, connected load, and demand factor.
- Compare summer and winter load profiles and explain why they can be so different.
- Apply efficiency-first thinking to reduce daily energy and peak load before sizing solar equipment.
- Classify loads as critical or non-critical, and explain why this matters for backup power during outages.

## 10.1 The Professional Load Audit Method

In Chapter 1, Lesson 4, you built your first load audit — a simple list of appliances, their power, and their hours per day. That was a good start. Now you will learn the **professional method**: the exact way a solar system designer builds a load audit before choosing a single piece of equipment. Every good design begins here.

### WORD TO KNOW

**Load audit** — A complete, organized list of every electrical device in a building, with its power, how it is used, and how often. A load audit is the first step of every solar system design.

A professional audit adds three things a simple list often misses: the true **nameplate rating** of each device, how much of the time a cycling device actually runs (its **duty cycle**), and whether a device is used every day or only some days of the week.

### WORD TO KNOW

**Nameplate rating** — The power (or other values) printed by the manufacturer on an appliance's label. It is measured under standard test conditions — the value in daily use can be a little different. (Chapter 5 covers a solar panel's own version of this idea, its rated power in watt-peak.)

You met **duty cycle** in Chapter 7, for a charge controller's fast electronic switching. The same idea applies here, but much slower: many home appliances switch themselves on and off automatically, so they do not run for the whole time they are plugged in.

### WORD TO KNOW

**Duty cycle** — The fraction of time a device is actually running (ON), compared with the total time it is switched on or available. A refrigerator with a 35% duty cycle runs for about 35 out of every 100 minutes, on average — its compressor cycles on and off by itself.

### EQUATION: EFFECTIVE RUNNING HOURS FROM DUTY CYCLE

$$t_{\text{eff}} = DC \times t_{\text{on}}$$

*In words: Effective hours = duty cycle × hours switched on*

| Symbol | Meaning                                                  | Unit                                |
|--------|----------------------------------------------------------|-------------------------------------|
| t_eff  | effective running hours, used for the energy calculation | hours (h)                           |
| DC     | duty cycle, written as a fraction                        | no unit (for example, 0.35 for 35%) |
| t_on   | hours the appliance is switched on or available          | hours (h)                           |

*For a device that is always plugged in, like a refrigerator, t\_on = 24 h. Then find daily energy the usual way: E = P × t\_eff.*

### WORKED EXAMPLE — A REFRIGERATOR'S EFFECTIVE HOURS

A refrigerator is rated 150 W. It is plugged in all day, and its duty cycle is 35%. Find its effective running hours and its daily energy.

1. Write the equation:  $t_{\text{eff}} = DC \times t_{\text{on}}$
2. Put in the numbers:  $t_{\text{eff}} = 0.35 \times 24 \text{ h} = 8.4 \text{ h}$
3. Find the daily energy:  $E = P \times t_{\text{eff}} = 150 \text{ W} \times 8.4 \text{ h} = 1260 \text{ Wh}$

**Answer: 8.4 effective hours per day; 1260 Wh (1.26 kWh) per day.**

### COMMON MISTAKE

**✗ Wrong:** Using the same duty cycle for every appliance, every time, from memory.

**✓ Right:** Duty cycle depends on the device AND the conditions. A fridge in a hot kitchen, or opened often, cycles more (a higher duty cycle) than one in a cool room. A water pump's duty cycle depends on tank size and family water use. Always check, measure, or use a realistic published range — do not guess.

Some appliances are not used every single day — an iron, a washing machine, a water pump for weekend irrigation. A professional audit averages these over a full week, so the daily energy figure is realistic for a whole month, not just for one busy day.

### EQUATION: AVERAGE DAILY ENERGY OVER A WEEK

$$E_{\text{day}} = \frac{P \times t \times d}{7}$$

*In words: Average daily energy = (power × hours per use × days used per week) ÷ 7*

| Symbol | Meaning                                       | Unit                        |
|--------|-----------------------------------------------|-----------------------------|
| E_day  | average daily energy, spread over a full week | watt-hours per day (Wh/day) |
| P      | power                                         | watts (W)                   |
| t      | hours used, each time the device is used      | hours (h)                   |
| d      | days used per week                            | days (1 to 7)               |

*If a device is used every day, d = 7, and this becomes the simple E = P × t rule from Chapter 1.*

### WORKED EXAMPLE — AVERAGING AN IRON'S ENERGY OVER A WEEK

An electric iron is rated 1000 W. It is used for 45 minutes (0.75 h) each time, 3 days a week. Find its average daily energy.

1. Write the equation:  $E_{\text{day}} = (P \times t \times d) \div 7$
2. Put in the numbers:  $E_{\text{day}} = (1000 \text{ W} \times 0.75 \text{ h} \times 3) \div 7$
3. Calculate the top:  $1000 \times 0.75 \times 3 = 2250$
4. Divide by 7:  $2250 \div 7 \approx 321.4 \text{ Wh}$

**Answer:  $\approx 321.4 \text{ Wh}$  per day, averaged over the week.**

### Example Home — professional load audit

| Appliance       | Qty | Rated power (W)    | Use pattern                                                            | Avg. daily energy (Wh) |
|-----------------|-----|--------------------|------------------------------------------------------------------------|------------------------|
| Refrigerator    | 1   | 150                | 35% duty cycle, always plugged in ( $\approx 8.4 \text{ h}$ effective) | 1260                   |
| LED lights      | 8   | 10 each (80 total) | 3 h/day, every day                                                     | 240                    |
| Television      | 1   | 100                | 3 h/day, every day                                                     | 300                    |
| Ceiling fan     | 1   | 60                 | 5 h/day, every day                                                     | 300                    |
| Washing machine | 1   | 500                | 1 h/use, 4 days/week                                                   | 286                    |
| Electric iron   | 1   | 1000               | 0.75 h/use, 3 days/week                                                | 321                    |
| Total           | —   | —                  | —                                                                      | 2707                   |

### WORKED EXAMPLE — TOTAL AVERAGE DAILY ENERGY FOR THE EXAMPLE HOME

Using the audit table above, find the home's total average daily energy, in Wh and kWh.

1. Add every row's average daily energy:  $1260 + 240 + 300 + 300 + 286 + 321$
2. Sum step by step:  $1260+240=1500$ ;  $+300=1800$ ;  $+300=2100$ ;  $+286=2386$ ;  $+321=2707 \text{ Wh}$
3. Convert to kWh:  $2707 \div 1000 \approx 2.71 \text{ kWh}$

**Answer:  $\approx 2707 \text{ Wh}$ , or about  $2.71 \text{ kWh}$  per day, averaged over a normal week. This is the Example Home used for the rest of this chapter.**

### ACTIVITY (HOME) — YOUR PROFESSIONAL LOAD AUDIT

1. Choose a home, classroom, or laboratory to audit (ask your teacher if a lab audit is better for your class).
2. List every appliance: name, quantity, and nameplate/rated power — read the label, like you did in Chapter 1.
3. For each appliance, decide if it cycles on and off by itself. If it does, estimate or look up a realistic duty cycle.
4. For each appliance, record how many hours per use and how many days per week it is used.

5. Calculate each appliance's average daily energy with the correct equation, then add them all up.

*You need: Paper and pen or a spreadsheet, A phone torch to read labels, Calculator or phone*

► *App tool: Build your audit in the app: Load Audit calculator (full mode)*

## 10.2 Daily Load Profiles: Day/Night, Summer/Winter

A load audit tells you the AVERAGE energy used in a day. But a solar system also needs to know something else: exactly WHEN that energy is used, hour by hour. This is called a **load profile** — and it is how we find the true peak load, not just the daily total.

### WORD TO KNOW

**Load profile** — A table or chart that shows how much power a building uses at each hour (or period) of the day. It shows when energy is used, not only how much.

Let's build a load profile for the Example Home from Lesson 1: refrigerator, LED lights, television, ceiling fan, and washing machine. We look at one real day — a 'wash day', when the washing machine also runs. On this one real day we use the washing machine's actual 500 Wh, not its 4-day-a-week average from Lesson 1. (The average is for monthly energy planning; a single day's profile needs that day's real numbers.)

### WORD TO KNOW

**Peak load** — The highest power drawn at any single moment of the day. It is usually much less than adding up every appliance's rated power, because not everything runs at the same time.

### EQUATION: PEAK LOAD (MAXIMUM DEMAND)

$$P_{\text{peak}} = P_1 + P_2 + \dots + P_n$$

*In words: Peak load = add together the power of every appliance that is ON at the busiest moment of the day*

| Symbol                                               | Meaning                                                 | Unit      |
|------------------------------------------------------|---------------------------------------------------------|-----------|
| P <sub>peak</sub>                                    | peak load, also called maximum demand                   | watts (W) |
| P <sub>1</sub> , P <sub>2</sub> , ... P <sub>n</sub> | the power of each appliance running at that same moment | watts (W) |

*Peak load is not the sum of every appliance in the building — only the ones running at the exact same moment. For a cycling appliance like a refrigerator, its compressor can switch on at any instant, so careful designers use its full running (nameplate) power for this check, not its daily average. This lesson uses average power in the profile tables to keep the arithmetic simple; Chapters 8 and 12 add safety margins for real equipment sizing.*

### Example Home — winter weekday load profile

| Time period | Appliances ON                      | Total power (W) |
|-------------|------------------------------------|-----------------|
| 00:00–10:00 | Refrigerator (average)             | 52.5            |
| 10:00–11:00 | Refrigerator + washing machine     | 552.5           |
| 11:00–14:00 | Refrigerator (average)             | 52.5            |
| 14:00–19:00 | Refrigerator + ceiling fan         | 112.5           |
| 19:00–22:00 | Refrigerator + lights + television | 232.5           |

| Time period | Appliances ON          | Total power (W) |
|-------------|------------------------|-----------------|
| 22:00–24:00 | Refrigerator (average) | 52.5            |

#### WORKED EXAMPLE — WINTER DAILY ENERGY AND PEAK LOAD

Using the winter profile table, find the home's total daily energy (in kWh) and its peak load.

1. Multiply each period's power by its length in hours:  $52.5 \times 10 = 525$ ;  $552.5 \times 1 = 552.5$ ;  $52.5 \times 3 = 157.5$ ;  $112.5 \times 5 = 562.5$ ;  $232.5 \times 3 = 697.5$ ;  $52.5 \times 2 = 105$
2. Add all six energies:  $525 + 552.5 + 157.5 + 562.5 + 697.5 + 105 = 2600$  Wh
3. Convert to kWh:  $2600 \div 1000 = 2.6$  kWh
4. Compare all six period powers to find the highest one: 552.5 W, during 10:00–11:00

**Answer: Daily energy = 2.6 kWh. Peak load = 552.5 W — and it happens mid-morning, not in the evening.**

#### WORD TO KNOW

**Connected load** — The sum of the nameplate (rated) power of every appliance in a building, as if every single one were switched on at the same time.

#### WORD TO KNOW

**Demand factor** — The ratio of the peak load to the connected load. It shows what fraction of all appliances are typically running at the same time.  $DF = \text{peak load} \div \text{connected load}$ .

#### EQUATION: DEMAND FACTOR

$$DF = \frac{P_{\text{peak}}}{P_{\text{connected}}}$$

*In words: Demand factor = peak load ÷ connected load*

| Symbol                 | Meaning                                     | Unit                                 |
|------------------------|---------------------------------------------|--------------------------------------|
| DF                     | demand factor, also called diversity factor | no unit — usually shown as a percent |
| P <sub>peak</sub>      | peak load                                   | watts (W)                            |
| P <sub>connected</sub> | connected load                              | watts (W)                            |

*Multiply DF by 100 to show it as a percent. A low demand factor means appliances rarely all run together — a normal, healthy sign in a home, not a mistake in your audit.*

#### WORKED EXAMPLE — THE EXAMPLE HOME'S WINTER DEMAND FACTOR

Find the connected load and the demand factor for the Example Home in winter.

1. Add the rated power of every appliance: 150 (fridge) + 60 (fan) + 80 (lights) + 100 (TV) + 500 (washing machine) = 890 W
2. Take the peak load found earlier: 552.5 W

3. Divide:  $DF = 552.5 \div 890 \approx 0.62$

4. Convert to percent:  $0.62 \times 100 = 62\%$

**Answer: Connected load = 890 W. Demand factor  $\approx 62\%$ .**

#### COMMON MISTAKE

**✗ Wrong:** Assuming the busiest-looking time of day (like the evening, when the family is home) is always the peak load moment.

**✓ Right:** Check every period. A single strong appliance running alone — a washing machine, a water pump, a kettle — can create a higher spike than the whole family's evening routine. In this home, the true peak (552.5 W) happens mid-morning, not in the evening (232.5 W).

Now let's see what happens in summer. Remember the Erbil family from Chapter 1, Lesson 4? Their air conditioner alone added  $2000 \text{ W} \times 8 \text{ h} = 16 \text{ kWh}$  a day. Let's put a similar air conditioner (2000 W, running 13:00–21:00) into the Example Home and rebuild its profile.

#### Example Home — summer weekday load profile (before efficiency changes)

| Time period | Appliances ON                                        | Total power (W) |
|-------------|------------------------------------------------------|-----------------|
| 00:00–10:00 | Refrigerator (average)                               | 52.5            |
| 10:00–11:00 | Refrigerator + washing machine                       | 552.5           |
| 11:00–13:00 | Refrigerator (average)                               | 52.5            |
| 13:00–19:00 | Refrigerator + air conditioner                       | 2052.5          |
| 19:00–21:00 | Refrigerator + air conditioner + lights + television | 2232.5          |
| 21:00–22:00 | Refrigerator + lights + television                   | 232.5           |
| 22:00–24:00 | Refrigerator (average)                               | 52.5            |

#### WORKED EXAMPLE — SUMMER DAILY ENERGY, PEAK LOAD, AND DEMAND FACTOR

Using the summer profile table, find the daily energy, peak load, connected load, and demand factor.

1. Multiply each period's power by its hours and add them:

$$(52.5 \times 10) + (552.5 \times 1) + (52.5 \times 2) + (2052.5 \times 6) + (2232.5 \times 2) + (232.5 \times 1) + (52.5 \times 2) = 525 + 552.5 + 105 + 12315 + 4465 + 232.5 + 105 = 18300 \text{ Wh}$$

2. Convert to kWh:  $18300 \div 1000 = 18.3 \text{ kWh}$

3. Find the peak: the highest period power is 2232.5 W, at 19:00–21:00, when the air conditioner overlaps with lights and television

4. Connected load:  $150 + 500 + 2000 + 80 + 100 = 2830 \text{ W}$

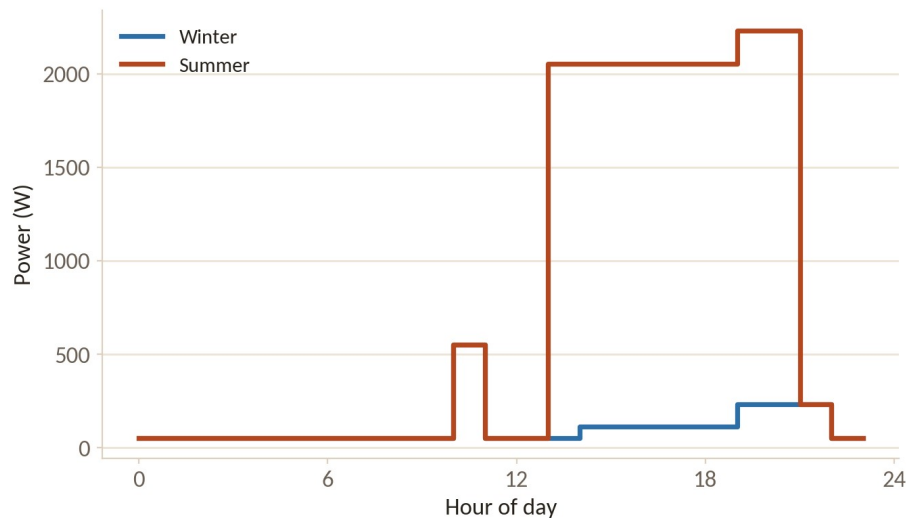
5. Demand factor:  $2232.5 \div 2830 \approx 0.79 = 79\%$

**Answer: Daily energy = 18.3 kWh. Peak load = 2232.5 W. Connected load = 2830 W. Demand factor  $\approx 79\%$ .**

#### CASE STUDY — WINTER VS. SUMMER: THE EXAMPLE HOME, REVISITED • KURDISTAN REGION (EXAMPLE

## FIGURES, FOLLOWING THE CHAPTER 1 ERBIL FAMILY)

Winter daily energy: 2.6 kWh. Summer daily energy: 18.3 kWh — about **7 times more**. Winter peak load: 552.5 W. Summer peak load: 2232.5 W — **4 times higher**. Winter demand factor: 62%. Summer demand factor: 79% — appliances are **MORE** likely to overlap in summer, because the air conditioner runs for so many hours that it overlaps with almost everything else. This is exactly the pattern the Erbil family found in Chapter 1: one appliance, the air conditioner, changes the whole shape of the home's energy story.



*The Example Home's load profile across 24 hours: winter (low, with one mid-morning spike) compared with summer (much higher, dominated by the air conditioner from 13:00 to 21:00).*

► [App simulation: Explore it live: Load Analysis simulation](#)

## 10.3 Efficiency First: Reducing Load Before Buying Panels

Here is one of the most important money-saving ideas in solar design: **reduce the load before you size the equipment**. Every watt you do not need is a watt you do not have to generate, store, and pay for — three times over. This is why professional designers always ask 'can we shrink this load?' before they ask 'how many panels do we need?'

### WORD TO KNOW

**Energy efficiency** — Getting the same useful result — light, cooling, washing, ironing — while using less electrical energy. This is different from a solar cell's efficiency (Chapter 4), which is about how much sunlight a panel converts to electricity — energy efficiency here is about the appliances using that electricity.

There are three families of efficiency action: better **technology** (an LED bulb instead of an old one), better **behavior** (turning things off, using fewer hours), and better **scheduling** (running big appliances at different times, so they do not all add up together).

### Common efficiency actions and their typical effect

| Action                           | Typical effect                                    |
|----------------------------------|---------------------------------------------------|
| Replace old bulbs with LED bulbs | Same brightness, often 80–85% less power per bulb |

| Action                                                                      | Typical effect                                                                                             |
|-----------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------|
| Replace a fixed-speed air conditioner with an inverter-type air conditioner | Similar cooling comfort, often 30–40% less energy, because the compressor slows down once the room is cool |
| Reduce air conditioner hours (shade, insulation, a higher set temperature)  | Directly cuts hours $\times$ power = less daily energy                                                     |
| Turn off lights and fans in empty rooms                                     | Removes energy use at zero cost                                                                            |
| Unplug chargers and electronics when not in use                             | Removes small standby losses that add up over a month                                                      |
| Stagger big appliances so they do not all run together                      | Lowers the peak load and demand factor, even if the daily energy stays the same                            |

### WORD TO KNOW

**Standby power** — The small amount of power a device uses even when switched off but still plugged in — sometimes called phantom load. A charger left plugged in with no phone attached might still use 0.3–0.5 W. (Chapter 8 covers an inverter's own idle draw, called standby consumption — the same idea, for a different device.)

### WORKED EXAMPLE — HOW MUCH DO 'SLEEPING' DEVICES COST OVER A MONTH?

A home leaves 6 chargers and small devices plugged in all day, even when not charging anything. Each one uses 0.4 W of standby power. Find the extra energy used in a month (30 days).

1. Total standby power:  $6 \times 0.4 \text{ W} = 2.4 \text{ W}$
2. Daily energy:  $E = 2.4 \text{ W} \times 24 \text{ h} = 57.6 \text{ Wh}$
3. Monthly energy:  $57.6 \text{ Wh} \times 30 = 1728 \text{ Wh}$
4. Convert to kWh:  $1728 \div 1000 \approx 1.73 \text{ kWh}$

**Answer:  $\approx 1.73 \text{ kWh}$  per month — small for one device, but real once you add up a whole home full of them.**

Now let's apply the biggest lever of all — technology and scheduling together — to the Example Home's summer profile from Lesson 2.

### WORKED EXAMPLE — RETROFITTING THE EXAMPLE HOME FOR SUMMER

The family replaces their 2000 W fixed-speed air conditioner with an inverter-type unit. It gives the same cooling comfort but averages 1300 W while running. They also run it for only 6 hours (13:00–19:00) instead of 8, choosing hours that end before the evening lights and television switch on. Find the new daily energy and new peak load.

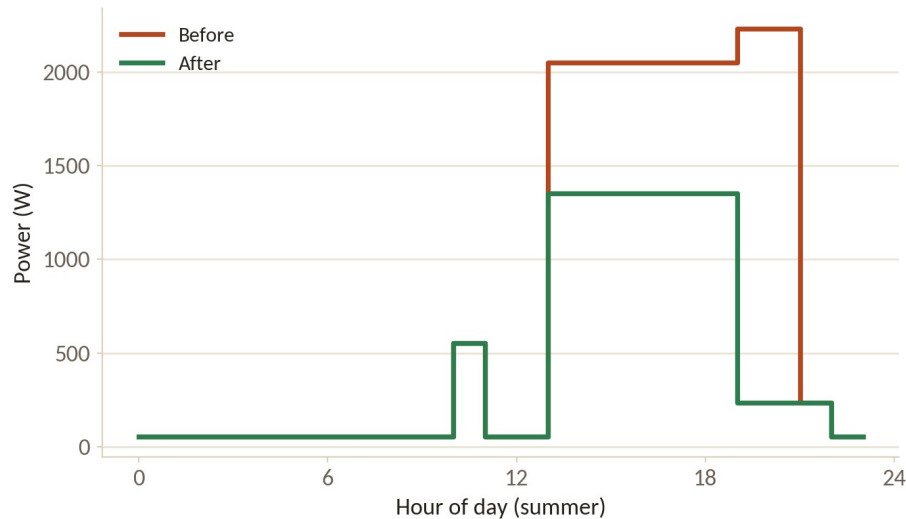
1. New air conditioner energy:  $1300 \text{ W} \times 6 \text{ h} = 7800 \text{ Wh}$
2. New total daily energy: 1260 (fridge) + 500 (washing machine) + 7800 (AC) + 240 (lights) + 300 (TV) = 10100 Wh = 10.1 kWh
3. New peak, 13:00–19:00 (fridge + AC only, lights/TV not yet on):  $52.5 + 1300 = 1352.5 \text{ W}$
4. Compare with the other periods: the washing machine hour is still 552.5 W, and the new evening period (fridge + lights + TV, AC now off) is only 232.5 W. The highest of these is 1352.5 W.

**Answer: New daily energy  $\approx 10.1 \text{ kWh}$  (was 18.3 kWh). New peak load = 1352.5 W (was 2232.5 W).**



### Before and after efficiency improvements (summer)

| Metric       | Before   | After    | Change          |
|--------------|----------|----------|-----------------|
| Daily energy | 18.3 kWh | 10.1 kWh | -8.2 kWh (-45%) |
| Peak load    | 2232.5 W | 1352.5 W | -880 W (-39%)   |



The Example Home's summer load profile before and after efficiency improvements. The 'after' curve is lower everywhere the air conditioner runs, and it no longer overlaps with the evening lighting peak.

#### COMMON MISTAKE

**✗ Wrong:** Solving a high electricity bill by buying a bigger solar array, more batteries, and a bigger inverter.

**✓ Right:** Reduce the load first. In the example above, better technology and better scheduling cut daily energy by 45% and peak load by 39% — for the cost of one air conditioner upgrade. That is almost always cheaper than paying for a solar and battery system nearly twice as big.

#### ACTIVITY (HOME) — FIND THREE EFFICIENCY ACTIONS

1. Look at your own load audit from Lesson 1 (or build a quick one now).
2. Find your single biggest energy user — usually cooling, heating, or a motor.
3. Write down three realistic efficiency actions: one technology change, one behavior change, and one scheduling change.
4. Estimate the Wh or kWh saved per day for each one, using the equations from this chapter.

You need: Your load audit from Lesson 1, Calculator or phone

► App simulation: Test your own efficiency ideas: [Load Analysis simulation](#)

## 10.4 Critical vs. Non-Critical Loads During Power Cuts

You already practice load prioritization every day. In Chapter 1, Lesson 5, a family chose what to run on a 5-ampere generator subscription — they could not run everything, so they made choices. A solar backup system faces the exact same limit. This lesson turns that everyday habit into a professional method.

#### WORD TO KNOW

**Critical load** — An appliance or circuit that must keep working during a power cut — for example, lights for safety, a refrigerator to stop food spoiling, or a medical device.

#### WORD TO KNOW

**Non-critical load** — An appliance that can wait until grid or generator power returns, without real harm — for example, a washing machine, a water heater, or an iron.

#### COMMON MISTAKE

✗ **Wrong:** Using the exact same critical-load list for every building, every time.

✓ **Right:** Decide critical loads for the specific building and the people in it. A water pump is critical on a farm with no storage tank (no pump means no water at all), but non-critical in a home with a full water tank. An air conditioner is non-critical for most homes, but critical for a health center or a person with a medical need.

#### Example priority tiers for a home

| Load                      | Tier                    | Why                                                                                       |
|---------------------------|-------------------------|-------------------------------------------------------------------------------------------|
| Refrigerator              | Essential               | Food spoils within hours without cooling, especially in summer heat                       |
| A few safety lights       | Essential               | People need light to move around safely and avoid accidents                               |
| Router and phone charging | Essential               | Communication matters most exactly when something has gone wrong                          |
| Television                | Deferrable              | Comfortable to have, but nobody is harmed by waiting                                      |
| Washing machine           | Deferrable              | Laundry can wait for grid or generator hours                                              |
| Air conditioner           | Depends on the building | Deferrable in most homes; essential in a health center or for a person with medical needs |
| Electric water heater     | Deferrable              | High power for comfort only; can wait, or use less hot water                              |

#### WORD TO KNOW

**Critical loads panel** — A separate electrical panel that carries only the most important circuits, like lights and the refrigerator. During a power cut, the backup system (battery and inverter) only needs to power this smaller panel — not the whole building.

Why does this matter so much? Because the size — and the price — of an inverter and a battery bank depends directly on the peak load and daily energy they must supply (Chapters 6, 8, and 12 show exactly how). A backup system for the WHOLE home must be large. A backup system for CRITICAL loads only can be much smaller.

### WORKED EXAMPLE — SIZING THE CRITICAL-LOADS-ONLY BACKUP FOR THE EXAMPLE HOME

The family chooses these critical loads: the refrigerator (150 W running power, 35% duty cycle), 3 of the 8 LED lights (10 W each, used 3 h/day like the rest), and a Wi-Fi router (10 W, always on). Find the critical-loads peak load and daily energy.

1. Peak load: use the refrigerator's full running power (150 W), not its average — the compressor can switch on at any moment.  $\text{Peak} = 150 + (3 \times 10) + 10 = 190 \text{ W}$
2. Refrigerator daily energy:  $150 \text{ W} \times 0.35 \times 24 \text{ h} = 1260 \text{ Wh}$
3. Lights daily energy:  $(3 \times 10 \text{ W}) \times 3 \text{ h} = 90 \text{ Wh}$
4. Router daily energy:  $10 \text{ W} \times 24 \text{ h} = 240 \text{ Wh}$
5. Total daily energy:  $1260 + 90 + 240 = 1590 \text{ Wh} = 1.59 \text{ kWh}$

**Answer: Critical peak load = 190 W. Critical daily energy  $\approx$  1.59 kWh — far smaller than powering the whole home.**

### Backup sizing: three options for the Example Home (summer)

| Backup option                                        | Peak load needed | Daily energy needed |
|------------------------------------------------------|------------------|---------------------|
| Whole home, no efficiency changes (Lesson 2)         | 2232.5 W         | 18.3 kWh            |
| Whole home, after efficiency improvements (Lesson 3) | 1352.5 W         | 10.1 kWh            |
| Critical loads only                                  | 190 W            | 1.59 kWh            |

Compare the first row and the last row:  $2232.5 \div 190 \approx 11.75$ , so the critical-loads-only backup needs about **12 times less peak power**. Daily energy is  $18.3 \div 1.59 \approx 11.5$ , so about **11.5 times less energy** too. That is the difference between a small, affordable inverter and battery, and a large, expensive one.

### SAFETY

Never connect a critical loads panel, a generator, and the grid without a proper transfer (changeover) switch. Feeding power backward into a 'dead' grid line can injure repair workers and damage equipment. This is the same rule you learned for generators in Chapter 1, Lesson 5 — a solar backup system needs the same respect.

### CASE STUDY — A RURAL HEALTH CENTER'S PRIORITY LIST • KURDISTAN REGION (EXAMPLE SCENARIO)

A small health center in a village loses grid power for several hours most days — the kind of daily load shedding Chapter 21 studies region by region. Its solar and battery backup is not large enough for the whole building, so the staff built a critical loads panel with only: the vaccine refrigerator, examination room lights, one medical device, and a phone for emergencies. The waiting room lights, water heater, and office computer wait for grid or generator hours. Because the critical list is so small, a modest battery keeps the vaccines safe and the clinic working through every outage — this is exactly the 'health center' project you will design in Chapter 22.

► *App tool: Audit your critical loads separately in the app*

### CHAPTER SUMMARY

- A professional load audit records quantity, nameplate (rated) power, duty cycle, and days per week used — not just power and hours.
- Duty cycle finds effective running hours for cycling appliances:  $t_{\text{eff}} = \text{DC} \times t_{\text{on}}$ . For appliances not used every day, average daily energy =  $(P \times t \times d) \div 7$ .
- A load profile shows power hour by hour. Peak load is the highest value on it — check every hour, because one strong appliance can spike higher than the general evening peak.
- Connected load is the sum of every appliance's rated power. Demand factor = peak load  $\div$  connected load, and it is normally well below 100%.
- Summer and winter load profiles can be very different — one large appliance, like an air conditioner, can multiply both daily energy and peak load several times over.
- Reduce load before sizing solar equipment: better technology, better behavior, and better scheduling (avoiding overlaps) all shrink daily energy and peak load together.
- Critical loads must keep working during a power cut; non-critical loads can wait. What counts as critical depends on the building and the people in it.
- A critical loads panel lets a backup battery and inverter be sized for only the essentials — often ten times smaller, and far cheaper, than backing up an entire building.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A borehole water pump is connected for 6 hours a day. Its duty cycle is 50% (it switches on and off automatically). Find its effective running hours.

**Problem 2 [Basic]** An electric iron is rated 1000 W. It is used for 30 minutes (0.5 h) each time, 3 days a week. Find its average daily energy, in Wh, averaged over the week.

**Problem 3 [Basic]** A home has these appliances: refrigerator 150 W, ceiling fan 60 W, LED lights 80 W (total), television 100 W, and washing machine 500 W. Find the home's connected load.

**Problem 4 [Basic]** At a certain moment, these appliances are running together: a refrigerator (50 W, currently running), two lamps (10 W each), and a fan (70 W). What is the load at that moment?

**Problem 5 [Standard]** A shop has two cycling appliances, both plugged in all day (24 h available): a display fridge rated 120 W with a 40% duty cycle, and a small freezer rated 100 W with a 50% duty cycle. Find their combined daily energy.

**Problem 6 [Standard]** A small workshop has a connected load of 1500 W. Its demand factor is 40%. Find its peak load.

**Problem 7 [Standard]** A small shop has a constant background load of 40 W (a security light and a small display fridge). From 07:00 to 09:00, it also runs a 1500 W coffee machine. From 17:00 to 21:00, it turns on extra shop lights (50 W) and a till/computer (90 W), on top of the background load. Find (a) the shop's total daily energy in kWh, and (b) its peak load.

**Problem 8 [Standard]** A shop has 8 old bulbs rated 60 W each, used 5 hours a day. It replaces them with 8 LED bulbs rated 9 W each, giving the same light, still used 5 hours a day. Find (a) the daily energy saving, and (b) the monthly saving (30 days), in kWh.

**Problem 9 [Standard]** A home leaves 10 small chargers and devices plugged in all day, each using 0.3 W of standby power. Find (a) the monthly standby energy in kWh, and (b) its cost at the example price of 100 IQD per kWh (example price, as in Chapter 1).

**Problem 10 [Challenge]** A shop currently has: fluorescent tube lights (160 W total, 10 h/day), a display fridge (200 W rated, 45% duty cycle, 24 h available), a fixed-speed air conditioner (1800 W, 6 h/day), and a computer/till (80 W, 10 h/day). The owner replaces the tube lights with LED tubes (72 W total, same hours) and the air conditioner with an inverter type (average 1100 W, same hours). Find (a) the daily energy before, (b) the daily energy after, and (c) the percentage reduction.

**Problem 11 [Challenge]** A family picks these critical loads for power cuts: a refrigerator (120 W running power, 40% duty cycle), 2 safety lights (10 W each, used 4 h/day), and a router (8 W, always on). The whole home's connected load (all appliances) is 2360 W. Find (a) the critical peak load, (b) the critical daily energy in kWh, and (c) the critical peak load as a percentage of the whole home's connected load.

**Problem 12 [Challenge]** A school laboratory has: LED tube lights (180 W total, 6 h/day, 08:00–14:00), 15 computers (120 W each, 5 h/day, 09:00–14:00), a chemical-storage fridge (150 W rated, 40% duty cycle, 24 h available), an air conditioner (1600 W, 6 h/day, 08:00–14:00), and a projector (200 W, 2 h/day, 15:00–17:00, a separate afternoon class). Find (a) the total daily energy in kWh, (b) the peak load during 09:00–14:00 (when lights, computers, the fridge, and the AC all overlap — use the fridge's running power for this check), (c) the connected load, (d) the demand factor, and (e) the critical-loads peak if the fridge and 2 of the LED tubes (18 W each) are marked critical.

**Problem 13 [Challenge]** Five houses share one small power line. Each house has a connected load of 800 W, but the measured peak load of all five houses together is only 2000 W. Find the group's demand factor, and explain in one sentence why it is usually lower for a group of houses than for a single house.

## CHAPTER ELEVEN

# Solar System Types

*Off-grid, on-grid, and hybrid — how each one is built, and how to choose*

### IN THIS CHAPTER YOU WILL LEARN TO

- Describe the architecture and energy flow of an off-grid solar system, from sunlight to load.
- Describe the architecture and energy flow of an on-grid (grid-tied) solar system, and explain why it gives no backup power during a blackout.
- Explain how a hybrid system combines solar, a battery, the grid, and a generator, and describe its energy flow.
- Compare off-grid, on-grid, and hybrid systems by grid connection, backup ability, and typical use.
- Choose a suitable system type for a real situation, using daily grid outage hours as a key factor.

## 11.1 Off-Grid Systems: Architecture and Energy Flow

There is not just one kind of solar system. There are three main types: **off-grid**, **on-grid**, and **hybrid**. Each type connects its parts in a different way, and each one sends energy on a different path. This chapter takes everything you learned about panels, batteries, charge controllers, inverters, wiring, and loads in Chapters 4 to 10, and puts the pieces together into complete systems. This lesson looks closely at the first type: off-grid.

### The three system types at a glance

| System type         | Connected to the grid? | Has a battery? | Best known for                                     |
|---------------------|------------------------|----------------|----------------------------------------------------|
| Off-grid            | No                     | Yes, always    | Full independence — for places with no grid at all |
| On-grid (grid-tied) | Yes                    | Usually not    | The lowest-cost way to cut an electricity bill     |
| Hybrid              | Usually yes            | Yes            | Savings and backup power together                  |

### WORD TO KNOW

**Grid** — The public network of power lines and power stations that supplies electricity to homes, shops, and factories. Also called the public grid or the national grid. Chapter 21 looks at Iraq's grid in detail.

### WORD TO KNOW

**Off-grid system** — A solar system that is not connected to the public grid at all. It produces and stores all the energy it needs by itself, usually with a battery bank.

Off-grid systems are the natural choice wherever the grid does not reach at all — mountain villages, remote farms, telecommunications towers, and isolated water pumps. They are also chosen by anyone who wants complete independence from the grid, wherever they live. In the Kurdistan Region, off-grid systems are common on farms and orchards, at remote relay towers, and on isolated irrigation pumps, far from the nearest power line.

**Off-grid energy flow: Sun → Array → Charge controller → Battery → Inverter → Loads**

| Step | Block                         | What happens here                                                                                                                                                      |
|------|-------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Sun                           | Sunlight reaches the solar array                                                                                                                                       |
| 2    | Solar array (Chapters 4–5)    | Sunlight becomes DC electricity                                                                                                                                        |
| 3    | Charge controller (Chapter 7) | Controls the charging current so the battery is charged safely, not overcharged                                                                                        |
| 4    | Battery (Chapter 6)           | Stores DC energy for use at night or on cloudy days                                                                                                                    |
| 5    | Off-grid inverter (Chapter 8) | Changes the battery's DC electricity into AC electricity for normal appliances                                                                                         |
| 6    | AC and DC loads               | Lights, fridge, and TV run on AC from the inverter; some systems also run small DC loads, like LED lights or a DC pump, straight from the battery, before the inverter |

#### EQUATION: OFF-GRID DAILY ENERGY BALANCE

$$E_{\text{array}} = E_{\text{day}} + E_{\text{battery}}$$

*In words: Solar energy produced in a day = energy used directly during the day + energy sent to charge the battery*

| Symbol               | Meaning                                            | Unit |
|----------------------|----------------------------------------------------|------|
| $E_{\text{array}}$   | total energy the solar array produces in one day   | kWh  |
| $E_{\text{day}}$     | energy used directly by loads while the sun shines | kWh  |
| $E_{\text{battery}}$ | energy sent to charge the battery                  | kWh  |

*This simple picture ignores losses in the wires, controller, and inverter. Chapter 12 adds real losses and shows the full sizing method.*

#### WORKED EXAMPLE — HOW MUCH ENERGY CHARGES THE BATTERY?

An off-grid array produces 4.0 kWh on a sunny day. The home uses 1.5 kWh directly while the sun shines. Ignoring losses, how much energy is left to charge the battery?

1. Write the equation:  $E_{\text{array}} = E_{\text{day}} + E_{\text{battery}}$
2. Rearrange it:  $E_{\text{battery}} = E_{\text{array}} - E_{\text{day}}$
3. Put in the numbers:  $E_{\text{battery}} = 4.0 - 1.5$
4. Calculate:  $E_{\text{battery}} = 2.5 \text{ kWh}$

**Answer: 2.5 kWh charges the battery, ready for use at night.**

### COMMON MISTAKE

✗ **Wrong:** If a home has solar panels, it does not need batteries.

✓ **Right:** Panels only make power while the sun shines. Without a battery bank (off-grid) or a grid connection (on-grid), the lights would go off at sunset or under a heavy cloud.

### SAFETY

A battery bank stores a large amount of energy in a small space. An off-grid system depends on it completely, so keep it in a cool, ventilated place, away from open flames and sparks, and follow the maker's connection order. Chapter 6 explains battery safety in full.

### CASE STUDY — SOLAR POWER FOR A MOUNTAIN RELAY STATION • NEAR DUHOK, KURDISTAN REGION (EXAMPLE SCENARIO)

A telecommunications relay tower sits on a mountain ridge, far from any grid line. Running a cable up the mountain would cost more than all the equipment together. Instead, engineers installed an **off-grid** solar system: an array, a charge controller, a battery sized for several cloudy days in a row, and a small inverter for the maintenance technician's tools. The tower has run for years with almost no fuel deliveries — a job that used to need a diesel generator and regular, difficult trips up the mountain road.

### ACTIVITY (CLASSROOM) — DRAW THE OFF-GRID ENERGY FLOW

1. Using the block-diagram table from this lesson, draw five boxes in order on paper: solar array, charge controller, battery, inverter, AC loads.
2. Draw an arrow between each box and write what flows along it — for example, 'DC electricity' or 'AC electricity'.
3. Circle the ONE box that lets the system keep working at night. Explain your choice to a partner.

*You need: Paper and pen or pencil, Ruler (optional)*

► *App tool: Review your daily energy need before choosing a system type*

► *App simulation: Explore: watch energy flow through an off-grid system*

## 11.2 On-Grid Systems: Architecture and Energy Flow

The second system type is built to work **together** with the public grid, not instead of it. This is the on-grid, or grid-tied, system — usually the simplest and cheapest way to use solar power.

### WORD TO KNOW

**On-grid system** — A solar system connected to the public grid, usually without a battery. It uses solar power first and draws any extra power it needs from the grid. Also called a grid-tied system.

**On-grid energy flow: Sun → Array → Grid-tie inverter → Loads and Meter ↔ Grid**

| Step | Block | What happens here                |
|------|-------|----------------------------------|
| 1    | Sun   | Sunlight reaches the solar array |



| Step | Block                         | What happens here                                                                              |
|------|-------------------------------|------------------------------------------------------------------------------------------------|
| 2    | Solar array (Chapters 4–5)    | Sunlight becomes DC electricity                                                                |
| 3    | Grid-tie inverter (Chapter 8) | Changes DC to AC and matches it exactly to the grid's voltage and frequency                    |
| 4    | Home's AC loads               | Use solar power first, moment by moment                                                        |
| 5    | Electricity meter             | Measures energy flowing in from the grid (import) and, where allowed, out to the grid (export) |
| 6    | Public grid                   | Supplies any extra power the home needs, and receives any solar surplus the home does not use  |

#### WORD TO KNOW

**Self-consumption** — The part of a solar system's energy that a home uses directly, instead of sending it out to the grid.

#### EQUATION: ON-GRID DAILY ENERGY BALANCE

$$E_{\text{solar}} + E_{\text{import}} = E_{\text{load}} + E_{\text{export}}$$

*In words: Solar energy produced + energy imported from the grid = energy used by the home + energy exported to the grid*

| Symbol              | Meaning                                   | Unit |
|---------------------|-------------------------------------------|------|
| $E_{\text{solar}}$  | energy the solar array produces that day  | kWh  |
| $E_{\text{import}}$ | energy drawn from the public grid         | kWh  |
| $E_{\text{load}}$   | total energy the home uses that day       | kWh  |
| $E_{\text{export}}$ | surplus solar energy sent out to the grid | kWh  |

*A basic on-grid system has no battery, so this balance happens automatically, moment by moment, through the meter. On a cloudy day import is high; on a sunny day with low home use, export can be high.*

#### WORKED EXAMPLE — A CLOUDY DAY AND A SUNNY DAY

A home's on-grid system behaves differently on two days. (a) Cloudy weekday: solar = 2.0 kWh, load = 6.0 kWh, and the home uses all of its solar directly, so export = 0. Find the import. (b) Sunny weekend day: solar = 5.0 kWh, load = 2.0 kWh, and the home uses solar first. Find the export.

- (a) Write the equation:  $E_{\text{solar}} + E_{\text{import}} = E_{\text{load}} + E_{\text{export}}$ . With no export,  $E_{\text{export}} = 0$ .
- (a) Put in the numbers:  $2.0 + E_{\text{import}} = 6.0 + 0$
- (a) Solve:  $E_{\text{import}} = 6.0 - 2.0 = 4.0$  kWh
- (b) The home can only self-consume as much solar as its load needs, so self-used solar = 2.0 kWh and  $E_{\text{import}} = 0$
- (b) Put in the numbers:  $5.0 + 0 = 2.0 + E_{\text{export}}$
- (b) Solve:  $E_{\text{export}} = 5.0 - 2.0 = 3.0$  kWh

**Answer:** (a) The home imports 4.0 kWh on the cloudy day. (b) The home exports 3.0 kWh on the sunny day.

#### WORD TO KNOW

**Net metering** — A billing arrangement where solar energy sent to the grid reduces the electricity bill, sometimes by running the meter backward. Rules are different in every country and area — Chapter 13 looks at what is realistic here.

On-grid systems are excellent at lowering electricity bills. But they have one surprising limit that every student of solar power must understand clearly: **a basic on-grid system gives no backup power at all**. The moment the public grid goes down, the system's grid-tie inverter switches itself off too — even in bright sunshine. You already met the safety reason in Chapter 8: **anti-islanding**. The inverter must not keep feeding electricity into a grid line that repair workers may be touching.

#### COMMON MISTAKE

**✗ Wrong:** A solar system will keep the lights on during a power cut, because it makes its own electricity.  
**✓ Right:** A basic on-grid (grid-tied) system automatically switches off during a power cut, even in bright sunshine, because of anti-islanding protection. Only systems with a battery — off-grid or hybrid — can power a home during an outage.

#### SAFETY

Never try to modify or bypass a grid-tie inverter's anti-islanding protection. It exists to protect the people repairing the lines. Any work on grid-tied wiring should be done, or checked, by a qualified technician.

#### CASE STUDY — THE SHOPKEEPER'S SURPRISE · A SHOP IN THE KURDISTAN REGION (EXAMPLE SCENARIO)

A shop owner installed a small on-grid solar system to cut his electricity bill. It worked well — his bill dropped by nearly half. Then, one afternoon during his busiest hour, the public grid went down for three hours. To his surprise, his lights, refrigerator, and card machine also went dark, even though bright sunshine was falling on his new panels. He called the installer, confused. The installer explained anti-islanding: a basic on-grid system cannot work without the grid, because it is designed to switch off the moment the grid disappears. If the shop owner wanted power during outages, he would need a battery — in other words, a hybrid system.

#### ACTIVITY (HOME) — INVESTIGATE A METER AND A BLACKOUT STORY

1. Look at your home's electricity meter, or a photo of one. Do you think it can only count energy coming IN, or could it also count energy going OUT to the grid?
2. Ask a family member or neighbor if they know anyone with solar panels connected to the grid.
3. If you can, ask that person what happens to their panels during a power cut. If you cannot ask anyone, use this lesson to predict the answer, and explain why.

*You need: Notebook, A visit to your electricity meter, or a photo of it*

## 11.3 Hybrid Systems and Choosing the Right Type

Off-grid gives full independence, but needs a big battery. On-grid is simple and low-cost, but gives no backup at all. What if a system could take the best of both? That is the **hybrid** system — the third and most flexible type, and the one many families in Iraq and the Kurdistan Region are now choosing.

### WORD TO KNOW

**Hybrid system** — A system that combines two or more power sources — usually solar, a battery, and the grid and/or a generator — and can switch between them, often automatically.

Hybrid energy flow: Sun → Array → Hybrid inverter-charger ↔ Battery, and ↔ Grid/Generator → Loads

| Step | Block                               | What happens here                                                                                                                                       |
|------|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Sun                                 | Sunlight reaches the solar array                                                                                                                        |
| 2    | Solar array (Chapters 4–5)          | Sunlight becomes DC electricity                                                                                                                         |
| 3    | Hybrid inverter-charger (Chapter 8) | Converts DC to AC for loads, sends extra solar to charge the battery, and manages the connection to the grid and a generator                            |
| 4    | Battery (Chapter 6)                 | Stores surplus solar energy for use at night or when the grid and generator are both off                                                                |
| 5    | Grid and/or generator               | Top up the battery or power loads directly when solar and battery are not enough, through a changeover switch or the inverter's own automatic switching |
| 6    | AC loads                            | Lights, fridge, TV, and other appliances — powered from whichever source is active at that moment                                                       |

Most hybrid inverters follow a simple order of priority, all through the day: - First, use solar power for the home's loads. - Second, use any extra solar to charge the battery. - Third, if solar and battery together are not enough, draw from the grid (if it is up) or start the generator. This order is what makes hybrid systems save money — solar and battery are used first, before any paid electricity. It is also what gives hybrid systems backup power: unlike an on-grid system, a hybrid system does not need to shut off when the grid goes down. It simply switches to the battery, without the anti-islanding shutdown you met in Lesson 2.

### WORD TO KNOW

**Generator** — A machine that burns fuel, such as diesel or petrol, to produce electricity. Often used as backup power during grid outages. Chapter 1 introduced the generator subscription — the payment for using a shared one.

### WORD TO KNOW

**Changeover switch** — A switch that connects only one power source to a building's wiring at a time — for example, the grid or a generator, never both together. Also called a transfer switch. An automatic version

is called an automatic transfer switch (ATS).

#### SAFETY

Never let the grid and a generator feed a building's wiring at the same time without a proper changeover switch, as Chapter 1 already warned. If both sources connect together, it can push electricity backward into the grid lines and injure repair workers, and it can also destroy your equipment. In a hybrid system, this switching is normally built into the hybrid inverter-charger — but any extra generator wiring must still be checked by a qualified technician.

#### COMMON MISTAKE

**✗ Wrong:** Adding hybrid solar always removes the need for the neighborhood generator completely.

**✓ Right:** A well-sized hybrid system greatly reduces generator running hours and cost, but the generator is usually still kept for cloudy days, unusually long outages, or times of unusually high use — especially in winter, when there are fewer sun hours.

#### CASE STUDY — GRID, GENERATOR, AND SOLAR WORKING TOGETHER • A FAMILY HOME IN THE KURDISTAN REGION (EXAMPLE SCENARIO)

A family in a Kurdistan Region town has the public grid, a 5-ampere neighborhood generator subscription (Chapter 1), and a new hybrid solar system with a battery. On a normal day: in the morning, the sun rises, and the array quickly covers the home's daytime loads and starts charging the battery. By early afternoon the battery is full. In the evening, the public grid goes down for its usual few hours. The hybrid inverter-charger switches to the battery automatically — the family barely notices, except for a flicker of less than a second. If the outage lasts longer than usual and the battery runs low, the system calls on the generator instead of leaving the home dark. The result: the family still pays for a small generator subscription, for emergencies, but uses it far less than before. On most days, the sun and the battery do the whole job.

#### Comparing the three system types

| Feature                                                   | Off-grid                                                          | On-grid (grid-tied)                                              | Hybrid                                                        |
|-----------------------------------------------------------|-------------------------------------------------------------------|------------------------------------------------------------------|---------------------------------------------------------------|
| Connected to the public grid?                             | No                                                                | Yes                                                              | Usually yes                                                   |
| Has a battery?                                            | Yes, always                                                       | No, in the basic type                                            | Yes                                                           |
| Works during a grid power cut?                            | Yes — independent of the grid                                     | No — switches off (anti-islanding)                               | Yes — switches to the battery                                 |
| Can reduce a generator's running hours?                   | Can replace it, if sized for the full load                        | No help — needs the grid to work at all                          | Yes — often by a large amount                                 |
| Typical use                                               | Remote sites with no grid: villages, farms, telecom towers, pumps | Homes and shops with a fairly reliable grid, wanting lower bills | Homes with daily outages, wanting savings and backup together |
| Relative cost and complexity (example, for the same home) | Medium to high — needs a full battery bank                        | Lowest — no battery needed                                       | Highest — battery plus smart switching                        |

Every idea in this chapter — architecture, energy flow, cost, and backup — leads to one practical question: how many hours a day does the grid go down where you live? This single number is one of the strongest clues for choosing the right system type.

#### How daily grid outage hours change your choice

| Typical daily grid outage                    | Best-fit system type                 | Why                                                                                                                  |
|----------------------------------------------|--------------------------------------|----------------------------------------------------------------------------------------------------------------------|
| About 0–2 hours a day (a reliable grid)      | On-grid (grid-tied)                  | Little benefit from a battery — on-grid gives the best savings for the lowest cost                                   |
| About 3–8 hours a day (common in many towns) | Hybrid                               | A battery sized for the outage window keeps essentials running, and the system still saves money the rest of the day |
| More than 8 hours a day, or no grid at all   | Off-grid, or hybrid with a generator | The system must be able to carry most or all of the load by itself                                                   |

#### EQUATION: BATTERY BACKUP TIME

$$t_{\text{backup}} = \frac{E_{\text{usable}}}{P_{\text{critical}}}$$

*In words: Backup time (hours) = usable battery energy ÷ average power of the critical loads*

| Symbol     | Meaning                                                                                                                   | Unit      |
|------------|---------------------------------------------------------------------------------------------------------------------------|-----------|
| t_backup   | how many hours the battery can power the chosen critical loads                                                            | hours (h) |
| E_usable   | battery energy set aside and usable for backup                                                                            | kWh       |
| P_critical | average power of just the critical loads (Chapter 10) you choose to back up, such as lights, a router, and a refrigerator | kW        |

*This is a simplified estimate for choosing a system type and a rough battery size. Chapter 12 gives the full battery-sizing method, including depth of discharge and safety margins.*

#### WORKED EXAMPLE — DOES THE BATTERY COVER THE DAILY OUTAGE?

A family wants backup for lights, a router, and a refrigerator, averaging 0.3 kW together. Their hybrid system reserves 3.0 kWh of usable battery energy for backup. Their area typically loses grid power for 8 hours a day. Is the battery enough?

1. Write the equation:  $t_{\text{backup}} = E_{\text{usable}} \div P_{\text{critical}}$
2. Put in the numbers:  $t_{\text{backup}} = 3.0 \text{ kWh} \div 0.3 \text{ kW}$
3. Calculate:  $t_{\text{backup}} = 10 \text{ hours}$
4. Compare with the daily outage: 10 hours of backup is more than the 8-hour outage

**Answer: Yes — 10 hours of backup comfortably covers the 8-hour daily outage.**

#### ACTIVITY (CLASSROOM) — CHOOSE THE RIGHT SYSTEM FOR REAL SITUATIONS

1. First, find your own area's typical daily grid outage — ask a family member, or think about when your neighborhood generator usually turns on and off. Write down the approximate number of hours.

2. Using the outage-hours table from this lesson, decide which system type best fits YOUR home, and write one sentence saying why.
3. Now decide the best system type for each situation below, with two reasons for each: (a) A small clinic in a town with about 5 hours of daily outage, where the medicine refrigerator is a critical load (Chapter 10) that must never stop. (b) A family farmhouse 20 km from the nearest grid line.
4. Compare your answers with a partner and discuss any differences.

*You need: Notebook, The comparison table and outage-hours table from this lesson*

► *App simulation: Explore: change the daily grid outage hours and see which system keeps the lights on*

## CHAPTER SUMMARY

- There are three main solar system types: off-grid, on-grid (grid-tied), and hybrid.
- An off-grid system has no grid connection and always needs a battery: array → charge controller → battery → off-grid inverter → loads.
- An on-grid (grid-tied) system works together with the public grid, usually with no battery: array → grid-tie inverter → home loads, meter, and grid.
- A basic on-grid system gives NO backup power. Its anti-islanding safety feature switches it off during every grid power cut, even in bright sunshine.
- A hybrid system combines solar, a battery, and the grid and/or a generator, usually through a hybrid inverter-charger, and can switch sources automatically.
- Hybrid systems both save money (solar and battery used first) and give backup power (they switch to the battery instead of shutting off).
- Choosing a system type depends on whether the grid is present, how many hours a day it is down, and whether backup power is needed.
- As a rough guide: 0–2 outage hours a day favors on-grid; 3–8 hours favors hybrid; more than 8 hours (or no grid) favors off-grid or hybrid with a generator.
- In Iraq and the Kurdistan Region, many homes already combine the public grid, a neighborhood generator, and now solar — hybrid systems fit this reality well, cutting generator hours and cost.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A family farm is 15 km from the nearest grid line. Bringing a grid connection would cost far more than a solar system. Which system type must they use, and why?

**Problem 2 [Basic]** A home has a very reliable grid connection (rare, short outages). The owner wants to lower the electricity bill but does not want to pay for a battery. Which system type fits best, and why?

**Problem 3 [Basic]** True or false, with a reason: 'An on-grid solar system will power your refrigerator during a public grid blackout.'

**Problem 4 [Basic]** An off-grid array produces 3.0 kWh on a sunny day. The home uses 1.0 kWh of that directly while the sun shines. Ignoring losses, how much energy charges the battery?

**Problem 5 [Standard]** A shop in a town center has about 4 hours of grid outage a day, mostly in the afternoon. The owner already has a small backup generator. Should the owner choose off-grid, on-grid, or hybrid? Give at least two reasons.

**Problem 6 [Standard]** A family pays for a 5-ampere neighborhood generator subscription (see Chapter 1) and wants their lights and refrigerator to keep working no matter what, at the lowest extra cost. Which system type should they choose? Describe how the grid, the generator, and solar would work together across a normal day.

**Problem 7 [Standard]** An on-grid home's system produces 5.0 kWh on a sunny weekday when nobody is home for most of the day, so the load is only 1.5 kWh. Using the energy balance from this chapter, find the self-used solar energy, the import, and the export.

**Problem 8 [Standard]** A health center wants at least 6 hours of hybrid battery backup for its critical loads (Chapter 10), which average 0.5 kW. How much usable battery energy must the system reserve for backup?

**Problem 9 [Standard]** List two advantages and two disadvantages of a hybrid system compared with a plain off-grid system, for a home that DOES have a grid connection.

**Problem 10 [Standard]** A solar streetlight on a remote road has no grid connection nearby. It must light up automatically for about 10 hours every night, all year, including cloudy weeks. Which system type fits, and what part of the design needs the most careful attention so the light never goes dark?

**Problem 11 [Challenge]** A remote village has no grid connection at all. A diesel generator currently runs the village mill for a few hours each evening. Decide the best system type for each of these, with a reason: (a) individual homes, needed mainly for lighting and phone charging; (b) the village mill, which needs a large, steady amount of power only in the evening.

**Problem 12 [Challenge]** A family's daily grid outage is 8 hours, usually in the evening. Their critical loads average 0.4 kW. Their installer offers two battery options: Option A stores 2.4 kWh usable, Option B stores 4.0 kWh usable. (a) Find the backup hours for each option. (b) Which option comfortably covers the daily outage? (c) Why might the family still choose to keep their generator connection, even with the better battery option?

**Problem 13 [Challenge]** A university building has a reliable grid connection (rare outages) and wants to demonstrate solar technology to students while cutting its electricity bill. The budget is limited, and the maintenance team does not want to deal with battery upkeep. Which system type fits best, and what is the main energy-flow risk they must accept?

**Problem 14 [Challenge]** Before installing hybrid solar, a family ran their neighborhood generator 8 hours a day, at a subscription cost of 50,000 IQD per month (example numbers, as in Chapter 1). After installing a hybrid system, solar and battery cover all but 2 hours of generator use each day. Assuming the generator's cost scales roughly with the hours used: (a) What is the new daily generator running time? (b) What is the new monthly generator cost? (c) How much do they save per month on the generator alone?

## CHAPTER TWELVE

# Off-Grid System Design

*The complete sizing method — where every earlier chapter comes together*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain the complete off-grid design chain, from daily energy demand to cables, and describe why the order of the steps matters.
- Calculate the minimum solar array size from a daily energy need, peak sun hours, and a performance ratio, and explain why off-grid systems are sized for the worst month, not the average.
- Calculate a battery bank's required capacity from daily energy use, days of autonomy, depth of discharge, and system voltage.
- Size a charge controller and an inverter together for one system, applying both the short-circuit-current rule and a battery-side power check.
- Build a system's performance ratio from individual loss factors, and estimate a system's daily and monthly energy production.
- Design a complete small off-grid home system from start to finish, keeping every number consistent from the load audit to the final component list.

## 12.1 The Complete Design Chain

You have now studied energy, sunlight, panels, batteries, controllers, and inverters, one chapter at a time. This chapter puts them all together. Here you will learn the complete method installers and engineers use to design a real, working, **off-grid** solar system — a system with no help at all from the public grid. Every later design chapter in this book (Chapter 13 for on-grid and hybrid, Chapter 14 for water pumping) builds on the method you learn here.

### WORD TO KNOW

**Off-grid system** — A solar system that is not connected to the national grid at all. It must produce and store all the energy it needs itself, usually with a battery. Chapter 11 compares this with other system types.

An off-grid system cannot borrow power from anywhere. If it is sized too small, lights go dark and the refrigerator stops — there is no backup. This is why off-grid design must be careful, complete, and done in the right order.

### WORD TO KNOW

**Design chain** — The ordered series of calculations that turns a home's daily energy need into a complete, correctly sized solar system: array, battery bank, charge controller, inverter, and cables — each step built on the step before it.

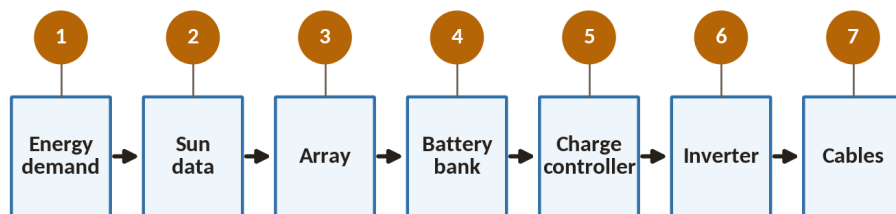


Picture the design chain as seven linked steps. Each step answers one question, and each step needs the answer from the step before it. Skip a step, or do them in the wrong order, and the whole chain can break.

### The complete off-grid design chain

| Step                   | Key question                                                     | First taught in       | In this chapter                           |
|------------------------|------------------------------------------------------------------|-----------------------|-------------------------------------------|
| 1. Energy demand       | How much energy does the home need each day?                     | Chapter 1, Chapter 10 | Recalled in Lesson 6                      |
| 2. Sun data            | How many peak sun hours does the site get, in its hardest month? | Chapter 3, Chapter 21 | Lesson 2                                  |
| 3. Array               | How big must the solar array be?                                 | Chapters 4–5          | Lesson 2                                  |
| 4. Battery bank        | How much storage, and at what system voltage?                    | Chapter 6             | Lesson 3                                  |
| 5. Charge controller   | What size and type of controller?                                | Chapter 7             | Lesson 4                                  |
| 6. Inverter            | What size and type of inverter?                                  | Chapter 8             | Lesson 4                                  |
| 7. Cables & protection | What cable size, fuses, and breakers?                            | Chapter 9             | Introduced here; full method in Chapter 9 |

### The off-grid design chain (7 steps)



*Each step needs the answer from the step before it.*

*The complete off-grid design chain: energy demand → sun data → array → battery bank → charge controller → inverter → cables and protection.*

Two loss ideas run alongside the whole chain, not as separate steps but as corrections you apply along the way: **system losses**, which reduce the array's usable output (Lessons 2 and 5), and **design margins**, which add safe extra size at several steps. You have already met small versions of both — the 1.25 safety factor for controllers (Chapter 7), and the 20–25% margin for inverters (Chapter 8).

#### WORD TO KNOW

**Design margin** — Extra size added to a component beyond the bare minimum calculation, to leave room for cloudy years, future loads, or ageing equipment.

Why does the ORDER of the chain matter so much? Because later steps depend on choices made earlier. The clearest example is **system voltage** — the DC voltage shared by the battery bank, the controller's output, and the inverter's input. If you choose the battery bank's voltage in Lesson 3 and the inverter's voltage in Lesson 4 without talking to each other, they may not match, and nothing will work safely.

#### COMMON MISTAKE

**X Wrong:** Buy an inverter because it looks powerful, then a battery bank that fits the budget, then panels left over from another project — and hope they all fit together.

**✓ Right:** Walk the whole chain in order, once, on paper: demand → sun data → array → battery → controller → inverter → cables. Every component's size and voltage should come FROM this chain, not from guesswork or what happened to be on sale.

#### CASE STUDY — ONE BOX AT A TIME: A SHOP IN DUHOK · DUHOK, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

A shop owner in Duhok wanted backup power and started buying equipment as money became available. First, an impressive 3000 W inverter, bought on a good discount. A year later, a modest battery bank he could afford — two 12 V batteries, giving only 24 V, when the inverter needed 48 V DC to work well at that power. He also already owned four old 12 V-nominal panels from a small lighting project, the wrong voltage class for the MPPT controller he then had to buy to make anything match. In the end, he spent money three separate times and still needed an electrician to redesign the whole system from scratch. Designing the full chain FIRST, on paper, before buying anything, would have cost nothing extra and saved him real money.

#### SAFETY

Never connect components with mismatched DC voltages, even if the wiring seems to 'fit.' A 24 V battery bank feeding a 48 V-rated inverter input, or a 12 V-nominal array wired into a system built for 48 V, can damage equipment instantly and create a fire risk. Decide the system voltage once, early in the chain, and use that same voltage at every DC step.

#### ACTIVITY (CLASSROOM) — TRACE THE CHAIN FOR YOUR OWN HOME

1. Do not calculate anything yet — just plan the questions.
2. For your own home (or the example home from Chapter 1), write down the seven steps of the design chain as a list.
3. Next to each step, write ONE question you would still need to answer before you could size that part (for example: 'Step 2 — what is my city's peak sun hours in the worst month?').
4. Compare your list with a classmate's. Did you both put the steps in the same order? Discuss why the order matters.

*You need: Paper and pen*

By the end of this chapter, you will size a complete system for one real kind of home: a small household in the Kurdistan Region that needs about 2.6 kWh of energy a day. Lesson 6 walks through every step of its design, start to finish, with every number checked. Lessons 2 to 5 first teach you each link of the chain on its own.

- App tool: Recall Step 1: check a load audit with the Load Audit calculator
- App simulation: See the whole design chain working together in the System Sizing simulation

## 12.2 Sizing the Array

Step 1 of the design chain gives you one number: the home's daily energy need, in kWh (Chapter 1 and Chapter 10 show how to find it from a load audit). Step 2 gives you a second number: how much sun the site gets. This lesson combines the two into Step 3 — the size of the solar array.

### WORD TO KNOW

**Peak sun hour** — A simple way to measure how much sunlight a place gets in a day, as if the sun shone at one fixed strong brightness (1000 W/m<sup>2</sup>) for that many hours, then stopped completely. More peak sun hours means more solar energy from the same size of array. Written PSH.

Real sunlight is weak at sunrise, strong at midday, and weak again at sunset — a curve, not a flat line. Peak sun hours squash that whole curve into one easy number. A place with 5.0 peak sun hours gets exactly as much total solar energy in a day as if the sun shone at its strongest, standard brightness for 5.0 hours and was completely dark the rest of the time. Chapter 3 explains where this number comes from in full.

There is one more correction before we can size anything. A solar array almost never produces its full rated (nameplate) power in real conditions — heat, dust, wiring, and equipment losses all take a share. This chapter uses a single number to hold all of these real losses together.

### WORD TO KNOW

**Performance ratio** — A single number that shows how much of a solar array's ideal output you actually get, once real losses like heat, dust, wiring, and equipment inefficiency are included. A performance ratio of 0.80 means the system delivers about 80% of its ideal output. Written PR.

A typical example performance ratio for a reasonably well-built system is about 0.75 to 0.85. Lesson 5 opens PR up and shows exactly what is inside it. For now, treat it as one dependable correction number.

### EQUATION: DAILY ENERGY FROM AN ARRAY

$$E_{\text{array}} = P_{\text{array}} \times \text{PSH} \times \text{PR}$$

*In words: Daily array energy = Array power × peak sun hours × performance ratio*

| Symbol  | Meaning                                                          | Unit                             |
|---------|------------------------------------------------------------------|----------------------------------|
| E_array | energy produced by the array in one day                          | kilowatt-hours per day (kWh/day) |
| P_array | the array's rated power (nameplate, at standard test conditions) | kilowatts (kWp)                  |
| PSH     | peak sun hours for that location and period                      | hours per day (h/day)            |
| PR      | performance ratio                                                | ratio, no unit (0 to 1)          |

*We write a solar array's rated power as kWp (kilowatt-peak) — the same unit as kW, but as a reminder that this is the panel's rating under Standard Test Conditions (Chapter 4), not what it produces every hour.*

### WORKED EXAMPLE — CHECKING THE EQUATION: A SMALL EXISTING ARRAY

A 2.0 kWp array sits at a site with 5.0 peak sun hours today, and its performance ratio is 0.80. How much

energy does it produce today?

1. Write the equation:  $E_{\text{array}} = P_{\text{array}} \times \text{PSH} \times \text{PR}$
2. Put in the numbers:  $E_{\text{array}} = 2.0 \text{ kW} \times 5.0 \text{ h} \times 0.80$
3. Calculate:  $E_{\text{array}} = 8.0 \text{ kWh}$

**Answer: 8.0 kWh for the day**

That equation tells us what an array ALREADY built will produce. But design works the other way around: we know the energy the home NEEDS, and we must find the array size that can deliver it. Simple algebra flips the equation around.

#### EQUATION: SIZING THE ARRAY

$$P_{\text{array}} = \frac{E_{\text{daily}}}{\text{PSH} \times \text{PR}}$$

*In words: Minimum array power = Daily energy need ÷ (Peak sun hours × Performance ratio)*

| Symbol  | Meaning                                           | Unit                    |
|---------|---------------------------------------------------|-------------------------|
| P_array | the minimum array power the design needs          | kilowatts (kWp)         |
| E_daily | the home's daily energy need, from the load audit | kilowatt-hours (kWh)    |
| PSH     | peak sun hours for the design period              | hours per day (h/day)   |
| PR      | performance ratio                                 | ratio, no unit (0 to 1) |

*This is the same equation as above, just rearranged to solve for P\_array. Always round the result UP to a real, buildable number of panels — never down.*

#### WORKED EXAMPLE — SIZING AN ARRAY FROM A LOAD AUDIT

A home's load audit shows it needs 4.0 kWh (4000 Wh) of energy per day. The site gets 4.5 peak sun hours in the design month. Using an example performance ratio of 0.80, find the minimum array size, and choose a practical number of panels.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH} \times \text{PR})$
2. Multiply the bottom first:  $\text{PSH} \times \text{PR} = 4.5 \times 0.80 = 3.6$
3. Divide:  $P_{\text{array}} = 4.0 \text{ kWh} \div 3.6 \text{ h} \approx 1.11 \text{ kWp}$  (1111 W)
4. Choose real panels: with 380 W panels,  $1111 \div 380 \approx 2.92 \rightarrow$  round up to 3 panels = 1140 W

**Answer: At least 1.11 kWp needed; three 380 W panels (1140 W) comfortably cover it**

One choice changes this answer more than any other: WHICH peak sun hours do you use? A year has easy months and hard months. Using the wrong one is one of the most common mistakes in off-grid design.

#### WORD TO KNOW

**Design month** — The month used to size an off-grid array — usually the month with the fewest peak sun hours (often winter here) — so the system still meets the load even in the hardest month of the year.

Why the worst month, and not the average? An off-grid home has no backup grid. If a home's load stays roughly the same all year, but the array is sized only for the sunny annual average, the system will fall short of the load every single winter — for months at a time, not just for a few cloudy days. Sizing for the design month protects the whole year.

As an example, Erbil's illustrative annual average peak sun hours are about 5.0–5.5 h/day (midpoint 5.3 h/day). In the cloudier winter months (December–January), this drops to about 2.7–3.2 h/day (midpoint 3.0 h/day). Chapter 21 studies the whole region's sun data in detail; here we simply use these example numbers to practise the method.

#### WORKED EXAMPLE — WORST MONTH VS. AVERAGE MONTH, ERBIL EXAMPLE

Using the SAME home from the last example (4.0 kWh/day, performance ratio 0.80), compare the array size needed if the design uses Erbil's example annual average peak sun hours (5.3 h/day) instead of its example winter peak sun hours (3.0 h/day).

1. Annual average:  $P_{\text{array}} = 4.0 \div (5.3 \times 0.80) = 4.0 \div 4.24 \approx 0.94 \text{ kWp (943 W)}$
2. Winter (design month):  $P_{\text{array}} = 4.0 \div (3.0 \times 0.80) = 4.0 \div 2.4 \approx 1.67 \text{ kWp (1667 W)}$
3. Compare:  $1667 - 943 = 724 \text{ W}$  more is needed for winter — about 77% bigger

**Answer: Sizing for the annual average needs about 943 W. Sizing for the design month (winter) needs about 1667 W — roughly 77% more panels.**

#### COMMON MISTAKE

**✗ Wrong:** Size an off-grid array using the site's annual average peak sun hours, because it looks like a fair, typical number.

**✓ Right:** Size an off-grid array using the design month — usually the month with the fewest peak sun hours — so the system still meets the load in winter, not only on the year's best days. (A system with a generator backup, covered in Chapter 13, can sometimes accept a smaller array and let the generator cover the worst weeks instead.)

#### Where the two numbers in this equation come from

| Number                                   | Comes from                                                | Typical example size                           |
|------------------------------------------|-----------------------------------------------------------|------------------------------------------------|
| Daily energy need ( $E_{\text{daily}}$ ) | The load audit (Chapter 1, Chapter 10)                    | A small home: roughly 2–5 kWh/day              |
| Peak sun hours (PSH)                     | The site's sun data, design month (Chapter 3, Chapter 21) | Kurdistan Region winter: roughly 2.5–3.5 h/day |
| Performance ratio (PR)                   | Built from loss factors (Lesson 5)                        | Typical example range: 0.75–0.85               |

#### ACTIVITY (CLASSROOM) — SIZE AN ARRAY TWO WAYS

1. Take a daily energy value from your own load audit, or use the 3.3 kWh/day example home from Chapter 1.
2. Find or estimate two peak sun hour values for your area: an annual average, and a design-month (worst-month) value.
3. Using a performance ratio of 0.80, calculate the minimum array size both ways.
4. Discuss: if you only had money for the smaller array, what would you have to accept or change?

*You need: Calculator or phone, Your load audit or the example values*

- App tool: Try it: look up peak sun hours for different cities and months
- App tool: Check your array sizing with the PV Array Sizing calculator

## 12.3 Sizing the Battery Bank

Step 4 of the design chain is the battery bank — the store of energy that keeps an off-grid home running at night, on cloudy days, and through short breaks in production. Before we size it, we must make one decision that affects every later step: the system voltage.

### WORD TO KNOW

**System voltage** — The DC voltage that the battery bank, the charge controller's output, and the inverter's input all share in one system — commonly 12 V, 24 V, or 48 V. Written  $V_{sys}$ .

Choose the system voltage once, based on the system's overall size, and then use that SAME voltage for the battery bank, the controller's battery-side connection, and the inverter's DC input. This is exactly the mistake warned about in Lesson 1 — components with different voltages cannot simply be wired together.

### Choosing a system voltage (general guide)

| System size (array or total load) | Common system voltage | Why                                                                                 |
|-----------------------------------|-----------------------|-------------------------------------------------------------------------------------|
| Small — under about 1 kW          | 12 V                  | Simple and common for very small home kits and lighting systems                     |
| Medium — about 1–3 kW             | 24 V                  | Keeps current, and cable size, reasonable as power grows                            |
| Larger — over about 3 kW          | 48 V                  | The same power moves at lower current, allowing thinner, cheaper cables (Chapter 9) |

This is a general guide, not a fixed rule — treat it as a starting point. A design with a higher-voltage array (common with MPPT) or a large motor (like a water pump) often moves to the next voltage up sooner, to keep currents low. Lesson 6 explains its own voltage choice for exactly this reason.

### WORD TO KNOW

**Battery bank** — Two or more batteries connected together, in series, parallel, or both, to give the voltage and capacity a system design needs.

Chapter 6 already gave you the equation for sizing a battery bank. It now becomes one link in this chapter's chain: its INPUT, the daily energy need, comes from Step 1 of the chain, and its OUTPUT must be built at the SAME system voltage chosen above.

### EQUATION: BATTERY BANK SIZING (RECALL CHAPTER 6)

$$C_{\text{bank}} = \frac{E_{\text{daily}} \times N_{\text{auto}}}{V_{\text{sys}} \times DoD}$$

*In words: Battery bank capacity = (Daily energy need × Days of autonomy) ÷ (System voltage × Depth of discharge)*

| Symbol | Meaning | Unit |
|--------|---------|------|
|--------|---------|------|

|         |                                                                            |                                  |
|---------|----------------------------------------------------------------------------|----------------------------------|
| C_bank  | required battery bank capacity                                             | ampere-hours (Ah)                |
| E_daily | energy the battery bank must supply each day                               | watt-hours (Wh)                  |
| N_auto  | days of autonomy — days with little or no sun the battery must cover alone | days                             |
| V_sys   | system voltage, decided above                                              | volts (V)                        |
| DoD     | maximum allowed depth of discharge for the battery type chosen (Chapter 6) | fraction from 0 to 1 (0.5 = 50%) |

*Always round the answer UP to a real number of whole batteries. Rounding down leaves the bank undersized exactly when it is needed most.*

### WORD TO KNOW

**Days of autonomy** — The number of days a battery bank must supply a home's full energy need by itself, with little or no help from the sun — for example, during a run of cloudy days.

### WORKED EXAMPLE — SIZING A BATTERY BANK FOR A REMOTE CABIN

A cabin needs 5000 Wh (5 kWh) of energy per day from its battery bank. The design uses 3 days of autonomy (a remote site — cloudy runs are hard to wait out), a 48 V system, and AGM batteries with a maximum DoD of 60% (0.6). Find the required bank capacity, and the number of 12 V, 200 Ah batteries needed.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (5000 \text{ Wh} \times 3) \div (48 \text{ V} \times 0.6)$
3. Calculate the top:  $5000 \times 3 = 15,000 \text{ Wh}$
4. Calculate the bottom:  $48 \times 0.6 = 28.8$
5. Divide:  $C_{\text{bank}} = 15,000 \div 28.8 \approx 520.8 \text{ Ah}$
6. Batteries in series for 48 V:  $48 \div 12 = 4$  batteries per string
7. Strings in parallel for capacity:  $520.8 \div 200 \approx 2.6 \rightarrow$  round up to 3 strings
8. Total batteries: 4 in series  $\times$  3 strings = 12 batteries (a '4S3P' bank), giving an actual 600 Ah

**Answer: At least 520.8 Ah at 48 V; in practice, 12 batteries (4 series  $\times$  3 parallel) of 12 V, 200 Ah, giving 48 V, 600 Ah**

### COMMON MISTAKE

**✗ Wrong:** Choose the battery bank's voltage on its own, based on what batteries are cheapest that week, without checking what the controller and inverter need.

**✓ Right:** Decide the system voltage ONCE, early in the design (see the table above), then build the battery bank, the controller's output, and the inverter's input all to that same voltage.

How many days of autonomy should a real design use? There is no single correct answer — it is a trade-off between reliability and cost. More autonomy means a bigger, more expensive battery bank, but a system that can survive longer without sun.

**Typical example autonomy choices by application**

| Application                                                     | Typical example autonomy | Why                                                                        |
|-----------------------------------------------------------------|--------------------------|----------------------------------------------------------------------------|
| Ordinary home with some other backup nearby (grid or generator) | 1–2 days                 | Short cloudy runs are the main risk; another backup exists for longer gaps |
| Remote home with no other backup at all                         | 2–3 days                 | Nothing else to fall back on during a cloudy week                          |
| Critical site — health center, telecom relay                    | 3–5 days or more         | Losing power is costly or dangerous; reliability matters more than cost    |

#### CASE STUDY — TWO HOMES, TWO AUTONOMY CHOICES • KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

Two families each design a small off-grid solar system with a similar daily energy need. The first lives in a town, with a neighborhood generator subscription as a backup during long cloudy runs. They choose 1 day of autonomy — a smaller, cheaper battery bank, accepting that the generator will occasionally cover a gap. The second family lives on a remote farm, an hour from the nearest generator connection. They choose 3 days of autonomy, paying for a bigger battery bank, because for them a few cloudy days with no other option at all is a much more serious problem than the extra cost. Both choices are reasonable engineering — the right autonomy depends on what backup already exists, not on a fixed rule.

#### ACTIVITY (CLASSROOM) — CHOOSE AUTONOMY AND SEE THE EFFECT

1. Use the cabin's daily energy need from the worked example above (5000 Wh) and its 48 V system.
2. Calculate the required battery bank capacity for 1 day of autonomy, then for 3 days, keeping DoD at 0.6.
3. Compare the two answers. How many more (or fewer) 200 Ah batteries does each design need?
4. Discuss: which choice would you recommend for a family with no other backup power at all?

*You need: Calculator or phone*

► *App tool: Check your battery bank sizing with the calculator*

## 12.4 Choosing the Controller and Inverter

Steps 5 and 6 of the design chain are the charge controller and the inverter. Chapters 7 and 8 taught you how to size each one on its own. This lesson applies both sets of rules TOGETHER, to one system, and adds one important check that matters most once everything is combined.

Recall Chapter 7's rule for a controller's current rating: it must safely handle the array's worst-case current, with a safety margin.

#### EQUATION: CHARGE CONTROLLER CURRENT RATING (RECALL CHAPTER 7)

$$I_{\text{controller}} \geq I_{\text{SC}} \times 1.25$$

*In words: Controller current rating ≥ Array short-circuit current × 1.25*

| Symbol                  | Meaning                                                                                                               | Unit        |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------|-------------|
| $I_{\text{controller}}$ | the minimum current rating the charge controller must have                                                            | amperes (A) |
| $I_{\text{SC}}$         | the total short-circuit current of the whole array, as wired (add $I_{\text{sc}}$ for every string wired in parallel) | amperes (A) |

*Round the answer UP to the next standard controller size (commonly 10, 20, 30, 40, 50, 60, 80, 100 A). Also check that the array's open-circuit voltage ( $V_{\text{oc}}$ ) stays below the controller's maximum PV input rating (Chapter 7).*



This rule protects the controller's array-side (PV input) connection. For an MPPT controller, one more check protects the BATTERY-side connection — and it is easy to forget. Chapter 7 explained that an MPPT controller's DC-DC converter turns extra array voltage into extra battery-side current. This means the current reaching the battery can be noticeably HIGHER than the array's own current, especially when the array's operating voltage is much higher than the battery voltage.

We can estimate this battery-side current using power conservation: at the array's rated power, roughly the same power (minus a small conversion loss) must flow out to the battery.

**A complete controller check has two parts:** (1) the short-circuit current rule above, which protects the array-side connection; and (2) a power check — array power ÷ system voltage — which estimates the battery-side current. Choose a controller whose rated current covers WHICHEVER of the two is larger.

#### WORKED EXAMPLE — SIZING A CONTROLLER: TWO CHECKS, ONE SYSTEM

An off-grid design uses six 200 W panels (each  $V_{oc} = 30$  V,  $I_{sc} = 8.5$  A,  $V_{mp} = 25$  V,  $I_{mp} = 8$  A), wired as two panels in series and three such strings in parallel (2S3P), feeding a 48 V battery bank through an MPPT controller. Find the minimum controller current using both checks.

1. String voltage and current (2 in series):  $V_{oc} = 2 \times 30 = 60$  V;  $I_{sc} = 8.5$  A (series does not add current)
2. Array current (3 strings in parallel):  $I_{SC}(\text{array}) = 3 \times 8.5 = 25.5$  A
3. Array  $V_{mp}$  and  $I_{mp}$ :  $V_{mp} = 2 \times 25 = 50$  V;  $I_{mp} = 3 \times 8 = 24$  A; array power  $P = 50 \times 24 = 1200$  W (check:  $6 \times 200$  W = 1200 W ✓)
4. Check 1 — short-circuit current rule:  $I_{\text{controller}} \geq 25.5 \times 1.25 = 31.9$  A → round up to 40 A
5. Check 2 — power check at 48 V:  $I_{\text{battery}} \approx 1200 \text{ W} \div 48 \text{ V} = 25.0$  A → round up to 30 A
6. Compare the two checks: 40 A (Check 1) is larger than 30 A (Check 2), so Check 1 governs here

**Answer: Choose a 40 A MPPT controller, rated for at least 60 V PV input (choose a 100 V-rated model for a safe cold-weather margin).**

#### COMMON MISTAKE

**X Wrong:** Size an MPPT controller using only the short-circuit current rule, and assume that number is always enough.

**✓ Right:** Also estimate the battery-side current with a simple power check (array power ÷ system voltage). When the array's operating voltage is much higher than the battery voltage, this second check can need a BIGGER controller than the current rule alone suggests — Lesson 6 shows a case exactly like this.

Now the inverter — Step 6. Chapter 8 gave you a four-step method: total the continuous loads, add a safety margin, find the surge power of the largest motor, and choose an inverter that covers both numbers.

#### EQUATION: MINIMUM CONTINUOUS INVERTER RATING (RECALL CHAPTER 8)

$$P_{\text{cont}} \geq P_{\text{total}} \times (1 + m)$$

*In words: Minimum continuous rating ≥ Total running watts × (1 + margin)*

| Symbol             | Meaning                                                | Unit      |
|--------------------|--------------------------------------------------------|-----------|
| $P_{\text{cont}}$  | minimum continuous inverter rating                     | watts (W) |
| $P_{\text{total}}$ | total running watts of all loads used at the same time | watts (W) |

|   |                                    |                  |
|---|------------------------------------|------------------|
| m | safety margin, typically 0.20–0.25 | decimal fraction |
|---|------------------------------------|------------------|

Round the result UP to a real, commercially available inverter size.

#### EQUATION: MINIMUM SURGE INVERTER RATING (RECALL CHAPTER 8)

$$P_{\text{surge}} \geq P_{\text{other}} + (P_{\text{motor}} \times k)$$

In words: Minimum surge rating ≥ Other running watts + (largest motor's running watts × surge factor)

| Symbol  | Meaning                                                       | Unit                |
|---------|---------------------------------------------------------------|---------------------|
| P_surge | minimum surge (peak) inverter rating                          | watts (W)           |
| P_other | running watts of other loads already on when the motor starts | watts (W)           |
| P_motor | running watts of the largest motor                            | watts (W)           |
| k       | starting surge factor for that motor (Chapter 8)              | multiplier, no unit |

Choose an inverter whose continuous AND surge ratings both cover their required minimum.

#### WORKED EXAMPLE — SIZING THE INVERTER FOR THE SAME HOME

The home from the controller example runs these loads together in the evening: five LED lamps (10 W each), a television (90 W), a refrigerator (110 W running, starting surge about 4×), a fan (70 W), and a router (60 W). Size the inverter.

1. Continuous loads: lamps  $5 \times 10 = 50$  W; TV 90 W; fridge 110 W; fan 70 W; router 60 W
2. Total continuous:  $50 + 90 + 110 + 70 + 60 = 380$  W
3. Add a 25% margin:  $380 \times 1.25 = 475$  W → round up to a 500 W continuous inverter
4. Fridge surge:  $110 \times 4 = 440$  W
5. Other loads already on when the fridge starts:  $380 - 110 = 270$  W
6. Minimum surge rating:  $270 + 440 = 710$  W

**Answer: Minimum continuous ≈ 475 W, minimum surge ≈ 710 W. A common commercial size of 500 W continuous / 1000 W surge covers both with room to spare.**

One last check ties the whole lesson together: the controller's battery-side output, the battery bank's voltage (Lesson 3), and the inverter's DC input must ALL be the same system voltage — 48 V in this example. A controller, battery, and inverter can each be perfectly well sized on their own and still fail as a system if their voltages do not match.

#### SAFETY

Connecting an inverter to the wrong DC voltage — for example, a 24 V-rated inverter on a 48 V battery bank, or the other way around — can destroy the inverter instantly, damage the batteries, and create a fire risk. Always check and match every DC voltage in the system before connecting anything.

#### COMMON MISTAKE

**X Wrong:** Size the controller and the inverter as two separate little projects, each using whatever system voltage seems convenient at the time.

✓ **Right:** Use the ONE system voltage decided in Lesson 3 for the battery bank, the controller's battery-side connection, and the inverter's DC input, every time.

► App tool: Check your controller sizing with the calculator

► App tool: Check your inverter sizing with the calculator

► App tool: Explore series and parallel wiring options with the String Configuration calculator

## 12.5 System Losses and Performance Ratio

Lesson 2 used the performance ratio (PR) as one dependable number, in the range 0.75–0.85. This lesson opens PR up and shows exactly what is inside it — the real losses between a panel's ideal rating and the power that actually reaches a lamp, a fridge, or a phone charger.

### WORD TO KNOW

**Derating factor** — A number less than 1 that reduces an ideal value to a more realistic one, to account for one specific real-world loss, such as heat or dust. A performance ratio is built by multiplying several derating factors together.

Each stage of the system — the panel itself, the wiring, the controller, the inverter — loses a little power. Each loss is written as a derating factor: a number a little less than 1. A 10% loss is a derating factor of 0.90; a 3% loss is 0.97. To combine several losses, you MULTIPLY their factors together — never add the percentages.

### EQUATION: PERFORMANCE RATIO FROM INDIVIDUAL LOSSES

$$PR = f_{\text{temp}} \times f_{\text{dust}} \times f_{\text{wire}} \times f_{\text{ctrl}} \times f_{\text{inv}}$$

*In words: Performance ratio = temperature factor × dust factor × wiring factor × controller factor × inverter factor*

| Symbol | Meaning                                                     | Unit                    |
|--------|-------------------------------------------------------------|-------------------------|
| PR     | overall performance ratio                                   | ratio, no unit (0 to 1) |
| f_temp | derating factor for heat (panels lose power when hot)       | ratio, no unit (0 to 1) |
| f_dust | derating factor for dust and soiling on the panels          | ratio, no unit (0 to 1) |
| f_wire | derating factor for cable (wiring) resistance losses        | ratio, no unit (0 to 1) |
| f_ctrl | derating factor for the charge controller's conversion loss | ratio, no unit (0 to 1) |
| f_inv  | derating factor for the inverter's conversion loss          | ratio, no unit (0 to 1) |

*A real design might list more or fewer categories than this. Always multiply every factor together — each one is a little less than 1, so the more loss categories you include, the more the combined total drops.*

### Typical example loss factors for a well-maintained system (illustrative — always check real datasheets and measurements)

| Loss source        | Typical example loss | Derating factor | Where explained                                                  |
|--------------------|----------------------|-----------------|------------------------------------------------------------------|
| Heat (temperature) | 10%                  | 0.90            | Hot regional summers reduce panel output (Chapter 4, Chapter 21) |
| Dust and soiling   | 5%                   | 0.95            | Dust settles on panels between cleanings (Chapter                |

| Loss source                  | Typical example loss | Derating factor | Where explained                                                  |
|------------------------------|----------------------|-----------------|------------------------------------------------------------------|
|                              |                      |                 | 5, Chapter 21)                                                   |
| Wiring (cable) resistance    | 3%                   | 0.97            | Resistance in DC and AC cables (Chapter 9)                       |
| Charge controller conversion | 3%                   | 0.97            | A small loss inside a well-matched MPPT converter (Chapter 7)    |
| Inverter conversion          | 6%                   | 0.94            | DC-to-AC conversion loss at a typical operating load (Chapter 8) |

#### WORKED EXAMPLE — BUILDING PERFORMANCE RATIO STEP BY STEP (THE LOSS WATERFALL)

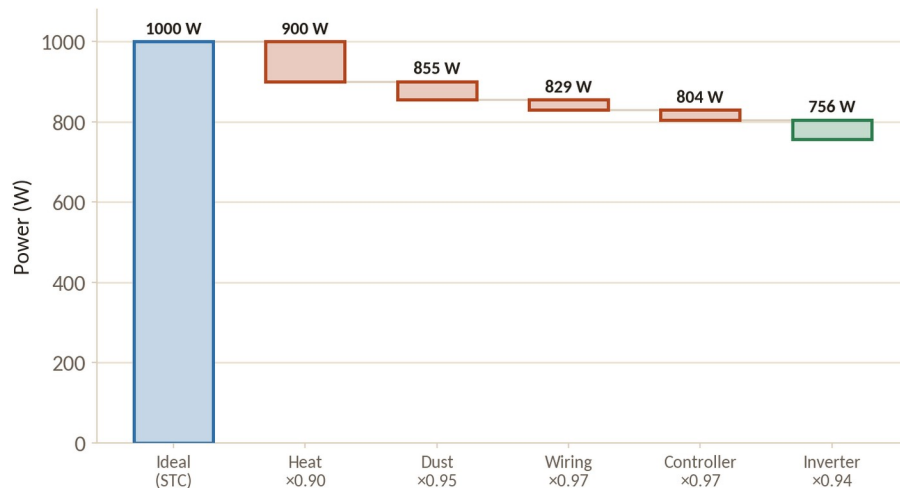
Start with 1000 W of ideal array output (at Standard Test Conditions) and apply the five example derating factors from the table above, one at a time. Find the final power delivered, and the overall performance ratio.

1. Start: 1000 W
2. After heat ( $\times 0.90$ ):  $1000 \times 0.90 = 900$  W
3. After dust ( $\times 0.95$ ):  $900 \times 0.95 = 855$  W
4. After wiring ( $\times 0.97$ ):  $855 \times 0.97 = 829.35$  W
5. After controller ( $\times 0.97$ ):  $829.35 \times 0.97 \approx 804.5$  W
6. After inverter ( $\times 0.94$ ):  $804.5 \times 0.94 \approx 756.2$  W
7. Overall PR:  $756.2 \div 1000 \approx 0.76$  (76%)

**Answer: About 756 W finally delivered from an ideal 1000 W — an overall performance ratio of about 0.76**

#### WORD TO KNOW

**Energy-loss waterfall** — A chart or table that shows power or energy being reduced step by step, from the panel's ideal rating down to what actually reaches the load, so you can see exactly where each loss happens.



*An energy-loss waterfall: 1000 W of ideal array output is reduced step by step by heat, dust, wiring, controller, and inverter losses, ending at about 756 W delivered.*

This example gives  $PR \approx 0.76$  — close to the lower end of the 0.75–0.85 range used earlier in this chapter. A cleaner site, a cooler mounting position, or a more efficient inverter could push PR closer to 0.85. For the rest of this book's worked examples, including Lesson 6, we use a round example performance ratio of **0.80** — a reasonable, middle-of-the-range planning figure when a full loss breakdown has not been done yet.

One nuance worth remembering: the controller factor in the table assumes a well-matched MPPT controller. Chapter 7 showed that a PWM controller loses power differently — from voltage mismatch between the array and the battery, not from conversion. A well-matched PWM system can lose very little extra power; a poorly matched one can lose 20% or more. Always think about which controller type you are using before reusing this table's exact numbers.

#### COMMON MISTAKE

**X Wrong:** Assume a panel's rated wattage (say, 400 W) is close to what it produces on a real roof, most of the time.

**✓ Right:** A real array's typical output is closer to  $P_{\text{array}} \times PSH \times PR$ . Once heat, dust, wiring, and equipment losses are included, real output is routinely 15–25% below what the nameplate alone suggests.

Design margins (Lesson 1) are a separate idea from PR, and both matter. PR corrects for losses that happen ALL the time, in normal operation. A design margin is extra size added on top, for things that are harder to predict — an unusually cloudy year, a home adding a few more lamps later, or equipment losing a little capacity as it ages.

#### ACTIVITY (CLASSROOM) — BUILD YOUR OWN PERFORMANCE RATIO

1. Choose your own example derating factors for temperature, dust, wiring, controller, and inverter — each a sensible number between about 0.90 and 0.99.
2. Multiply all five together to find your own example PR.
3. Compare your PR with this lesson's example (0.76) and with the book's rounded planning figure (0.80). Is yours higher or lower, and why?
4. Using your PR, a 2.0 kWp array, and 5.0 peak sun hours, calculate the daily energy this array would produce.

You need: Calculator or phone

- App tool: Try it: build a performance ratio from your own loss factors
- App tool: Estimate daily and monthly energy production with the calculator
- App simulation: See it: watch how each loss factor changes the final output

## 12.6 A Complete Worked Design, Start to Finish

This lesson designs one complete off-grid system, start to finish, for a small household in the Kurdistan Region with no connection to the national grid. Every step uses the methods from Lessons 2 to 5, in the order set out in Lesson 1. Every number below is carried forward exactly from the step before it — check the arithmetic yourself as you read.

**Step 1 — Energy demand.** The household's appliances, and the hours they run on a normal day, are listed below (Chapter 1, Chapter 10 method).

### Step 1: the household's daily loads

| Appliance                             | Power (W)           | Hours per day | Energy (Wh) |
|---------------------------------------|---------------------|---------------|-------------|
| 6 LED lamps                           | $6 \times 10 = 60$  | 5             | 300         |
| Television                            | 80                  | 4             | 320         |
| Refrigerator (effective run)          | 130                 | 8             | 1040        |
| 2 ceiling fans                        | $2 \times 60 = 120$ | 6             | 720         |
| 3 phone/device chargers               | $3 \times 10 = 30$  | 4             | 120         |
| Water pump (fills the household tank) | 200                 | 0.5           | 100         |
| Total                                 | —                   | —             | 2600        |

### WORKED EXAMPLE — STEP 1: TOTAL DAILY ENERGY NEED

Using the table above, find the household's total daily energy need, in Wh and kWh.

1. Add every appliance's energy:  $300 + 320 + 1040 + 720 + 120 + 100 = 2600$  Wh
2. Convert to kWh:  $2600 \div 1000 = 2.6$  kWh

**Answer:  $E_{\text{daily}} = 2600$  Wh = 2.6 kWh per day**

**Step 2 — Sun data.** We use an example Kurdistan Region city, Erbil. This home has no other backup power at all, so — following Lesson 2's rule — the array must be sized for the design month, not the sunny annual average. Erbil's example winter (December–January) peak sun hours are about 2.7–3.2 h/day; we use the rounded midpoint, PSH = 3.0 h/day. We also use this chapter's standard planning performance ratio, PR = 0.80 (Lesson 5).

### WORKED EXAMPLE — STEP 3: SIZING THE ARRAY

Using  $E_{\text{daily}} = 2600$  Wh, PSH = 3.0 h/day, and PR = 0.80, find the minimum array size, then choose real panels.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH} \times \text{PR})$

2. Put in the numbers:  $P_{\text{array}} = 2600 \text{ Wh} \div (3.0 \text{ h} \times 0.80)$
3. Calculate the bottom:  $3.0 \times 0.80 = 2.4$
4. Divide:  $P_{\text{array}} = 2600 \div 2.4 \approx 1083.3 \text{ W}$  (1.08 kWp)
5. Choose panels: with an example 400 W panel ( $V_{\text{oc}} = 49 \text{ V}$ ,  $I_{\text{sc}} = 10.5 \text{ A}$ ,  $V_{\text{mp}} = 40 \text{ V}$ ,  $I_{\text{mp}} = 10 \text{ A}$ ),  $1083.3 \div 400 \approx 2.7 \rightarrow$  round up to 3 panels = 1200 W

**Answer: At least 1.08 kWp needed; three 400 W panels (1200 W total) chosen — about 11% above the bare minimum**

How should the three panels be wired? In parallel, all three strings of one panel each. Wired in parallel: array  $V_{\text{oc}}$  stays at one panel's value, 49 V — safely below almost any MPPT controller's input limit. If instead all three were wired in series,  $V_{\text{oc}}$  would be  $3 \times 49 = 147 \text{ V}$ , which is too close to (or above) many common controllers' 100 V or 150 V limits, especially once cold mornings push  $V_{\text{oc}}$  even higher. Parallel wiring is the safer, simpler choice here.

Array as wired:  $V_{\text{oc}} = 49 \text{ V}$ ,  $I_{\text{sc}} = 3 \times 10.5 = 31.5 \text{ A}$ ,  $V_{\text{mp}} = 40 \text{ V}$ ,  $I_{\text{mp}} = 3 \times 10 = 30 \text{ A}$ , giving a rated power of  $40 \text{ V} \times 30 \text{ A} = 1200 \text{ W}$  (matching  $3 \times 400 \text{ W}$  ✓).

**Step 4 — Battery bank.** This home has no grid and no generator to fall back on, but the family accepts a modest risk to control cost, so the design uses 2 days of autonomy — near the lower end of Lesson 3's 'remote home' range (a more cautious design could choose 3 days instead). The system voltage is 24 V (Lesson 3's medium-size guide; a 12 V system here would need very high currents for this array and pump, and 24 V keeps cables reasonable). The batteries are flooded lead-acid, the most common and affordable choice in local markets, with a maximum DoD of 50% (0.5).

#### WORKED EXAMPLE — STEP 4: SIZING THE BATTERY BANK

Using  $E_{\text{daily}} = 2600 \text{ Wh}$ ,  $N_{\text{auto}} = 2$  days,  $V_{\text{sys}} = 24 \text{ V}$ , and  $\text{DoD} = 0.5$ , find the required battery bank capacity, and a real battery count.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (2600 \times 2) \div (24 \times 0.5)$
3. Calculate the top:  $2600 \times 2 = 5200 \text{ Wh}$
4. Calculate the bottom:  $24 \times 0.5 = 12$
5. Divide:  $C_{\text{bank}} = 5200 \div 12 \approx 433.3 \text{ Ah}$
6. Batteries in series for 24 V:  $24 \div 12 = 2$  batteries per string
7. Strings in parallel for capacity, using 200 Ah batteries:  $433.3 \div 200 \approx 2.2 \rightarrow$  round up to 3 strings
8. Total batteries: 2 in series  $\times$  3 strings = 6 batteries (a '2S3P' bank), giving an actual 600 Ah

**Answer: At least 433.3 Ah at 24 V required; six 12 V, 200 Ah batteries (2S3P) chosen, giving 24 V, 600 Ah**

Check the real autonomy this gives: usable energy =  $24 \text{ V} \times 600 \text{ Ah} \times 0.5 = 7200 \text{ Wh}$  (7.2 kWh); actual autonomy =  $7200 \div 2600 \approx 2.8$  days — a little more than the 2-day target, simply because whole batteries must be bought, not fractions of one. Notice the two different jobs Steps 2 and 4 do: the design-month PSH protects the array against the whole SEASON being weak; the autonomy days protect the battery against a short run of cloudy days on top of that.

As a quick comparison: if this family instead chose LiFePO<sub>4</sub> batteries (DoD = 0.80), the same equation gives  $C_{\text{bank}} = (2600 \times 2) \div (24 \times 0.8) \approx 270.8 \text{ Ah}$  — about 37.5% smaller than the lead-acid requirement, because

lithium allows a much deeper discharge (Chapter 6). The trade-off, as always, is the higher price of lithium batteries today.

**Step 5 — Charge controller.** Apply both checks from Lesson 4: the short-circuit current rule, and the battery-side power check.

#### WORKED EXAMPLE — STEP 5: SIZING THE CHARGE CONTROLLER

Using the array's  $I_{sc} = 31.5\text{ A}$  and rated power  $1200\text{ W}$ , and the  $24\text{ V}$  system voltage, find the minimum controller current using both checks from Lesson 4.

1. Check 1 — short-circuit current rule:  $I_{\text{controller}} \geq 31.5\text{ A} \times 1.25 = 39.4\text{ A} \rightarrow$  round up to  $40\text{ A}$
2. Check 2 — power check at  $24\text{ V}$ :  $I_{\text{battery}} \approx 1200\text{ W} \div 24\text{ V} = 50.0\text{ A} \rightarrow$  this is right at the  $50\text{ A}$  standard size, so round up further, to  $60\text{ A}$ , for a real safety margin
3. Compare: Check 2 ( $60\text{ A}$ ) is larger than Check 1 ( $40\text{ A}$ ), so Check 2 governs

**Answer: Choose a 60 A MPPT controller, rated for at least 100 V PV input (the array's  $49\text{ V}$   $V_{oc}$  is safely inside this).**

Compare this with Lesson 4's own example, where the simple current rule already gave the larger, governing number. Here, the power check governs instead, because this array's operating voltage ( $40\text{ V}$ ) is proportionally much higher above the  $24\text{ V}$  battery than in Lesson 4's example. This is exactly why Lesson 4 insisted on doing BOTH checks, every time.

**Step 6 — Inverter.** In the evening, the family typically runs the lamps, television, fridge, fans, and chargers together — but not the water pump, which runs briefly in the early morning to fill the household tank, before anyone is using lights or the television. Because a refrigerator's compressor cycles on and off unpredictably through the whole day, a careful design assumes it COULD be running at any moment, including when the pump starts.

#### WORKED EXAMPLE — STEP 6: SIZING THE INVERTER

Find the minimum continuous and surge inverter ratings for this home.

1. Continuous loads, evening (pump off): lamps  $60 + \text{TV } 80 + \text{fridge } 130 + \text{fans } 120 + \text{chargers } 30 = 420\text{ W}$
2. Add a 25% margin:  $420 \times 1.25 = 525\text{ W} \rightarrow 500\text{ W}$  is not enough, so round up to a  $1000\text{ W}$  continuous inverter
3. Surge moment: the pump starts ( $200\text{ W}$  running, surge factor about  $5\times$ ) while only the fridge ( $130\text{ W}$ ) might already be running
4. Pump surge:  $200 \times 5 = 1000\text{ W}$
5. Minimum surge rating:  $130 + 1000 = 1130\text{ W}$
6. Check a  $1000\text{ W}$  continuous /  $2000\text{ W}$  surge inverter: continuous  $1000 \geq 525\text{ ✓}$ ; surge  $2000 \geq 1130\text{ ✓}$

**Answer: Choose a 1000 W continuous / 2000 W surge, pure sine wave inverter, with a  $24\text{ V}$  DC input (matching the battery bank).**

**Step 7 — Cables and protection.** Every connection in this system — array to controller, controller to battery, battery to inverter — needs correctly sized cable, plus fuses or breakers close to the battery and the array. This chapter has sized every component's current; Chapter 9 uses those same currents to size the cables themselves and choose the protection devices.

#### Final component list

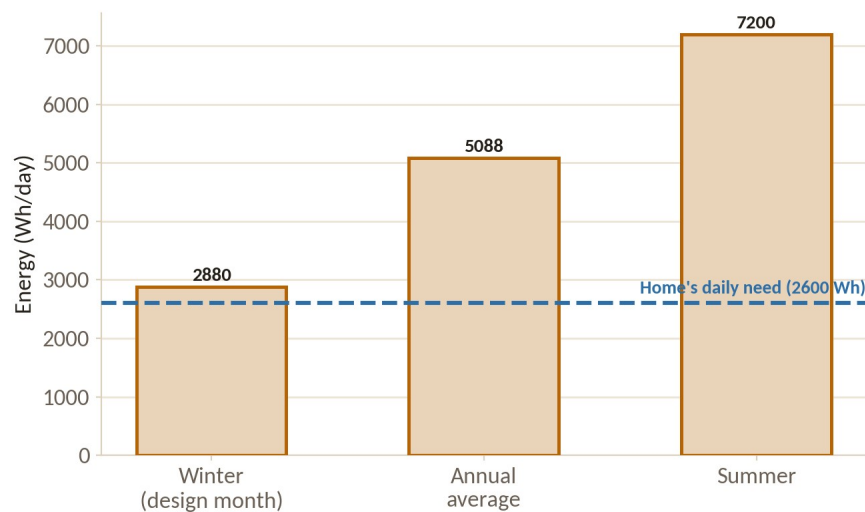


| Component           | Specification                                                                                                                       |
|---------------------|-------------------------------------------------------------------------------------------------------------------------------------|
| Solar array         | 3 × 400 W monocrystalline panels (example: Voc 49 V, Isc 10.5 A each), wired in parallel — 1200 W total, array Voc 49 V, Isc 31.5 A |
| Charge controller   | 60 A MPPT, rated for at least 100 V PV input                                                                                        |
| Battery bank        | 6 × 12 V, 200 Ah flooded lead-acid deep-cycle batteries, wired 2 series × 3 parallel (2S3P) — 24 V, 600 Ah                          |
| Inverter            | 1000 W continuous / 2000 W surge, pure sine wave, 24 V DC input                                                                     |
| Cables & protection | Sized from the currents above — full method in Chapter 9                                                                            |

One design question remains: how does this system perform outside the design month? The array was sized for winter's weak sun, so it should have a real surplus for most of the year.

#### Monthly production vs. demand (example: array 1200 W, PR 0.80)

| Period                | Example PSH | Array energy produced | Home's daily need | Surplus      |
|-----------------------|-------------|-----------------------|-------------------|--------------|
| Winter (design month) | 3.0 h/day   | 2880 Wh/day           | 2600 Wh/day       | +280 Wh/day  |
| Annual average        | 5.3 h/day   | 5088 Wh/day           | 2600 Wh/day       | +2488 Wh/day |
| Summer                | 7.5 h/day   | 7200 Wh/day           | 2600 Wh/day       | +4600 Wh/day |



*Example monthly array production compared with the home's steady daily need. Winter is the tight, design-limiting month; most of the year produces a comfortable surplus that keeps the battery bank full.*

This is normal and correct for an off-grid design: sizing for the worst month means most of the year produces more than the home needs. That surplus keeps the battery bank topped up, and gives some headroom for a few extra cloudy days beyond the 2-day autonomy target.

#### COMMON MISTAKE

**X Wrong:** Finish a design by checking that each component — array, battery, controller, inverter — is 'big enough' on its own, and stop there.

**✓ Right:** Also check the WHOLE chain together: does the array's actual output (Step 3) exceed the home's need (Step 1)? Do the battery bank, controller, and inverter all share the same system voltage (24 V here)? A design is only complete when every step is checked against its neighbors, not just against its own minimum.

## SAFETY

Before any of this is built: confirm every connection order and safety rule from earlier chapters — battery first, then array, when connecting a controller (Chapter 7); correct fuses and breakers close to the battery (Chapter 6, Chapter 9); a pure sine wave inverter for the fridge and pump motors (Chapter 8); and ventilated, shaded battery placement in this region's summer heat (Chapter 6). A correct calculation is not the same as a safe installation.

## ACTIVITY (CLASSROOM) — REDESIGN IT FOR YOUR OWN SITUATION

1. Replace this lesson's load table with your own home's appliances and hours (or another building you know).
2. Choose a design-month peak sun hours value for your own city, and this chapter's example performance ratio of 0.80.
3. Repeat all six steps: energy demand, sun data, array, battery bank, controller, and inverter. Keep every number consistent from step to step, exactly as this lesson did.
4. Finally, check your hand-calculated design against the Design wizard in the app, using the same input numbers.

*You need: Calculator or phone, Your own load list*

## CHAPTER SUMMARY

- The off-grid design chain has seven linked steps: energy demand → sun data → array → battery bank → controller → inverter → cables. Each step depends on the ones before it.
- System voltage is chosen once, early in the design, and used for the battery bank, the controller's output, and the inverter's input alike.
- Array sizing:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH} \times \text{PR})$ . Off-grid arrays are sized using the design month — usually the lowest-sun month — not the annual average, unless a generator will cover the gap.
- Battery bank sizing:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$ . Design-month sizing protects against the whole season being weak; autonomy days protect against short cloudy runs on top of that.
- A charge controller needs two checks: the short-circuit current rule ( $I_{\text{sc}} \times 1.25$ ) for the array-side connection, and a power check (array power ÷ system voltage) for the battery-side current. Use whichever check gives the bigger number.
- An inverter needs both a continuous rating (total running watts × a safety margin) and a surge rating (other running loads + the largest motor's surge power).
- Performance ratio (PR) is built by multiplying individual derating factors — heat, dust, wiring, controller, and inverter losses. This book uses an example PR of about 0.80 for planning.
- Sizing an off-grid array for the worst month means most of the year produces a real surplus — this is

normal, and keeps the battery bank full.

- A complete design checks the WHOLE chain together, not just each component alone: matched voltages, and array output that truly covers the home's need.
- Always confirm every earlier chapter's safety rules — connection order, fusing, waveform choice, and battery placement — before building any real system.

► *App tool: Continue the chain: size the cables and protection for this system in Chapter 9*

► *App simulation: Check this complete design, start to finish, in the System Sizing simulation*

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A cabin needs 2000 Wh per day. The design month gives 5.0 peak sun hours. Using a performance ratio of 0.80, find the minimum array size, in W.

**Problem 2 [Basic]** A small home needs 1800 Wh per day from its battery bank. The design uses 1 day of autonomy, a 12 V system, and a battery with a maximum depth of discharge of 0.5. Find the required battery bank capacity, in Ah.

**Problem 3 [Basic]** A small array has a short-circuit current ( $I_{sc}$ ) of 7 A. Using the 1.25 safety factor, find the minimum controller current rating, then choose a standard size from 10, 20, 30, or 40 A.

**Problem 4 [Basic]** Loads running together total 220 W of continuous power. Using a 25% safety margin, find the minimum continuous inverter rating, then choose a standard size from 300, 500, or 1000 W.

**Problem 5 [Standard]** A home needs 5500 Wh per day. Its design month gives 3.5 peak sun hours, and the performance ratio is 0.75. Find the minimum array size in W, then choose a number of 330 W panels.

**Problem 6 [Standard]** A home needs 4000 Wh per day from its battery bank, with 3 days of autonomy, a 24 V system, and AGM batteries with a maximum DoD of 0.6. Find the required capacity in Ah, and the number of 12 V, 100 Ah batteries needed (series and parallel).

**Problem 7 [Standard]** An array of 8 panels, each  $V_{oc} = 32$  V,  $I_{sc} = 9$  A,  $V_{mp} = 27$  V,  $I_{mp} = 8.5$  A, is wired as two panels in series with four such strings in parallel (2S4P), feeding a 24 V battery bank through an MPPT controller. Find the minimum controller current using both the short-circuit current rule and the power check, and state which one governs.

**Problem 8 [Standard]** A borehole pump motor runs at 550 W, with a starting surge of about 4 times its running power. Other loads running at the same moment total 150 W. Find (a) the minimum surge inverter rating and (b) the minimum continuous inverter rating with a 25% margin, then choose a standard inverter size from the pairs 1000/2000 W or 1500/3000 W.

**Problem 9 [Standard]** A system has these example derating factors: temperature 0.92, dust 0.93, wiring 0.98, controller 0.96, and inverter 0.95. (a) Find the overall performance ratio. (b) Using this PR, find the daily energy produced by a 2.5 kWp array at 5.0 peak sun hours.

**Problem 10 [Challenge]** A small off-grid shop in Sulaymaniyah has these daily loads: 10 LED lights (12 W each, 6 h/day), one drinks refrigerator (140 W, 10 h/day effective), one ceiling fan (65 W, 8 h/day), and one computer (90 W, 6 h/day). The design month gives 3.2 peak sun hours, with a performance ratio of 0.80. The shop wants 1 day of autonomy at a 24 V system voltage, using AGM batteries with DoD = 0.6. Panels are 350 W each; batteries are 12 V, 150 Ah. Find: (a) the daily energy need; (b) the array size and panel count; (c) the battery

bank capacity and battery count; (d) the inverter's minimum continuous rating (25% margin) and surge rating (the fridge's surge is about 4×, and all other loads may already be running when it starts).

**Problem 11 [Challenge]** A rural one-room classroom, fully off-grid, has these daily loads: 8 LED lights (10 W each, 5 h/day), a laptop-charging station (60 W, 4 h/day), a small printer (80 W, 1 h/day), and a fan (70 W, 5 h/day). The design month gives 3.5 peak sun hours, with a performance ratio of 0.78. The school accepts 1 day of autonomy at a 12 V system voltage, using lead-acid batteries with DoD = 0.5. Panels are 300 W each; batteries are 12 V, 100 Ah. Find: (a) the daily energy need; (b) the array size and panel count; (c) the battery bank capacity and battery count; (d) the inverter's minimum continuous rating (use a 20% margin this time) and surge rating (the fan's surge is about 2×).

**Problem 12 [Challenge]** A solar LED streetlight in a remote area runs at 50 W for 10 hours every night, with no daytime load. It uses two 150 W panels (each  $V_{oc} = 22$  V,  $I_{sc} = 8.6$  A) wired in parallel, matched to a 12 V nominal battery through a PWM controller. The design uses 3 days of autonomy (a hard-to-reach site), a single 12 V LiFePO<sub>4</sub> battery with DoD = 0.8, a design-month PSH of 3.0 h/day, and PR = 0.75. Find: (a) the daily energy need; (b) the minimum array size, and whether the two 150 W panels are enough; (c) the required battery capacity, and whether a single 12 V, 200 Ah LiFePO<sub>4</sub> battery is enough; (d) the minimum controller current and a standard size. Also explain why this system needs no inverter.

## CHAPTER THIRTEEN

# On-Grid and Hybrid System Design

*Designing systems that work together with the grid and a generator*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain why grid-tied arrays are normally sized using the annual average peak sun hours instead of the design month used for off-grid arrays, and calculate an array size that offsets a target share of a home's consumption.
- Explain how net metering and net billing work, and calculate a simple electricity bill under each, given example import and export rates.
- Describe the architecture and source priority of a hybrid system that combines solar, a battery, the grid, and a generator.
- Calculate the battery bank a hybrid system needs to cover its typical daily grid outage, instead of the multi-day autonomy used for a fully off-grid system.
- Calculate how much a correctly sized solar array and battery reduce a generator's daily run hours, and explain the trade-off in choosing a generator's autostart threshold.
- Describe what is realistic for grid-connected and hybrid solar systems in Iraq and the Kurdistan Region today, and explain why students must confirm current local rules themselves.

## 13.1 Grid-Tie Sizing to Offset Consumption

Chapter 12 designed a system with no grid at all. This chapter designs systems that WORK WITH the grid — starting with the simplest case: a home that stays connected to the public grid (Chapter 11's on-grid system) and adds solar panels to cut its grid bill. This lesson answers the first design question: how big should that array be?

Recall from Chapter 11: an on-grid system (also called grid-tied) usually has no battery. During the day it uses solar power first — this is called self-consumption — and a grid-tie inverter (Chapter 8) sends any extra power out to the grid. At night, or whenever the sun is not enough, the home simply draws power from the grid as normal. There is no autonomy to plan for, because the grid is always the backup.

### WORD TO KNOW

**Consumption offset** — The target share of a home's average yearly energy use that a solar array is designed to produce. An offset of 70% means the array is sized to produce about 70% of the home's average annual consumption, not necessarily 70% every single day.

Because the grid is always available as backup, a grid-tied array does NOT need to survive the year's worst month on its own — Chapter 12's biggest rule for off-grid design does not apply here. Instead, designers size a grid-tied array using the site's ANNUAL AVERAGE peak sun hours, and choose an offset target that fits the family's budget and goals.

### EQUATION: SIZING A GRID-TIE ARRAY FOR A CONSUMPTION OFFSET

$$P_{\text{array}} = \frac{\text{Offset} \times E_{\text{daily}}}{PSH_{\text{avg}} \times PR}$$

In words: Minimum array power = (Offset fraction × Daily energy use) ÷ (Annual average peak sun hours × Performance ratio)

| Symbol  | Meaning                                                                            | Unit                       |
|---------|------------------------------------------------------------------------------------|----------------------------|
| P_array | the minimum array power the design needs                                           | kilowatts (kWp)            |
| Offset  | the target share of the home's average consumption the array should produce        | fraction, no unit (0 to 1) |
| E_daily | the home's average daily energy use, over the whole year                           | kilowatt-hours (kWh)       |
| PSH_avg | the site's ANNUAL AVERAGE peak sun hours — not the design month used in Chapter 12 | hours per day (h/day)      |
| PR      | performance ratio                                                                  | ratio, no unit (0 to 1)    |

This equation has almost the same shape as Chapter 12's array equation. Two things change: PSH is now the ANNUAL AVERAGE, and an Offset fraction is added — a grid-tied array does not have to supply 100% of the load by itself, because the grid fills any gap.

### WORKED EXAMPLE — CHECKING THE EQUATION: HOW MUCH DOES AN EXISTING ARRAY OFFSET?

A neighbor already has a 2.0 kWp grid-tied array. The site's annual average peak sun hours are 5.3 h/day (Erbil, as in Chapter 12), and the performance ratio is 0.80. The home's average daily consumption is 12 kWh. Find the array's daily energy production, and the percent of consumption it offsets.

1. Write the production equation (Chapter 12):  $E_{\text{array}} = P_{\text{array}} \times PSH_{\text{avg}} \times PR$
2. Put in the numbers:  $E_{\text{array}} = 2.0 \text{ kW} \times 5.3 \text{ h} \times 0.80$
3. Calculate:  $E_{\text{array}} = 8.48 \text{ kWh per day}$
4. Offset % =  $(E_{\text{array}} \div E_{\text{daily}}) \times 100 = (8.48 \div 12) \times 100 \approx 70.7\%$

**Answer: About 8.48 kWh per day, offsetting about 70.7% of the home's average consumption**

### WORKED EXAMPLE — SIZING AN ARRAY FOR A 90% OFFSET TARGET

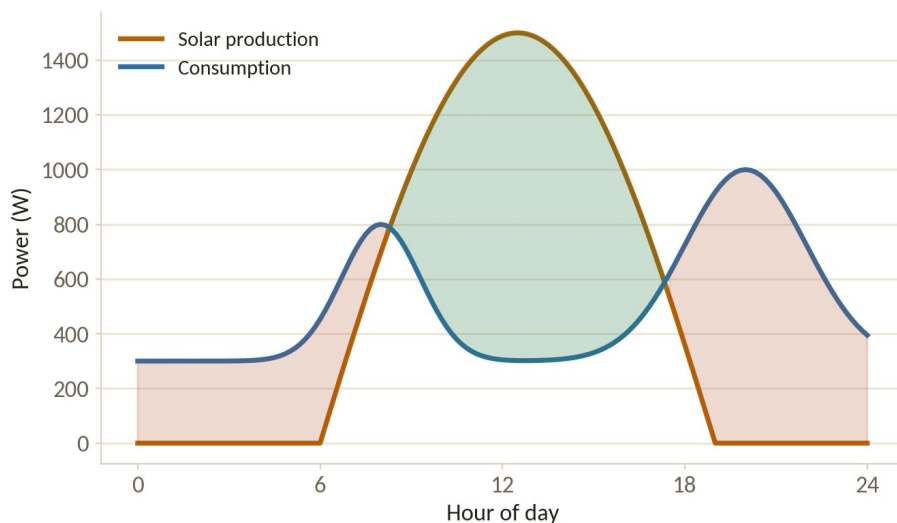
A family's average daily consumption is 12 kWh (12,000 Wh). They want their array to offset 90% of this over the year. Using Erbil's example annual average peak sun hours (5.3 h/day) and a performance ratio of 0.80, find the minimum array size, and choose a practical number of 400 W panels.

1. Write the equation:  $P_{\text{array}} = (\text{Offset} \times E_{\text{daily}}) \div (PSH_{\text{avg}} \times PR)$
2. Multiply the bottom first:  $PSH_{\text{avg}} \times PR = 5.3 \times 0.80 = 4.24$
3. Multiply the top:  $\text{Offset} \times E_{\text{daily}} = 0.90 \times 12,000 = 10,800 \text{ Wh}$
4. Divide:  $P_{\text{array}} = 10,800 \div 4.24 \approx 2547.2 \text{ W (2.55 kWp)}$
5. Choose panels: with 400 W panels,  $2547.2 \div 400 \approx 6.37 \rightarrow$  round up to 7 panels = 2800 W

**Answer: At least 2.55 kWp needed; seven 400 W panels (2800 W total) comfortably cover a 90% offset**

### Off-grid vs. grid-tied array sizing

| Question                             | Off-grid (Chapter 12)                              | Grid-tied (this lesson)                         |
|--------------------------------------|----------------------------------------------------|-------------------------------------------------|
| Which peak sun hours?                | Design month (usually the weakest month)           | Annual average                                  |
| If the array falls short one month?  | The home can run out of power — there is no backup | The grid fills the gap automatically            |
| If the array makes more than needed? | Extra is wasted once the battery is full           | Extra can be exported to the grid (Lesson 2)    |
| Typical sizing target                | 100% of the daily need, every single day           | A chosen offset share of the ANNUAL average use |



A grid-tied home's daily solar production compared with its energy consumption. Around midday, production can exceed consumption (exported to the grid); in the morning, evening, and night, consumption exceeds production (imported from the grid).

#### COMMON MISTAKE

**✗ Wrong:** Size a grid-tied array using the design month's peak sun hours, the same method used for off-grid systems in Chapter 12.

**✓ Right:** Size a grid-tied array using the site's ANNUAL AVERAGE peak sun hours. Using the design month (the weakest month) makes a grid-tied array far bigger, and far more expensive, than it needs to be — the grid already covers any shortfall in winter.

One more component to choose: the grid-tie inverter (Chapter 8) that connects the array to the grid. Unlike an off-grid inverter, it is not sized from the home's loads — the grid always supplies whatever the array cannot. Installers normally choose a grid-tie inverter rated close to the array's DC power, often about 90–110% of the array's rated wattage. A full sizing method is outside this lesson's scope; always check the manufacturer's datasheet for the inverter's maximum DC input power and voltage window before pairing it with a specific array.

#### CASE STUDY — CHOOSING AN OFFSET TARGET IN ERBIL • ERBIL, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

A family in Erbil compared two on-grid design options with their installer. Option A targeted a 100% offset,

needing a bigger, more expensive array to try to match their full annual use. Option B targeted a 70% offset, using a smaller array that still cut their grid bill by a large share. They chose Option B: the smaller array cost noticeably less and left them with a shorter, easier payback (Chapter 15 studies payback in full). A 100% (or higher) offset target can make good sense too, especially where export credit is generous — but Lesson 2 shows why the local metering rule changes this decision a great deal.

#### ACTIVITY (CLASSROOM) — CHOOSE AN OFFSET TARGET FOR YOUR OWN HOME

1. Estimate your own home's (or the Chapter 1 example home's) average daily energy use, in kWh.
2. Choose an offset target between 50% and 100%, and write one sentence explaining why you chose it.
3. Using Erbil's example annual average peak sun hours (5.3 h/day) and a performance ratio of 0.80, calculate the minimum array size for your target.
4. Compare your answer with a classmate who chose a different offset target. How much bigger is a 100% target than a 50% target, for the same home?

*You need: Calculator or phone, Your own load audit or the Chapter 1 example home*

► *App tool: Look up annual average peak sun hours for different cities*

► *App tool: Check your offset array sizing with the PV Array Sizing calculator*

► *App simulation: Compare on-grid, off-grid, and hybrid energy flows in the System Types simulation*

## 13.2 Net Metering Basics

Chapter 11 introduced net metering as a billing idea. This lesson opens it up with numbers, so you understand exactly how it works — and, just as importantly, how it can differ from one place to another. Read this lesson as a way to understand the IDEA, not as a promise of what is available where you live.

#### WORD TO KNOW

**Grid import** — Electrical energy flowing FROM the public grid INTO a home or building. Measured in kWh, usually shown on a bill as normal electricity use.

#### WORD TO KNOW

**Grid export** — Electrical energy flowing FROM a home or building's solar system OUT TO the public grid, usually because the array is producing more than the home needs at that moment.

A grid-tied home's electricity meter can measure both directions: grid import when the home needs more power than the array makes, and grid export when the array makes more than the home needs. Net metering is a way of billing that combines the two.

#### EQUATION: NET METERING: A SIMPLE BILL (SAME RATE FOR IMPORT AND EXPORT)

$$Bill = (E_{\text{import}} - E_{\text{export}}) \times \text{tariff}$$

*In words: Bill = (Energy imported – Energy exported) × tariff*

| Symbol | Meaning                                                              | Unit                        |
|--------|----------------------------------------------------------------------|-----------------------------|
| Bill   | the amount owed for the billing period, assuming imports are greater | currency (for example, IQD) |



|          |                                                                                                             |                                         |
|----------|-------------------------------------------------------------------------------------------------------------|-----------------------------------------|
|          | than exports                                                                                                |                                         |
| E_import | total grid import for the period                                                                            | kilowatt-hours (kWh)                    |
| E_export | total grid export for the period                                                                            | kilowatt-hours (kWh)                    |
| tariff   | the price per kWh, applied at the SAME rate to both import and export — the idea behind 'true' net metering | currency per kWh (for example, IQD/kWh) |

If exports are greater than imports instead, the result is a credit, not a bill. Real programs handle that credit in different ways — for example, carrying it forward to next month's bill.

### WORKED EXAMPLE — A DAY'S BILL UNDER TRUE NET METERING

In one day, a home imports 8 kWh from the grid and exports 6 kWh of solar power to the grid. Using an example tariff of 100 IQD/kWh, applied equally to import and export, find the day's bill, and compare it with what the bill would have been with no solar at all (12 kWh, all imported).

1. Write the equation:  $\text{Bill} = (E_{\text{import}} - E_{\text{export}}) \times \text{tariff}$
2. Put in the numbers:  $\text{Bill} = (8 - 6) \times 100$
3. Calculate:  $\text{Bill} = 2 \times 100 = 200 \text{ IQD}$
4. Bill with no solar: the home would have imported all 12 kWh it used (8 + the 4 kWh it self-consumed from solar):  $12 \times 100 = 1200 \text{ IQD}$
5. Savings:  $1200 - 200 = 1000 \text{ IQD}$ , about 83% less

**Answer: 200 IQD for the day, compared with 1200 IQD with no solar — a saving of about 1000 IQD (83%)**

Notice something powerful in that example: the home used 12 kWh in total, and the array only produced 10 kWh (4 kWh used directly plus 6 kWh exported) — yet the family only paid for a NET 2 kWh. Under true, 1:1 net metering, only the TOTAL energy imported minus exported over the whole period matters. It does not matter whether the solar power was used the instant it was made, or exported at noon and 'borrowed back' at night — the grid acts like a free, perfect energy store, as long as this billing rule applies.

### WORD TO KNOW

**Net billing** — A billing arrangement where energy exported to the grid is credited at a DIFFERENT (often lower) rate than the price charged for energy imported. This is different from true net metering, where both directions use the same rate.

### EQUATION: NET BILLING: DIFFERENT RATES FOR IMPORT AND EXPORT

$$\text{Bill} = (E_{\text{import}} \times \text{tariff}_{\text{import}}) - (E_{\text{export}} \times \text{tariff}_{\text{export}})$$

In words:  $\text{Bill} = (\text{Energy imported} \times \text{import tariff}) - (\text{Energy exported} \times \text{export tariff})$

| Symbol        | Meaning                                                              | Unit                        |
|---------------|----------------------------------------------------------------------|-----------------------------|
| Bill          | the amount owed for the billing period                               | currency (for example, IQD) |
| E_import      | total grid import for the period                                     | kilowatt-hours (kWh)        |
| tariff_import | the price paid per kWh imported                                      | currency per kWh            |
| E_export      | total grid export for the period                                     | kilowatt-hours (kWh)        |
| tariff_export | the price credited per kWh exported — under net billing, often LOWER | currency per kWh            |

|  |                        |  |
|--|------------------------|--|
|  | than the import tariff |  |
|--|------------------------|--|

*Net billing is a common real-world alternative to true net metering. Because export is usually credited less than import costs, using your own solar power directly (self-consumption) becomes more valuable than exporting it.*

#### WORKED EXAMPLE — THE SAME DAY, UNDER NET BILLING INSTEAD

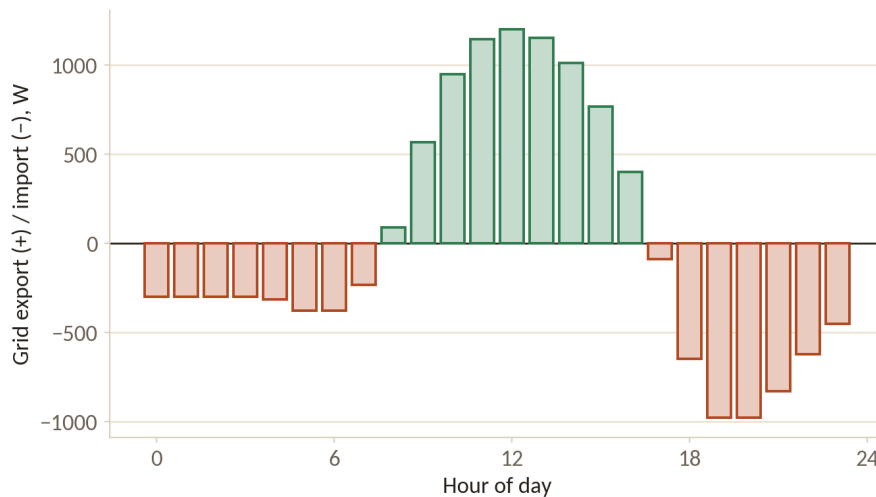
Using the SAME day as before (8 kWh imported, 6 kWh exported), suppose the utility instead uses net billing: import still costs 100 IQD/kWh, but export is credited at only 50 IQD/kWh (example rates). Find the day's bill.

1. Write the equation:  $\text{Bill} = (E_{\text{import}} \times \text{tariff}_{\text{import}}) - (E_{\text{export}} \times \text{tariff}_{\text{export}})$
2. Put in the numbers:  $\text{Bill} = (8 \times 100) - (6 \times 50)$
3. Calculate:  $\text{Bill} = 800 - 300 = 500 \text{ IQD}$
4. Compare: 500 IQD (net billing) is more than 200 IQD (true net metering), but still much less than 1200 IQD (no solar)

**Answer: 500 IQD for the day — a smaller saving than true net metering's 200 IQD bill, because export is credited at only half the import rate**

#### Three ways export can be credited (illustrative — always confirm the real local rule)

| Arrangement       | How export is credited                                                                   | Effect on the customer                                                                                                                   |
|-------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| True net metering | Same rate as import, 1:1                                                                 | Only the TOTAL net energy (import – export) matters — usually the biggest saving of the three                                            |
| Net billing       | A separate, often lower, rate than import                                                | Self-consumption becomes worth more than export; a smaller saving than true net metering for the same solar production                   |
| Feed-in tariff    | A fixed published rate paid for ALL solar energy produced, separate from the import bill | Used in some countries, often for a fixed number of years; the customer is paid for production directly, not only for the export surplus |



*Grid import and export over one day for a grid-tied home: import in the early morning and evening, export around midday when solar production is highest.*

### COMMON MISTAKE

**✗ Wrong:** Assume net metering works the same way everywhere, with a guaranteed 1:1 credit for every kWh exported to the grid.

**✓ Right:** Net metering and net billing rules differ by country, by utility, and even by area, and they can change over time as policy changes. Before counting on any export credit in a real design, confirm the CURRENT rule directly with the local electricity provider.

### SAFETY

Never connect a solar array to the grid without an approved grid-tie or hybrid inverter and the correct switchgear. A grid-tie inverter's anti-islanding feature (Chapter 8) automatically disconnects the array from the grid the instant the grid goes down — this protects repair workers from a line that looks dead but is secretly still carrying power from your panels. Never remove, disable, or bypass this feature, and never let anyone without the right training and approval connect a system to the public grid.

So how does this apply in Iraq and the Kurdistan Region? The picture here is different from countries with a long-established net-metering law. Grid electricity in the region is often supplied alongside a separate neighborhood generator during outages (Chapter 1, Chapter 21), and a single, nationwide, published net-metering or net-billing program — with a fixed export rate open to any home — is not yet a standard, widely available option everywhere at the time this book was written. Because of this, MOST home and small-business solar systems built in the region today are designed as off-grid or hybrid systems (Lesson 3) that store extra solar energy in a battery for later use, instead of depending on exporting it to the grid for a credit.

Rules can also differ between the federal Iraqi electricity system, the Kurdistan Region's own electricity directorates, and even between one governorate, city, or feeder (Chapter 21) and another — and they can change as new policies are introduced. This book cannot tell you the exact rule for your own street today, and this lesson is educational content, not legal advice. Before designing any system that depends on export credit, always confirm the current rule yourself, directly with your local electricity directorate or utility office.

### CASE STUDY — BEFORE ASSUMING NET METERING IS AVAILABLE • SULAYMANIYAH, KURDISTAN REGION

### (ILLUSTRATIVE EXAMPLE)

An engineering student in Sulaymaniyah first planned a fully grid-tied design for her family's home, assuming she could export extra solar power for a bill credit. Before finishing the design, she visited her local electricity directorate office to confirm the rule, following exactly the advice above. She learned that, at that time, there was no simple net-metering arrangement available for an ordinary home on her family's feeder. She changed her design to a hybrid system instead (Lesson 3) — one that stores extra solar energy in a battery for the evening, rather than counting on the grid to store it for her. The lesson: confirm the current local rule BEFORE finishing a design that depends on exporting power to the grid.

### ACTIVITY (FIELD) — INVESTIGATE YOUR LOCAL RULE

1. Find the contact information for your local electricity directorate or utility office (ask your teacher if you are not sure who this is).
2. Prepare two questions: (1) Is any net metering or net billing arrangement currently available for a home like yours? (2) If yes, what is the current import and export rate, and are there any limits, such as a maximum system size?
3. Contact the office, or interview a local solar installer or engineer if the office is hard to reach, and record what you learn.
4. Share your findings with the class. Compare what different students learned — did everyone hear the same rule?

*You need: Paper and pen, Phone, for a call, if possible*

► *App tool: Estimate your array's daily and monthly production to compare with consumption*

► *App tool: See how bill savings feed into a full payback calculation in Chapter 15*

► *App simulation: Explore bill savings under different assumptions in the Financial & Environmental simulation*

## 13.3 Hybrid System Design

Chapter 11 defined a hybrid system as one that combines solar, a battery, and the grid and/or a generator, switching between them automatically. This lesson designs one properly — the architecture, the order the system chooses a power source, and how big the array and battery need to be.

A hybrid inverter (Chapter 8) is the heart of the system: it manages the array's DC power, the battery's charge and discharge, AC power from the grid, and often a generator too, all in one box. Many hybrid inverters are also inverter-chargers (Chapter 8) — they can charge the battery from the grid or generator, not only from solar.

### WORD TO KNOW

**Source priority** — The order in which a hybrid system chooses where to draw power from at each moment — usually solar first, then the battery, then the grid, and the generator last.

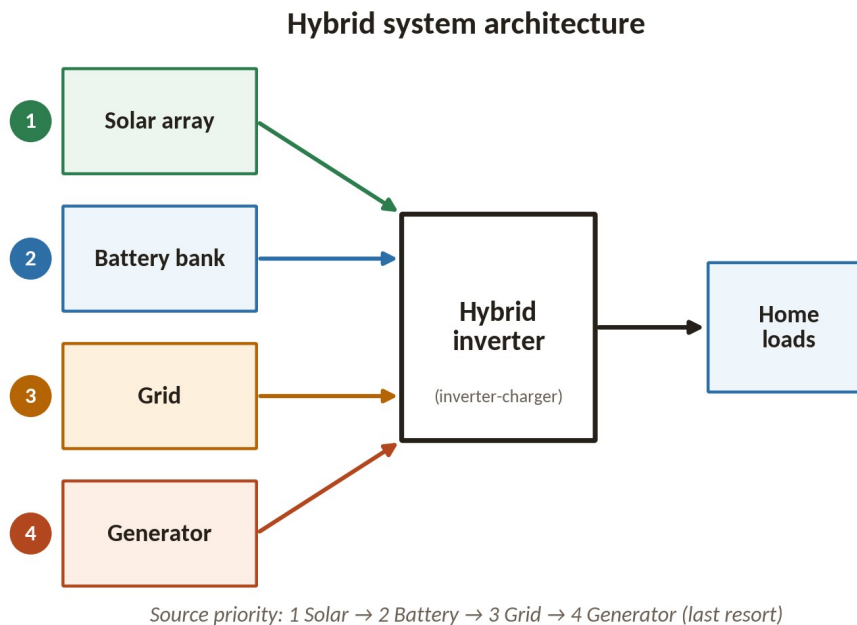
Most hybrid inverters let an installer set this source priority. A common default order, used by many hybrid systems, looks like this:

#### A typical hybrid system's source priority (adjustable)

| Situation                        | Typical source used                            | Why               |
|----------------------------------|------------------------------------------------|-------------------|
| Sun is shining, battery not full | Solar charges the battery and powers the loads | Free energy first |

| Situation                             | Typical source used                                                          | Why                                                                            |
|---------------------------------------|------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Sun is shining, battery full          | Solar powers the loads directly; extra may be exported or limited (Lesson 2) | Avoid overcharging the battery                                                 |
| No sun, battery has charge            | Battery powers the loads                                                     | Stored solar energy is normally cheaper than fuel, once the system is paid for |
| No sun, battery low, grid available   | Grid powers the loads and recharges the battery                              | The cheapest available backup when the grid is on                              |
| No sun, battery low, grid unavailable | Generator powers the loads and recharges the battery (Lesson 4)              | Last resort — usually the most expensive energy of the four (Chapter 1)        |

This order is usually adjustable. A family with very cheap grid electricity might prefer to lean on the grid a little more and save the battery for real outages. But solar first and generator last is nearly always correct — solar is free once installed, and generator fuel is normally the most expensive energy source available (Chapter 1).



*A hybrid system's architecture: solar array, battery bank, the grid, and a generator all connect through one hybrid inverter-charger, which powers the home's loads and follows the system's source priority.*

How big should the array and battery be? Unlike Chapter 12's off-grid method or this chapter's Lesson 1, there is no single fixed rule for a hybrid system — it can lean toward either design philosophy already in this book, and most real systems sit somewhere between the two extremes.

#### Two hybrid sizing philosophies

| Approach  | Array sizing method                                    | Battery sizing method                                      | Result                                                         |
|-----------|--------------------------------------------------------|------------------------------------------------------------|----------------------------------------------------------------|
| Grid-lean | Offset-based, annual average peak sun hours (Lesson 1) | Small — covers only the typical daily outage (this lesson) | Lower cost; leans on the grid and generator more in a bad week |

| Approach     | Array sizing method                                      | Battery sizing method                                 | Result                                                          |
|--------------|----------------------------------------------------------|-------------------------------------------------------|-----------------------------------------------------------------|
| Self-reliant | Off-grid style, design-month peak sun hours (Chapter 12) | Larger — closer to full days of autonomy (Chapter 12) | Higher cost; rarely needs the grid or generator, even in winter |

#### WORKED EXAMPLE — COMPARING A GRID-LEAN AND A SELF-RELIANT ARRAY FOR THE SAME HOME

Using the same 12 kWh/day home from Lesson 1, compare the array size needed for: (a) a grid-lean design, 90% offset, using Erbil's annual average peak sun hours (5.3 h/day) and PR = 0.80 — already sized in Lesson 1; (b) a self-reliant design that aims to cover close to the full daily need even in winter, using Erbil's design-month peak sun hours (3.0 h/day, Chapter 12) and the same PR.

1. (a) Grid-lean, from Lesson 1:  $P_{\text{array}} = (0.90 \times 12,000) \div (5.3 \times 0.80) \approx 2547 \text{ W}$  (2.55 kWp)
2. (b) Self-reliant:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH}_{\text{design}} \times \text{PR}) = 12,000 \div (3.0 \times 0.80) = 12,000 \div 2.4 = 5000 \text{ W}$  (5.0 kWp)
3. Compare:  $5000 \div 2547 \approx 1.96$  — the self-reliant array is about twice the size
4. Choose panels for (b): with 400 W panels,  $5000 \div 400 = 12.5 \rightarrow$  round up to 13 panels = 5200 W

**Answer: Grid-lean: about 2.55 kWp (7 panels, from Lesson 1). Self-reliant: about 5.0 kWp (13 panels) — roughly double, for far less reliance on the grid and generator.**

#### COMMON MISTAKE

**X Wrong:** Assume that simply having 'a hybrid system' — solar, battery, grid, and generator all connected — automatically means less generator use than before.

**✓ Right:** A hybrid system only reduces generator use if the array and battery are big enough to cover a meaningful share of the daily need. A hybrid system with a tiny, undersized array and battery can still need the generator just as often as a simple grid-plus-generator setup. Lesson 4 shows how to check this properly.

Now size the battery. Off-grid batteries (Chapter 12) are sized in DAYS OF AUTONOMY, built to survive a run of cloudy weather with no help at all. A hybrid system's battery usually has a smaller, different job: bridging the home's typical DAILY grid outage (Chapter 1, Chapter 21), because the grid — or a generator — recharges it again once power returns.

#### WORD TO KNOW

**Backup hours** — The number of hours a hybrid system's battery must supply backup power by itself during a typical grid outage, before the grid returns or a generator is needed.

#### EQUATION: BATTERY BANK FOR HYBRID BACKUP

$$C_{\text{bank}} = \frac{P_{\text{critical}} \times t_{\text{backup}}}{V_{\text{sys}} \times \text{DoD}}$$

*In words: Battery bank capacity = (Critical load power × backup hours) ÷ (System voltage × Depth of discharge)*

| Symbol | Meaning                        | Unit              |
|--------|--------------------------------|-------------------|
| C_bank | required battery bank capacity | ampere-hours (Ah) |

|            |                                                                                                       |                      |
|------------|-------------------------------------------------------------------------------------------------------|----------------------|
| P_critical | total power of the critical loads (Chapter 10) the battery must keep running during an outage         | watts (W)            |
| t_backup   | backup hours — hours of backup the battery must supply, usually the expected daily grid outage length | hours (h)            |
| V_sys      | system voltage (Chapter 12)                                                                           | volts (V)            |
| DoD        | maximum allowed depth of discharge for the battery type chosen (Chapter 6)                            | fraction from 0 to 1 |

*This is the same shape as Chapter 12's off-grid battery equation, but backup hours replaces days of autonomy — a hybrid system usually only needs to bridge ONE outage window, not several days with no help at all. A family with a very unreliable grid or generator might still choose to size closer to the self-reliant approach above, adding extra hours for safety.*

#### WORKED EXAMPLE — SIZING A HYBRID BATTERY BANK FOR AN EVENING OUTAGE

A home's critical loads (Chapter 10) during an evening power cut are: lights, a refrigerator, fans, and a television, totaling 350 W. The neighborhood grid typically goes off for about 6 hours each evening (Chapter 21). The system uses a 24 V system voltage and LiFePO4 batteries with a maximum depth of discharge of 0.8. Find the required battery bank capacity, and choose a real battery bank.

1. Write the equation:  $C_{\text{bank}} = (P_{\text{critical}} \times t_{\text{backup}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (350 \text{ W} \times 6 \text{ h}) \div (24 \text{ V} \times 0.8)$
3. Calculate the top:  $350 \times 6 = 2100 \text{ Wh}$
4. Calculate the bottom:  $24 \times 0.8 = 19.2$
5. Divide:  $C_{\text{bank}} = 2100 \div 19.2 \approx 109.4 \text{ Ah}$
6. Choose real batteries: two 12 V, 150 Ah LiFePO4 batteries in series give 24 V, 150 Ah — already more than the 109.4 Ah required, with no extra parallel string needed

**Answer: At least 109.4 Ah at 24 V required; two 12 V, 150 Ah LiFePO4 batteries in series (24 V, 150 Ah) comfortably cover the daily evening outage**

#### SAFETY

A hybrid inverter connects to the grid, the battery, and often a generator, all at once. Never let a generator and the grid feed the system's AC input at the same time unless the hybrid inverter and changeover switch (Chapter 11) are specifically designed and rated for that. Also check the generator's own rated output against the hybrid inverter's charger rating before connecting them — an undersized generator asked to power the loads AND charge the battery at the same time can overload and stall.

#### CASE STUDY — A HYBRID SYSTEM FOR A FAMILY SHOP IN DUHOK · DUHOK, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

A small family shop in Duhok kept its national grid connection, added a modest solar array and battery, and kept its existing generator as a last resort. On most days, the array and battery alone cover the shop's lighting, refrigerator, and till during the evening grid outage. On a run of cloudy days, or on a day when the shop runs extra equipment for a delivery, the battery empties earlier than usual, and the generator's automatic starter (Lesson 4) switches it on to finish the evening. The owner did not have to choose ONE power source — the hybrid design lets solar, battery, grid, and generator each do the job they are best at.

### ACTIVITY (CLASSROOM) — PLAN A HYBRID SYSTEM'S PRIORITIES AND BACKUP

1. For a home or building you know, list its loads and mark which ones are critical (Chapter 10) during a power cut.
2. Write out a source priority order for the system — you may use this lesson's typical order, or explain why you would change it.
3. Estimate the area's typical daily grid outage length, in hours.
4. Using this lesson's equation, calculate the minimum battery bank capacity needed to cover that outage for the critical loads alone.

*You need: Calculator or phone, Your load list from Chapter 10, or a new one*

► *App tool: Check your hybrid battery bank sizing with the calculator*

► *App tool: Compare grid-lean and self-reliant array sizes with the PV Array Sizing calculator*

► *App simulation: See a hybrid system's energy flow, with adjustable grid outage hours, in the System Types simulation*

## 13.4 Backup Priorities and Reducing Generator Hours

Lesson 3 looked at priority from the SOURCE side — which power source the system uses first. This lesson looks at priority from the LOAD side — which appliances get power first when supply is limited — and then uses both ideas together to reduce how many hours the generator actually has to run.

Chapter 10 introduced critical and non-critical loads, and the critical loads panel — a separate panel carrying only the most important circuits. In a hybrid system, this panel is exactly what the battery is sized to protect (Lesson 3): during an outage, the hybrid inverter keeps the critical loads panel running from the battery, while non-critical loads simply wait for the grid or generator to return.

**A more detailed backup priority, for larger or more critical buildings**

| Priority tier                             | Example loads                                                   | Backup rule                                                                                    |
|-------------------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Tier 1 — must never lose power            | Medical refrigeration, safety lighting, communication equipment | Powered by the battery at all times; usually the first loads counted when choosing P_critical  |
| Tier 2 — important, short gaps acceptable | Household refrigerator, router, some lighting                   | Powered by the battery during normal outages; may be shed briefly if the battery runs very low |
| Tier 3 — can wait for grid or generator   | Washing machine, water heater, air conditioner                  | Left off the critical loads panel entirely; only powered when the grid or generator is running |

### WORD TO KNOW

**Generator autostart** — A hybrid system feature that starts the generator automatically once the battery's state of charge drops to a chosen threshold, and stops it again once the battery is recharged or the grid returns — without anyone needing to start it by hand.

The autostart threshold — the battery state of charge (Chapter 6) at which the generator switches on — is one of the most powerful settings in a hybrid system. It directly controls the trade-off between generator hours and battery stress.



### Generator autostart threshold: a trade-off

| Autostart threshold (battery SoC)                | Effect on generator hours                                     | Effect on the battery                                                                                          |
|--------------------------------------------------|---------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Higher threshold (for example, start at 50% SoC) | Generator starts sooner and more often — MORE generator hours | Shallower discharges each cycle — generally gentler on the battery (Chapter 6)                                 |
| Lower threshold (for example, start at 20% SoC)  | Generator starts later and less often — FEWER generator hours | Deeper discharges each cycle — check the battery's safe depth of discharge (Chapter 6) before setting this low |

### COMMON MISTAKE

**✗ Wrong:** Set the generator autostart threshold as low as possible — for example, 10% battery state of charge — to save the most fuel.

**✓ Right:** A very low autostart threshold forces deep, frequent battery discharges, which can shorten a battery's cycle life (Chapter 6) faster than the fuel savings are worth. Balance generator savings against battery health — many designs set the threshold near the battery's own safe depth-of-discharge limit, not below it.

### EQUATION: GENERATOR RUN TIME FROM THE ENERGY BALANCE

$$t_{\text{gen}} = \frac{E_{\text{outage}} - E_{\text{batt}} - E_{\text{solar}}}{P_{\text{gen}}}$$

*In words: Generator hours = (Outage energy need – Battery energy supplied – Solar energy supplied) ÷ Generator's average power*

| Symbol   | Meaning                                                                                          | Unit            |
|----------|--------------------------------------------------------------------------------------------------|-----------------|
| t_gen    | hours the generator must run to cover the remaining need                                         | hours (h)       |
| E_outage | total energy the loads need during the outage                                                    | watt-hours (Wh) |
| E_batt   | energy the battery supplies toward that need                                                     | watt-hours (Wh) |
| E_solar  | energy solar supplies directly during the outage window — often 0 for an evening or night outage | watt-hours (Wh) |
| P_gen    | the generator's average power output while running                                               | watts (W)       |

*This equation is really Chapter 1's  $E = P \times t$ , rearranged, applied to whatever energy is LEFT after solar and the battery have done their share. If the battery and solar together can supply the whole  $E_{\text{outage}}$ , the top of the equation reaches zero, and the generator is not needed that day at all.*

### WORKED EXAMPLE — FINDING THE GENERATOR'S RUN TIME

One evening, a shop's loads need 4000 Wh of energy during a 6-hour outage. The hybrid battery supplies 2400 Wh of this before running low, and no solar is available, because the outage is after sunset. The generator, once started, supplies the rest while running at an average loading of 2000 W. Find how long the generator must run.

1. Write the equation:  $t_{\text{gen}} = (E_{\text{outage}} - E_{\text{batt}} - E_{\text{solar}}) \div P_{\text{gen}}$
2. Put in the numbers:  $t_{\text{gen}} = (4000 - 2400 - 0) \div 2000$
3. Calculate the top:  $4000 - 2400 = 1600 \text{ Wh}$

4. Divide:  $t_{\text{gen}} = 1600 \div 2000 = 0.8 \text{ h}$
5. Convert to minutes:  $0.8 \times 60 = 48 \text{ minutes}$

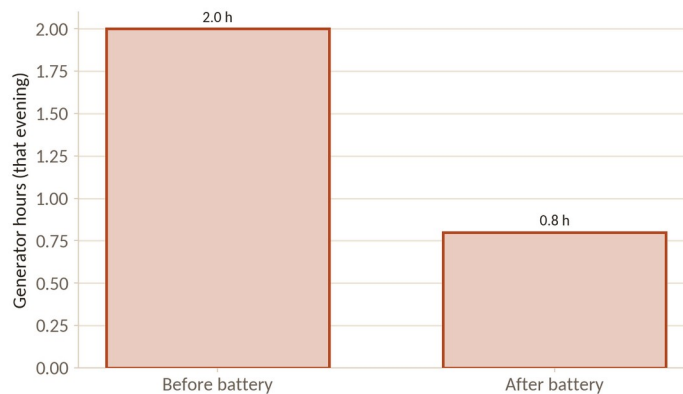
**Answer: 0.8 hours, or 48 minutes**

#### WORKED EXAMPLE — HOW MUCH DID THE BATTERY REDUCE GENERATOR HOURS?

Using the same shop from the last example: before the hybrid system was installed, the generator alone had to supply the full 4000 Wh outage need, at the same average loading of 2000 W. Find (a) the generator hours needed before the battery was added, (b) the percent reduction in generator hours after adding the battery, and (c) the hours saved in a 30-day month.

1. (a) Before:  $t_{\text{gen}}(\text{before}) = E_{\text{outage}} \div P_{\text{gen}} = 4000 \div 2000 = 2.0 \text{ h}$
2. After, from the last example:  $t_{\text{gen}}(\text{after}) = 0.8 \text{ h}$
3. (b) Reduction =  $(2.0 - 0.8) \div 2.0 \times 100 = 1.2 \div 2.0 \times 100 = 60\%$
4. (c) Hours saved per evening:  $2.0 - 0.8 = 1.2 \text{ h}$ . Over 30 days:  $1.2 \times 30 = 36 \text{ hours}$

**Answer: Generator hours dropped from 2.0 h to 0.8 h per evening — a 60% reduction, saving about 36 hours of generator run time a month**



*Generator hours needed to cover the same evening outage, before and after adding a correctly sized battery: from 2.0 hours down to 0.8 hours, a 60% reduction.*

Fewer generator hours also means less fuel burned, and less spent on fuel and maintenance every month. Chapter 15 turns saved hours like these into real currency, and compares the result with the system's cost.

#### SAFETY

Reducing generator hours is never a reason to bypass a changeover switch or automatic transfer switch (Chapter 11) to save a few minutes, or to run extension cords instead of a proper backup connection. These safety devices exist to stop the generator and the grid from ever meeting on the same wires — bypassing them risks equipment damage, fire, and danger to utility workers, no matter how much fuel it might seem to save.

#### CASE STUDY — CUTTING GENERATOR HOURS IN SULAYMANIYAH • SULAYMANIYAH, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

Before installing solar, a family in Sulaymaniyah ran their shared neighborhood generator subscription

every evening the national grid was off — often 4 to 6 hours a night (Chapter 1). After adding a modest hybrid system, sized using this chapter's methods, the battery alone covered most evenings completely, and the generator was only needed on longer cloudy runs, or on evenings with unusually heavy use. Over a full month, their estimated generator use dropped from about 150 hours to under 30 hours — a saving that paid for a meaningful share of the system over time (Chapter 15 studies the full financial picture).

#### ACTIVITY (CLASSROOM) — DESIGN A GENERATOR-REDUCTION PLAN

1. Take the battery bank you sized in Lesson 3's activity, or this lesson's worked example.
2. Estimate the evening outage energy need for the same loads: power × outage hours.
3. Using this lesson's equation, calculate the generator hours needed with and without the battery's contribution.
4. Discuss: where would you set the generator's autostart threshold for this family, and why?

*You need: Calculator or phone, Your results from Lesson 3's activity*

► *App tool: Revisit your battery sizing — a bigger battery normally means fewer generator hours*

► *App simulation: Adjust grid outage hours and see the unmet load a generator must cover, in the System Types simulation*

#### CHAPTER SUMMARY

- A grid-tied array is normally sized using the site's ANNUAL AVERAGE peak sun hours, not the design month used for off-grid arrays (Chapter 12), because the grid always fills any shortfall.
- Consumption offset is the target share of a home's average annual energy use that a grid-tied array is sized to produce:  $P_{\text{array}} = (\text{Offset} \times E_{\text{daily}}) \div (\text{PSH}_{\text{avg}} \times \text{PR})$ .
- Net metering credits exported energy at the same rate as imported energy; under true net metering, only the TOTAL net energy over a billing period decides the bill, not when the energy was used.
- Net billing credits exported energy at a different, often lower, rate than import — making self-consumption more valuable than export.
- Net metering and net billing rules differ by country, utility, and area, and can change over time. In Iraq and the Kurdistan Region, formal residential net-metering programs are not yet standard everywhere — always confirm the current local rule directly with the electricity provider.
- A hybrid system combines solar, a battery, the grid, and a generator, usually following a source priority: solar first, then the battery, then the grid, then the generator last.
- A hybrid system's battery is normally sized to cover the typical daily grid outage (backup hours), not the multi-day autonomy used for off-grid batteries:  $C_{\text{bank}} = (P_{\text{critical}} \times t_{\text{backup}}) \div (V_{\text{sys}} \times \text{DoD})$ .
- Hybrid array and battery sizing sits on a spectrum from grid-lean (smaller, cheaper, leans on the grid and generator) to self-reliant (larger, closer to off-grid sizing) — bigger is not automatically better; it is a cost-versus-reliance trade-off.
- Generator run hours can be calculated from an energy balance:  $t_{\text{gen}} = (E_{\text{outage}} - E_{\text{battery}} - E_{\text{solar}}) \div P_{\text{gen}}$  — the same  $E = P \times t$  idea from Chapter 1, applied to whatever energy solar and the battery could not supply.
- The generator's autostart threshold trades generator hours against battery stress: a lower threshold means fewer generator hours but deeper, more frequent battery discharges — balance it against the battery's safe depth of discharge (Chapter 6).

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A home uses 6 kWh per day on average (annual average). The site's annual average peak sun hours are 5.0 h/day, and the performance ratio is 0.80. Find the minimum array size for a 50% offset, in W.

**Problem 2 [Basic]** In one month, a home imports 300 kWh from the grid and exports 120 kWh of solar to the grid. Using true net metering (the same rate for import and export) at an example tariff of 100 IQD/kWh, find the month's bill.

**Problem 3 [Basic]** A hybrid system's critical loads total 250 W. The daily grid outage is 4 hours. The system voltage is 12 V, and the battery's maximum depth of discharge is 0.5. Find the required battery bank capacity, in Ah.

**Problem 4 [Basic]** An evening outage needs 2000 Wh of energy. A battery supplies 800 Wh of this. The generator supplies the rest, running at an average loading of 1000 W. Find the generator run time, in hours and in minutes.

**Problem 5 [Standard]** A shop's average daily consumption is 20 kWh. The owner wants a 70% offset. The site's annual average peak sun hours are an example 5.5 h/day, and the performance ratio is 0.78. Find the minimum array size, then choose a number of 450 W panels.

**Problem 6 [Standard]** A home's solar system produces 15 kWh on an average day. Of this, 6 kWh is used directly in the home (self-consumption), and the rest is exported. The home's total daily consumption is 18 kWh (it imports the remaining need from the grid beyond its self-consumed solar). Using an example import tariff of 100 IQD/kWh: (a) find the energy exported and imported; (b) find the bill under true net metering; (c) find the bill under net billing, where export is credited at only 60 IQD/kWh.

**Problem 7 [Standard]** A hybrid system's critical loads total 480 W. The typical daily grid outage is 5 hours. The system uses a 48 V system voltage and AGM batteries with a maximum depth of discharge of 0.7. Find the required battery capacity in Ah, and the number of 12 V, 100 Ah batteries needed (series and parallel).

**Problem 8 [Standard]** A family's average daily consumption is 9 kWh. Compare two design approaches for the same home: (a) grid-lean, an 80% offset target using an annual average peak sun hours of 5.0 h/day and PR = 0.80; (b) self-reliant, sized to cover close to the full daily need using a design-month peak sun hours of 2.8 h/day and the same PR. Find the array size for each, and how many times bigger the self-reliant array is.

**Problem 9 [Standard]** Before adding solar, a family's generator supplied all 3600 Wh of their evening outage energy, running at an average loading of 1200 W. After adding a hybrid system, a battery now supplies 2400 Wh of that need before the generator starts. Find (a) the generator hours needed before, (b) the generator hours needed after, (c) the percent reduction in generator hours.

**Problem 10 [Challenge]** A small clinic in a Kurdistan Region town has an average daily energy consumption of 18 kWh. The clinic wants a hybrid system. (a) Size the array for a 65% offset, using an annual average peak sun hours of 5.2 h/day and PR = 0.80, and choose a number of 450 W panels. (b) The clinic's critical loads (lights, a medicine refrigerator, and some equipment) total 900 W, and the typical daily grid outage is 5 hours. Using a 48 V system and LiFePO<sub>4</sub> batteries (DoD = 0.8), find the required battery capacity in Ah, and the number of 12 V, 200 Ah batteries needed (series and parallel). (c) On an unusual day, maintenance work on the grid line stretches the outage to 9 hours instead of 5. Using the FULL usable energy of the battery bank installed in (b) — system voltage × actual Ah × DoD — find how long the generator must run to cover the rest of that day's 900 W outage need, running at an average loading of 1800 W. (d) Find the percent reduction in generator hours this battery gives, compared with having no battery at all for this same 9-hour outage.

**Problem 11 [Challenge]** A household's solar system produces 20 kWh on an average day. Of this, 8 kWh is used directly in the home (self-consumption), and the rest is exported. The home's total daily consumption is 24 kWh. Using an example import tariff of 120 IQD/kWh: (a) find the daily energy exported and imported. (b) find the daily bill under true net metering (export credited at the same 120 IQD/kWh rate). (c) find the daily bill under a net billing example, where export is credited at only 45 IQD/kWh. (d) compare both bills with the no-solar bill (24 kWh, all imported), and state which arrangement benefits the household more.

**Problem 12 [Challenge]** A rural primary school has an average daily consumption of 14 kWh, from lights, fans, computers, and a water pump. The school wants a hybrid system with a 75% offset target. (a) Using an annual average peak sun hours of 5.4 h/day and  $PR = 0.80$ , find the minimum array size and choose a number of 400 W panels. (b) The school's critical loads during a power cut — lights and computers only, no fans or pump — total 260 W, and the typical daily grid outage is 6 hours. Using a 24 V system and AGM batteries ( $DoD = 0.6$ ), find the required battery Ah, and the battery count using 12 V, 100 Ah batteries (series and parallel). (c) One evening, the battery had already used some of its charge earlier in the day, so only 1200 Wh of usable battery energy is left for the evening backup. The generator supplies the rest of the  $260\text{ W} \times 6\text{ h}$  outage need, running at an average loading of 900 W. Find the new generator run time, and the percent reduction compared with having no battery at all that evening.

## CHAPTER FOURTEEN

# Solar Water Pumping

*Moving water with sunlight — for wells, farms, and irrigation*

### IN THIS CHAPTER YOU WILL LEARN TO

- Describe the main types of solar water pumps — surface, submersible, DC, and AC — and explain when each is used.
- Calculate a pump's total dynamic head, flow rate, and hydraulic power, converting flow rate units carefully.
- Calculate the daily electrical energy a pump needs and size a solar array to supply it.
- Explain why solar pumping systems usually store water in a tank instead of energy in a battery, and size a simple storage tank.
- Plan a simple irrigation schedule that matches pumping hours to sunlight and watering hours to low-evaporation times.

## 14.1 Pump Types and How They Work

Water and sunlight often arrive together. Farms need the most water on hot, sunny days — exactly when a solar panel produces the most power. This simple match makes water pumping one of the best jobs for solar energy anywhere in the world, including Iraq and the Kurdistan Region. This lesson introduces the machines that do the work: solar water pumps.

### WORD TO KNOW

**Pump** — A machine that moves a fluid — in this course, always water — from one place to another. A pump adds energy to water, usually to lift it higher or push it further through a pipe.

Pumps can be grouped in two useful ways: by WHERE they sit compared with the water (surface or submersible), and by WHAT KIND of electric current drives their motor (DC or AC). This lesson looks at both groupings.

### WORD TO KNOW

**Surface pump** — A pump that stays above the water, usually on the ground or a platform, and pulls water up into itself through a suction pipe. Also called a suction pump.

### WORD TO KNOW

**Suction lift** — The vertical distance a surface pump pulls water upward by suction, before pushing it onward. Limited by air pressure to about 10 m in theory, and to about 6–7 m in real, practical systems.

Why is suction lift limited at all? A surface pump does not really 'pull' water up by magic. It lowers the pressure inside its suction pipe, and normal air pressure pushing down on the water's surface forces the water up to fill that lower pressure. Air pressure is strong, but it is not unlimited. Once a pump tries to lift water higher than about 6–7 m by suction, it cannot keep enough water in the pipe, and it loses its flow — engineers call this **losing its prime**.

#### COMMON MISTAKE

**✗ Wrong:** A surface pump can be installed at any height above the water, as long as its motor is strong enough.

**✓ Right:** Keep a surface pump's suction lift under about 6–7 m, no matter how strong its motor is. Beyond that limit, air pressure alone cannot support the column of water. Install the pump closer to the water, or choose a submersible pump instead.

#### WORD TO KNOW

**Submersible pump** — A pump built to work fully underwater. It is sealed so water cannot damage its motor, and it is lowered into a borehole, well, or tank, where it **PUSHES** water up and out through a pipe, instead of pulling it from above.

#### WORD TO KNOW

**Borehole** — A narrow, deep hole drilled into the ground to reach groundwater, usually lined with a pipe casing. Boreholes are a common water source for farms, orchards, and rural homes across Iraq and the Kurdistan Region.

Because a submersible pump **PUSHES** water instead of pulling it, it has no suction-lift limit at all. Its real limit is simply how much total head (Lesson 2) it is built and powered to overcome. This is exactly why submersible pumps, not surface pumps, are used in most boreholes.

#### Surface pumps vs. submersible pumps

| Feature              | Surface pump                                              | Submersible pump                                                      |
|----------------------|-----------------------------------------------------------|-----------------------------------------------------------------------|
| Typical water source | Shallow well, tank, canal, or river, close to the surface | Deep borehole or well                                                 |
| Depth limit          | Suction lift limit: about 6–7 m                           | No suction limit — pushes water up from any practical depth           |
| Cooling              | Motor sits in open air                                    | Motor is cooled by the surrounding water                              |
| Access for repair    | Easy — the pump is right there, above ground              | Harder — the whole pump must be pulled up out of the well or borehole |

#### WORD TO KNOW

**Centrifugal pump** — The most common type of pump. A spinning part called an impeller throws water outward with force, creating flow. Most solar surface and submersible pumps use this design. It gives a steady flow, but that flow changes with head — Lesson 2 explains this with a pump curve.

Now the second grouping: what kind of electricity drives the pump's motor.

#### WORD TO KNOW

**DC pump** — A pump whose motor runs directly on direct current (DC). It usually connects straight to a solar array through a small pump controller, with no separate inverter needed.

#### WORD TO KNOW

**AC pump** — A pump whose motor runs on alternating current (AC) — the same kind of motor used in ordinary mains-powered pumps. In a solar system, something must first change the array's DC power into AC power for the motor.

#### WORD TO KNOW

**Pump controller** — The device between a solar array and a pump. It matches the array's changing DC power to what the pump motor needs at that moment, and it protects the pump. For an AC pump, it also changes DC into AC, similar to an inverter (Chapter 8), but built specially for a pump motor.

#### SAFETY

Never let a pump run dry — meaning, without water around it or flowing through it. A dry pump has no water to cool it or lubricate its seals, and a submersible pump especially can overheat and fail within minutes. A good pump controller includes automatic dry-run protection, switching the pump off if the water level or flow drops too low. Always check that this feature is fitted and working before leaving a pump unattended.

#### COMMON MISTAKE

✗ **Wrong:** Connect any ordinary AC water pump from a hardware store straight to a solar array.

✓ **Right:** An AC pump needs a properly sized inverter or a dedicated solar pump controller between it and the array. Bare DC array wires cannot run an AC motor at all, and an undersized inverter can trip, or be damaged, the moment the motor starts (Chapter 8).

#### Choosing a pump type — a simple starting guide

| Water source or situation                                           | Likely pump choice                               |
|---------------------------------------------------------------------|--------------------------------------------------|
| Shallow canal, tank, or well (under about 6–7 m to the water)       | Surface pump                                     |
| Deep borehole                                                       | Submersible pump                                 |
| Small household, garden, or livestock-trough system                 | Often DC — simple, and needs no inverter         |
| Larger farm or irrigation system, or a pump reused from mains power | Often AC, with a dedicated solar pump controller |

#### CASE STUDY — TWO NEIGHBORS, TWO PUMP CHOICES • A VILLAGE IN THE KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)



Two neighboring farms each need a solar water pump. The first farm draws water from an irrigation canal that runs close to field level — only about 1.5 m below where the pump will sit. A simple surface pump, powered by a small DC solar array, does the job well, and the farmer can easily lift it out for cleaning or repair. The second farm's only water source is a borehole drilled 35 m deep. A surface pump could never work here — no pump can suck water up 35 m, since suction lift tops out at about 6–7 m. This farm instead needs a submersible pump, lowered deep into the borehole on its own cable and pipe, pushing water up from far below. Same goal, two very different water sources, two completely different pumps.

#### ACTIVITY (FIELD) — PUMP DETECTIVE

1. Find a water pump you can see — at home, at school, on a farm, or in a photo or video.
2. Decide: is it a surface pump or a submersible pump? What clue told you?
3. Decide: does it look like it runs on AC or DC? Is there an inverter, a pump controller, or a normal plug nearby?
4. Write down the water source it uses, and estimate how far the water must travel — up, along, or both.

*You need: Notebook or phone, A real pump to observe, if possible — otherwise research one online or ask a family member*

## 14.2 Head, Flow, and Hydraulic Power

To size any solar pump, you must answer two questions: how HIGH (or how far) must the water go, and how MUCH water is needed? Together with the weight of water and gravity, these two answers give the power a pump must deliver. This lesson builds that idea step by step, with an equation you will use for the rest of the chapter.

#### WORD TO KNOW

**Static head** — The real vertical height water must be lifted, measured straight up from the water source's surface to the point where the water is delivered — for example, the top of a storage tank. Measured in meters (m).

For a borehole, static head has two parts: the depth down to the water, plus the height back up to the delivery point. And there is a small trap here — while a pump is running, the water level inside a well often drops a little lower than its resting level. This extra drop is called **drawdown**. A careful design adds the expected drawdown to the resting water depth before finding the real static head.

#### WORD TO KNOW

**Friction head loss** — The extra equivalent height 'lost' as water rubs against the inside of pipes, valves, and fittings on its way to its destination. It depends on pipe length, pipe width, and flow rate — narrower pipes and higher flow rates cause more friction loss.

#### WORD TO KNOW

**Total dynamic head** — The full height-equivalent a pump must overcome: the static head plus the friction head loss. Written H, or TDH. This is the head used in the hydraulic power equation.

#### EQUATION: TOTAL DYNAMIC HEAD

$$H = H_{\text{static}} + H_{\text{friction}}$$

In words: Total dynamic head = static head + friction head loss

| Symbol                | Meaning                                                                      | Unit       |
|-----------------------|------------------------------------------------------------------------------|------------|
| H                     | total dynamic head (TDH) — the full height-equivalent the pump must overcome | meters (m) |
| H <sub>static</sub>   | static head — the real vertical lift, including any drawdown                 | meters (m) |
| H <sub>friction</sub> | friction head loss — the extra height 'lost' to pipe friction                | meters (m) |

A full pipe-friction calculation uses tables based on pipe length, width, and material, which is beyond this course. For hand calculations here, when a detailed value is not given, estimate H<sub>friction</sub> as about 10% of H<sub>static</sub>.

### WORKED EXAMPLE — TOTAL DYNAMIC HEAD FOR A BOREHOLE PUMP

A submersible pump lifts water from a borehole. While the pump runs, the water surface sits 18 m below ground (this already includes drawdown). The delivery pipe then rises 4 m further to reach the top of a storage tank. Estimate the friction head loss as 10% of the static head. Find the total dynamic head.

1. Find the static head:  $H_{\text{static}} = 18 + 4 = 22 \text{ m}$
2. Estimate the friction head loss:  $H_{\text{friction}} = 10\% \times 22 = 2.2 \text{ m}$
3. Add them:  $H = H_{\text{static}} + H_{\text{friction}} = 22 + 2.2 = 24.2 \text{ m}$

**Answer:  $H \approx 24.2 \text{ m}$**

### WORD TO KNOW

**Flow rate** — The volume of water a pump moves in a given time. Written Q. Common units include liters per minute (L/min), liters per second (L/s), and cubic meters per hour (m<sup>3</sup>/h).

### Converting flow rate to m<sup>3</sup>/s (needed for the hydraulic power equation)

| Starting unit                                 | To get m <sup>3</sup> /s | Example                                                                    |
|-----------------------------------------------|--------------------------|----------------------------------------------------------------------------|
| Liters per second (L/s)                       | Divide by 1000           | $60 \text{ L/s} \div 1000 = 0.06 \text{ m}^3/\text{s}$                     |
| Liters per minute (L/min)                     | Divide by 60,000         | $45 \text{ L/min} \div 60,000 = 0.00075 \text{ m}^3/\text{s}$              |
| Liters per hour (L/h)                         | Divide by 3,600,000      | $3000 \text{ L/h} \div 3,600,000 \approx 0.000833 \text{ m}^3/\text{s}$    |
| Cubic meters per hour (m <sup>3</sup> /h)     | Divide by 3600           | $3.0 \text{ m}^3/\text{h} \div 3600 \approx 0.000833 \text{ m}^3/\text{s}$ |
| Cubic meters per minute (m <sup>3</sup> /min) | Divide by 60             | $0.5 \text{ m}^3/\text{min} \div 60 \approx 0.00833 \text{ m}^3/\text{s}$  |

Quick mental method for L/min: divide by 60 to get L/s, then divide by 1000 to get m<sup>3</sup>/s. That is the same as dividing by 60,000 in one step. Get comfortable with this table — mixing up flow rate units is the single most common mistake in pump calculations.

### WORD TO KNOW

**Hydraulic power** — The real, useful power delivered to the water itself — the power needed, in theory, to lift a certain flow of water through a certain head. Written P<sub>hyd</sub>. This is the pump's OUTPUT in terms of

water, not the electrical power it draws from the array.

#### EQUATION: HYDRAULIC POWER

$$P_{\text{hyd}} = \rho \times g \times Q \times H$$

*In words: Hydraulic power = water density × gravity × flow rate × total head*

| Symbol           | Meaning                                                                         | Unit                                           |
|------------------|---------------------------------------------------------------------------------|------------------------------------------------|
| P <sub>hyd</sub> | hydraulic power — the useful power delivered to the water                       | watts (W)                                      |
| ρ                | density of water — always 1000 kg/m <sup>3</sup> for fresh water in this course | kilograms per cubic meter (kg/m <sup>3</sup> ) |
| g                | gravitational acceleration — always 9.81 m/s <sup>2</sup> on Earth              | meters per second squared (m/s <sup>2</sup> )  |
| Q                | flow rate — the volume of water moved each second                               | cubic meters per second (m <sup>3</sup> /s)    |
| H                | total dynamic head                                                              | meters (m)                                     |

*ρ and g are constants in this course: always 1000 kg/m<sup>3</sup> and 9.81 m/s<sup>2</sup>. Q MUST be in m<sup>3</sup>/s for this equation to give an answer in watts — always convert flow rate to m<sup>3</sup>/s first, using the table above.*

#### WORKED EXAMPLE — HYDRAULIC POWER FOR THE BOREHOLE PUMP

The borehole pump from the last worked example has a total dynamic head of 24.2 m. It delivers a flow rate of 45 liters per minute (L/min). Find the hydraulic power.

1. Convert the flow rate to m<sup>3</sup>/s FIRST:  $Q = 45 \text{ L/min} \div 60,000 = 0.00075 \text{ m}^3/\text{s}$
2. Write the equation:  $P_{\text{hyd}} = \rho \times g \times Q \times H$
3. Put in the numbers:  $P_{\text{hyd}} = 1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 0.00075 \text{ m}^3/\text{s} \times 24.2 \text{ m}$
4. Multiply step by step:  $1000 \times 9.81 = 9810$
5.  $9810 \times 0.00075 = 7.3575$
6.  $7.3575 \times 24.2 \approx 178.1$

**Answer: P<sub>hyd</sub> ≈ 178 W**

That 178 W is the power delivered to the water. It is NOT the electrical power the pump draws from the array — no real pump or motor is perfect. Some of the electrical power always becomes heat and friction inside the pump instead of useful hydraulic power.

#### WORD TO KNOW

**Pump efficiency** — The share of a pump's electrical (or shaft) input power that becomes useful hydraulic power in the water; the rest is lost as heat and friction inside the pump and motor. This is different from a solar panel's efficiency (Chapter 4), which is about turning sunlight into electricity, and from general energy efficiency (Chapter 10), which is about appliances doing the same job using less electricity.

#### EQUATION: ELECTRICAL POWER A PUMP NEEDS

$$P_{\text{input}} = \frac{P_{\text{hyd}}}{\eta_{\text{pump}}}$$

In words: Electrical input power = hydraulic power ÷ pump efficiency

| Symbol  | Meaning                                                 | Unit                                       |
|---------|---------------------------------------------------------|--------------------------------------------|
| P_input | the electrical power the pump draws from its controller | watts (W)                                  |
| P_hyd   | hydraulic power                                         | watts (W)                                  |
| η_pump  | pump-and-motor efficiency                               | ratio, no unit (0 to 1, e.g. 0.45 for 45%) |

η\_pump is written as a decimal fraction, the same way as depth of discharge (Chapter 6) and performance ratio (Chapter 12). Small solar submersible pumps often have a combined pump-and-motor efficiency of only about 35–55%. Larger, well-matched pumps can reach 60% or more. Always use the manufacturer's datasheet value when one is available.

#### WORKED EXAMPLE — ELECTRICAL POWER FOR THE BOREHOLE PUMP

The pump above needs 178 W of hydraulic power. Its datasheet gives a combined pump-and-motor efficiency of 45%. Find the electrical power the pump must draw.

1. Write the equation:  $P_{\text{input}} = P_{\text{hyd}} \div \eta_{\text{pump}}$
2. Put in the numbers:  $P_{\text{input}} = 178 \text{ W} \div 0.45$
3. Calculate:  $P_{\text{input}} \approx 395.6 \text{ W}$

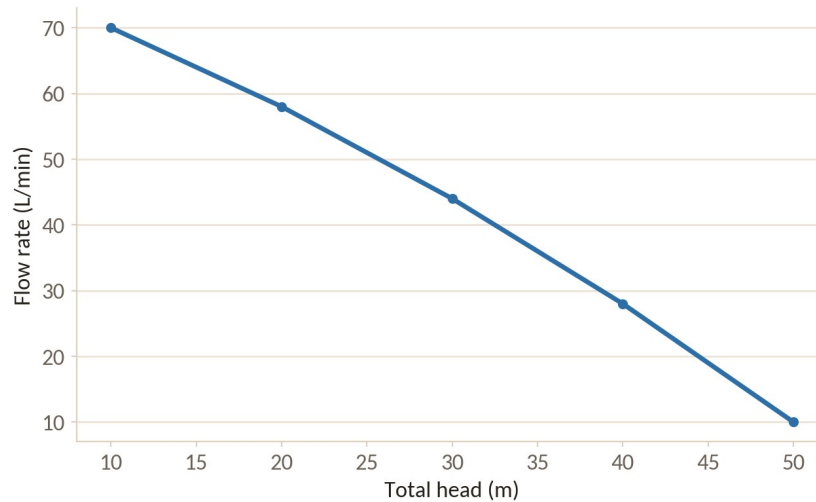
**Answer: P\_input ≈ 396 W**

#### WORD TO KNOW

**Pump curve** — A graph or table from a pump's manufacturer showing how much flow (Q) the pump delivers at each possible head (H). For most pumps, flow drops as head rises. The pump's real operating point is always wherever the system's actual head crosses this curve — not simply the highest flow number printed on the box.

#### Example performance curve for a small solar submersible pump

| Total head (m) | Flow rate (L/min) |
|----------------|-------------------|
| 10             | 70                |
| 20             | 58                |
| 30             | 44                |
| 40             | 28                |
| 50             | 10                |



*Example performance curve for a small solar submersible pump: as head goes up, the flow it can deliver goes down.*

#### COMMON MISTAKE

**✗ Wrong:** Assume a pump will always deliver the maximum flow rate written on its box or label, no matter the actual head.

**✓ Right:** Always check the pump's performance curve (or datasheet table) AT your system's actual total dynamic head. The same pump can deliver very different flow rates at different heads — sometimes far less than its 'headline' number.

#### ACTIVITY (HOME) — MEASURE A REAL FLOW RATE

1. Find a tap, hose, or pump outlet you can safely use.
2. Time how long it takes to fill a container of known volume — for example, a 10-liter bucket.
3. Calculate the flow rate in liters per minute:  $Q = \text{volume} \div \text{time}$ .
4. Convert your answer to  $\text{m}^3/\text{s}$  using the table above.

*You need: A bucket or container of known volume, A stopwatch or phone timer*

► *App tool: Try it: calculate hydraulic and electrical power for your own head and flow numbers*

### 14.3 Sizing the Array for a Pump

Lesson 2 found hydraulic and electrical power at ONE instant. But to size a solar array, we need ENERGY for a whole day — how much the pump must lift over 24 hours. This lesson turns yesterday's power equation into a daily-energy equation, then follows Chapter 12's design chain to reach a final array size, in watts.

#### CASE STUDY — AN ORCHARD BOREHOLE: FROM DIESEL TO SUN • KURDISTAN REGION ORCHARD (ILLUSTRATIVE COMPOSITE EXAMPLE)

A family orchard of about 2 hectares relies on a 30 m deep borehole for irrigation water — far beyond a surface pump's suction-lift limit (Lesson 1), so a submersible pump is the only realistic choice. For many years, a diesel-powered pump supplied the water: reliable, but costly, needing regular fuel deliveries, oil changes, and noisy running for hours on every irrigation day. The family decided to replace it with a solar-powered submersible pump, feeding a new elevated storage tank (Lesson 4 explains why a tank, not a

battery, is the natural choice here). Their engineer's first task was exactly the calculation on this page: find the daily water need and total head, then size the array.

The engineer measured the orchard's daily water need as 18 m<sup>3</sup> (18,000 liters), and the borehole's total dynamic head, including friction, as 30 m. Since  $Q \times t = V$  (flow rate  $\times$  time = volume), the hydraulic power equation from Lesson 2 can be rewritten to use a whole day's VOLUME instead of an instant's flow rate.

#### EQUATION: DAILY HYDRAULIC ENERGY NEEDED

$$E_{\text{hyd}} = \frac{\rho \times g \times V_{\text{daily}} \times H}{3600}$$

*In words: Daily hydraulic energy = (water density  $\times$  gravity  $\times$  daily volume  $\times$  total head)  $\div$  3600*

| Symbol  | Meaning                                                   | Unit                                           |
|---------|-----------------------------------------------------------|------------------------------------------------|
| E_hyd   | hydraulic energy needed per day                           | watt-hours per day (Wh/day)                    |
| $\rho$  | density of water — always 1000 kg/m <sup>3</sup>          | kilograms per cubic meter (kg/m <sup>3</sup> ) |
| g       | gravitational acceleration — always 9.81 m/s <sup>2</sup> | meters per second squared (m/s <sup>2</sup> )  |
| V_daily | the total volume of water needed per day                  | cubic meters per day (m <sup>3</sup> /day)     |
| H       | total dynamic head                                        | meters (m)                                     |

*Dividing by 3600 converts joules (J) into watt-hours (Wh), because 1 Wh = 3600 J — the same idea as Chapter 1's  $E = P \times t$ , just built from  $\rho$ ,  $g$ ,  $V$ , and  $H$  instead of  $P$  and  $t$  directly.*

#### EQUATION: DAILY HYDRAULIC ENERGY — SHORTCUT FORM

$$E_{\text{hyd}} = 2.725 \times V_{\text{daily}} \times H$$

*In words: Daily hydraulic energy (Wh) = 2.725  $\times$  daily volume (m<sup>3</sup>)  $\times$  total head (m)*

| Symbol  | Meaning                                  | Unit                                       |
|---------|------------------------------------------|--------------------------------------------|
| E_hyd   | hydraulic energy needed per day          | watt-hours per day (Wh/day)                |
| V_daily | the total volume of water needed per day | cubic meters per day (m <sup>3</sup> /day) |
| H       | total dynamic head                       | meters (m)                                 |

*This is exactly the equation above, simplified — because  $\rho$ ,  $g$ , and 3600 never change in this course,  $\rho \times g \div 3600 = 1000 \times 9.81 \div 3600 = 2.725$  exactly. Keep  $V_{\text{daily}}$  in m<sup>3</sup> (not liters) and  $H$  in m for this shortcut to work.*

#### WORKED EXAMPLE — DAILY HYDRAULIC ENERGY FOR THE ORCHARD

Using  $V_{\text{daily}} = 18 \text{ m}^3$  and  $H = 30 \text{ m}$ , find the orchard's daily hydraulic energy need.

1. Write the full equation:  $E_{\text{hyd}} = (\rho \times g \times V_{\text{daily}} \times H) \div 3600$
2. Put in the numbers:  $E_{\text{hyd}} = (1000 \times 9.81 \times 18 \times 30) \div 3600$

3. Multiply the top:  $1000 \times 9.81 \times 18 \times 30 = 5,297,400$

4. Divide by 3600:  $E_{\text{hyd}} \approx 1471.5 \text{ Wh}$

5. Check with the shortcut:  $E_{\text{hyd}} = 2.725 \times 18 \times 30 = 2.725 \times 540 = 1471.5 \text{ Wh}$  ✓ (same answer)

**Answer:  $E_{\text{hyd}} \approx 1471.5 \text{ Wh}$  (1.47 kWh) per day**

Just like in Lesson 2, this hydraulic energy is not what the pump actually draws electrically. Divide by the pump-and-motor efficiency to find the real daily electrical energy — the same idea as Lesson 2's power equation, just applied to a whole day of energy instead of one instant of power.

#### EQUATION: ELECTRICAL ENERGY THE PUMP NEEDS EACH DAY

$$E_{\text{elec}} = \frac{E_{\text{hyd}}}{\eta_{\text{pump}}}$$

*In words: Daily electrical energy = daily hydraulic energy ÷ pump efficiency*

| Symbol               | Meaning                                      | Unit                        |
|----------------------|----------------------------------------------|-----------------------------|
| $E_{\text{elec}}$    | electrical energy the pump must draw per day | watt-hours per day (Wh/day) |
| $E_{\text{hyd}}$     | hydraulic energy needed per day              | watt-hours per day (Wh/day) |
| $\eta_{\text{pump}}$ | pump-and-motor efficiency                    | ratio, no unit (0 to 1)     |

*Round nothing until the very last step of a design — carry full decimal numbers through the chain, and only round the final, buildable answer.*

#### WORKED EXAMPLE — DAILY ELECTRICAL ENERGY FOR THE ORCHARD

The orchard's pump-and-motor combination is 42% efficient. Find the electrical energy needed per day.

1. Write the equation:  $E_{\text{elec}} = E_{\text{hyd}} \div \eta_{\text{pump}}$

2. Put in the numbers:  $E_{\text{elec}} = 1471.5 \text{ Wh} \div 0.42$

3. Calculate:  $E_{\text{elec}} \approx 3503.6 \text{ Wh}$

**Answer:  $E_{\text{elec}} \approx 3503.6 \text{ Wh}$  (about 3.50 kWh) per day**

#### WORD TO KNOW

**Pumping season** — The months of the year when a pump actually needs to run — for example, the dry growing season for crop irrigation. A pump array is often sized using the peak sun hours of the pumping season itself, not the worst month of the whole year, if the pump is not needed outside that season.

Recall Chapter 12's array-sizing equation: array power = daily energy need ÷ (peak sun hours × performance ratio). The very same equation now sizes a pump's array — just fed by  $E_{\text{elec}}$  instead of a home's appliance energy.

#### EQUATION: SIZING THE ARRAY FOR A PUMP

$$P_{\text{array}} = \frac{E_{\text{elec}}}{PSH \times PR}$$

In words: Minimum array power = daily electrical energy ÷ (peak sun hours × performance ratio)

| Symbol  | Meaning                                      | Unit                        |
|---------|----------------------------------------------|-----------------------------|
| P_array | the minimum array power the design needs     | watts-peak (Wp)             |
| E_elec  | electrical energy the pump must draw per day | watt-hours per day (Wh/day) |
| PSH     | peak sun hours for the pumping season        | hours per day (h/day)       |
| PR      | performance ratio                            | ratio, no unit (0 to 1)     |

Use the peak sun hours of the actual pumping season, and this book's example performance ratio range of about 0.75–0.85, unless a better number is known. A pump that must run every day of the year (like a village drinking-water supply) should instead use Chapter 12's design-month rule.

#### WORKED EXAMPLE — SIZING THE ORCHARD'S SOLAR ARRAY

The orchard pump needs 3503.6 Wh of electrical energy per day. The farm irrigates mainly in the summer growing season, when the example peak sun hours are 7.5 h/day. Using a performance ratio of 0.80, find the minimum array size, and choose a practical number of panels.

1. Write the equation:  $P_{\text{array}} = E_{\text{elec}} \div (PSH \times PR)$
2. Multiply the bottom:  $PSH \times PR = 7.5 \times 0.80 = 6.0$
3. Divide:  $P_{\text{array}} = 3503.6 \text{ Wh} \div 6.0 \text{ h} \approx 583.9 \text{ W}$
4. Choose real panels: with example 400 W panels,  $583.9 \div 400 \approx 1.46 \rightarrow$  round up to 2 panels = 800 W

**Answer: At least about 584 W (0.58 kWp) needed; two 400 W panels (800 W total) comfortably cover it**

#### COMMON MISTAKE

**X Wrong:** Size a pump's array using the site's worst winter peak sun hours, just like an off-grid home in Chapter 12.

**✓ Right:** For a seasonal pump load — like summer irrigation — size the array using the peak sun hours of the actual pumping season. Using winter's worst-case sun hours for a pump that never runs in winter wastes money on an oversized array. A pump that must run all year round, such as a village drinking-water supply, should still follow Chapter 12's design-month rule.

#### WORKED EXAMPLE — WHAT IF THE DESIGN USED WINTER SUN HOURS INSTEAD?

Compare the array size needed if the design mistakenly used this region's winter peak sun hours (3.0 h/day) instead of the summer pumping-season value (7.5 h/day), keeping the same 3503.6 Wh/day need and PR = 0.80.

1. Multiply the bottom:  $PSH \times PR = 3.0 \times 0.80 = 2.4$
2. Divide:  $P_{\text{array}} = 3503.6 \text{ Wh} \div 2.4 \text{ h} \approx 1459.8 \text{ W}$
3. Compare with the summer answer:  $1459.8 \div 583.9 \approx 2.5$

**Answer: About 1460 W would be 'needed' — exactly 2.5 times bigger than the correct summer-sized array, because the peak sun hours dropped by exactly that same 2.5× factor**



### The orchard, before and after

| Feature         | Diesel pump (before)                                             | Solar pump (after)                                                              |
|-----------------|------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Running cost    | Needs regular diesel fuel; cost rises and falls with fuel prices | No fuel — sunlight is free                                                      |
| Noise           | Loud engine while running                                        | Silent                                                                          |
| Maintenance     | Regular oil changes and engine service                           | Occasional cleaning; no engine to service                                       |
| Water timing    | Can run whenever fuel is available                               | Runs mainly in daylight, so a storage tank is needed for other times (Lesson 4) |
| Local emissions | Diesel exhaust at the site                                       | None while running                                                              |

### ACTIVITY (CLASSROOM) — SIZE AN ARRAY FOR YOUR OWN EXAMPLE

1. Pick an example (or real, if you know one) daily water need in  $\text{m}^3$  and a total dynamic head in m.
2. Choose an example pump-and-motor efficiency between 35% and 55%, and calculate the daily hydraulic and electrical energy.
3. Choose an example peak sun hours value for the pumping season, and a performance ratio of 0.80, then calculate the minimum array size.
4. Compare your array size with a classmate's — whose site needs the bigger array, and why?

*You need: Calculator or phone*

► App tool: Try it: look up peak sun hours for different cities and months

► App tool: Check your full pump-to-array calculation with the Solar Water Pump calculator

## 14.4 Water Storage and Irrigation Scheduling

An off-grid home (Chapter 12) stores its extra solar energy in a battery, so lights and appliances can run after dark. A solar pumping system faces the very same problem — the sun does not shine at night, or on a cloudy day — but its everyday solution is usually different. Instead of a battery full of electricity, most solar pumping systems use a tank full of water.

### WORD TO KNOW

**Storage tank** — A container that holds pumped water for later use — for drinking, irrigation, or livestock. It lets a solar pump run only while the sun shines, while water is still available at any hour.

Why is a tank usually a better 'battery' for a pumping system than an actual battery? Water storage is simple, it does not wear out from repeated use the way a battery's chemistry does (Chapter 6), and building or buying tank capacity is often the cheapest kind of energy reserve a pumping system can have.

### Battery storage vs. water tank storage

| Feature               | Battery (Chapter 6)                            | Water tank                                                          |
|-----------------------|------------------------------------------------|---------------------------------------------------------------------|
| What is really stored | Chemical energy, later released as electricity | Water already lifted to height — ready to use or release by gravity |

| Feature                          | Battery (Chapter 6)                                                  | Water tank                                                                   |
|----------------------------------|----------------------------------------------------------------------|------------------------------------------------------------------------------|
| Lifespan                         | Limited cycle life; wears out and needs replacing (Chapter 6)        | Lasts decades with simple upkeep — no charge/discharge cycles to wear it out |
| Complexity                       | Needs correct charging stages, and care with heat and deep discharge | No chemistry, no settings — just keep it clean and structurally sound        |
| Typical cost per unit of reserve | Relatively high, and rises with capacity and battery quality         | Often the cheapest way to add a day or more of reserve to a pumping system   |

This does not mean solar pumping systems never use a battery at all. A small battery is sometimes still added — for example, to run a security light at the well, or to keep a controller's electronics powered overnight. But for the water itself, a tank is almost always the simpler, cheaper choice.

#### SAFETY

A full tank is very heavy. Recall from Lesson 2 that water's density is  $1000 \text{ kg/m}^3$  — so  $1 \text{ m}^3$  of water has a mass of 1000 kg, one tonne. A  $10 \text{ m}^3$  tank, completely full, weighs about 10 tonnes. Always have a qualified person check that a tank's stand, tower, or roof support is strong enough BEFORE it is filled. An improperly supported tank can collapse.

#### WORD TO KNOW

**Gravity-fed system** — A water system where an elevated tank supplies water to fields or taps using only gravity, with no extra pump needed for delivery.

#### COMMON MISTAKE

**X Wrong:** Build the storage tank at ground level, right next to the field, because it is the easiest and cheapest to construct.

**✓ Right:** Where possible, elevate the tank — on a tower, platform, or natural high ground. A raised tank delivers water to the field by gravity, with no extra pump or energy needed. A ground-level tank usually needs a second pump just to distribute the water, adding cost and complexity.

#### WORD TO KNOW

**Days of water storage** — The number of days a full tank can supply a system's daily water need by itself, with little or no help from the pump — the water version of Chapter 12's 'days of autonomy' idea for batteries.

#### EQUATION: SIZING A STORAGE TANK

$$V_{\text{tank}} = V_{\text{daily}} \times N_{\text{store}}$$

*In words: Tank capacity = daily water need × days of storage*

| Symbol | Meaning | Unit |
|--------|---------|------|
|--------|---------|------|

|         |                                          |                                                               |
|---------|------------------------------------------|---------------------------------------------------------------|
| V_tank  | required tank capacity                   | cubic meters (m <sup>3</sup> ), or liters                     |
| V_daily | the total volume of water needed per day | cubic meters per day (m <sup>3</sup> /day), or liters per day |
| N_store | days of water storage desired            | days                                                          |

Keep V\_daily and V\_tank in the SAME volume unit (both m<sup>3</sup>, or both liters). This is the water version of Chapter 12's battery bank equation — but with no voltage or depth-of-discharge term to worry about.

#### WORKED EXAMPLE — TANK SIZE FOR THE ORCHARD

The orchard from Lesson 3 needs 18 m<sup>3</sup> of water a day. The family wants 1.5 days of storage, enough to smooth out one cloudy day and give some flexibility in when they irrigate. Find the minimum tank capacity.

1. Write the equation:  $V_{\text{tank}} = V_{\text{daily}} \times N_{\text{store}}$
2. Put in the numbers:  $V_{\text{tank}} = 18 \text{ m}^3 \times 1.5 \text{ days}$
3. Calculate:  $V_{\text{tank}} = 27 \text{ m}^3$

**Answer:  $V_{\text{tank}} = 27 \text{ m}^3$  (27,000 liters)**

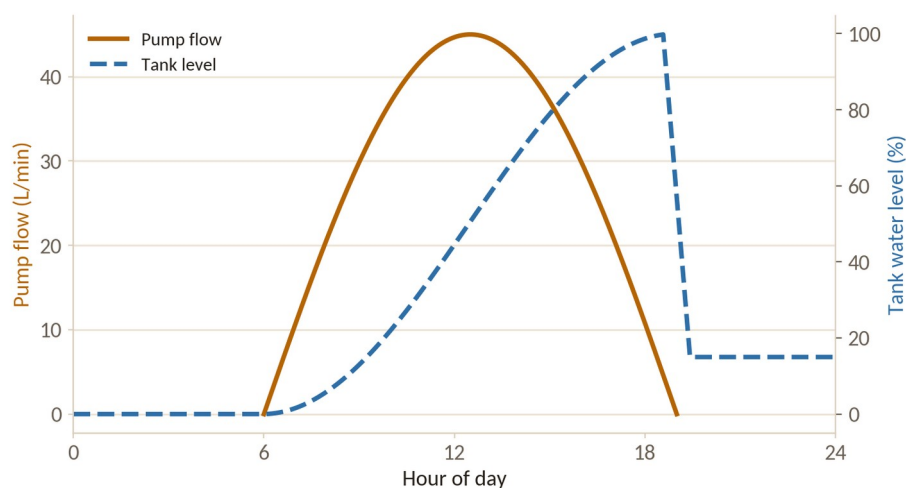
#### WORKED EXAMPLE — HOW LONG MUST THE PUMP RUN?

A small greenhouse needs 2400 liters (2.4 m<sup>3</sup>) of water a day. Its solar pump delivers an average of 40 L/min while the sun is strong. How many minutes, and hours, must it run each day to meet the need?

1. Write the relationship:  $\text{time} = \text{volume} \div \text{flow rate}$
2. Put in the numbers:  $t = 2400 \text{ L} \div 40 \text{ L/min}$
3. Calculate:  $t = 60 \text{ minutes} = 1.0 \text{ hour}$

**Answer: About 1.0 hour of pumping per day**

That greenhouse pump easily finishes its 1-hour job within a sunny day, even a hazy or partly cloudy one — as long as at least an hour of reasonably strong sunshine occurs. On a very cloudy, low-light day, though, pumping may slow down or stop for hours. This is exactly why the storage tank matters: as long as the tank fills up on sunnier days, one weak day does not usually stop irrigation completely.



A typical solar pumping day: pump flow rises and falls with sunlight through the day, while the tank's water level climbs steadily until it is released for irrigation.

#### WORD TO KNOW

**Irrigation** — Supplying water to crops or land on purpose, instead of relying only on rain. Common methods include flooding a field, spraying water through sprinklers, or dripping water slowly at each plant's roots.

#### WORD TO KNOW

**Irrigation scheduling** — Planning WHEN and HOW MUCH to irrigate, based on the crop's water needs, the weather, and — for solar pumping — the hours of strong sunlight and the water already sitting in storage.

A solar pump works best while the sun is strong, usually mid-morning to mid-afternoon. But watering crops in the strong midday sun can waste water — much of it evaporates before it ever reaches the roots. A storage tank solves this conflict neatly: pump during the sunny middle of the day, straight into the tank, then release the water to the field in the cooler early morning or evening, by gravity, whenever it suits the crop best.

#### Matching irrigation method to a solar pump

| Method                     | Typical water-use efficiency | Fit with a small solar pump                                                                  |
|----------------------------|------------------------------|----------------------------------------------------------------------------------------------|
| Flood or furrow irrigation | Low, about 40–60%            | Needs a large flow rate for a short time — often needs a bigger pump, array, and tank        |
| Sprinkler irrigation       | Medium, about 65–80%         | Needs steady pressure — works well with a tank placed high enough for gravity pressure       |
| Drip irrigation            | High, about 85–95%           | Needs only a small, steady flow rate — often the best match for a small solar pump and array |

#### ACTIVITY (CLASSROOM) — PLAN AN IRRIGATION SCHEDULE

1. Pick a real or example crop, field, or garden, and estimate its daily water need in liters.
2. Choose an example pump flow rate, and calculate how many hours of pumping it needs (as in the greenhouse example).
3. Choose a tank size using this lesson's tank equation and a sensible days-of-storage value.
4. Write a simple daily schedule: which hours the pump runs (matched to sunlight), and which hours the tank releases water for irrigation (matched to cooler, low-evaporation times).

*You need: Notebook or phone, Example data, or your own local knowledge*

► *App tool: Try it: convert between liters and cubic meters for your own tank sizing*

## CHAPTER SUMMARY

- Solar pumps are surface (above the water, suction lift limited to about 6–7 m) or submersible (underwater, used in deep boreholes); the motor can run on DC (simple, straight from the array through a pump controller) or AC (needs an inverter or a dedicated pump controller).
- Total dynamic head (TDH) = static head + friction head loss; a simple planning estimate adds about 10% of the static head for friction.
- Hydraulic power:  $P_{\text{hyd}} = \rho \times g \times Q \times H$ , with  $\rho = 1000 \text{ kg/m}^3$ ,  $g = 9.81 \text{ m/s}^2$ , and  $Q$  ALWAYS converted to  $\text{m}^3/\text{s}$  first — mixing up flow rate units is the most common mistake in pump calculations.
- A pump's real electrical power (or energy) need equals its hydraulic power (or energy) divided by its pump-and-motor efficiency, often only 35–55% for small solar pumps.
- Daily hydraulic energy (Wh) =  $2.725 \times \text{daily volume (m}^3) \times \text{total head (m)}$ ; array size = daily electrical energy  $\div$  (peak sun hours  $\times$  performance ratio) — the same equation family as Chapter 12, but usually sized to the pumping season's sun hours, not the year's worst month.
- A pump's performance curve shows that flow drops as head rises — always check a pump's flow at the system's actual head, never trust its maximum 'headline' number alone.
- Solar pumping systems usually store water in a tank instead of storing energy in a battery: tanks are simpler, last longer, and are usually the cheaper reserve. Tank capacity = daily water need  $\times$  days of storage.
- An elevated tank delivers water by gravity, with no second pump needed — a gravity-fed system.
- Irrigation scheduling matches pumping hours to sunlight and watering hours to low-evaporation times, like early morning or evening; drip irrigation's small, steady flow rate is often the best match for a small solar pump.
- Across Iraq and the Kurdistan Region, replacing diesel-powered pumps with solar pumps on farms and orchards cuts fuel trips, noise, and running cost, while naturally matching water production to the growing season's strong sunshine.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** Convert a flow rate of 90 liters per minute (L/min) into  $\text{m}^3/\text{s}$ .

**Problem 2 [Basic]** Convert a flow rate of 5000 liters per hour (L/h) into  $\text{m}^3/\text{s}$ .

**Problem 3 [Basic]** A pump's static head is 12 m. Using this chapter's simple estimate of 10% for friction loss, find the total dynamic head.

**Problem 4 [Basic]** A pump moves water at  $0.001 \text{ m}^3/\text{s}$  through a total dynamic head of 15 m. Find the hydraulic power. (Use  $\rho = 1000 \text{ kg/m}^3$ ,  $g = 9.81 \text{ m/s}^2$ .)

**Problem 5 [Standard]** A pump delivers 60 liters per minute through a total dynamic head of 18 m. Find (a) the flow rate in  $\text{m}^3/\text{s}$  and (b) the hydraulic power.

**Problem 6 [Standard]** A borehole's resting water level is 10 m below ground. While pumping, drawdown adds another 2 m. The delivery pipe then rises 3 m further to reach the tank. Estimate friction loss as 10% of the static head. Find the total dynamic head.

**Problem 7 [Standard]** A pump needs 250 W of hydraulic power. Its pump-and-motor efficiency is 40%. Find the electrical input power it needs.

**Problem 8 [Standard]** A village well must supply  $8 \text{ m}^3$  of water a day through a total dynamic head of 22 m. The pump-and-motor efficiency is 40%. Find (a) the daily hydraulic energy and (b) the daily electrical energy needed.

**Problem 9 [Standard]** Using the village well's electrical energy need from the last problem (1199 Wh/day), with peak sun hours of 6.0 h/day and a performance ratio of 0.80, find the minimum array size.

**Problem 10 [Challenge]** A cooperative farm needs  $25 \text{ m}^3$  of water a day for its greenhouses, lifted through a total dynamic head of 28 m. The chosen pump-and-motor combination is 44% efficient. (a) Find the daily hydraulic energy. (b) Find the daily electrical energy needed. (c) Using the growing season's example peak sun hours of 7.0 h/day and a performance ratio of 0.78, find the minimum array size and choose a number of 450 W panels. (d) If the design had mistakenly used the region's winter peak sun hours of 3.2 h/day instead, how much bigger (in %) would the wrongly sized array be?

**Problem 11 [Challenge]** A farm's daily irrigation need is  $14 \text{ m}^3$  of water. During the growing season, cloudy runs of up to 3 days sometimes occur. Using this chapter's tank-sizing method, (a) find the minimum tank capacity needed to cover 3 days of reserve. (b) If tanks are locally available only in a standard  $10 \text{ m}^3$  size, how many tanks should the farm buy, and what is the real total capacity?

**Problem 12 [Challenge]** A remote livestock watering station needs  $6 \text{ m}^3$  of water a day. The borehole's total dynamic head is 40 m. The submersible pump chosen has a pump-and-motor efficiency of 38%, and its performance curve shows it delivers 25 L/min when working against a 40 m head. (a) Find the daily hydraulic and electrical energy needed. (b) Using a year-round peak sun hours value of 5.5 h/day (this station is needed every day of the year, so Chapter 12's design-month rule applies) and a performance ratio of 0.75, find the minimum array size. (c) Running at its rated 25 L/min, how many hours would the pump need to run to pump the full daily need, and is this realistic within the available sun hours?

## CHAPTER FIFTEEN

# Money and the Environment

*Whether a solar system is worth it — in money and in clean air*

### IN THIS CHAPTER YOU WILL LEARN TO

- Break down the full cost of a solar system into its main parts: panels, batteries, controller, inverter, cabling, and installation.
- Calculate and compare the cost per kWh of solar, grid, and generator electricity, using example numbers.
- Calculate the simple payback period and the lifetime savings of a solar system.
- Calculate the CO<sub>2</sub> avoided by a solar system, using a clearly labeled example emission factor.
- Explain the main financial and environmental benefits of solar power for homes and businesses in Iraq and the Kurdistan Region.

## 15.1 The Real Cost of a Solar System

Every family, school, or shop asking about solar power asks the same first question: **how much does it really cost?** The honest answer is: more than just the panels. Through this chapter we follow one example system — a 3.3 kWp home hybrid solar system (10 panels of 330 W each) that produces about 14.5 kWh per day, or about 5300 kWh in a year. (*Chapter 12 shows how to calculate production from array size, sun hours, and system losses. This chapter starts from that finished number and focuses on money and the environment.*) All prices in this chapter are clearly labeled example numbers for practice, not real market quotes.

### WORD TO KNOW

**Capital cost** — The one-time money paid to buy and install a system. Also called the upfront cost.

### WORD TO KNOW

**Operating cost** — The ongoing money needed to run a system after it is installed — for example, fuel, repairs, and maintenance.

A generator has a **low capital cost** (it is cheap to buy) but a **high operating cost** (it needs fuel every day). A solar system is the opposite: a **higher capital cost**, but a very **low operating cost** — sunlight is free. This one idea explains almost everything in this chapter.

A complete solar system has six main cost groups: - **Solar panels** — turn sunlight into electricity - **Batteries** — store energy for use at night or during power cuts - **Charge controller** — protects the battery from over-charging - **Inverter** — changes DC electricity into AC for normal appliances - **Cabling, mounting, and protection** — wires, connectors, roof structure, fuses, and breakers - **Installation labor** — the skilled work of putting it all together safely

### WORD TO KNOW

**Balance of system** — All the parts of a solar system except the panels and batteries — for example, the charge controller, inverter, cables, mounting structure, and protection devices. Often shortened to BOS.

#### Example cost breakdown: the 3.3 kWp example system (example numbers for practice)

| Part                              | Example cost (IQD) | Share of total |
|-----------------------------------|--------------------|----------------|
| Solar panels (10 × 330 W)         | 2,000,000          | 25.0%          |
| Batteries                         | 2,800,000          | 35.0%          |
| Charge controller                 | 400,000            | 5.0%           |
| Inverter                          | 1,200,000          | 15.0%          |
| Cabling, mounting, and protection | 600,000            | 7.5%           |
| Installation labor                | 1,000,000          | 12.5%          |
| Total                             | 8,000,000          | 100%           |

Notice that the panels — the part everyone thinks about first — are only about a quarter of the total price. The batteries, the part many people forget to budget for, are the single biggest cost in this example. This pattern is common for systems with battery storage.

#### EQUATION: COST SHARE OF ONE PART

$$S = \frac{c}{C} \times 100$$

*In words: Percentage share = (cost of one part ÷ total system cost) × 100*

| Symbol | Meaning                                     | Unit                   |
|--------|---------------------------------------------|------------------------|
| S      | percentage share of one part                | %                      |
| c      | cost of one part, for example the batteries | IQD (example currency) |
| C      | total cost of the whole system              | IQD (example currency) |

*Use this to check, in percent, how big any one part of a quotation really is.*

#### WORKED EXAMPLE — WHAT SHARE IS THE INVERTER?

Using the cost table above, find what percentage of the total system cost is the inverter.

1. Write the equation:  $S = (c \div C) \times 100$
2. Put in the numbers:  $S = (1,200,000 \div 8,000,000) \times 100$
3. Calculate:  $S = 0.15 \times 100 = 15\%$

**Answer: 15% of the total cost**

#### Typical cost shares for a battery-based solar system (illustrative ranges)

| Part         | Typical share of total cost |
|--------------|-----------------------------|
| Solar panels | 20% – 30%                   |
| Batteries    | 25% – 40%                   |



| Part                              | Typical share of total cost |
|-----------------------------------|-----------------------------|
| Charge controller                 | 3% – 7%                     |
| Inverter                          | 10% – 20%                   |
| Cabling, mounting, and protection | 5% – 10%                    |
| Installation labor                | 10% – 15%                   |

These ranges are illustrative, not fixed rules. The real share depends on battery technology (lithium batteries cost more than lead-acid but last longer), local prices, and how much work a family can safely do itself.

#### COMMON MISTAKE

**✗ Wrong:** Comparing suppliers only by the price of the solar panels.

**✓ Right:** Compare the FULL system price. Panels are often less than a third of the total cost — a cheap panel-only quotation can hide a missing battery, no installation, or a weak inverter.

#### SAFETY

Before paying any deposit, get a written quotation that lists every part, its brand, and its warranty. Never pay the full price in advance to a supplier you do not know. Ask other customers about their experience first. A clear written agreement protects both the buyer and the seller.

#### CASE STUDY — THREE QUOTATIONS FOR ONE ROOF • SULAYMANIYAH (EXAMPLE NUMBERS)

A family in Sulaymaniyah asked three suppliers for a price on the same size of system. Quotation A, at 5,500,000 IQD, listed only panels and an inverter — the family would still need to buy batteries and pay for installation separately. Quotation B, at 7,800,000 IQD, included everything but used a budget battery with no written warranty. Quotation C, at 8,000,000 IQD, included every part in the table above, a name-brand battery, and a two-year warranty on workmanship. At first glance, Quotation A looked cheapest. Once the family added the missing battery and installation cost, it became the most expensive of the three — and it still had no warranty at all.

#### ACTIVITY (FIELD) — COLLECT REAL QUOTATIONS

1. Visit, call, or message two or three local solar suppliers.
2. Ask for a written quotation for a system close to your home's size (use your Chapter 1 appliance list as a guide).
3. Check whether each quotation lists panels, batteries, controller, inverter, cabling, AND installation — or only some of them.
4. Compare the total prices and what each one actually includes.

*You need: Phone or a visit to a shop, Notebook or the app's notes*

You now know what makes up a solar system's price. But is that price a good deal? To answer that, we need one more idea: the cost of every kilowatt-hour the system will ever produce. That is the subject of the next lesson.

## 15.2 Comparing Solar, Grid, and Generator Costs

A solar system costs a lot of money at once. A grid bill or a generator subscription costs a little money every month. To compare them fairly, we must convert all of them into the same measure: **the cost of one kilowatt-hour**.

### WORD TO KNOW

**Tariff** — The price charged for each unit of energy, usually in currency per kWh. Electricity bills and generator subscriptions are both based on a tariff.

### WORD TO KNOW

**Levelized cost of energy** — The average cost of one kWh of energy from a system over its whole working life. Found by dividing the total cost by the total energy produced. Often shortened to LCOE.

### EQUATION: COST PER KWH (LEVELIZED COST OF ENERGY)

$$\text{LCOE} = \frac{C}{E \times n}$$

*In words: Cost per kWh = System cost ÷ (Yearly energy produced × Number of years)*

| Symbol | Meaning                                                                       | Unit                       |
|--------|-------------------------------------------------------------------------------|----------------------------|
| LCOE   | levelized cost of energy — the average cost of one kWh over the system's life | IQD/kWh (example currency) |
| C      | total system cost (the capital cost)                                          | IQD (example currency)     |
| E      | energy produced per year                                                      | kWh/year                   |
| n      | number of years the system is expected to work (its lifetime)                 | years                      |

*This chapter uses a system lifetime of 20 years. Panels alone often work for 25 years or more, but batteries and inverters usually need replacing before then — 20 years is a reasonable planning figure. (See the mistake box in Lesson 3 for a fuller picture.)*

### WORKED EXAMPLE — THE EXAMPLE SYSTEM'S COST PER KWH

The example 3.3 kWp system from Lesson 1 cost 8,000,000 IQD and produces about 14.5 kWh per day. Find its yearly production and its simple LCOE over a 20-year lifetime.

1. Find yearly production:  $E = 14.5 \text{ kWh/day} \times 365 \text{ days} \approx 5300 \text{ kWh/year}$
2. Find lifetime energy:  $5300 \text{ kWh/year} \times 20 \text{ years} = 106,000 \text{ kWh}$
3. Write the equation:  $\text{LCOE} = C \div (E \times n)$
4. Put in the numbers:  $\text{LCOE} = 8,000,000 \div 106,000$
5. Calculate:  $\text{LCOE} \approx 75 \text{ IQD/kWh}$

**Answer: About 75 IQD per kWh (example numbers)**

Now compare that to what a family already pays. The **grid tariff** is usually given to you directly — for example, the 100 IQD per kWh used as an example price in Chapter 1. No extra calculation is needed; the tariff already IS the cost per kWh.

The **generator** is trickier, because a subscription is sold in amperes per month, not in kWh directly. Chapter 1 worked through exactly this calculation for a 5-ampere subscription — we repeat it here in the same style.

#### WORKED EXAMPLE — GENERATOR COST PER KWH (REVIEWED FROM CHAPTER 1)

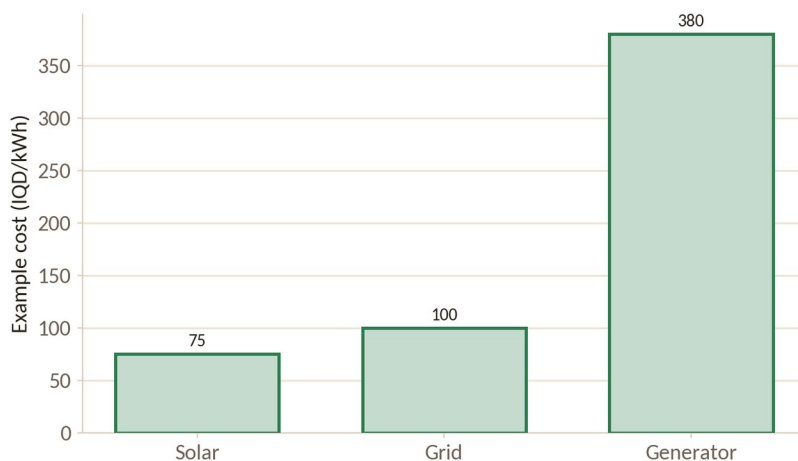
A 5-ampere generator subscription costs 50,000 IQD per month (example numbers). The generator can run up to 8 hours a day, but a family's real average use is about half of that maximum possible energy. Find the real cost per kWh.

1. Available power:  $P = V \times I = 220 \text{ V} \times 5 \text{ A} = 1100 \text{ W} = 1.1 \text{ kW}$
2. Maximum possible energy:  $1.1 \text{ kW} \times 8 \text{ h} \times 30 \text{ days} = 264 \text{ kWh}$  per month
3. Realistic energy used (about half of maximum):  $264 \div 2 = 132 \text{ kWh}$  per month
4. Cost per kWh:  $50,000 \text{ IQD} \div 132 \text{ kWh} \approx 380 \text{ IQD/kWh}$

**Answer: About 380 IQD per kWh (example numbers) — the same result found in Chapter 1**

#### Cost per kWh: solar vs. grid vs. generator (example numbers)

| Energy source                         | Example cost per kWh          | Note                                       |
|---------------------------------------|-------------------------------|--------------------------------------------|
| Solar (this chapter's example system) | $\approx 75 \text{ IQD/kWh}$  | Over a 20-year lifetime, capital cost only |
| Public grid                           | $100 \text{ IQD/kWh}$         | Example tariff, from Chapter 1             |
| Neighborhood generator                | $\approx 380 \text{ IQD/kWh}$ | Realistic use, from Chapter 1              |



Bar chart comparing example cost per kWh: solar ( $\approx 75 \text{ IQD}$ ), grid ( $100 \text{ IQD}$ ), and generator ( $\approx 380 \text{ IQD}$ ).

In this example, solar is cheaper than the grid, and about five times cheaper than the generator. This is exactly why solar power is spreading fast in Iraq and the Kurdistan Region: it turns an expensive, unreliable running cost (fuel and subscriptions) into a one-time capital cost, followed by nearly free energy.

#### COMMON MISTAKE

**X Wrong:** Comparing a solar system's total price directly to a monthly electricity bill.

**✓ Right:** Convert everything to the same units — cost per kWh — before comparing. A large one-time number (8,000,000 IQD) and a small monthly number (15,000 IQD) cannot be compared directly; only their cost per kWh can.

### CASE STUDY — A YEAR OF MIXED BILLS · ERBIL (EXAMPLE NUMBERS)

A teacher in Erbil added up a full year of energy costs. In a typical month, about half of the family's energy came from the grid at 100 IQD/kWh, and the other half came from the neighborhood generator, during daily power cuts, at about 380 IQD/kWh. Blended together, the family was really paying about  $(100 + 380) \div 2 = 240$  IQD for every kWh they used — more than double the grid price alone, because of the expensive generator hours. When they compared this blended price to the example solar LCOE of about 75 IQD/kWh, the decision became easy to explain to the rest of the family.

The 100 IQD/kWh grid price and 380 IQD/kWh generator price used above are simple, flat example numbers, useful for learning the method. Real tariffs are often more complex. For example, since May 2025 the Kurdistan Region has been rolling out Project Runaki, a real electricity reform with a tiered tariff — the price per kWh rises as monthly usage rises, instead of staying flat. Chapter 21 covers Project Runaki fully; the table below repeats its real, sourced tariff for quick reference here.

**Real data: Project Runaki residential tariff (Kurdistan Region, announced May 2025 — see Chapter 21)**

| Monthly usage block | Price per kWh (IQD) |
|---------------------|---------------------|
| 1–400 kWh           | 72                  |
| 401–800 kWh         | 108                 |
| 801–1200 kWh        | 175                 |
| 1201–1600 kWh       | 265                 |
| Above 1600 kWh      | 350                 |

Compare these real numbers with this lesson's example solar LCOE of about 75 IQD/kWh: solar beats even the cheapest Runaki tier (72 IQD/kWh) once installation, maintenance, and financing are also considered, and beats the higher tiers by a wide margin. A household that regularly reaches the 265 or 350 IQD/kWh tiers has an especially strong case for solar, since solar panels effectively remove kWh from the most expensive part of the bill first. Chapter 21 works through a full example of this effect on payback time.

### ACTIVITY (HOME) — FIND YOUR OWN BLENDED COST PER KWH

1. Get your last grid electricity bill (kWh used and amount paid) and your generator subscription (amperes and monthly cost).
2. Calculate your grid cost per kWh: bill amount  $\div$  kWh used.
3. Calculate your generator cost per kWh using the method in this lesson (amperes  $\rightarrow$  watts  $\rightarrow$  realistic monthly kWh  $\rightarrow$  cost per kWh).
4. Compare both numbers to this chapter's example solar LCOE of about 75 IQD/kWh.

*You need: Electricity bill, Generator subscription receipt, Calculator*

Knowing the cost per kWh is powerful, but families usually ask a simpler question: **how many years until the system pays for itself?** That is the next lesson.

## 15.3 Payback Period and Lifetime Savings

A solar system needs money before it saves money. This lesson answers the question every buyer asks: **how long until I get my money back — and how much do I gain after that?**

## WORD TO KNOW

**Payback period** — The time needed for the money saved by a system to equal the money it cost to buy and install.

To find the payback period, we first need the **annual savings** — how much money the system saves every year. This is simply the energy it produces multiplied by the price of the energy it replaces.

## EQUATION: SIMPLE PAYBACK PERIOD

$$T = \frac{C}{S}$$

*In words: Payback period = System cost ÷ Annual savings*

| Symbol | Meaning                                                                | Unit                        |
|--------|------------------------------------------------------------------------|-----------------------------|
| T      | simple payback period                                                  | years                       |
| C      | system cost (the capital cost)                                         | IQD (example currency)      |
| S      | money saved per year by using the system instead of buying that energy | IQD/year (example currency) |

*Annual savings (S) = energy produced per year × the price of the energy it replaces. In this chapter's example, the solar energy replaces expensive generator electricity.*

## WORKED EXAMPLE — PAYBACK PERIOD OF THE EXAMPLE SYSTEM

The example 3.3 kWp system cost 8,000,000 IQD (Lesson 1) and produces about 5300 kWh per year (Lesson 2). Assume this energy replaces generator electricity that costs about 380 IQD/kWh (example, from Lesson 2). Find the annual savings and the simple payback period.

1. Find annual savings:  $S = E \times \text{price} = 5300 \text{ kWh/year} \times 380 \text{ IQD/kWh}$
2. Calculate:  $S \approx 2,014,000 \text{ IQD per year}$
3. Write the equation:  $T = C \div S$
4. Put in the numbers:  $T = 8,000,000 \div 2,014,000$
5. Calculate:  $T \approx 4.0 \text{ years}$

**Answer: About 4.0 years**

Four years might sound like a long time, but the panels are expected to keep working for 25 years or more. Everything the system produces AFTER the payback point is close to pure saving.

## WORD TO KNOW

**Lifetime savings** — The total money saved by a system over its whole working life, after subtracting what the system cost.

## EQUATION: LIFETIME SAVINGS

$$N = (S \times n) - C$$

*In words: Lifetime savings = (Annual savings × Number of years) – System cost*

| Symbol | Meaning                                             | Unit                        |
|--------|-----------------------------------------------------|-----------------------------|
| N      | net lifetime savings                                | IQD (example currency)      |
| S      | money saved per year                                | IQD/year (example currency) |
| n      | number of years (the system's assumed working life) | years                       |
| C      | system cost (the capital cost)                      | IQD (example currency)      |

*This simple version does not yet subtract maintenance or battery/inverter replacement costs — see the mistake box below.*

#### WORKED EXAMPLE — LIFETIME SAVINGS OVER 20 YEARS

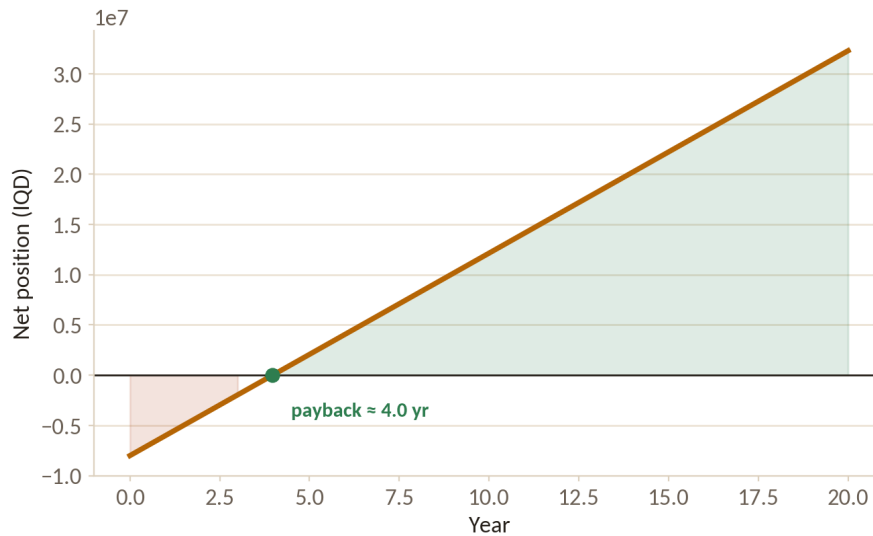
Using the same example system (cost 8,000,000 IQD, annual savings ≈ 2,014,000 IQD/year), find the net savings over a 20-year system life.

1. Write the equation:  $N = (S \times n) - C$
2. Put in the numbers:  $N = (2,014,000 \times 20) - 8,000,000$
3. Calculate the value of 20 years of energy:  $2,014,000 \times 20 = 40,280,000$  IQD
4. Subtract the system cost:  $N = 40,280,000 - 8,000,000 = 32,280,000$  IQD

**Answer: About 32,280,000 IQD (example numbers) — over four times the original system cost**

#### Cumulative value and net position over time (example numbers)

| Year | Cumulative value of energy produced (IQD) | Net position: value – system cost (IQD) |
|------|-------------------------------------------|-----------------------------------------|
| 0    | 0                                         | -8,000,000                              |
| 1    | 2,014,000                                 | -5,986,000                              |
| 2    | 4,028,000                                 | -3,972,000                              |
| 3    | 6,042,000                                 | -1,958,000                              |
| 4    | 8,056,000                                 | +56,000                                 |
| 5    | 10,070,000                                | +2,070,000                              |
| 10   | 20,140,000                                | +12,140,000                             |
| 15   | 30,210,000                                | +22,210,000                             |
| 20   | 40,280,000                                | +32,280,000                             |



Cumulative savings curve for the example system: the net position starts at -8,000,000 IQD and crosses zero — the payback point — shortly after year 4.

#### COMMON MISTAKE

**X Wrong:** Assuming the battery and inverter will last as long as the panels, so lifetime savings need no extra cost.

**✓ Right:** Batteries — and sometimes inverters — usually need replacing before the panels wear out. A careful lifetime-savings estimate sets money aside for at least one battery replacement. (Chapter 6 explains battery lifetime in detail.)

What if a family cannot pay the full capital cost at once? This is where **financing** helps.

#### WORD TO KNOW

**Financing** — A way to pay for something over time, in smaller regular payments, instead of paying the whole cost at once.

#### WORKED EXAMPLE — A SIMPLE INSTALLMENT PLAN

A shop owner buys the example 8,000,000 IQD system using a 24-month, interest-free installment plan (example terms). Find the monthly payment, and compare it to the average monthly savings of about 167,800 IQD.

1. Monthly payment:  $8,000,000 \div 24 \approx 333,300$  IQD per month
2. Compare to average monthly savings: about 167,800 IQD per month
3. Net monthly cash flow during the loan:  $167,800 - 333,300 \approx -165,500$  IQD per month
4. After the 24 months, the loan is finished and the full monthly saving ( $\approx 167,800$  IQD) belongs to the shop

**Answer:** The shop pays about 165,500 IQD per month more than it saves during the 24-month loan, then keeps the full  $\approx 167,800$  IQD/month saving afterward

Financing makes the large capital cost easier to manage, but it does not remove it — the shop is really pre-paying for years of future free energy. A shorter loan than the payback period means tighter monthly cash flow at first, but the system still pays for itself in the same total time.

#### ACTIVITY (HOME) — CALCULATE YOUR OWN PAYBACK

1. Get a real quotation (from Lesson 1's activity) or use this lesson's example numbers.
2. Estimate your own annual savings: multiply your expected solar production by the price of the energy it would replace (grid or generator).
3. Use this lesson's equation to calculate your own payback period.
4. Compare your result with a classmate's — whose system pays back faster, and why?

*You need: Quotation or example numbers, Calculator*

#### CASE STUDY — A SHOP WITH A FAST PAYBACK · DUHOK (EXAMPLE NUMBERS)

A small shop in Duhok installs a system similar in size to this chapter's example, but almost all of its load — lights, a drinks fridge, phone chargers — runs during opening hours, in daylight. Very little battery storage is needed, which lowers the system's capital cost. The solar energy also replaces the shop's most expensive electricity: generator hours during the busy midday power cut. With a lower cost and a higher avoided price, the shop's payback period is about 2.5 years — noticeably faster than a typical home, where more energy is used in the evening after the sun has set. Businesses and buildings with daytime-heavy loads are often the fastest and easiest solar paybacks.

► *App tool: Try it: calculate payback and lifetime savings for your own numbers*

Money is only half the story. The next lesson looks at the other reason solar power matters: clean air.

## 15.4 CO<sub>2</sub> Savings and Environmental Benefits

Every kilowatt-hour a solar system produces is a kilowatt-hour that does NOT have to be made by burning diesel, petrol, or coal. This lesson turns that idea into numbers — and looks at the other environmental benefits too.

#### WORD TO KNOW

**Carbon dioxide** — A gas released when fuels like diesel, petrol, or coal are burned. It is the main gas causing climate change.

#### WORD TO KNOW

**Greenhouse gas** — A gas in the air that traps heat from the sun, like a blanket around the Earth. Carbon dioxide (CO<sub>2</sub>) is the most common greenhouse gas produced by human activities.

#### WORD TO KNOW

**Emission factor** — A number that shows how much CO<sub>2</sub> (or another pollutant) is released for each unit of energy — for example, kilograms of CO<sub>2</sub> per kWh.

#### EQUATION: CO<sub>2</sub> AVOIDED



$$M = E \times f$$

In words: CO2 avoided = Energy produced × Emission factor

| Symbol | Meaning                                             | Unit       |
|--------|-----------------------------------------------------|------------|
| M      | mass of CO2 avoided                                 | kg CO2     |
| E      | energy produced, or energy replaced                 | kWh        |
| f      | emission factor of the energy source being replaced | kg CO2/kWh |

This chapter uses an illustrative emission factor of about 0.7 kg CO2 per kWh, typical of a small diesel generator. Real, sourced grid and generator factors for our region are studied in Chapter 21.

#### WORKED EXAMPLE — YEARLY CO2 AVOIDED BY THE EXAMPLE SYSTEM

The example system produces about 5300 kWh per year. Using the illustrative emission factor of 0.7 kg CO2/kWh, find the CO2 avoided per year, in kg and in tonnes.

1. Write the equation:  $M = E \times f$
2. Put in the numbers:  $M = 5300 \text{ kWh} \times 0.7 \text{ kg CO2/kWh}$
3. Calculate:  $M \approx 3710 \text{ kg CO2 per year}$
4. Convert to tonnes:  $3710 \div 1000 \approx 3.7 \text{ tonnes CO2 per year}$

**Answer: About 3710 kg (≈3.7 tonnes) of CO2 avoided per year**

#### WORKED EXAMPLE — LIFETIME CO2 AVOIDED (20 YEARS)

Using the same system, find the CO2 avoided over a 20-year lifetime.

1. Multiply the yearly figure by the number of years:  $3710 \text{ kg/year} \times 20 \text{ years}$
2. Calculate:  $\approx 74,200 \text{ kg CO2}$
3. Convert to tonnes:  $74,200 \div 1000 \approx 74.2 \text{ tonnes CO2}$

**Answer: About 74,200 kg (≈74.2 tonnes) of CO2 avoided over 20 years**

Big numbers like 'tonnes of CO2' can be hard to picture. A common trick is to compare them to something familiar, like trees.

#### WORKED EXAMPLE — HOW MANY TREES IS THAT?

Using an illustrative absorption rate of about 20 kg of CO2 per tree per year, how many trees would it take to absorb the same CO2 that the example system avoids in one year (≈3710 kg)?

1. Write the idea:  $\text{number of trees} = \text{CO2 avoided} \div \text{CO2 absorbed per tree}$
2. Put in the numbers:  $3710 \text{ kg} \div 20 \text{ kg per tree}$
3. Calculate:  $\approx 185 \text{ trees}$

**Answer: About 185 trees' worth of CO2 absorption, every year (illustrative comparison)**

**Illustrative emission factors for comparison (not sourced local data)**

| Energy source                                                 | Illustrative CO2 emission factor        |
|---------------------------------------------------------------|-----------------------------------------|
| Coal power plant                                              | ≈ 0.9 – 1.0 kg CO2/kWh                  |
| Small diesel generator                                        | ≈ 0.7 kg CO2/kWh (used in this chapter) |
| Natural gas power plant                                       | ≈ 0.4 – 0.5 kg CO2/kWh                  |
| Solar PV, over its full lifecycle (mostly from manufacturing) | ≈ 0.04 – 0.05 kg CO2/kWh                |

Notice that even solar panels are not perfectly at zero — making the glass, metal, and silicon takes energy too. But over its full life, a solar system's total footprint is many times smaller than any fuel-burning source.

#### WORD TO KNOW

**Carbon footprint** — The total amount of greenhouse gas, mainly CO2, produced by a person's, family's, or system's activities.

#### COMMON MISTAKE

**X Wrong:** Believing solar power has completely zero environmental impact.

**✓ Right:** Making, transporting, and eventually recycling panels and batteries all use some energy and materials. The honest claim is not 'zero impact' — it is 'far less impact than burning fuel,' which the numbers above show clearly.

CO2 is not the only benefit. Diesel generators also release smoke, soot, and noise directly into neighborhoods — solar panels release none of these.

#### CASE STUDY — A QUIETER, CLEANER STREET • A KURDISTAN REGION NEIGHBORHOOD (ILLUSTRATIVE)

On many streets in Iraq and the Kurdistan Region, a diesel generator runs for hours every day, filling the air with noise and diesel smoke. Families who add solar power and reduce their generator hours often notice the change before they ever check a CO2 number: less noise in the evening, less black soot on walls and washing lines, and cleaner air for children playing outside. These local, everyday benefits arrive alongside the CO2 savings calculated in this lesson — they are two sides of the same improvement.

#### SAFETY

Old lead-acid batteries contain acid and lead, which are dangerous to health and the environment if thrown in normal trash or burned. Take old batteries to a proper recycler, or return them to the seller — many sellers accept an old battery as part of a new purchase. Never open a battery case, and keep old batteries away from children.

#### ACTIVITY (HOME) — A WEEK OF GENERATOR WATCHING

1. For one week, note how many hours your neighborhood generator runs each day.
2. Use your generator subscription's amperes and the method from Chapter 1 to estimate the weekly energy it supplies.
3. Using this lesson's emission factor (0.7 kg CO2/kWh), estimate the weekly and yearly CO2 released.
4. Discuss: how much of that could a home solar system avoid?

*You need: Notebook, Calculator, Your generator subscription details*

► *App tool: Try it: calculate CO2 avoided for your own system*

► *App simulation: Explore: the financial and environmental simulation — costs, payback, and CO2 together*

You have now followed a solar system's whole story: what it costs, how that compares to the grid and the generator, when it pays for itself, and how much CO2 and local pollution it avoids. This is the evidence a family, a school, or a business needs to decide — with real numbers, not guesses.

## CHAPTER SUMMARY

- A solar system's capital cost has six main parts: panels, batteries, charge controller, inverter, cabling/mounting/protection, and installation labor.
- Batteries are often the single biggest cost in a battery-based system — bigger than the panels.
- Compare suppliers by the FULL price and full parts list, not just the panel price.
- Cost per kWh (LCOE) = system cost ÷ (yearly energy × lifetime years). It lets you compare solar, grid, and generator fairly.
- In this chapter's example numbers, solar (≈75 IQD/kWh) is cheaper than the grid (100 IQD/kWh) and far cheaper than the generator (≈380 IQD/kWh).
- Simple payback period = system cost ÷ annual savings. In the example, payback is about 4 years.
- Lifetime savings = (annual savings × years) – system cost, minus any maintenance or replacement costs.
- Financing spreads the capital cost into smaller payments, but the system still needs the same total time to pay for itself.
- CO2 avoided = energy produced × emission factor. This chapter uses an illustrative 0.7 kg CO2/kWh for a diesel generator.
- Beyond CO2, solar power also means less noise, less smoke, and cleaner air for the whole neighborhood.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A system costs 6,000,000 IQD in total (example numbers). The battery bank costs 1,800,000 IQD. What percentage of the total cost is the battery bank?

**Problem 2 [Basic]** A small generator subscription costs 30,000 IQD per month (example numbers). In a realistic month it delivers about 90 kWh of energy. What is the real cost per kWh?

**Problem 3 [Basic]** A small solar system costs 3,000,000 IQD (example numbers). It saves the owner 750,000 IQD per year. What is the simple payback period?

**Problem 4 [Basic]** A solar system produces 2000 kWh in one year. Using the example emission factor of 0.7 kg CO2 per kWh, how much CO2 does it avoid in one year, in kg and in tonnes?

**Problem 5 [Standard]** A small off-grid system has these example costs: panels 1,500,000 IQD, batteries 1,500,000 IQD, controller 250,000 IQD, inverter 900,000 IQD, cabling and mounting 350,000 IQD, installation 500,000 IQD. Find (a) the total system cost, and (b) the percentage share of the batteries and the inverter.

**Problem 6 [Standard]** An off-grid system costs 5,000,000 IQD (example numbers, see Problem 5) and is expected to produce 2500 kWh per year. Assuming a 20-year working life, what is its simple cost per kWh (LCOE)?

**Problem 7 [Standard]** A 2 kWp array gets 5 peak sun hours per day in an example location. The system's performance ratio is 0.75. Find (a) the daily energy production, and (b) the annual energy production (use 365 days).

**Problem 8 [Standard]** A family's solar system cost 4,500,000 IQD (example numbers). It produces 3000 kWh per year, replacing generator electricity that costs about 300 IQD/kWh (example price). Find (a) the annual savings, and (b) the simple payback period.

**Problem 9 [Standard]** In one example comparison, solar costs about 80 IQD/kWh (LCOE) and the grid costs 120 IQD/kWh (example tariff). (a) How many IQD cheaper is solar, per kWh? (b) What percentage cheaper is solar than the grid?

**Problem 10 [Standard]** A solar system avoids 2800 kg of CO<sub>2</sub> per year. Using an illustrative absorption rate of 20 kg CO<sub>2</sub> per tree per year, how many trees would be needed to absorb the same amount of CO<sub>2</sub>?

**Problem 11 [Challenge]** A hybrid solar system for a small clinic costs 12,000,000 IQD in total (example numbers). Its array produces 20 kWh per day on average. The clinic previously relied on a generator costing about 350 IQD/kWh (example, realistic use). Assume a 20-year system life. Find: (a) the annual energy production, (b) the annual savings, (c) the simple payback period, (d) the net lifetime savings over 20 years (ignore maintenance and replacement costs).

**Problem 12 [Challenge]** Two solar systems are compared using the illustrative emission factor of 0.7 kg CO<sub>2</sub>/kWh and a 20-year lifetime for both. System A produces 4000 kWh/year. System B produces 9000 kWh/year. Find (a) the lifetime CO<sub>2</sub> avoided by each system, in tonnes, and (b) how many times more CO<sub>2</sub> System B avoids compared to System A.

**Problem 13 [Challenge]** A shop owner buys a 6,000,000 IQD solar system (example numbers) using a 12-month, interest-free installment plan (example terms). The system saves the shop about 1,800,000 IQD per year in avoided generator costs. Find (a) the monthly installment payment, (b) the average monthly savings, (c) the net monthly cash flow during the 12-month installment period (savings minus payment) — is it positive or negative? (d) After the 12 months, how much does the shop save per month with nothing owed?

PART FOUR

# BUILDING AND CARING FOR SYSTEMS

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## CHAPTER SIXTEEN

# Site Assessment and System Planning

*What to check and measure before any equipment is bought*

### IN THIS CHAPTER YOU WILL LEARN TO

- List the steps of a complete site survey, and record roof condition, usable space, measurements, and photos on a survey form.
- Calculate a site's usable area, and estimate how many panels fit in the available space.
- Carry out a shading survey through the day and across the seasons, and calculate whether a nearby obstruction will shade the array.
- Read and sketch a simple site plan and a single-line diagram for a home solar system.
- Prepare an installation plan and a tools list for a solar installation.
- Explain what a complete quotation should include, and calculate a quotation price from cost, contingency, and margin.

## 16.1 The Site Survey Checklist

Chapters 10 to 15 taught you how to design a solar system on paper: how big the array should be, how many batteries, which inverter. But every one of those calculations assumed you already knew the real facts about the site — the roof's condition, its usable space, its orientation, and its shading. This chapter is where you go and get those real facts, before any equipment is bought. A good site survey saves money, prevents mistakes, and can even prevent accidents.

### WORD TO KNOW

**Site survey** — A visit to a building or piece of land to check, measure, and record everything needed before designing or installing a solar system. Also called a site assessment.

A complete site survey checks and records several things: - The building and the roof or ground condition - The usable space for the array - Measurements: dimensions, orientation, and tilt - Shading, now and through the year (Lesson 2) - The existing electrical system and access route - Photos of everything above. Miss one of these, and a design built later in the office can be wrong — sometimes badly wrong.

### WORD TO KNOW

**Load-bearing capacity** — How much extra weight a roof or structure can safely carry, including the solar panels, the mounting rack, wind, and people working on it.

Start with the roof or ground itself, not the equipment. Look for cracks, rust, sagging, or water stains — signs that a structure may be weaker than it looks. Note the roof material: flat concrete, corrugated metal sheet, and sloped tile are all common in this region (Chapter 5). A solar array, its rack, and the wind pushing on it (Chapter 5) all add real weight and force that the roof must carry safely, for twenty years or more. For anything beyond a

small home system, or any roof that looks doubtful, bring in a qualified structural engineer before going any further — exactly as Chapter 5 recommended for mounting work.

#### COMMON MISTAKE

**✗ Wrong:** Judging a site only by how well the panels and rack will fit and look, without checking the roof or structure itself.

**✓ Right:** Check the roof or structure's condition and load-bearing capacity FIRST. A perfectly sized array on a weak roof is still a serious safety risk.

#### SAFETY

A site survey often means climbing onto a roof. Use a stable ladder, and never step directly on fragile roofing sheets, skylights, or weakened concrete. Check the weather before climbing up, and avoid the hottest hours of the day in summer — wear sun protection and carry water. Never survey a roof alone; always have a second person nearby who can help or call for assistance. Chapter 17 covers full work-at-height safety for installation; a survey visit deserves the same basic care.

#### WORD TO KNOW

**Roof pitch** — The steepness of a roof's slope, often given in degrees. A flat roof has a pitch close to 0°.

Now measure. Bring a tape measure or a measuring wheel, a spirit level, a clinometer, and a compass — a phone with the right apps can often do the last three. Record the roof's length, width, and pitch, and sketch a rough outline as you go; Lesson 3 turns this sketch into a proper drawing.

#### WORD TO KNOW

**Clinometer** — A small tool used to measure an angle above the horizontal — for example, a roof's pitch, or the height angle of a nearby obstruction. Many phone apps work as a clinometer.

#### WORD TO KNOW

**True south** — The compass direction that points exactly toward the geographic South Pole. It is different from magnetic south, the direction a simple compass needle points to (Chapter 5).

Panels in the Northern Hemisphere work best facing true south (Chapter 5), not magnetic south. A simple compass points to magnetic south, which can be several degrees away from true south — the exact difference is the magnetic declination (Chapter 5). Many phone compass apps show true north or true south directly; if not, look up your city's current declination and correct the compass reading by hand. Record the roof or wall's real facing direction, in degrees from true south.

#### WORD TO KNOW

**Obstruction** — Anything on or near a site that blocks sunlight or takes up space where panels could go — for example, a water tank, a chimney, a satellite dish, or a vent pipe.

#### WORD TO KNOW

**Setback** — A strip of clear space, required by safety and fire rules, that must be kept free of panels near the edges of a roof or array.

#### WORD TO KNOW

**Usable area** — The part of a roof or site that is actually free for solar panels, after removing the space lost to obstructions and setbacks.

Find every obstruction on the roof — water tanks, vent pipes, satellite dishes, stairwell exits — and measure their footprint. Also apply any required setback: many local fire and safety rules ask for a clear strip around the edges of a roof, and sometimes a walkway between rows of panels. Usable area is what remains once obstructions and setbacks are subtracted from the total: Usable area = Total roof area – Area lost to obstructions – Area lost to setbacks

#### Example filled-in site survey form — the Example School, Erbil

| Survey item                       | Recorded information                                                                               |
|-----------------------------------|----------------------------------------------------------------------------------------------------|
| Site name and owner               | Example School, Erbil (example)                                                                    |
| Date of survey                    | 14 March (example)                                                                                 |
| Surveyor                          | Student survey team (example)                                                                      |
| Building and roof type            | Two-story classroom block; flat concrete roof                                                      |
| Roof condition                    | No cracks found; two small areas of ponding water noted for repair                                 |
| Roof pitch                        | 0° (flat)                                                                                          |
| Total roof area                   | 120 m <sup>2</sup>                                                                                 |
| Obstructions found                | Water tank (2 m × 2 m, 1.5 m tall); two roof vent pipes                                            |
| Area lost to obstructions         | 10 m <sup>2</sup>                                                                                  |
| Required setback (edge clearance) | 0.9 m clear strip around all edges                                                                 |
| Area lost to setback              | 14 m <sup>2</sup>                                                                                  |
| Usable roof area                  | 96 m <sup>2</sup> (120 – 10 – 14)                                                                  |
| Roof orientation                  | Long edge faces about 10° east of true south                                                       |
| Roof access                       | Fixed steel ladder at the north stairwell; in fair condition                                       |
| Shading obstruction nearby        | Two-story building, 8 m to the south, roofline about 6 m higher than this roof                     |
| Existing distribution board       | Ground floor, near the main entrance; in working condition                                         |
| Roof-to-equipment-room distance   | About 15 m of cable route, through a service duct                                                  |
| Photos taken                      | Roof overview from four directions, each obstruction, the access route, and the distribution board |

#### WORKED EXAMPLE — FINDING THE EXAMPLE SCHOOL'S USABLE ROOF AREA

Using the survey form above, find the usable roof area.



1. Start with the total roof area: 120 m<sup>2</sup>
2. Subtract the area lost to obstructions: 120 – 10 = 110 m<sup>2</sup>
3. Subtract the area lost to setbacks: 110 – 14 = 96 m<sup>2</sup>

**Answer: 96 m<sup>2</sup> — matches the survey form.**

#### EQUATION: NUMBER OF PANELS THAT FIT

$$N = \frac{A_{\text{usable}}}{A_{\text{panel}} \times f}$$

*In words: Number of panels = Usable area ÷ (one panel's area × a spacing allowance factor)*

| Symbol   | Meaning                                                            | Unit                                                        |
|----------|--------------------------------------------------------------------|-------------------------------------------------------------|
| N        | the number of panels that fit                                      | count (a whole number)                                      |
| A_usable | the usable area found above                                        | square meters (m <sup>2</sup> )                             |
| A_panel  | one panel's area, including its frame                              | square meters (m <sup>2</sup> )                             |
| f        | a spacing allowance factor for row gaps, walkways, and frame edges | no unit — a multiplier, for example 1.2 for 20% extra space |

*Always round DOWN to a whole number of panels — a fraction of a panel does not fit. This gives the maximum panel count the space allows; Chapter 12 shows how to check if this is actually enough panels for the building's energy need.*

#### WORKED EXAMPLE — HOW MANY PANELS FIT ON THE EXAMPLE SCHOOL'S ROOF?

The Example School's usable roof area is 96 m<sup>2</sup> (from the survey form above). Using Panel B from Chapter 5 (330 W, about 1.94 m<sup>2</sup> each) and a 20% spacing allowance (f = 1.2), how many panels fit, and what array size does this give?

1. Write the equation:  $N = A_{\text{usable}} \div (A_{\text{panel}} \times f)$
2. Put in the numbers:  $N = 96 \div (1.94 \times 1.2)$
3. Calculate the bottom:  $1.94 \times 1.2 \approx 2.33 \text{ m}^2$
4. Divide:  $N = 96 \div 2.33 \approx 41.2$
5. Round DOWN to a whole number:  $N = 41$  panels
6. Find the array size:  $41 \times 330 \text{ W} = 13,530 \text{ W} \approx 13.5 \text{ kWp}$

**Answer: 41 panels fit, giving an array of about 13.5 kWp.**

#### CASE STUDY — THE ROOF THAT NEEDED AN ENGINEER FIRST • KURDISTAN REGION (A COMMON, REALISTIC SCENARIO)

A shop owner wanted a 5 kW system on his flat concrete roof. During the site survey, the surveyor noticed thin cracks near one corner of the roof and a patch of paint that had bubbled from years of water sitting in the same spot. Instead of moving straight to a quotation, the surveyor recommended a quick visit from a structural engineer. The engineer found that the roof's steel reinforcement had corroded in that corner, and the roof could not safely carry the planned array's weight and wind load without repair. The repair cost some extra money and delayed the project by two weeks — but it was far cheaper, and far safer, than fixing a collapsed corner after the array and racks were already installed. The survey's checklist, not the

sales conversation, is what caught the problem.

#### ACTIVITY (FIELD) — SURVEY A REAL ROOF

1. As a team, choose a real roof to survey — your school, university, or home, with permission from the owner.
2. Walk the roof (or view it safely from a ladder or an upper window) and note its condition: material, cracks, rust, water damage.
3. Measure or pace out the roof's length and width, and estimate its total area.
4. Find and measure every obstruction: water tanks, vent pipes, satellite dishes, stairwell exits.
5. Use a compass to find true south (correct for magnetic declination, Chapter 5), and note the roof's orientation.
6. Take photos: a wide view from each side, each obstruction close up, the access route, and the existing distribution board.
7. Fill in a survey form like the example in this lesson, and calculate the usable area.

*You need: Tape measure or measuring wheel, Compass or phone compass app, Camera or phone, Notebook or the app's survey checklist, Adult supervision and the owner's permission*

► *App tool: Check the roof's measured orientation and tilt against the recommendation from Chapter 5*

## 16.2 The Shading Survey: Through the Day and Across the Seasons

A roof can look perfectly sunny on the day of your visit — and still lose a large share of its energy to shading at other times. Chapter 5 introduced shading and its effect on panel output. This lesson teaches the full method: checking shading through the day, AND through the seasons of the year, before a design is finalized.

#### WORD TO KNOW

**Shading survey** — A careful check of everything that blocks, or could block, sunlight from a solar array — done at different times of the day and across the seasons of the year.

Shading changes with two things: the time of day, and the time of year. Through the day, the Sun moves from east to west, so an obstruction to your east mainly matters in the morning, and one to your west mainly matters in the afternoon (Chapter 3). Through the year, the Sun's height in the sky changes with the seasons (Chapter 3) — low in winter, high in summer. An obstruction that misses the array completely in June can shade it badly in December. This is exactly why a shading survey done only once, in one season, can be misleading.

#### WORD TO KNOW

**Obstruction angle** — The angle, measured upward from the horizontal, from the array to the top of a nearby obstruction.

#### EQUATION: OBSTRUCTION (SHADING) ANGLE

$$\theta = \arctan\left(\frac{h}{d}\right)$$

*In words: Obstruction angle =  $\arctan(\text{height of the obstruction above the array} \div \text{horizontal distance to the obstruction})$*

| Symbol   | Meaning                                                         | Unit        |
|----------|-----------------------------------------------------------------|-------------|
| $\theta$ | the obstruction angle                                           | degrees (°) |
| h        | the height of the obstruction's top above the array's own plane | meters (m)  |
| d        | the horizontal distance from the array to the obstruction       | meters (m)  |

Compare  $\theta$  with the Sun's altitude (Chapter 3) at the time and date you care about. If  $\theta$  is BIGGER than the Sun's altitude, the obstruction blocks the sun at that moment. If  $\theta$  is SMALLER, the array is clear.

#### WORKED EXAMPLE — DOES THE NEIGHBORING BUILDING SHADE THE EXAMPLE SCHOOL'S ARRAY IN WINTER?

Lesson 1's survey found a two-story building 8 m to the south of the array, with its roofline about 6 m higher than the array. Find the obstruction angle, and check whether it blocks the sun at solar noon on the December solstice in Erbil (noon altitude about 30°, from Chapter 3).

1. Write the equation:  $\theta = \arctan(h \div d)$
2. Put in the numbers:  $\theta = \arctan(6 \div 8) = \arctan(0.75)$
3. Calculate:  $\theta \approx 36.9^\circ$
4. Compare:  $36.9^\circ$  is BIGGER than Erbil's December solstice noon altitude of about  $30^\circ$

**Answer: Yes — the building's obstruction angle (about  $36.9^\circ$ ) is higher than the Sun's winter noon altitude (about  $30^\circ$ ), so it blocks direct sun on the array at solar noon in December. Because winter is already the design month for an off-grid array (Chapter 12), this loss matters and should not be ignored.**

#### WORD TO KNOW

**Horizon profile** — A record of the height, in degrees, of every obstruction around a site, matched to its compass direction, as seen from the array's own position.

Professional surveyors walk around the array position and record the obstruction angle in every compass direction — not just south. The result is called a horizon profile: a simple table or chart of 'how high is the sky blocked, in every direction.'

#### Example shading survey log — a horizon profile around the array

| Compass direction | Obstruction observed            | Distance (m) | Height above array (m) | Obstruction angle  |
|-------------------|---------------------------------|--------------|------------------------|--------------------|
| N (0°)            | None — open sky                 | —            | —                      | 0°                 |
| NE (45°)          | Low garden wall                 | 3            | 1                      | $\approx 18^\circ$ |
| E (90°)           | Neighboring single-story house  | 6            | 2.5                    | $\approx 23^\circ$ |
| SE (135°)         | Water tank on our own roof      | 4            | 1.5                    | $\approx 21^\circ$ |
| S (180°)          | Two-story building              | 8            | 6                      | $\approx 37^\circ$ |
| SW (225°)         | Neighboring building corner     | 10           | 5                      | $\approx 27^\circ$ |
| W (270°)          | Distant trees across the street | 20           | 3                      | $\approx 9^\circ$  |

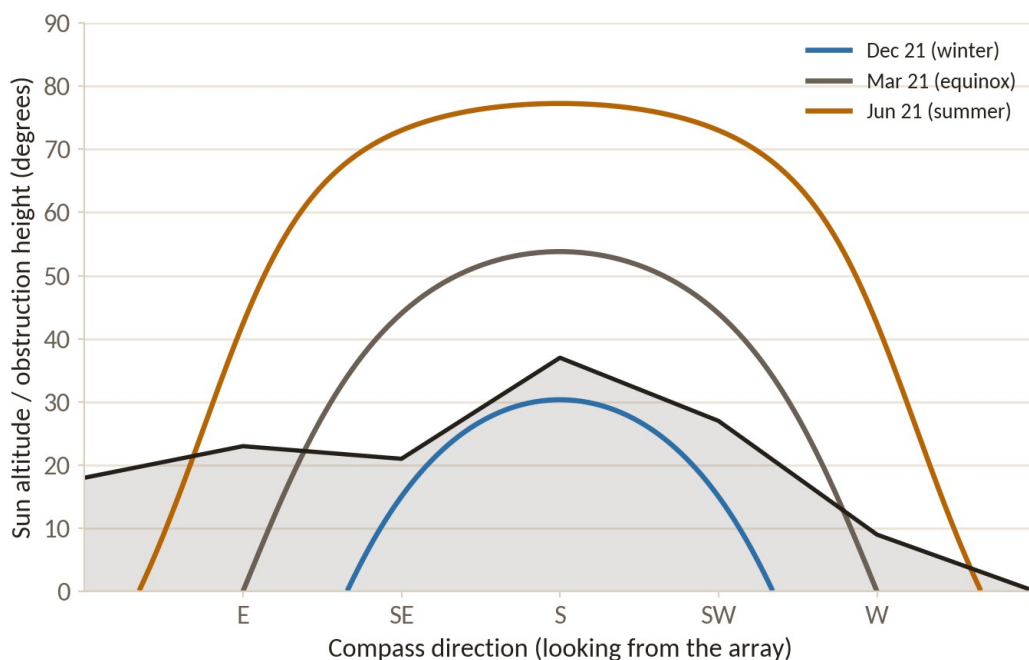
| Compass direction | Obstruction observed | Distance (m) | Height above array (m) | Obstruction angle |
|-------------------|----------------------|--------------|------------------------|-------------------|
| NW (315°)         | None — open sky      | —            | —                      | 0°                |

Notice that direction matters as much as angle. In the Northern Hemisphere, the Sun spends almost the whole productive day somewhere between the southeast and the southwest (Chapter 3). An obstruction due north of the array — even a fairly tall one — rarely causes real shading, because the Sun is almost never in the northern sky here. The South row above, at about 37°, stands out from the rest of the table: it is the one direction that genuinely needs the closest attention, exactly as the worked example found.

#### WORD TO KNOW

**Sun path diagram** — A chart that shows the Sun's altitude and compass direction for every hour of the day, across the months of the year, for one latitude.

The full professional method plots the horizon profile from the table above onto a sun path diagram for the site's latitude. Wherever the horizon line rises above the Sun's path for a given month, the array is shaded at that date and time. This is exactly what the app's sun-position tool draws for you, for any city and any date.



*An example sun path diagram for Erbil's latitude, with the horizon profile from the survey table plotted on top as a dark skyline. Curved lines show the Sun's path for the equinox, the June solstice, and the December solstice. Wherever the skyline rises above a curve, the array is shaded at that date and time — the diagram shows this happening to the December curve on the southern side, matching the worked example.*

► [App simulation: Explore it live: see the Sun's path for any city and date, and check your own horizon profile against it](#)

#### WORD TO KNOW

**Inter-row shading** — One row of panels casting a shadow onto the row behind it, usually when the sun is low in the sky. Chapter 5 introduced this idea; a shading survey is where you check it properly, for a real

site.

If your site has more than one row of tilted panels, apply the same idea between the rows themselves. Chapter 5 gave a simple rule of thumb for row spacing. A real shading survey checks this properly: use this lesson's obstruction-angle method, with the row behind treated as the 'array' and the row in front treated as the 'obstruction,' at your site's lowest winter Sun altitude.

#### CASE STUDY — A SHOP THAT ONLY CHECKED SHADING IN JULY • KURDISTAN REGION (A COMMON, REALISTIC SCENARIO)

A shop owner asked for a shading check in July, on a bright, clear afternoon. The installer looked around, saw no shadows reaching the roof, and gave the go-ahead. The system was installed and worked well all summer. In December, the owner noticed the south-facing edge of the array produced far less power every day between about 11:00 and 13:00 — right around solar noon. The cause was a neighboring building's roofline, 7 m to the south and about 5.5 m higher than the array. Using this lesson's method, its obstruction angle is  $\arctan(5.5 \div 7) \approx 38^\circ$ . In July, the Sun was so high in the sky (about  $77^\circ$  at solar noon, Chapter 3) that a  $38^\circ$  obstruction never came close to blocking it. In December, the Sun's noon altitude drops to about  $30^\circ$  — well below the building's  $38^\circ$  obstruction angle — so its shadow reaches the array every day, right in the middle of winter, the very month an off-grid design depends on most (Chapter 12). A shading survey done in only one season had missed the problem completely.

#### COMMON MISTAKE

**✗ Wrong:** Doing a shading check only once, on a clear day, and assuming the result holds true for the rest of the year.

**✓ Right:** Check shading using the obstruction-angle method (or a sun path diagram) for the Sun's LOWEST altitude at your site — usually around the December solstice in the Northern Hemisphere — because that is when shadows are longest and obstructions are most likely to cause a problem.

#### ACTIVITY (FIELD) — MAP YOUR SITE'S HORIZON PROFILE

1. At the array's planned position, use a compass to find eight directions: N, NE, E, SE, S, SW, W, NW.
2. In each direction, find the tallest nearby obstruction and measure its distance and its height above the array, using a tape measure, or estimate both carefully.
3. Use a clinometer, or the obstruction-angle equation, to find the obstruction angle in each direction.
4. Fill in a table like this lesson's horizon profile, and mark which directions need the closest attention (south, southeast, and southwest).
5. Compare your worst-case angle with Erbil's example December solstice noon altitude (about  $30^\circ$ , Chapter 3), or look up your own city's value.

*You need: Compass or phone compass app, Clinometer or phone clinometer app, Tape measure or estimated distances, Notebook*

## 16.3 Drawings and the Single-Line Diagram

A site survey collects facts. Drawings turn those facts into something you, an installer, a supplier, and sometimes an inspector can all read the same way. This lesson covers the two drawings every solar project needs: a site plan, and a single-line diagram.

#### WORD TO KNOW

**Site plan** — A drawing, seen from above, that shows a site's layout — a roof or piece of ground, buildings, and the solar array — drawn to scale.

#### WORD TO KNOW

**Drawing scale** — The ratio between a distance on a drawing and the real distance it represents — for example, 1:100, where 1 cm on the drawing equals 100 cm in real life.

You do not need expensive software to make a useful site plan. Graph paper, a ruler, and the measurements from Lesson 1 are enough. Choose a scale that fits your paper, mark true north, and draw the roof or ground outline, every obstruction, and the planned array layout, all at the same scale.

#### EQUATION: DRAWING SCALE

$$Scale = \frac{L_{\text{drawing}}}{L_{\text{real}}}$$

*In words: Scale = Length on the drawing ÷ length in real life*

| Symbol    | Meaning                                                    | Unit                                                     |
|-----------|------------------------------------------------------------|----------------------------------------------------------|
| Scale     | the drawing's scale, usually written as a ratio like 1:100 | no unit — a ratio                                        |
| L_drawing | a length measured on the drawing                           | for example, centimeters (cm)                            |
| L_real    | the same length measured in real life                      | the SAME unit as L_drawing, for example centimeters (cm) |

*Both lengths must use the same unit before dividing. A scale of 1:100 means 1 cm on the drawing equals 100 cm (1 m) in real life.*

#### WORKED EXAMPLE — CHOOSING A SCALE FOR A HAND-DRAWN SITE PLAN

The Example School's roof is 12 m long (Lesson 1's survey). You want to draw it as a 12 cm line on your paper. What scale is this drawing?

1. Convert both lengths to the same unit: 12 m = 1200 cm
2. Write the equation: Scale = L\_drawing ÷ L\_real
3. Put in the numbers: Scale = 12 cm ÷ 1200 cm
4. Simplify: Scale = 1/100

**Answer:** A scale of 1:100 — every 1 cm on the paper equals 1 m (100 cm) in real life.

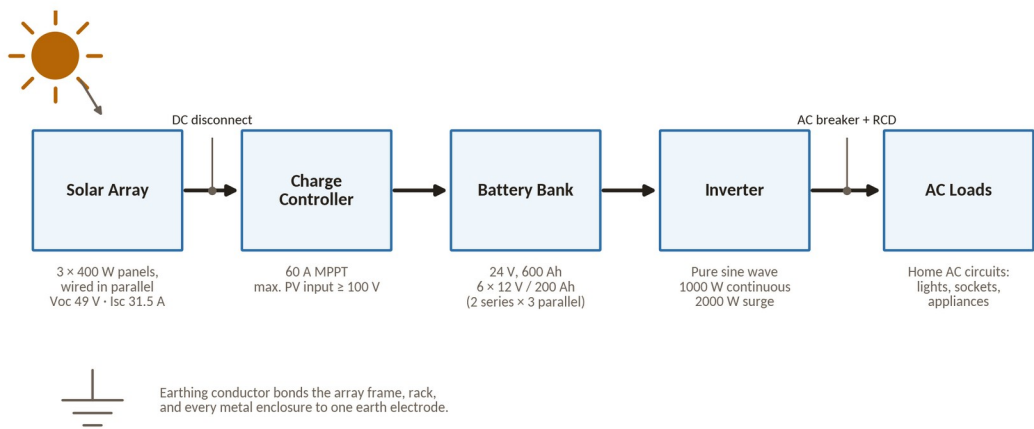
#### WORD TO KNOW

**Single-line diagram** — A simplified drawing of a solar system that shows its main components and how they connect, using one line for each circuit instead of every real wire. Often shortened to SLD.

Chapter 9 showed a complete system wiring diagram, with every cable, fuse, and connection drawn out. A single-line diagram (SLD) is simpler: one line stands for a whole circuit, and symbols or labels show each major component, its rating, and how the energy flows from the array to the loads. An SLD is usually enough for a quotation, a permit application, or a quick explanation to a customer; the full wiring diagram from Chapter 9 is what the installer uses during the actual work.

What a single-line diagram usually shows

| Component                 | What it shows on the SLD                                                                             |
|---------------------------|------------------------------------------------------------------------------------------------------|
| Solar array               | Number of panels, wiring (series/parallel), and the array's Voc, Isc, and rated power (Chapters 4–5) |
| DC combiner and fuse      | Where strings join together, and the fuse rating protecting each one (Chapter 9)                     |
| DC disconnect             | The switch used to safely isolate the array from the rest of the system (Chapter 9)                  |
| Charge controller         | Type (PWM or MPPT) and current rating (Chapter 7)                                                    |
| Battery bank              | System voltage, total capacity, and how the batteries are wired (Chapter 6)                          |
| Inverter                  | Continuous and surge power rating, and waveform type (Chapter 8)                                     |
| AC breaker and disconnect | Rating of the protection on the AC side (Chapter 9)                                                  |
| Distribution board        | Where the inverter's AC output reaches the building's loads                                          |
| Earthing symbol           | Where frames, racks, and enclosures connect to the earth electrode (Chapter 9)                       |



A single-line diagram of the small home off-grid system designed in Chapter 12: 3 x 400 W panels wired in parallel (array Voc 49 V, Isc 31.5 A) → DC combiner/fuse → DC disconnect → 60 A MPPT charge controller → 24 V, 600 Ah battery bank (6 x 12 V, 200 Ah, wired 2 series x 3 parallel) → battery fuse/disconnect → 1000 W continuous / 2000 W surge pure sine inverter → AC breaker and RCD → distribution board → loads. An earthing conductor connects the panel frames, the rack, and every enclosure to a single earth electrode.

A good SLD labels every major component with its real rating — not just its name. Compare the example above with Chapter 12's complete worked design: the same array, controller, battery bank, and inverter, now drawn as a real document instead of a set of calculations.

#### WORD TO KNOW

**As-built drawing** — A final drawing that shows exactly how a system was actually built, including any changes made during installation.

Plans change during real installations — a cable route is moved, a different breaker size is used, a panel is added. An as-built drawing is updated to match what was ACTUALLY built, not just what was planned. Chapter 18 uses this drawing to start the system's record book, and Chapter 19 uses it to troubleshoot faults years later.

#### COMMON MISTAKE

**X Wrong:** Keeping the original design drawing as the only record, even after changes were made on site.

**✓ Right:** Update the drawing to an as-built version at the end of every installation. A wrong drawing is worse than no drawing, because it looks trustworthy while being incorrect.

#### ACTIVITY (CLASSROOM) — DRAW YOUR OWN SITE PLAN AND SINGLE-LINE DIAGRAM

1. Using Lesson 1's survey of a real roof, choose a scale that fits your paper, and draw a site plan: outline, obstructions, true north, and a possible array layout.
2. List the main components a system for that roof would need: array, charge controller (or grid-tie inverter), battery bank if any, inverter, and protection devices.
3. Draw a simple single-line diagram connecting these components in order, labeling each one with an example rating.
4. Compare your drawing with a classmate's. Can they read it and understand the system without your help?

*You need: Lesson 1's survey notes, Graph paper or plain paper, Ruler, Pencil*

► *App tool: Revisit Chapter 12's array sizing calculator to check the numbers behind a single-line diagram*

## 16.4 The Installation Plan, Tools List, and Preparing a Quotation

The survey (Lesson 1), the shading check (Lesson 2), and the drawings (Lesson 3) give you everything needed to plan the actual work and put a price on it. This final lesson covers the installation plan, the tools list, and preparing a quotation.

#### WORD TO KNOW

**Installation plan** — A written plan that lists the tasks, the order of work, the people, the tools, and the time needed to install a solar system safely.

A good installation plan answers five questions: what tasks need doing, in what order, who will do them, what tools and equipment they need, and how long each part should take. Writing it down, before work starts, catches problems early and keeps a team working safely and efficiently together.

Most home and small commercial installations follow a similar order: - Confirm the site is ready (Lessons 1–3) and materials have arrived - Install the mounting rack - Mount and secure the panels - Run and protect the DC



cabling (Chapter 9) - Place and connect the battery bank, in a shaded, ventilated spot (Chapter 6) - Install the charge controller and inverter - Complete the AC wiring and protection devices (Chapter 9) - Test and commission the system (Chapter 18) Chapter 17 covers each of these steps in full detail.

#### WORD TO KNOW

**Bill of materials** — A complete list of every part needed for a project, with the quantity of each. Often shortened to BOM.

A bill of materials (BOM) is built directly from the single-line diagram (Lesson 3): every labeled component becomes one line in the list, with its exact quantity. A complete BOM prevents one of the most common causes of installation delay — arriving on site to find one connector, one breaker, or one length of cable is missing.

#### Basic tools for a small solar installation

| Tool                                                   | Used for                                                           |
|--------------------------------------------------------|--------------------------------------------------------------------|
| Tape measure and measuring wheel                       | Roof and cable-route measurements (Lesson 1)                       |
| Spirit level and clinometer                            | Checking mounting level and tilt angle (Lesson 1, Chapter 5)       |
| Compass                                                | Finding true south and recording orientation (Lesson 1, Chapter 5) |
| Multimeter                                             | Checking voltage, current, resistance, and continuity (Chapter 2)  |
| Drill and driver set                                   | Fixing racks and enclosures                                        |
| Spanners and MC4 tool                                  | Tightening mounting hardware and connecting panels (Chapter 9)     |
| Wire strippers and crimping tool                       | Preparing and terminating cables and MC4 connectors (Chapter 9)    |
| Torque wrench                                          | Tightening electrical terminals to the correct force (Chapter 9)   |
| Ladder and fall-protection equipment                   | Safe roof access (this chapter's and Chapter 17's safety notes)    |
| Personal protective equipment (gloves, safety glasses) | Protecting the installer during every task                         |

#### SAFETY

Before opening any existing distribution board or touching existing wiring during a survey or planning visit, assume it is live. Never open a panel you are not trained and authorized to work in. If you must check something inside it, ask a qualified electrician to open it for you, or use a clamp meter from outside where possible. This is exactly the same rule Chapter 9 gave for a live system: prove it is de-energized before you touch it.

Now for the price. Chapter 15 showed what a quotation costs from the CUSTOMER's side. This lesson shows the same document from the INSTALLER's side — how a company builds that price.

#### WORD TO KNOW

**Scope of work** — A clear, written list of exactly what work a supplier or installer will do — and will not do

— for a project.

#### WORD TO KNOW

**Quotation** — A written offer from a supplier or installer that lists the equipment, the work, and the price for a job.

A written scope of work, alongside the quotation price, protects both sides of the deal. It states exactly which equipment, which work, and which extras (like a new distribution board, or roof repair) are included — and which are not.

#### WORD TO KNOW

**Margin** — The extra amount a supplier adds on top of their own costs, to cover profit and business expenses, when preparing a quotation price.

#### WORD TO KNOW

**Contingency** — Extra money added to a budget or quotation to cover unexpected costs or problems.

#### EQUATION: QUOTATION PRICE FROM COST AND MARGIN

$$P = C \times (1 + m)$$

*In words: Quotation price = Total cost  $\times$  (1 + margin)*

| Symbol | Meaning                                                                | Unit                                           |
|--------|------------------------------------------------------------------------|------------------------------------------------|
| P      | the final quotation price shown to the customer                        | currency, for example IQD                      |
| C      | the supplier's total cost, including materials, labor, and contingency | currency, for example IQD                      |
| m      | margin, written as a decimal fraction                                  | no unit — a fraction, for example 0.20 for 20% |

*Contingency is usually added to the cost total BEFORE the margin, not after. Margin as a decimal: 15% = 0.15, 20% = 0.20.*

#### WORKED EXAMPLE — BUILDING A QUOTATION PRICE

A supplier's estimate for a small home system: materials cost 6,000,000 IQD, and labor costs 1,000,000 IQD (example numbers). The company adds a 5% contingency, then a 20% margin. What price should appear on the quotation?

1. Add materials and labor:  $6,000,000 + 1,000,000 = 7,000,000$  IQD
2. Add 5% contingency:  $7,000,000 \times 0.05 = 350,000$  IQD
3. Total cost:  $C = 7,000,000 + 350,000 = 7,350,000$  IQD
4. Write the equation:  $P = C \times (1 + m)$
5. Put in the numbers:  $P = 7,350,000 \times (1 + 0.20) = 7,350,000 \times 1.20$
6. Calculate:  $P \approx 8,820,000$  IQD

**Answer: About 8,820,000 IQD (example numbers for practice).**

### What a complete, professional quotation should include

| Section           | What it should show                                                                      |
|-------------------|------------------------------------------------------------------------------------------|
| Scope of work     | Exactly what is included, and what is not                                                |
| Bill of materials | Every part, its brand or model, and its quantity                                         |
| Price breakdown   | Cost of equipment, labor, and any extra work — not just one total                        |
| Timeline          | Expected start date and how many days the work will take                                 |
| Payment terms     | Deposit amount, and when the rest is due                                                 |
| Warranty          | Equipment warranty (from the manufacturer) and workmanship warranty (from the installer) |
| Validity          | How long the quoted price stays valid                                                    |

#### CASE STUDY — THE QUOTATION THAT DID NOT SAY ENOUGH • KURDISTAN REGION (A COMMON, REALISTIC SCENARIO)

A family accepted a one-page quotation for 7,000,000 IQD that simply said '5 kW solar system, complete.' When the crew arrived, the family learned that the price did not include repairing a damaged section of the distribution board, or the cost of extra cable because the battery room was farther from the roof than the installer had assumed. The final bill came to 8,400,000 IQD — 20% more than the quotation — and the family felt misled, even though the installer felt the extra work was obviously necessary once they saw the site. Neither side was fully wrong; the real problem was a quotation with no clear scope of work and no bill of materials. A second supplier's quotation for a similar job, using this lesson's checklist, listed the distribution board repair and every cable run as separate, priced lines — so there were no surprises for either side.

#### COMMON MISTAKE

**✗ Wrong:** Writing a quotation as a single total price, with no breakdown of what is included.

**✓ Right:** Always include a scope of work and a bill of materials with the price. A detailed quotation protects the customer from surprises and protects the installer from disputes.

#### ACTIVITY (CLASSROOM) — PREPARE A SIMPLE QUOTATION

1. Using your Lesson 1 survey, Lesson 3 single-line diagram, and a simple bill of materials, list every part needed and an example price for each (ask a local shop, or use example prices from Chapter 15).
2. Add up the materials cost and an estimated labor cost.
3. Add a contingency (for example, 5%) and a margin (for example, 15–20%), using this lesson's equation.
4. Write a one-page quotation with a scope of work, using this lesson's checklist table.
5. Exchange your quotation with another student or group, and check it against the checklist — is anything missing?

*You need: Your Lesson 1 survey form, Your Lesson 3 single-line diagram or sketch, Calculator or phone, Example prices (Chapter 15, or a real local quote)*

## CHAPTER SUMMARY

- A site survey checks and records a site's roof or structure condition, load-bearing capacity, usable area, measurements, orientation, shading, electrical system, access, and photos — before any equipment is bought.
- Usable area = Total roof area – Area lost to obstructions – Area lost to setbacks. Number of panels that fit = Usable area ÷ (one panel's area × a spacing allowance factor), rounded down.
- A shading survey checks obstructions through the day AND across the seasons. Obstruction angle =  $\arctan(\text{height above the array} \div \text{horizontal distance})$ . If this angle is bigger than the Sun's altitude at a given time, the array is shaded.
- The Sun spends most of the productive day in the southern sky (Northern Hemisphere), so obstructions to the south, southeast, and southwest deserve the closest attention; the December solstice, with the Sun at its lowest, is usually the worst-case check.
- A horizon profile records the obstruction angle in every compass direction; plotted on a sun path diagram, it shows exactly which dates and hours are shaded.
- A site plan (drawn to scale) and a single-line diagram (one line per circuit, with components and ratings labeled) turn survey facts into documents an installer, supplier, or inspector can read.
- An as-built drawing is updated to match what was actually installed, and becomes the starting point for the system's record book (Chapter 18) and future troubleshooting (Chapter 19).
- An installation plan lists the tasks, order, people, tools, and time needed; a bill of materials, built from the single-line diagram, lists every part and its quantity.
- A complete quotation states the scope of work, the bill of materials, a price breakdown, a timeline, payment terms, and warranty — not just one total number. Quotation price = Total cost × (1 + margin), where total cost includes materials, labor, and contingency.

► *App tool: Once you have a real quotation price, estimate the payback period with Chapter 15's calculator*

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A site survey finds visible cracks and water stains on a flat concrete roof where a family wants to install solar panels. What should the surveyor recommend before any design work continues?

**Problem 2 [Basic]** A roof is 10 m by 8 m. Obstructions on the roof take up 6 m<sup>2</sup> of space, and the required setback takes up 10 m<sup>2</sup>. Find the usable roof area.

**Problem 3 [Basic]** List the four main groups of information a complete site survey should record.

**Problem 4 [Basic]** Why should a surveyor take photos during a site visit, even after writing detailed notes?

**Problem 5 [Basic]** A wall is 6 m long. You draw it as a 6 cm line on paper. What is the scale of your drawing?

**Problem 6 [Standard]** A chimney is 2.5 m higher than the array and 5 m away, measured horizontally. Find the obstruction angle. Will it block the sun at solar noon on the December solstice in Erbil (noon altitude about 30°, from Chapter 3)?

**Problem 7 [Standard]** A usable roof area is 70 m<sup>2</sup>. Using Panel B from Chapter 5 (about 1.94 m<sup>2</sup> each) and a 20% spacing allowance, how many panels fit, and what is the resulting array size?

**Problem 8 [Standard]** A shading survey finds two obstructions with the same obstruction angle: one due north of the array, and one due west. Which one is more likely to actually reduce the array's energy production, and why?

**Problem 9 [Standard]** Materials for a job cost 4,000,000 IQD and labor costs 800,000 IQD. The company adds a 5% contingency, then a 15% margin. Find the final quotation price.

**Problem 10 [Standard]** During a site survey, the surveyor finds the existing distribution board is old, has no visible earthing wire, and some breakers are unlabeled. Should this stop the solar project completely? What should the survey report recommend?

**Problem 11 [Standard]** The array on a roof is 15 m of cable route from the equipment room where the batteries and inverter will go. The installer plans to add 3 m of extra cable at each end for routing and connections. What total cable length should appear on the bill of materials for this one run?

**Problem 12 [Challenge]** A survey of a flat roof finds: total area 200 m<sup>2</sup>, a stairwell exit taking 8 m<sup>2</sup>, a water tank taking 6 m<sup>2</sup>, and a required setback strip taking 30 m<sup>2</sup>. (a) Find the usable area. (b) Using Panel A from Chapter 5 (450 W, about 2.17 m<sup>2</sup> each) with a 25% spacing allowance, how many panels fit? (c) What array size, in kW, does this give?

**Problem 13 [Challenge]** A site's only significant obstruction is a tree with its top 7 m higher than the array, 10 m to the south. (a) Find the obstruction angle. (b) Using Erbil's example noon Sun altitudes (equinox 54°, June solstice 77°, December solstice 30°, from Chapter 3), in which of these three periods would the tree most likely shade the array at solar noon? (c) What does this mean for how the array's winter energy production should be planned, given that winter is already the design month in Chapter 12?

**Problem 14 [Challenge]** Two quotations arrive for the same 5 kW system. Quotation A: 9,000,000 IQD, with a full bill of materials, a clear scope of work, a 5-year workmanship warranty, and photos of completed projects. Quotation B: 7,200,000 IQD, a one-page price with no bill of materials, no scope of work, and no warranty mentioned. (a) Find the price difference in IQD, and as a percentage of Quotation B's price. (b) List at least three questions the buyer should ask Quotation B's supplier before deciding. (c) Using this chapter's ideas, explain why the cheaper quotation might not be the better value.

## CHAPTER SEVENTEEN

# Installation Step by Step

*Turning a design into a safe, working system*

### IN THIS CHAPTER YOU WILL LEARN TO

- Install a mounting structure on a flat roof, including ballast, alignment, and row spacing.
- Fix panels to the structure and connect them together correctly and safely.
- Run and protect cables the professional way, from the array to the equipment room.
- Place batteries, charge controllers, and inverters where they get enough ventilation and stay cool.
- Follow safe practices for working at height and working with DC electricity.
- Complete a commissioning checklist before a new system is switched on for the first time.

## 17.1 Mounting Structures on a Flat Roof

Chapter 16 ends with a finished design: a single-line diagram, a list of equipment, and a plan for the roof. This chapter turns that plan into a real, working system — safely. We start at the very beginning: the structure that will hold the panels for the next twenty years or more.

Chapter 5 already introduced the rack, the tilt frame, ballast, clamps, and wind load. This lesson does not repeat those ideas — it shows you how to actually build the structure, step by step, on the flat concrete roofs that are so common across Iraq and the Kurdistan Region.

### Step-by-step: a ballasted tilt-frame installation

| Step                                | What to do                                                                         | Why it matters                                                                 |
|-------------------------------------|------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| 1. Re-check the plan                | Compare the roof to the site survey and single-line diagram from Chapter 16.       | Roofs change — a new water tank or satellite dish can appear after the survey. |
| 2. Mark the layout                  | Mark row positions, spacing, and walkways with chalk or tape.                      | Fixing mistakes after ballast is loaded is much harder.                        |
| 3. Inspect the roof surface         | Check the concrete and waterproofing for cracks or damage.                         | A damaged roof should be repaired BEFORE it carries any new load.              |
| 4. Assemble rack sections           | Build tilt-frame sections on the flat roof surface, close to their final position. | Easier and safer than assembling piece by piece at full height or on an edge.  |
| 5. Position and align rows          | Set true south orientation and the row-to-row spacing (see below).                 | A few degrees of error, repeated across many rows, adds up.                    |
| 6. Level and join sections          | Use a spirit level; bolt or clip rack sections together as one structure.          | A joined structure resists wind far better than loose, separate pieces.        |
| 7. Add ballast                      | Load the correct ballast weight, evenly, as specified in the design.               | Too little ballast risks the whole row lifting in strong wind.                 |
| 8. Final check before fixing panels | Walk the whole layout again: spacing,                                              | The last easy chance to fix a layout                                           |

| Step | What to do                        | Why it matters               |
|------|-----------------------------------|------------------------------|
|      | level, ballast, cleared walkways. | mistake before panels go on. |

#### WORD TO KNOW

**Roof penetration** — A hole made through a roof's surface, for example to bolt down a mounting frame. Every penetration must be sealed well, or it can leak for years.

Most home and shop installers in the region choose the ballasted, non-penetrating method for Step 7 above, exactly because it avoids roof penetrations on a flat concrete roof that must keep out winter rain. A bolted (penetrating) frame is still used sometimes — for example, on a very lightweight roof that cannot carry heavy ballast, or in an area with very strong wind, where extra anchoring is needed. If you must drill, always follow the roof manufacturer's or a qualified contractor's sealing method — never just fill a hole with sealant and hope.

#### WORD TO KNOW

**Parapet** — A low wall built around the edge of a flat roof. It can be a useful place to fix an anchor point, but it is not always strong enough to bear heavy loads.

A parapet looks solid, but do not assume it can carry weight or hold an anchor point without checking — some parapets are just a thin decorative wall. Keep ballast and racks set back from the roof edge and away from the parapet unless a qualified person has confirmed it is safe to load.

#### WORD TO KNOW

**Mounting rail** — A straight metal bar fixed to a rack or roof, that solar panels are clamped onto in a row.

#### WORD TO KNOW

**Torque** — The turning force used to tighten a nut or bolt. Bolts need the correct torque — not too loose, which can work loose over time, and not too tight, which can crack the material.

Every rack, rail, and clamp bolt has a torque value in its installation manual, usually in newton-meters (N-m). A torque wrench checks this directly. Without one, a good habit is 'snug plus a quarter turn' for small bolts — firm, but not forced with a long pipe for extra leverage.

#### WORD TO KNOW

**Galvanic corrosion** — Faster rusting that happens when two different metals touch each other and stay wet, such as an aluminum rail against a plain steel bolt. Using matched metals, or a barrier between them, prevents it.

#### COMMON MISTAKE

**X Wrong:** Fixing an aluminum rail with ordinary steel bolts and washers, because that is what was in the toolbox.

**✓ Right:** Use bolts, washers, and clips made for the rail material — usually stainless steel or aluminum-

compatible hardware. Mixing the wrong metals can quietly weaken a joint over years of rain and dew, long before it looks rusted.

#### SAFETY

Structure and load: before loading any roof with racks, panels, and ballast, confirm the roof can safely carry the extra weight — for anything beyond a small system, this needs a qualified person, especially on an older building (Chapter 5). Never stack ALL the ballast or panels in one small area while working; spread the load and stage materials in small groups. Keep walkways and the area below clear of tools and loose parts, and warn anyone below before lifting or moving anything.

#### SAFETY

Heat and PPE: roof surfaces and metal parts get extremely hot in the summer sun here — hot enough to burn bare skin on contact. Wear gloves, sturdy shoes, and eye protection when drilling or cutting. Work in the early morning or late afternoon where possible, drink water often, and take shade breaks — heat exhaustion is a real risk on a summer roof.

One layout detail deserves its own number: the gap between rows. Chapter 5 gave the rule of thumb — leave a gap of at least two to two-and-a-half times the panel's vertical rise between the back of one row and the front of the next, so the front row does not shade the row behind it. Now let's turn that rule into a real measurement you can mark on the roof.

#### EQUATION: MINIMUM ROW SPACING (GAP) RULE OF THUMB

$$D \geq k \times L \times \sin(\beta)$$

*In words: Minimum gap  $\geq$  spacing factor  $\times$  panel length  $\times$  sine of the tilt angle*

| Symbol  | Meaning                                                                             | Unit                     |
|---------|-------------------------------------------------------------------------------------|--------------------------|
| D       | minimum gap between the back of one row and the front of the next                   | meters (m)               |
| k       | spacing factor from the rule of thumb (typically 2 to 2.5)                          | no unit (a plain number) |
| L       | the panel's length measured up the slope — the dimension mounted facing up the tilt | meters (m)               |
| $\beta$ | the panel's tilt angle                                                              | degrees (°)              |

*This is a simplified rule of thumb, not an exact sun-path calculation, but it is good enough to plan and mark a real layout. For an exact check at your site's latitude, use the Tilt & Orientation calculator.*

#### WORKED EXAMPLE — ROW SPACING FOR A PANEL A ARRAY IN ERBIL

Panel A (Chapter 5) is 2.094 m long and will be mounted with that side running up the slope, tilted at 36° (Erbil's recommended tilt). Using the minimum spacing factor,  $k = 2$ , find the minimum gap between rows.

1. Find the panel's vertical rise:  $\text{rise} = L \times \sin(\beta) = 2.094 \times \sin(36^\circ) \approx 2.094 \times 0.588 \approx 1.23 \text{ m}$
2. Apply the rule of thumb:  $D \geq k \times \text{rise} = 2 \times 1.23 \approx 2.46 \text{ m}$
3. Round up for a practical margin: plan for about 2.5 m minimum gap between rows

**Answer: About 2.5 m minimum gap between the back of one row and the front of the next.**



► App tool: Check the exact spacing for your own city and tilt angle

### Ballasted vs. bolted: practical installation considerations

| Consideration              | Ballasted (non-penetrating)             | Bolted (penetrating)                       |
|----------------------------|-----------------------------------------|--------------------------------------------|
| Roof damage risk           | Very low — no holes made                | A hole is made; must be sealed correctly   |
| Weight added to the roof   | Higher — ballast blocks add real weight | Lower — held by bolts, not weight          |
| Changing the layout later  | Easier — lift and move blocks           | Harder — old holes must be re-sealed       |
| Skill and tools needed     | Basic tools; careful weight calculation | Drilling, sealing, and flashing skills     |
| Typical use in this region | Most flat concrete roofs                | Lightweight roofs, or very high-wind sites |

### CASE STUDY — WHEN BALLAST WAS NOT ENOUGH · KURDISTAN REGION (EXAMPLE SCENARIO)

A small shop owner mounted a 12-panel array on his flat roof using a tilt frame, following advice from a friend rather than a proper design. He used only half the ballast weight the rack maker recommended, thinking the panels' own weight would be enough. During a strong spring windstorm, one row of the array lifted at the back and blew over, cracking three panels and damaging the roof's waterproofing where the frame scraped across it. The repair — new panels, a re-sealed roof, and a full re-installation with the correct ballast — cost far more than buying the right amount of ballast the first time. (*This is an example scenario for practice, not a specific real project.*) The lesson: ballast weight is a real engineering number, not a guess, and it depends on rack height, tilt angle, and local wind conditions.

### SAFETY

Weather: never work on a roof, or leave loose materials on one, during high wind, rain, or a lightning storm (Chapter 9's lightning warning applies here too). Check the local weather before starting, and have a plan to secure everything and get down safely if conditions change during the work.

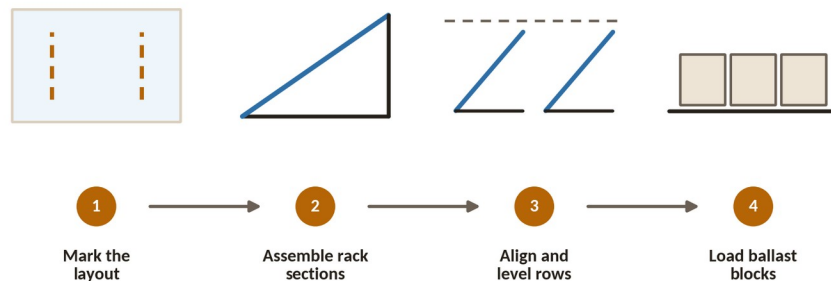


*Photo sequence of a ballasted tilt-frame installation: marking the layout, assembling rack sections on the roof, aligning and leveling rows, and loading ballast blocks evenly along the frame.*

### ACTIVITY (FIELD) — MARK A REAL LAYOUT

1. With your teacher, choose a real or practice flat roof area.
2. Using the tilt angle and row-spacing gap from this lesson, mark two rows of a mock layout with chalk, tape, or string.
3. Check your marked layout with a tape measure — is the gap between rows correct, and does the layout avoid the roof edge and any parapet?
4. Discuss as a group: where would you route the cable down to the equipment room from this layout? (Lesson 2 continues from here.)

*You need: Tape measure, Chalk, tape, or string, This lesson's row-spacing result*

## 17.2 Fixing Panels, Then Running and Protecting Cables

The structure is up (Lesson 1). Now the panels themselves go on, get connected together, and get wired safely to the rest of the system. This lesson covers both jobs, because on a real site they usually happen together, row by row.

**Fixing panels.** Panels sit on the mounting rails and are held down by clamps — a mid clamp between two neighboring panels, an end clamp at the outer edge of each row (Chapter 5). Follow the panel manufacturer's manual for exactly where the clamps go: every panel frame has marked or recommended clamping zones, usually a little way in from each corner. Clamping in the wrong place — too close to a corner, or in the middle of a long edge — can flex the frame and crack the glass or cells inside, sometimes not until months later.

### COMMON MISTAKE

**X Wrong:** Clamping a panel wherever is convenient, as long as it feels tight.

**✓ Right:** Clamp only at the zones shown in the panel's manual. A tight clamp in the wrong place can still damage the panel over time, even if nothing breaks immediately.

Tighten every clamp bolt to its correct torque (Lesson 1) — snug and even, working along the row, then check again once the whole row is fixed. Leave the small expansion gap the manufacturer recommends between panels; metal and glass both expand a little in summer heat.

### SAFETY

While fixing panels, remember Chapter 9's warning: a connected string of panels produces a real voltage in daylight, even before it is wired to anything else. Keep MC4 connectors capped and separated until you are ready to connect that circuit, and treat every exposed metal contact as if it were live.

**Connecting panels.** Once a row is fixed, connect its panels together following your string plan from the design stage (Chapter 7's string configuration). Push each MC4 connector together firmly until it clicks — a half-connected plug can arc or overheat. Keep connectors clean and dry before mating them, and never force a connector that does not fit; check for the correct connector type and gender first.

Before moving to the next row, double-check polarity (Chapter 9) at every join — positive to positive, negative to negative — using the cable's markings, not memory. A reverse-polarity mistake can damage a charge controller or inverter the instant the circuit is completed.

### SAFETY

Before making the FINAL connection in any string — the one that completes the circuit back to the combiner box or controller — stop and re-check every earlier connection: polarity, full clicks, and clamp torque. Once that last connection is made, the whole string becomes an active, dangerous circuit.

**Running cables.** Plan the shortest safe path from each row to the combiner point or equipment room, but 'shortest' is not the only rule. Avoid sharp bends — a tight bend can crack a cable's insulation over time; keep bends gentle, roughly four to five times the cable's own diameter at the smallest point. Avoid walkways and roof-access routes, so cables are not a trip hazard or crushed underfoot. Keep DC array cables and AC cables in separate runs where possible, so the two 'electrical worlds' from Chapter 9 are never confused or damaged together.

#### WORD TO KNOW

**Conduit** — A pipe or tube, made of plastic or metal, that protects a cable running through or along a wall, floor, or roof.

#### WORD TO KNOW

**Cable tray** — An open metal channel, like a ladder or tray, that supports and protects many cables running together along the same route.

#### Choosing a way to protect a cable run

| Method                                | Best for                                                 | Key point                                                               |
|---------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------|
| PV cable clipped directly to the rack | Short runs across open racking                           | Use UV-rated clips made for outdoor cable; check clips regularly        |
| Conduit (rigid or flexible)           | Runs across an open roof, down a wall, or through a hole | Must itself be UV-rated if used outdoors; keep ends sealed              |
| Cable tray                            | Several cables running together over a longer distance   | Keeps cables tidy, supported, and easy to inspect or add to later       |
| Trunking (a covered channel)          | Indoor runs, or along a wall to an equipment room        | Tidy and easy to open for maintenance; less tough than conduit outdoors |

#### WORD TO KNOW

**Cable gland** — A fitting that lets a cable pass into an enclosure or conduit while sealing tightly around it, keeping out water and dust, and holding the cable firmly.

#### WORD TO KNOW

**Drip loop** — A downward loop left in a cable just before it enters a connector or enclosure, so that any water running down the cable drips off at the bottom of the loop instead of flowing inside.

#### WORD TO KNOW

**Strain relief** — A fitting or method that stops the weight or pulling force on a cable from being carried by

its electrical connection, protecting the connection from damage over time.

Put these together at every entry point: a cable gland (or equivalent fitting) sized for the cable, a drip loop just before it, and enough slack that pulling on the cable outside does not pull on the connection inside — that is strain relief in practice. This one habit prevents a large share of the water-damage and loose-connection faults that Chapter 19 will later teach you to find.

#### WORKED EXAMPLE — HOW MUCH CABLE TO BUY FOR THE ARRAY-TO-ROOM RUN

The array is 9 m in a straight line from where the cable enters the equipment room. The real route is not straight: add 2 m to go around a parapet corner, 3 m for the vertical drop down an outside wall, and 1 m total for drip loops and connection slack at both ends. Add a 10% spare allowance for the whole route, and round up to the next whole meter. How much cable should be bought for ONE conductor of this run?

1. Add the route segments:  $9 + 2 + 3 + 1 = 15$  m
2. Add 10% spare:  $15 \times 1.10 = 16.5$  m
3. Round up to the next whole meter: 17 m

**Answer: About 17 m for one conductor. A DC circuit needs a positive AND a negative conductor of this length (unless using twin-core PV cable, which has both in one jacket) — always measure the real route, never the straight-line map distance.**

A route that is longer than planned changes more than the shopping list — it can also push a cable's voltage drop over the limit. Chapter 9 sized this array's cable for an assumed 8 m run: design current 16.25 A, a 12 V system, a 3% voltage-drop limit, giving a minimum size of about  $12.64 \text{ mm}^2$  — rounded up to  $16 \text{ mm}^2$ . Now recheck it with a real, measured route of 13 m.

#### WORKED EXAMPLE — RECHECKING VOLTAGE DROP WITH THE REAL ROUTE LENGTH

Using Chapter 9's formula ( $V_{\text{drop}} = (2 \times \rho \times L \times I) \div A$ , with copper  $\rho \approx 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ ), check whether the  $16 \text{ mm}^2$  cable chosen for an assumed 8 m run is still large enough for a real, measured route of 13 m, carrying the same 16.25 A design current on a 12 V system with a 3% limit.

1. Find the allowed voltage drop:  $3\% \times 12 \text{ V} = 0.36 \text{ V}$
2. Check  $16 \text{ mm}^2$  at the real length:  $V_{\text{drop}} = (2 \times 0.0175 \times 13 \times 16.25) \div 16 \approx 7.39 \div 16 \approx 0.46 \text{ V}$
3. As a percentage:  $(0.46 \div 12) \times 100 \approx 3.8\%$  — above the 3% limit, so  $16 \text{ mm}^2$  now FAILS
4. Find the new minimum cross-section:  $A_{\text{min}} = (2 \times 0.0175 \times 13 \times 16.25) \div 0.36 \approx 7.39 \div 0.36 \approx 20.5 \text{ mm}^2$
5. Round up to the next standard size: choose  $25 \text{ mm}^2$

**Answer: No — the real 13 m route needs at least  $25 \text{ mm}^2$ , not  $16 \text{ mm}^2$ . Always recheck voltage drop with the cable's real, measured length; even a few extra meters can push you to the next standard size.**

► *App tool: Recheck any real route length with the Cable Sizing calculator*

#### SAFETY

Rodents and other animals sometimes chew unprotected cable, especially in farm buildings, sheds, and remote sites — a chewed cable can short-circuit or start a fire long after installation. Protect any cable a rodent could reach with conduit or trunking, not just clips.

### COMMON MISTAKE

**✗ Wrong:** Pulling a cable tight with no slack, so it looks neat, then connecting it straight into an enclosure.

**✓ Right:** Leave a drip loop and a little slack at every connection. A tight, straight cable with no loop lets water run straight into the enclosure, and gives no room for the connection to be re-made later without cutting the cable shorter each time.

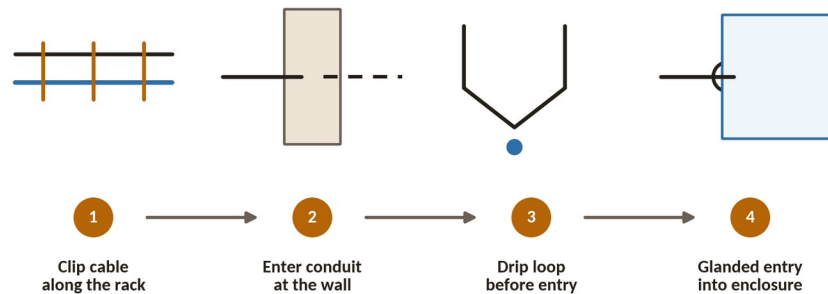


*Photo sequence of cable routing on a real installation: clipping cable along the rack, entering conduit at a wall penetration, a drip loop before the equipment room, and a labeled, glanded entry into the enclosure.*

### ACTIVITY (CLASSROOM) — SKETCH YOUR CABLE ROUTE

1. Using your roof layout from Lesson 1 (or a given example roof plan), sketch the cable route from the array to an equipment room.
2. Mark the protection method for each segment: clipped, conduit, cable tray, or trunking.
3. Mark where a drip loop is needed.
4. Estimate the total one-way route length, add your own reasonable slack and spare allowance, and state how much cable you would order.

*You need: Your Lesson 1 roof sketch, or a given example plan, Paper and pen, Ruler*

## 17.3 Placing Batteries and Electronics Safely

A battery bank, charge controller, and inverter can be correctly sized (Chapters 6 to 8) and still cause problems for years if they are placed in the wrong spot. This lesson is about location: where these parts go, and why.

In most homes and small shops in the region, the battery bank, charge controller, and inverter are placed together in one spot — a utility room, a storeroom, or a dedicated cabinet — close to where the main DC and AC cables meet. This keeps cable runs short (good for voltage drop, Lesson 2) and makes maintenance easier, since everything is in one place.

### WORD TO KNOW

**Ventilation** — The movement of fresh air through a space, which carries away heat and any gas that has collected there.

Chapter 6 explained that flooded lead-acid batteries release hydrogen gas while charging — invisible, and explosive if it collects in a closed space. Ventilation is the fix: fresh air must be able to move through the battery's space, carrying that gas safely away before it can build up.

#### Ventilation needs by battery type

| Battery type                 | Gas released while charging                                            | Ventilation need                                                      |
|------------------------------|------------------------------------------------------------------------|-----------------------------------------------------------------------|
| Flooded lead-acid            | Hydrogen — a meaningful amount                                         | High — open vents, top and bottom, or a fan for a large bank          |
| AGM / gel (sealed lead-acid) | Hydrogen — a very small amount normally, unless damaged or overcharged | Moderate — still needs airflow, but less than flooded                 |
| LiFePO4 (lithium)            | Normally none in ordinary use                                          | Lower gas risk, but still needs cool air for temperature and lifespan |

Even a 'low gas' battery still needs ventilation for a second reason: heat.

#### WORD TO KNOW

**Ambient temperature** — The temperature of the air around a piece of equipment, not the temperature inside it. A hot room gives equipment a hot ambient temperature to work in, even if the equipment itself is working normally.

Batteries, charge controllers, and inverters all make some heat while they work (Chapters 6 to 8 — no conversion is ever 100% efficient). If the surrounding air is already hot and still, that heat has nowhere to go. The equipment runs hotter than its rating expects, which — just like the cable derating in Chapter 9 — can shorten its life or force it to reduce its own output to protect itself.

Battery life is especially sensitive to heat. As a rough guide, many lead-acid batteries lose about half of their expected life for every 10°C they run above 25°C. A battery rated for 6 years at 25°C might last only about 3 years in a hot, poorly ventilated room that stays near 35°C — and summers here can easily push an unventilated indoor space well above that.

#### WORKED EXAMPLE — BATTERY LIFE IN A HOT ROOM (A ROUGH ESTIMATE)

A battery is rated for 8 years of service life at 25°C. Using the rough 'half-life per 10°C' guide, estimate its life if it is placed in a poorly ventilated room that stays near 35°C, and again near 45°C.

1. 35°C is 10°C above 25°C: one halving. Estimated life  $\approx 8 \div 2 = 4$  years
2. 45°C is 20°C above 25°C: two halvings. Estimated life  $\approx 8 \div 2 \div 2 = 2$  years

**Answer: Roughly 4 years at 35°C, and roughly 2 years at 45°C — a rough guide only, but a clear warning that heat is expensive. Good ventilation and shade are some of the cheapest 'maintenance' a system can get.**

#### WORD TO KNOW

**Thermal runaway** — A dangerous chain reaction inside a battery, where rising heat makes the chemical reaction go faster, which then makes even more heat. It can end in fire. It is rare, especially in LiFePO4 batteries, but becomes more likely if a battery is damaged, overcharged, or allowed to overheat badly.

### SAFETY

Fire and gas: never place batteries in a fully sealed box or cupboard with no airflow at all. Keep open flame, sparks, and smoking away from any battery space. Keep a suitable fire extinguisher nearby, and know where it is before you need it.

### SAFETY

If you must check or work inside a small, poorly ventilated battery space on a hot day, do not stay in it long without a fresh-air break — heat and any gas can build up around YOU, the worker, not only around the equipment.

### WORD TO KNOW

**Clearance** — The empty space that must be kept open around a piece of equipment, for safe airflow, access, and repair.

Every inverter and charge controller manual gives clearance distances — for example, so many centimeters free on each side and above. Leaving less than this traps heat exactly where the equipment needs to lose it, and also makes it harder to reach for testing or repair later.

### WORKED EXAMPLE — FINDING THE WALL SPACE TO RESERVE

An inverter's manual asks for 15 cm clearance on each side and 30 cm above. The unit itself is 40 cm wide and 50 cm tall. Find the minimum wall space (width × height) to reserve for it. (These numbers are an example from one manual — always check your own model.)

1. Width: left clearance + unit width + right clearance =  $15 + 40 + 15 = 70$  cm
2. Height: unit height + top clearance =  $50 + 30 = 80$  cm

**Answer: Reserve at least about 70 cm wide by 80 cm tall of clear wall space for this inverter.**

### Choosing a good spot for batteries and electronics

| Feature to look for                            | Why it matters                                                                             |
|------------------------------------------------|--------------------------------------------------------------------------------------------|
| Cool and shaded, away from direct sun          | Heat shortens battery life and can force electronics to reduce output                      |
| Ventilated, not sealed airtight                | Removes heat and any battery gas safely                                                    |
| Dry, not a flood-prone or damp spot            | Water near batteries and electronics is a shock and short-circuit risk                     |
| Off the bare floor, on a sturdy shelf or stand | Keeps batteries clear of damp and makes cleaning easier; the surface must hold real weight |
| Away from flammable storage                    | Reduces fire risk if a fault ever produces heat or sparks                                  |
| Accessible but not in a busy walkway           | Easy to inspect and maintain, but not in everyone's way                                    |
| Secure from children and tampering             | Batteries and live electrical parts are dangerous to touch                                 |
| Close to where cables naturally meet           | Shorter DC cable runs mean less voltage drop (Lesson 2)                                    |

### CASE STUDY — A HOT CUPBOARD, A SHORT LIFE • KURDISTAN REGION (EXAMPLE SCENARIO)

A small telecom relay site installed a battery bank inside a metal cabinet placed in direct summer sun, with its door kept shut to protect the batteries from dust. Inside the cabinet's small, sealed space, daytime temperatures often climbed far above the surrounding air temperature. The batteries needed replacing after about two years, well short of their rated life. (*This is an example scenario for practice.*) When the site was rebuilt, the new cabinet was moved into permanent shade, fitted with a screened, ventilated top and bottom, and given proper clearance around the equipment inside. The lesson matches this lesson's rule of thumb: heat is not a small side issue for batteries — it is one of the biggest costs a poor location can create.

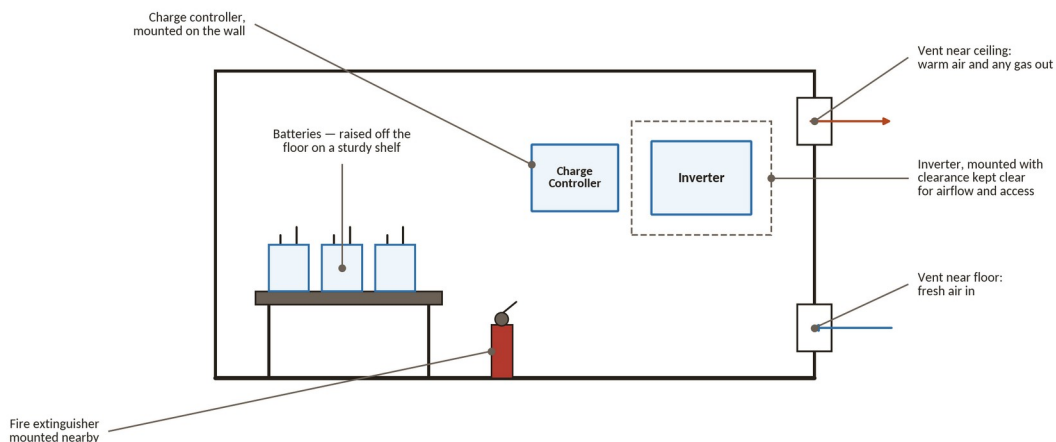
### COMMON MISTAKE

**✗ Wrong:** Placing the battery bank and inverter inside a small, sealed cupboard to hide the wiring and save space.

**✓ Right:** Batteries and electronics need airflow. A small, sealed cupboard traps heat and any gas. Use a ventilated cabinet, add proper vent openings, or choose a more open, airy spot instead.

### SAFETY

Even when you are only placing or moving batteries — not wiring them yet — treat every terminal as live. Cover terminals, remove rings and metal jewelry, use insulated tools, and never rest a metal tool across two terminals (Chapter 6). Batteries are also heavy: lift with your legs, or use two people, not your back alone.



*A well-planned battery and electronics space: units raised off the floor, vent openings top and bottom, clear space around each unit, and a fire extinguisher mounted nearby.*

► [App simulation: Revisit: see how temperature affects charging and battery life](#)

### ACTIVITY (HOME) — RATE THREE SPOTS IN YOUR HOME

1. Choose three possible spots in or around your home where a battery bank and inverter could go (for example: a storeroom, a covered balcony, an outdoor metal cabinet).
2. For each spot, check it against the table in this lesson: ventilation, shade, dryness, floor strength,



distance from flammables, access, and security.

3. Score each spot from 1 to 8 (one point for each feature it has).

4. Choose the best spot, and write one sentence saying what you would change to make it even better.

*You need: Paper and pen, A walk around your home*

## 17.4 Safe Work at Height, Safe Work with DC, and Commissioning

This final lesson brings together the two biggest physical dangers in solar installation work — falling, and electric shock or arc — and then shows you the last step before any new system is switched on: the commissioning checklist.

**Safe work at height.** Most solar work happens on a roof. A fall from even a single story can cause serious injury or death, so height safety is not an optional extra — it is part of the job itself.

### WORD TO KNOW

**Personal protective equipment (ppe)** — Equipment worn by a worker to reduce the risk of injury, such as gloves, safety glasses, a helmet, and non-slip boots.

### Basic PPE for roof and installation work

| Item                                          | Protects against                                            |
|-----------------------------------------------|-------------------------------------------------------------|
| Non-slip, closed shoes or boots               | Slipping on a roof; dropped tools or materials              |
| Gloves                                        | Cuts from cable and sheet metal; hot surfaces; battery acid |
| Safety glasses                                | Dust, metal filings, and arc or spark risk                  |
| Helmet (where there is a falling-object risk) | Head injury from dropped tools or materials                 |
| Sun protection (hat, light long sleeves)      | Heat and sun exposure during long roof work                 |

### WORD TO KNOW

**Safety harness** — A set of straps worn around the body and legs, connected by a lanyard to a secure anchor point, to stop a person falling a dangerous distance if they slip at height.

### WORD TO KNOW

**Anchor point** — A strong, fixed structural point used to attach a safety harness's lanyard. It must be able to hold a falling person's weight safely.

Use a harness and anchor point on steep, high, or otherwise risky roofs — never rely on a parapet as an anchor point without checking it can truly hold a person's weight (Lesson 1). On simple, low, flat roofs with a solid edge or guardrail, some sites work safely without a full harness — always follow your local safety rules and your supervisor's judgment, not just this general guide.

### SAFETY

Ladders: use the right length, inspect it before every use, and set it at a safe angle — a simple guide is the 4-to-1 rule: for every 4 units of height to the point it rests against, move the base out 1 unit. Keep three

points of contact at all times (two hands and a foot, or two feet and a hand), and never overreach sideways — move the ladder instead.

#### SAFETY

Never work alone on a roof (Chapter 5). Keep tools tethered or in a closed bag, never loose in a pocket or balanced on an edge, and keep the ground area below clear or clearly warned so no one walks underneath while work is happening above.

#### SAFETY

Never work at height in high wind, rain, or a lightning storm, and never on a wet or icy surface. Check the weather before starting, and have a clear plan to get everyone down safely if conditions change.

#### COMMON MISTAKE

**X Wrong:** Skipping a harness or extra care 'just for a quick job' on a roof.

**✓ Right:** Most falls happen during short, 'quick' tasks, precisely because normal care is skipped. Treat every trip onto a roof the same way, no matter how small the job looks.

**Safe work with DC.** Chapter 9 already gave two of the most important safety facts in this whole course: DC arcs do not switch off by themselves the way many AC arcs do, and a solar panel makes voltage the moment light reaches it — it cannot be 'switched off' just by disconnecting something downstream while the sun is still shining on it. This section turns those facts into a safe way of working.

#### WORD TO KNOW

**Live** — Carrying electric current, or connected to a voltage source, so that touching it could give a dangerous shock. The opposite is de-energized (dead) — safely disconnected, but only after this has been tested and confirmed, never just assumed.

#### WORKED EXAMPLE — HOW DANGEROUS IS ONE STRING, REALLY?

Ten Panel A modules ( $V_{oc} = 49.5 \text{ V}$  each, Chapter 5) are connected in series to make one string. What is the string's approximate open-circuit voltage in full sun?

1. In series, voltage adds up (Chapter 5):  $V_{\text{string}} \approx n \times V_{oc\_module}$
2.  $V_{\text{string}} \approx 10 \times 49.5 \text{ V} = 495 \text{ V}$

**Answer: About 495 V — far above the voltage of ordinary household electricity, and present the moment the sun shines on a connected string, with no switch needed.**

#### SAFETY

Treat every array circuit as live until you have personally tested and confirmed otherwise — never assume a circuit is safe just because a switch looks open or a breaker looks off. Use a meter rated for the voltage present, check it against a known live source first, then test the circuit.

## WORD TO KNOW

**Lockout-tagout** — A safety procedure where a switch or disconnect is physically locked in the OFF position, and labeled with a tag, so nobody can switch it back on while a person is working on that circuit.

Before working on any part of the system: open and isolate every relevant disconnect, in the correct order (Chapter 9), then lock it out and tag it if the equipment allows this. If a panel or string still faces the sun and cannot be fully de-energized, cover it with an opaque sheet, or plan the work for early morning, evening, or a cloudy period — remember, a lit panel always makes voltage.

## SAFETY

When testing or working on a circuit you believe is de-energized: use insulated tools, wear gloves rated for the voltage present, remove rings, watches, and metal jewelry (Chapter 6), and use the 'one-hand rule' where practical — keep one hand in a pocket while testing, so current has less chance of crossing the chest if something goes wrong.

## COMMON MISTAKE

**✗ Wrong:** Unplugging a loaded MC4 connector by hand in full sunlight, to save the time of finding a disconnect switch.

**✓ Right:** A loaded DC connector can arc when pulled apart, and a DC arc can sustain itself. Always use a rated disconnect, or de-energize the circuit first (Chapter 9's warning, worth repeating here).

**The commissioning checklist.** Commissioning has two parts. This lesson covers the first part: a careful walk-through BEFORE the system is powered up for the first time, to catch mistakes while they are still easy and safe to fix. Chapter 18 covers the second part in full: testing performance once the system is running.

## WORD TO KNOW

**Commissioning** — The process of checking, testing, and officially confirming that a newly installed system is safe and working correctly, before it is used normally or handed to its owner.

### Example pre-power-up commissioning checklist

| Area               | Check                                                                           |
|--------------------|---------------------------------------------------------------------------------|
| Mechanical         | All rack, rail, and clamp bolts are tight to the correct torque (Lesson 1)      |
| Mechanical         | Ballast is complete and even; walkways and roof drains are clear                |
| Panels and strings | Every panel is firmly clamped; no visible cracks or damage                      |
| Panels and strings | Every string matches the design's string configuration (Chapter 7)              |
| Connections        | Every MC4 connector is fully clicked together; correct polarity everywhere      |
| Cables             | Cables are protected along their whole route, with drip loops and glands fitted |
| Cables             | Cables are labeled clearly, so the circuit is obvious to a                      |

| Area                      | Check                                                                                         |
|---------------------------|-----------------------------------------------------------------------------------------------|
|                           | future technician                                                                             |
| Earthing and bonding      | Every rack, frame, and enclosure is earthed and bonded, and connections are tight (Chapter 9) |
| Protection                | Correct fuses, breakers, and disconnects are fitted, and every disconnect is labeled          |
| Batteries and electronics | Terminals covered; ventilation and clearance in place (Lesson 3)                              |
| Site                      | No tools, offcuts, or loose materials left on the roof or in the equipment room               |

Only once every item on a checklist like this is confirmed should the system be energized — usually in a specific order given by the equipment manuals (often battery, then controller, then array, then inverter and loads, but always check the manufacturer's own sequence). Watch the readings at each step; a reading that looks wrong is much easier to fix right now than after everything is connected and covered up.

#### WORKED EXAMPLE — A QUICK CHECK BEFORE GOING FURTHER

Before connecting a 10-panel string ( $V_{oc} = 49.5 \text{ V}$  each) to the charge controller, the installer measures its open-circuit voltage with a meter and gets a reading of 483 V. Is this reasonable, and is it safe to proceed to the next checklist step?

1. Find the expected value:  $V_{\text{string}} \approx 10 \times 49.5 = 495 \text{ V}$
2. Compare: 483 V is close to 495 V — real panels vary a little with temperature and sunlight, so a small difference is normal
3. A reading close to expected suggests the string is wired correctly in series, with no obvious open connection

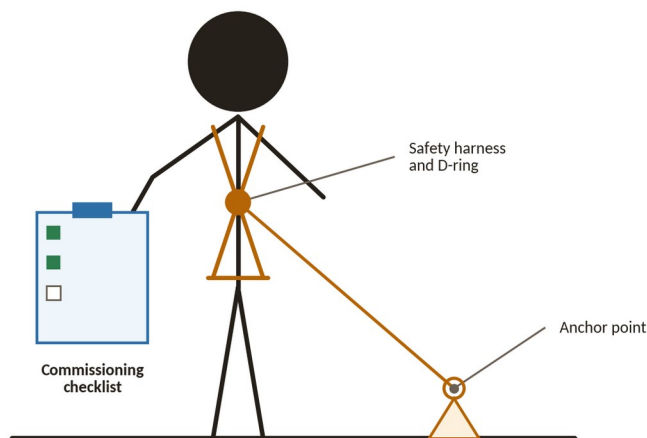
**Answer: Yes — 483 V is close enough to the expected 495 V to be reasonable. (If the reading had been far off — for example, only 250 V, about half — that would point to a wiring fault, such as a string wired as two separate parts instead of one. Chapter 18 covers full performance testing.)**

The app's Guides section includes this checklist as an interactive, step-by-step tool with photos and warnings, so you can tick off each item on-site, on your phone, instead of relying on memory or a loose paper sheet.

#### COMMON MISTAKE

**X Wrong:** Skipping the checklist for a 'simple' system, because the installer has done this many times before.

**✓ Right:** The checklist exists exactly because experienced installers still make small mistakes under time pressure. A five-minute walk-through can prevent a dangerous fault or an expensive repair.



*A technician using a harness and anchor point while completing a final checklist walk-through on a rooftop array before power-up.*

#### ACTIVITY (LABORATORY) — RUN THE COMMISSIONING CHECKLIST

1. With your teacher, use this lesson's checklist on a real or demonstration solar system.
2. Go through every item as a team, and mark each one done, or note what still needs fixing.
3. Only after every item passes, follow the correct power-up order for your specific equipment, with your teacher supervising.
4. Record any issues you found and fixed — this is the first entry in the system's record book (Chapter 18).

*You need: A real or demonstration small solar system, This lesson's checklist, Teacher supervision*

#### CHAPTER SUMMARY

- Turn a design into a real structure step by step: check the plan, mark the layout, inspect the roof, assemble and align the rack, then add ballast — most flat roofs in the region use a ballasted, non-penetrating tilt frame.
- Use the correct torque on every bolt, match hardware metals to avoid galvanic corrosion, and always confirm the roof and its structure can carry the extra load and local wind.
- Space rows apart using the rule of thumb  $D \geq k \times L \times \sin(\beta)$ , with  $k$  between 2 and 2.5, so one row does not shade the row behind it.
- Clamp panels only where the manufacturer's manual allows, connect strings following the design plan, and always double-check polarity at every join.
- Protect every cable along its real route with the right method — clipped, conduit, tray, or trunking — and always add a drip loop and strain relief at each entry point.
- Always recheck voltage drop using the cable's real, measured route length, not the original straight-line design estimate.
- Place batteries and electronics somewhere cool, ventilated, dry, and clear — heat and trapped gas are

two of the biggest, most avoidable risks to a system's life and safety.

- Work at height only with the right PPE and ladder technique, and — where the roof calls for it — a harness and secure anchor point; never work alone or in bad weather.
- Treat every DC circuit as live until you have tested and confirmed otherwise; a lit solar panel always makes voltage, and a loaded DC connector can arc if pulled apart.
- Complete a full commissioning checklist before powering up a new system for the first time — it is the last, easiest chance to catch a mistake.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A design calls for 45 kg of ballast at one panel position. Each concrete paver weighs 9 kg. How many pavers are needed for that position?

**Problem 2 [Basic]** List four items of personal protective equipment (PPE) a technician should wear while mounting panels on a roof in summer, and say what each one protects against.

**Problem 3 [Basic]** A worker wants to unplug a loaded MC4 connector by hand in full sunlight, to save the time of finding the nearest disconnect switch. Is this safe? Explain in one or two sentences.

**Problem 4 [Basic]** A cable route needs 6 m across the roof, 2.5 m down the wall, and 0.5 m of slack at each end. Find the total one-way length needed, before adding any spare allowance.

**Problem 5 [Standard]** Panel B (Chapter 5, 1.960 m × 0.992 m) will be installed in Duhok, where the recommended tilt is about 37°, mounted with its 1.960 m side running up the slope. Using the minimum spacing factor  $k = 2$ , find the minimum row-to-row gap.

**Problem 6 [Standard]** A 24 V system's DC cable was sized for an assumed 6 m one-way run at a 12 A design current, giving a 4 mm<sup>2</sup> cable for a 3% voltage-drop limit. The real, measured route turned out to be 11 m one-way. (a) Is 4 mm<sup>2</sup> still large enough? (b) If not, what standard size should be used instead? (Use copper  $\rho \approx 0.0175 \Omega \cdot \text{mm}^2/\text{m}$ .)

**Problem 7 [Standard]** A family wants to place their battery bank and inverter inside a small, airtight metal cabinet in direct sun on the roof, to save space and keep it out of sight. List THREE problems with this plan, and suggest a fix for each.

**Problem 8 [Standard]** An inverter's manual requires 20 cm clearance on each side and 40 cm above. The unit is 45 cm wide and 60 cm tall. Find the minimum wall space (width × height) to reserve for it.

**Problem 9 [Standard]** A technician sets up a straight ladder to reach a flat roof 4 m above the ground. Using the 4-to-1 rule, how far from the wall should the base of the ladder be placed?

**Problem 10 [Challenge]** A flat roof is 12 m wide (east–west) by 8 m deep (north–south). Panel A (2.094 m × 1.038 m) will be mounted in tilt frames at 36° in Erbil, portrait orientation (the 2.094 m side running up the north–south slope, and the 1.038 m side facing east–west). Using Lesson 1's minimum row gap of 2.5 m: (a) How many rows fit in the 8 m depth? (b) How many panels fit across the 12 m width in each row? (c) What is the total number of panels, and the total array power in kW?

**Problem 11 [Challenge]** During the final walk-through before switching on a new home system, a technician notices: (a) one MC4 connector is not fully clicked together; (b) the earthing wire from the rack is connected

but not tight; (c) a battery terminal cover is missing; (d) the array disconnect switch has no label. For EACH finding, say whether it is safe to proceed, and what must be done first.

**Problem 12 [Challenge]** A team must replace one faulty panel in the middle of a 10-panel string ( $V_{oc} = 49.5 \text{ V}$  each) on a flat roof at midday in summer. (a) What is the string's approximate total open-circuit voltage? (b) Why is it dangerous to simply unclip the MC4 connectors on either side of the faulty panel while the sun is shining? (c) Describe a safe way to do this job.

## CHAPTER EIGHTEEN

# Testing and Commissioning

*Proving that a finished solar system works as designed*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain what to measure when testing a new solar system, including Voc, Isc, operating voltage and current, and battery voltages.
- Compare a system's expected performance with its measured performance, using the performance ratio equation.
- Calculate percent differences and a measured performance ratio from real test data.
- Choose and safely use the right test instrument — multimeter, clamp meter, or irradiance meter — for each measurement.
- Prepare acceptance and handover documents, and start a system's record book.

## 18.1 What to Measure

Chapter 17 finished with a pre-power-up commissioning checklist — a careful walk-through BEFORE a new system is switched on for the first time. That is the first half of commissioning. This chapter covers the second half: testing the system's real performance once it is running, and proving, with real numbers, that it works the way it was designed to.

Testing performance is not one measurement — it is a small family of measurements, done in a sensible order. This lesson introduces the four main groups. Lesson 3 covers the exact tools and the full step-by-step order.

### Four groups of measurements during commissioning

| Measurement                   | When to test                                                       | What it mainly checks                                                                      |
|-------------------------------|--------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Open-circuit voltage (Voc)    | Before the array is connected to the controller                    | Wiring is correct, and Voc is safely below the controller's maximum input voltage          |
| Short-circuit current (Isc)   | Before connecting, using a suitably rated meter                    | Panels and strings are producing current close to their rating, for the sunlight available |
| Operating voltage and current | While the system is running normally, connected to its load        | The real, working performance of the array and controller together                         |
| Battery voltages              | Resting, under charge, and under load; bank total AND each battery | The battery bank's health, state of charge, and whether every battery is balanced          |

Chapters 4, 5, and 7 already introduced **open-circuit voltage (Voc)** and **short-circuit current (Isc)** — a panel's highest possible voltage and highest possible current. Commissioning uses both again, now for a practical purpose: checking that a real, installed array matches its datasheet and its design.



Voc is usually the very first electrical test on a new array, done BEFORE the array is connected to the charge controller. This is the safest moment to test: with an open circuit, no current flows at all. It also confirms two things before any power flows — the panels are wired correctly, and the array's voltage is safely below the controller's maximum input rating (Chapter 7). Chapter 17 already showed a quick version of this idea, comparing a measured string voltage (483 V) with its expected value (495 V) and judging it 'close enough.' This lesson gives you an exact tool to make that judgment precise.

#### EQUATION: PERCENT DIFFERENCE BETWEEN A MEASURED AND EXPECTED VALUE

$$\text{Diff} = \frac{X_{\text{measured}} - X_{\text{expected}}}{X_{\text{expected}}} \times 100\%$$

*In words: Percent difference = (Measured value - Expected value) ÷ Expected value × 100%*

| Symbol     | Meaning                                                                                 | Unit                                                     |
|------------|-----------------------------------------------------------------------------------------|----------------------------------------------------------|
| Diff       | the percent difference between the measured and expected values                         | percent (%)                                              |
| X_measured | the real value you measure during a test                                                | any consistent unit — volts, amps, watts, kWh, and so on |
| X_expected | the value you expected before testing, usually from a datasheet or a design calculation | the same unit as X_measured                              |

*The result is a percentage. A positive result means the measured value is higher than expected; a negative result means it is lower. A small percent difference (a few percent) is normal — real test conditions are almost never exactly the same as datasheet or design conditions. Use this same tool for Voc, Isc, operating readings, and battery voltages.*

#### WORKED EXAMPLE — CHECKING A STRING'S VOC AGAINST ITS DATASHEET

An off-grid home system (the design from Chapter 12) uses 400 W panels with a datasheet Voc of 49.0 V. Wired in parallel, the array's Voc should also be 49.0 V. Before connecting to the controller, a technician measures 50.5 V on a cool morning. Find the percent difference, and say whether this is normal.

1. Write the equation:  $\text{Diff} = (\text{measured} - \text{expected}) \div \text{expected} \times 100\%$
2. Put in the numbers:  $\text{Diff} = (50.5 - 49.0) \div 49.0 \times 100\%$
3. Calculate the top:  $50.5 - 49.0 = 1.5$
4. Divide and multiply:  $1.5 \div 49.0 \times 100\% \approx 3.1\%$

**Answer: About +3.1% — normal. A panel's Voc rises a little in cooler-than-STC temperatures, so a slightly higher reading on a cool morning is expected, not a fault.**

Isc behaves differently from Voc. Instead of an open circuit, Isc is measured by connecting the array's two leads together through a suitably rated meter, so the array is briefly forced to its maximum current at zero voltage. Unlike Voc, Isc changes almost in direct proportion to how much sunlight is actually falling on the panels at that moment — so before comparing a measured Isc with the datasheet, you must first correct the datasheet value for the REAL irradiance at test time.

#### EQUATION: EXPECTED SHORT-CIRCUIT CURRENT AT A REAL IRRADIANCE

$$I_{\text{predicted}} = I_{\text{SC}} \times \frac{G}{G_{\text{STC}}}$$

*In words: Predicted Isc at test time = Isc at STC × (measured irradiance ÷ 1000 W/m²)*

| Symbol      | Meaning                                                                                        | Unit                                                    |
|-------------|------------------------------------------------------------------------------------------------|---------------------------------------------------------|
| I_predicted | the short-circuit current predicted for the real irradiance measured during the test           | amperes (A)                                             |
| I_SC        | the panel's or array's short-circuit current at standard test conditions (the datasheet value) | amperes (A)                                             |
| G           | the real irradiance measured at the moment of the test                                         | watts per square meter (W/m <sup>2</sup> )              |
| G_STC       | the standard test conditions reference irradiance                                              | watts per square meter (W/m <sup>2</sup> ), always 1000 |

Short-circuit current scales almost directly with irradiance. This is different from Voc, which barely changes with sunlight level but does change with temperature.

#### WORKED EXAMPLE — CHECKING ISC AT REAL, LESS-THAN-STC SUNLIGHT

The same array (three 400 W panels in parallel, each I<sub>sc</sub> = 10.5 A at STC, so array I<sub>sc</sub> = 31.5 A) is tested with a clamp meter while an irradiance meter reads 850 W/m<sup>2</sup>. The clamp meter reads 26.2 A. Find the predicted I<sub>sc</sub> at 850 W/m<sup>2</sup>, then the percent difference from the measurement.

1. Write the equation:  $I_{\text{predicted}} = I_{\text{SC}} \times (G \div G_{\text{STC}})$
2. Put in the numbers:  $I_{\text{predicted}} = 31.5 \text{ A} \times (850 \div 1000)$
3. Calculate:  $I_{\text{predicted}} = 31.5 \times 0.85 \approx 26.8 \text{ A}$
4. Percent difference:  $(26.2 - 26.8) \div 26.8 \times 100\% \approx -2.1\%$

**Answer: Predicted I<sub>sc</sub> ≈ 26.8 A; measured 26.2 A is about -2.1% different — a small, normal difference (connector resistance, meter accuracy, a little haze).**

#### COMMON MISTAKE

**✗ Wrong:** Connect an ordinary multimeter directly across a whole array's leads to measure I<sub>sc</sub>, without first checking the meter's maximum current rating.

**✓ Right:** Check the expected I<sub>sc</sub> against the meter's rated current range BEFORE connecting it. Many multimeters can safely handle only a small current (often 10 A) on their current setting. For an array-level I<sub>sc</sub> test, use a clamp meter — it measures current without breaking the circuit open, and has no small internal fuse to blow.

Once the array is connected and the system is running normally, it no longer sits at Voc or I<sub>sc</sub>. It sits at its operating point, decided moment to moment by the controller and the load.

#### WORD TO KNOW

**Operating voltage** — The real voltage measured at a point in a solar system while it is running normally, connected to its load. Different from Voc, which is measured with no current flowing at all.

#### WORD TO KNOW

**Operating current** — The real current measured at a point in a solar system while it is running normally, connected to its load. Different from I<sub>sc</sub>, which is measured with the two terminals connected directly together.

### Ideal (STC) values vs. real operating values

| Quantity                | Ideal (STC) value           | What to expect in real operation                                                                                                                    |
|-------------------------|-----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|
| Array operating voltage | V <sub>mp</sub> (Chapter 4) | Close to V <sub>mp</sub> with a well-tracking MPPT controller in strong sun; forced down near the battery voltage with a PWM controller (Chapter 7) |
| Array operating current | I <sub>mp</sub> (Chapter 4) | Changes through the day with real irradiance and temperature — usually highest near solar noon on a clear day                                       |

The fourth group is battery voltages — and here, one single number is not enough. A healthy battery bank shows different, predictable voltages depending on exactly when and how you measure it. A battery's **resting voltage** — its voltage after it has had no charging and no load for a while, for example one to two hours — gives the most reliable picture of its state of charge (SoC, Chapter 6). A reading taken right after charging or a heavy load can be misleadingly high or low.

### Typical 12 V lead-acid battery: resting voltage and state of charge (example)

| Resting voltage (no load, rested) | Approximate state of charge     |
|-----------------------------------|---------------------------------|
| 12.7 V                            | 100%                            |
| 12.4 V                            | 75%                             |
| 12.2 V                            | 50%                             |
| 12.0 V                            | 25%                             |
| 11.8 V or below                   | 0% (empty), or possibly a fault |

This table is a typical, approximate example — always check the real battery's own datasheet, and for a 24 V or 48 V bank, simply multiply these voltages by 2 or 4. Chapter 19 uses this same idea when troubleshooting a battery later in the system's life. In a bank of several batteries wired in series, always check EACH battery's own voltage, not only the bank's total. A bank of six 12 V batteries reading a reasonable total can still be hiding one weak battery, if the other five are strong enough to cover for it.

### SAFETY

Batteries release hydrogen gas while charging (Chapter 6) — invisible, and explosive in a closed space. When testing battery voltages, especially under charge or under load, avoid any spark near the battery tops, keep the area ventilated, and never test with a bare flame nearby.

### ACTIVITY (CLASSROOM) — PREDICT BEFORE YOU MEASURE

1. Choose a solar panel or small system you can access — in class, at home, or from an earlier chapter's example.
2. From its datasheet, write down the expected V<sub>oc</sub> and I<sub>sc</sub> at standard test conditions.
3. If you cannot test it directly, use this lesson's equation to adjust the expected I<sub>sc</sub> for a lower irradiance value your teacher gives you:  $I_{\text{predicted}} = I_{\text{SC}} \times (G \div 1000 \text{ W/m}^2)$ .
4. Compare your prediction with a classmate's. Discuss why real test conditions are almost never exactly

STC.

You need: A panel or system datasheet, Calculator or phone

## 18.2 Expected vs. Actual Performance

Lesson 1 checked single moments — a Voc reading, an Isc reading. This lesson steps back and asks a bigger question: over a whole day, is the FINISHED system producing the amount of energy its design promised?

Chapter 12 introduced performance ratio (PR) as a single number that shows how much of an array's ideal output you actually get, once real losses — heat, dust, wiring, controller, and inverter losses — are included. There, PR was used to help DESIGN a system, before it was even built, using an assumed planning figure such as 0.80. Now the system exists. This lesson uses the same idea the other way around: measure the real energy the system produces, and calculate the system's real, measured PR — proof of how the finished system actually performs.

### WORD TO KNOW

**Plane-of-array irradiation** — The total sunlight energy that falls on a solar array's own tilted surface over a period of time, usually one day. It uses the same idea as daily solar energy (Chapter 3), measured directly in the array's own mounting plane. Written H\_POA. Numerically equal to that period's peak sun hours, in hours.

Why 'numerically equal to peak sun hours'? Chapter 3 defined peak sun hours (PSH) as the number of hours the sun would need to shine at a standard 1000 W/m<sup>2</sup> to deliver the same total energy as the real day. Dividing a day's plane-of-array irradiation, in kWh/m<sup>2</sup>, by that same 1000 W/m<sup>2</sup> reference gives exactly the same number, now in hours. A day with H\_POA = 5.0 kWh/m<sup>2</sup> is a 5.0 peak-sun-hour day. This is the same tool Chapter 12 used for design — here, instead of a typical or assumed value, H\_POA is a real number measured on-site, usually with an irradiance meter (Lesson 3).

### EQUATION: PERFORMANCE RATIO FROM REAL MEASUREMENTS

$$PR = \frac{E_{\text{actual}}}{P_{\text{rated}} \times H_{\text{POA}}}$$

In words: Performance ratio = Actual energy output ÷ (Rated power × Plane-of-array irradiation)

| Symbol   | Meaning                                                                                                        | Unit                                                  |
|----------|----------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| PR       | the system's measured performance ratio for the period tested                                                  | ratio, no unit (0 to 1), often shown as a percentage  |
| E_actual | the real, measured electrical energy the system produced in the period, from an energy meter or controller log | kilowatt-hours (kWh)                                  |
| P_rated  | the array's rated (nameplate) power at standard test conditions                                                | kilowatts-peak (kWp)                                  |
| H_POA    | the plane-of-array irradiation for the same period                                                             | kilowatt-hours per square meter (kWh/m <sup>2</sup> ) |

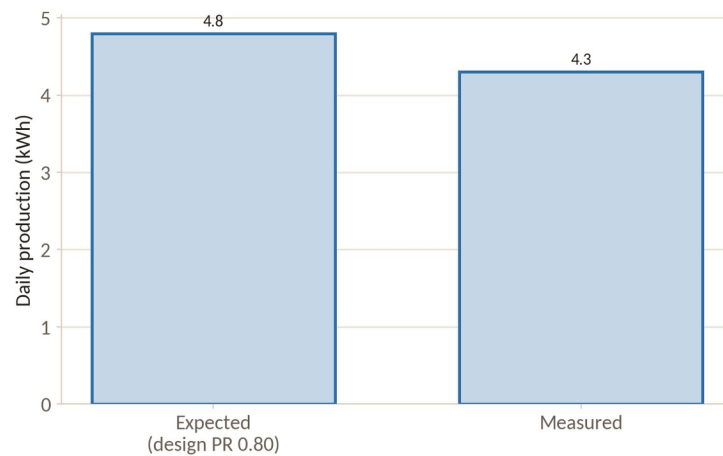
This is the same performance ratio idea from Chapter 12, used the other way around: instead of assuming a planning PR to help design a system, this equation calculates a REAL, measured PR once the system exists and can be tested.

### WORKED EXAMPLE — CHECKING A COMMISSIONED SYSTEM: EXPECTED VS. MEASURED PRODUCTION

The system from Chapter 12 (a 1.2 kWp array, design PR 0.80) is commissioned on a mild spring day. An irradiance meter logs a plane-of-array irradiation of 5.0 kWh/m<sup>2</sup> for the day (equal to 5.0 peak sun hours). The battery bank's energy meter shows the array delivered 4.3 kWh that day. Find the measured performance ratio, and compare it with the system's design PR of 0.80.

1. Write the equation:  $PR = E_{\text{actual}} \div (P_{\text{rated}} \times H_{\text{POA}})$
2. Put in the numbers:  $PR = 4.3 \text{ kWh} \div (1.2 \text{ kWp} \times 5.0 \text{ kWh/m}^2)$
3. Calculate the bottom:  $1.2 \times 5.0 = 6.0$
4. Divide:  $PR = 4.3 \div 6.0 \approx 0.717$  (about 72%)
5. Compare with the design PR:  $0.80 - 0.717 = 0.083$ , which is about 10% of the design value ( $0.083 \div 0.80 \times 100 \approx 10.4\%$ )

**Answer: Measured PR  $\approx$  0.72 (72%), about 10% below the design PR of 0.80 — close enough to be a real, working system, but low enough to be worth a second look (dust, a little shading, or a connection worth checking; Chapter 19 covers full troubleshooting).**



*Expected vs. measured daily production for the commissioned system: about 4.8 kWh expected at the 0.80 design PR, compared with 4.3 kWh actually measured — a real, working system with a small, worth-checking gap.*

#### A general guide for judging a performance ratio gap (example guideline, not a fixed rule)

| Gap between measured and design PR (relative) | What it usually suggests                                                             |
|-----------------------------------------------|--------------------------------------------------------------------------------------|
| Within about 5%                               | Normal — day-to-day weather and measurement variation                                |
| About 5% to 15%                               | Worth checking — dust, minor shading, a loose connection, or an optimistic design PR |
| More than about 15–20%                        | A real problem is likely — investigate systematically (Chapter 19)                   |

#### COMMON MISTAKE

**X Wrong:** Judge a system's health from a single cloudy, hazy, or unusual day's performance ratio, and declare it faulty.

**✓ Right:** Compare PR over several clear days, or over a full week or month when possible. Weather noise on any single day is normal — a fair judgement needs more than one data point.

### WORKED EXAMPLE — A MONTHLY PERFORMANCE RATIO CHECK

Over one 30-day month, a 3.0 kWp array's energy meter shows a total production of 390 kWh. The site's total plane-of-array irradiation for the same month is 165 kWh/m<sup>2</sup> (an average of 5.5 peak sun hours per day). Find the system's measured PR for the month.

1. Write the equation:  $PR = E_{\text{actual}} \div (P_{\text{rated}} \times H_{\text{POA}})$
2. Put in the numbers:  $PR = 390 \text{ kWh} \div (3.0 \text{ kWp} \times 165 \text{ kWh/m}^2)$
3. Calculate the bottom:  $3.0 \times 165 = 495$
4. Divide:  $PR = 390 \div 495 \approx 0.79$  (about 79%)

**Answer: Measured PR  $\approx$  0.79 — inside the normal example range (0.75–0.85) used throughout this book. A whole month of data supports that the system is healthy.**

### CASE STUDY — WHY WAS THE NEW SHOP SYSTEM'S PR LOWER THAN EXPECTED? • SULAYMANIYAH, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE)

A team installed a small rooftop system on a shop in Sulaymaniyah. On the first sunny commissioning day, the measured performance ratio came out around 0.65 — noticeably below the 0.80 design figure. Instead of guessing, the team worked through the array methodically. They checked Voc and Isc first (both close to expected, so the wiring and the panels themselves were healthy). They then walked the roof at midday and found that a neighbor's new water tank, built after the original site survey (Chapter 16), cast a shadow across one whole string for almost two hours around noon. Because the strings were wired in parallel behind one controller, the shaded string quietly pulled down the whole array's output for that part of the day. The fix was not a faulty panel or bad wiring — it was a change on the roof next door. The lesson: a low measured PR is a signal to investigate calmly, in order, not proof that something was built wrong.

The measured PR in this lesson needs real irradiation data, from an irradiance meter or another reliable source. But once a system is commissioned, its normal output on a clear day — like today's 4.3 kWh — also becomes a simple baseline for the future. On a later day, you can compare fresh output against THIS baseline directly, without needing fresh irradiance data every time. This fast, practical check, using the commissioning record you start in Lesson 4, is exactly the tool Chapter 19 uses for everyday troubleshooting. Both tools answer the same question — is this system performing normally? — but this chapter's performance ratio is the more exact, physics-based version, most useful right at commissioning, before a history of normal days even exists.

► *App tool: Try it: build or check a performance ratio from your own loss factors*

► *App tool: Compare measured production against the calculator's expected estimate*

► *App simulation: Revisit: see how each loss factor changes a system's final output*

## 18.3 Test Instruments and Procedures

Lessons 1 and 2 explained WHAT to measure and how to judge the results. This lesson covers the physical tools for the job, and the safe, sensible order to use them in.

### Common commissioning test instruments

| Instrument             | What it measures                                                    | Typical use in commissioning                                 |
|------------------------|---------------------------------------------------------------------|--------------------------------------------------------------|
| Multimeter (Chapter 2) | Voltage, current within its rated range, resistance, and continuity | Voc, battery voltages, continuity checks on cables and fuses |

| Instrument       | What it measures                                                                                                                            | Typical use in commissioning                                                                                                                         |
|------------------|---------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Clamp meter      | Current, without breaking the circuit open; usually a higher current range than a multimeter                                                | Isc, operating current, and current on battery and inverter cables                                                                                   |
| Irradiance meter | The power of sunlight reaching a surface ( $\text{W}/\text{m}^2$ ); some models also add up readings over time into $\text{kWh}/\text{m}^2$ | Comparing a test moment's Isc or operating current with the light actually available; measuring plane-of-array irradiation for a PR check (Lesson 2) |

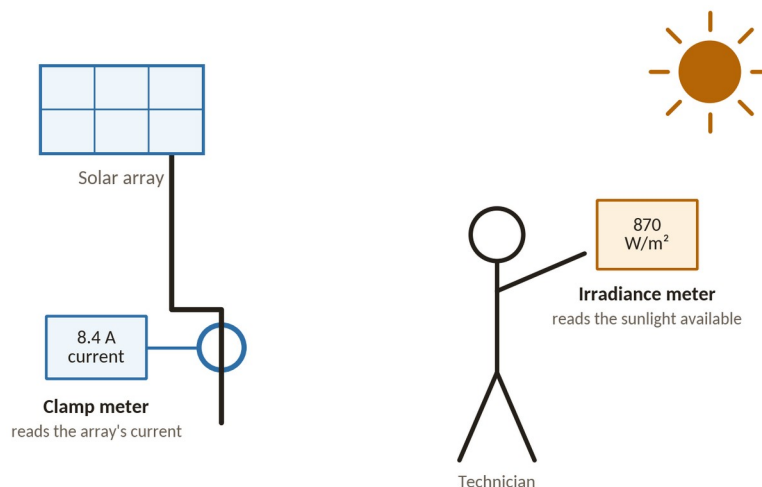
#### WORD TO KNOW

**Clamp meter** — A test tool that measures electric current by clamping around a single wire, without breaking the circuit open. It can safely measure higher currents than most multimeters, and is a common choice for testing a solar array's current.

#### WORD TO KNOW

**Irradiance meter** — A tool that measures the power of sunlight falling on a surface, in watts per square meter ( $\text{W}/\text{m}^2$ ). Some models also add up (integrate) readings over time to give the total irradiation, in  $\text{kWh}/\text{m}^2$ , for a chosen period. Also called a solar meter, or, in scientific use, a pyranometer.

One detail matters more than it looks: always hold an irradiance meter in the SAME plane as the array — the same tilt angle and the same direction — so its reading matches the array's own plane-of-array irradiance (Lesson 2), not a different, flat horizontal reading.



*A technician uses a clamp meter to read an array's operating current, while a handheld irradiance meter — held in the same plane as the array — logs the sunlight available at that same moment.*

#### SAFETY

Solar arrays cannot be switched off by daylight alone — a panel makes voltage the moment light reaches it (Chapter 17). Treat every array circuit as live until you have personally tested and confirmed otherwise.

Wear the correct PPE (Chapter 17), remove metal jewelry, keep one hand in a pocket where practical (the 'one-hand rule'), use a meter rated for the voltage present, and never work alone on a live test. Batteries add their own hazard: never let a metal tool bridge a battery's two terminals, and keep sparks away from a charging battery's hydrogen gas (Chapter 6).

## WORD TO KNOW

**Commissioning checklist** — A written, ordered list of every test and check that must be completed, in the right order, before a newly installed system is accepted as working correctly. Chapter 17 covers the pre-power-up part of this list — wiring, torque, and safety. Chapter 18 covers the testing part, once the system is running.

### A typical commissioning test sequence for an off-grid system

| Step | What to do                                                                                  | Check before moving on                                                                                          |
|------|---------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| 1    | Confirm Chapter 17's pre-power-up checklist is complete                                     | No damaged parts, no loose connections, correct labels in place                                                 |
| 2    | Test each string's Voc, with the array NOT yet connected to the controller                  | Measured Voc is close to the expected value (Lesson 1), and safely below the controller's maximum input voltage |
| 3    | Check polarity at every connector before connecting anything                                | Positive to positive, negative to negative — never guess                                                        |
| 4    | Connect the battery to the controller first, then connect the array                         | Controller powers on and shows a normal display                                                                 |
| 5    | Test Isc, using a correctly rated ammeter or clamp meter                                    | Measured Isc is close to the predicted value for the sunlight level at test time (Lesson 1)                     |
| 6    | Check operating voltage and current, and battery voltages, with the system running normally | Readings are close to expected, and battery voltages are healthy and even across the bank                       |
| 7    | Record every result, close out any punch list items, and complete acceptance                | All test results are written down (Lesson 4), and the system is ready for handover                              |

## COMMON MISTAKE

**✗ Wrong:** Leave a multimeter set to measure resistance or current, then connect it across a live voltage source, the way you would measure voltage.

**✓ Right:** Always check and set the multimeter to the correct function and range — voltage, current, or resistance — that matches what you are about to measure, BEFORE connecting it to a live circuit. Connecting a meter set to resistance or current mode across a voltage source can damage the meter or blow its fuse instantly.

## ACTIVITY (LABORATORY) — COMMISSIONING LAB: TEST A SMALL DEMONSTRATION SYSTEM

1. Before connecting anything, write down the expected Voc and Isc for your demonstration panel or array,



from its datasheet.

2. With the array NOT yet connected to the controller, measure  $V_{oc}$  with a multimeter across the array's leads. Record it.
3. With a clamp meter, or a suitably rated ammeter, briefly measure  $I_{sc}$ , then disconnect. Record it.
4. Connect the battery to the controller first, then connect the array (recall the safe connection order).
5. Once the system is running, measure the operating voltage and current at the controller's array input. Record them.
6. Measure the battery's voltage at rest, then again with a load switched on. Record both.
7. Calculate the percent difference between each measured value and its expected value. Which readings are close? Which, if any, need a second look?

*You need: Multimeter, Clamp meter (if available), The demonstration system's datasheets, Paper and pen or a checklist sheet*

Write down every result as you go — do not trust memory. Lesson 4 turns these results into the first pages of the system's record book.

## 18.4 Acceptance, Handover Documents, and the System Record Book

Testing is done. The numbers look reasonable, or a few were fixed along the way. What makes a system officially finished? This lesson covers the paperwork and final steps that turn a tested system into a properly handed-over one.

### WORD TO KNOW

**Punch list** — A written list of small items still to finish or fix — found during testing — before a system receives final, unconditional acceptance.

### CASE STUDY — ONE WEAK BATTERY, FOUND BEFORE IT BECAME A BIGGER PROBLEM • ERBIL, KURDISTAN REGION (ILLUSTRATIVE EXAMPLE, CONTINUING THIS CHAPTER'S EXAMPLE SYSTEM)

During the commissioning lab for the Chapter 12 home system, the team checked all six batteries in the bank individually, not just the total bank voltage. Five batteries rested at 12.6–12.7 V, comfortably close to full. The sixth, battery #4, rested at only 12.1 V — noticeably lower, even though the bank's total voltage still looked broadly reasonable at first glance, because the other five batteries were covering for it. The team added 'battery #4: recheck and retest' to the punch list, gave it a full charge on its own, and measured it again three days later. It returned to 12.6 V and held steady under a small test load, so the team judged it a slow-charging unit from storage, not a faulty battery, and closed the punch list item. If it had stayed low after recharging, the right next step would have been replacing it before final acceptance — a battery bank is only as strong as its weakest battery.

### WORD TO KNOW

**Acceptance** — The formal step where the system's owner, or a responsible engineer, agrees — based on the test results — that a finished system meets its design and is ready for regular use.

A punch list does not always have to stop acceptance completely. A small remaining item can sometimes be accepted 'subject to' finishing it by an agreed date, written clearly on both the punch list and the acceptance

form. A large or safety-related item — a wrong fuse rating, a missing earth connection, a badly shaded string — should be fixed BEFORE acceptance, not promised for later.

#### WORD TO KNOW

**Handover documents** — The complete set of papers and records given to a system's owner when installation and testing are finished, including test results, datasheets, warranty papers, and basic operating instructions. Also called a handover pack.

#### A typical handover pack

| Document                                             | Purpose                                                                                           |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Datasheets for every major component                 | Keeps the exact model and its ratings available for future reference                              |
| As-built drawing or single-line diagram (Chapter 16) | Shows exactly how the system was actually built, which can differ a little from the original plan |
| Test / commissioning report                          | This chapter's results: Voc, Isc, operating readings, battery voltages, and measured PR           |
| Warranty papers                                      | Proof of purchase date and warranty length for each component                                     |
| Basic operating instructions                         | Shows the owner what normal operation looks like, day to day                                      |
| Safety and emergency information                     | Who to call, and how to safely shut the system down if needed                                     |

#### WORD TO KNOW

**System record book** — A notebook or file, kept with the system, that starts with its as-built drawing (Chapter 16) and commissioning test results, and then keeps a complete, dated history of every later test, repair, and maintenance visit — Chapter 19 and Chapter 20 both rely on it.

The results from this chapter's tests — sometimes called the system's commissioning record — become the first, most important pages of the record book. They set the baseline that every later test is compared against: Chapter 19 uses them to judge whether a later day's production is normal, and Chapter 20 continues the same book with cleaning, inspection, and maintenance entries.

#### The first page of a system's record book (example)

| Date                  | Who                | What was measured or done                             | Result                                            |
|-----------------------|--------------------|-------------------------------------------------------|---------------------------------------------------|
| Day 1 (commissioning) | Commissioning team | Array Voc (expected 49.0 V)                           | 50.5 V — normal for a cool morning                |
| Day 1 (commissioning) | Commissioning team | Array Isc at 850 W/m <sup>2</sup> (predicted ≈26.8 A) | 26.2 A — normal                                   |
| Day 1 (commissioning) | Commissioning team | Measured daily performance ratio (design 0.80)        | 0.72 — about 10% low; recheck over the next month |
| Day 1 (commissioning) | Commissioning team | Battery bank check (6                                 | 5 batteries 12.6–12.7 V;                          |

| Date  | Who                          | What was measured or done            | Result                                     |
|-------|------------------------------|--------------------------------------|--------------------------------------------|
|       |                              | batteries)                           | battery #4 at 12.1 V — added to punch list |
| Day 4 | Commissioning team           | Battery #4 retested after recharging | 12.6 V — punch list item closed            |
| Day 4 | Owner and commissioning team | System acceptance                    | Signed; handover pack delivered            |

### SAFETY

Before handover, confirm every disconnect switch, fuse, and breaker is clearly labeled (Chapter 9), and that the owner knows where the main system disconnect is and how to use it in an emergency.

### COMMON MISTAKE

**✗ Wrong:** Finish an installation, tell the owner it works, and leave without giving any written record.

**✓ Right:** Always leave the owner with written test results, a handover pack, and the start of a record book. Memory fades, but a written record does not — it protects both the installer and the owner if a question or warranty claim comes up later.

### ACTIVITY (CLASSROOM) — CREATE THE FIRST PAGE OF A RECORD BOOK

1. Using your own commissioning lab results from Lesson 3 (or this chapter's example system), list every value you measured: Voc, Isc, operating voltage and current, and battery voltages.
2. Write the expected value next to each measured value, and calculate the percent difference for each.
3. Decide, for each reading: accept as normal, or add it to a punch list for a second look.
4. Design one page of a simple record book template, with columns for date, who tested it, what was measured, and the result. Fill in today's entry.

*You need: Your commissioning lab results (or the chapter's example system), Paper or a spreadsheet*

### CHAPTER SUMMARY

- Commissioning has two parts (Chapter 17): a pre-power-up walk-through, then this chapter's performance testing once the system runs.
- Test Voc and Isc before connecting the array to the controller — the safest time, and it confirms the wiring before the system is energized.
- Once the system is running, operating voltage and current show its real working point — usually close to, but not exactly, Vmp and Imp.
- Check battery voltages several ways: resting, under load, under charge, and — in a bank — battery by battery, to catch one weak unit hiding behind a normal bank total.
- Percent difference,  $\text{Diff} = (\text{measured} - \text{expected}) \div \text{expected} \times 100\%$ , is a simple, general tool for judging any test reading.
- Measured performance ratio,  $\text{PR} = \text{actual energy output} \div (\text{rated power} \times \text{plane-of-array irradiation})$ , uses real, measured data instead of the assumed PR used at the design stage (Chapter 12).

- A single day's PR can be noisy; compare over a week or month when possible before deciding there is a real problem.
- Use the right instrument for the job: a multimeter for voltage, resistance, and small currents; a clamp meter for larger currents without breaking the circuit; and an irradiance meter, held in the array's own plane, for sunlight measurements.
- A punch list records anything still to finish or fix before final acceptance; acceptance can sometimes be given 'subject to' closing a small punch list item by an agreed date.
- Handover documents and the system's record book — started on commissioning day — give the owner, and any future technician, a complete, trustworthy history of the system.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A panel's datasheet  $V_{oc}$  is 45.0 V. A field test measures 46.8 V. Find the percent difference between measured and expected, to one decimal place.

**Problem 2 [Basic]** A module's  $I_{sc}$  at standard test conditions is 9.0 A. Find the predicted  $I_{sc}$  at an irradiance of  $600 \text{ W/m}^2$ .

**Problem 3 [Basic]** Using this chapter's typical resting-voltage table for a 12 V lead-acid battery ( $100\% \approx 12.7 \text{ V}$ ,  $75\% \approx 12.4 \text{ V}$ ,  $50\% \approx 12.2 \text{ V}$ ,  $25\% \approx 12.0 \text{ V}$ ,  $0\% \approx 11.8 \text{ V}$ ), a technician measures a battery's resting voltage as 12.4 V. What is its approximate state of charge?

**Problem 4 [Basic]** An off-grid system's controller display shows an operating current of 27.5 A. The array's rated  $I_{mp}$  is 30 A. Find the percent difference between the operating current and  $I_{mp}$ .

**Problem 5 [Standard]** A 2.0 kWp array's energy meter shows 7.5 kWh produced in a day when the plane-of-array irradiation was  $5.5 \text{ kWh/m}^2$ . (a) Find the measured performance ratio, as a percentage. (b) If the system's design PR was 0.80, is this gap large enough to be worth investigating, using this chapter's rule of thumb?

**Problem 6 [Standard]** Over a 30-day month, a 3.5 kWp array's meter shows 500 kWh produced. The month's total plane-of-array irradiation is  $180 \text{ kWh/m}^2$  (an average of 6.0 peak sun hours per day). Find the measured monthly PR, as a percentage.

**Problem 7 [Standard]** A 48 V battery bank uses 4 batteries of 12 V each, in series. At rest, three read 12.6 V each and the fourth reads 11.9 V. (a) What is the bank's total resting voltage? (b) Using the resting-voltage table in this chapter, roughly what is the weak battery's state of charge, and what should the commissioning team do?

**Problem 8 [Standard]** An array's  $I_{sc}$  at STC is 18.0 A. A clamp meter test is done when an irradiance meter reads  $700 \text{ W/m}^2$ , and the clamp meter reads 12.9 A. (a) What  $I_{sc}$  would you predict at  $700 \text{ W/m}^2$ ? (b) What is the percent difference between the measured and predicted  $I_{sc}$ ?

**Problem 9 [Standard]** An array's datasheet gives  $V_{mp} = 36.0 \text{ V}$  and  $I_{mp} = 11.1 \text{ A}$  at STC. While the system runs normally, the controller's display shows an operating voltage of 33.5 V and an operating current of 10.2 A. Find the percent difference for both voltage and current, and state whether this looks normal for a working MPPT system.

**Problem 10 [Challenge]** A small rural clinic's off-grid system uses four 350 W panels wired in parallel (array rated power 1.4 kWp; each panel  $V_{oc} = 46.0 \text{ V}$ ,  $I_{sc} = 9.8 \text{ A}$ ), a 48 V battery bank, and a 60 A MPPT controller. During commissioning: (a) Before connecting to the controller, a technician measures the array's  $V_{oc}$  as 47.8 V. Find the percent difference from the expected array  $V_{oc}$ . (b) An irradiance meter reads  $900 \text{ W/m}^2$  during the  $I_{sc}$

test; the clamp meter reads 34.9 A. Find the predicted  $I_{sc}$  at that irradiance and the percent difference from the measurement. (c) Over the first full day, the plane-of-array irradiation totals  $5.8 \text{ kWh/m}^2$ , and the energy meter logs 5.6 kWh delivered to the battery bank. Find the measured PR, as a percentage, and compare it with the clinic's design PR of 0.78.

**Problem 11 [Challenge]** A commissioning team collects these results for a small home system (array rated power 1.6 kWp, array  $I_{sc}$  at STC = 31.5 A, design PR 0.80):  $V_{oc}$  — expected 49.0 V, measured 49.3 V.  $I_{sc}$  at  $950 \text{ W/m}^2$  — measured 23.4 A. Daily PR — plane-of-array irradiation  $5.4 \text{ kWh/m}^2$ , energy delivered 5.5 kWh. (a) Find the percent difference for the  $V_{oc}$  reading. (b) Find the predicted  $I_{sc}$  at  $950 \text{ W/m}^2$ , and the percent difference for the  $I_{sc}$  reading. (c) Find the measured PR, as a percentage. (d) Based on all three results, which single reading points most clearly to a real problem, and what kind of fault would you suspect?

**Problem 12 [Challenge]** A telecom relay's 48 V battery bank has four 12 V, 100 Ah batteries in series. Six months after commissioning, a routine record-book check finds these resting voltages: 12.5 V, 12.5 V, 12.6 V, and 11.7 V. (a) Find the bank's total resting voltage. (b) Using this chapter's resting-voltage table, estimate the weak battery's approximate state of charge, and compare it with the others. (c) The site's last full day gave a measured PR of 0.58, well below the site's design PR of 0.80. Is this alone enough to be sure the weak battery is the cause of the low PR? Explain your reasoning. (d) What should go on the punch list, and what should the technician write in the record book?

## CHAPTER NINETEEN

# Finding and Fixing Problems

*A systematic method for troubleshooting common solar system faults, with a multimeter and good judgment*

### IN THIS CHAPTER YOU WILL LEARN TO

- Apply the symptom → cause → check → fix method to any solar system problem, instead of guessing.
- Recognize the common causes of low production, a battery that empties too fast, inverter alarms, and loose or corroded connections.
- Use a multimeter to run continuity, resting-voltage, open-circuit, and voltage-drop tests, and explain what each result means.
- Calculate a battery's approximate state of charge from its resting voltage, and calculate the power wasted at a bad connection.
- Decide when a problem is safe to fix yourself and when it is time to call a qualified professional.

## 19.1 The Troubleshooting Method

Every solar system, however well it is designed and built, will someday have a problem. A panel might make less power than before. A battery might feel emptier than usual. An inverter might beep and show a strange message. Good technicians do not panic, and they do not guess. They use a method.

### WORD TO KNOW

**Troubleshooting** — Finding and fixing the reason something is not working, using a logical method instead of guessing.

This chapter's method has four steps, always in the same order: **symptom → cause → check → fix**. Guessing and replacing parts is slow and expensive. This method is fast and cheap, because it finds the real problem before you spend any money.

### WORD TO KNOW

**Symptom** — A sign that something is wrong — what you notice or measure, like 'the lights are dim' or 'the battery is empty by midnight.' A symptom points toward a cause, but it is not the cause itself.

A symptom almost always has more than one **possible cause**. A dim light could mean a weak battery, a loose wire, an old bulb, or low sunlight that day. Do not stop at the first idea — write down two or three possible causes before you touch anything.

### WORD TO KNOW

**Root cause** — The real, underlying reason for a fault. Fixing only the symptom without finding the root cause often means the same problem comes back.

## WORD TO KNOW

**Fault** — Something wrong in a system that stops it from working correctly, or makes it work worse than it should.

After you list possible causes, **check** them — starting with the cheapest, safest, and simplest check first. A five-minute look at a switch or a connector costs nothing. Buying a new battery costs a lot, and it does not help if the battery was never the problem. Only after a check confirms the root cause should you **fix** it.

### The method in action: an everyday example

| Symptom                               | Possible cause                | Check                                                                            | Fix                                     |
|---------------------------------------|-------------------------------|----------------------------------------------------------------------------------|-----------------------------------------|
| A torch (flashlight) does not turn on | The batteries are dead        | Test the batteries in another device, or measure their voltage with a multimeter | Replace the batteries                   |
| A torch (flashlight) does not turn on | The batteries are in backward | Open the battery compartment and look at the + and – marks                       | Turn the batteries the right way around |
| A torch (flashlight) does not turn on | The bulb or LED is burned out | Swap in a bulb or LED known to be good, if one is available                      | Replace the bulb or LED                 |

Notice something important in the table: the SAME symptom has THREE different possible causes, and each one needs a different fix. This is exactly why you must check before you fix. Guessing wrong wastes time and money, and sometimes the new part does not solve the problem at all.

### WORKED EXAMPLE — USING THE METHOD: A LIGHT THAT WILL NOT TURN ON

A small solar-powered LED light indoors does not turn on after dark, though it worked fine every night last month. Use the method to find out why.

1. Symptom: the light does not turn on after dark.
2. Possible causes: the switch is off; the battery has no charge; a wire has come loose; the LED itself has failed.
3. Check, cheapest and safest first: look at the switch — it is already ON. Check the small charge indicator on the light's controller — it shows very low charge.
4. This points toward a charging problem rather than the light itself, so the next check should move to the panel and its wiring, not to the LED.

**Answer: The root cause is most likely a charging problem (for example, a dusty or disconnected panel), not the light or its switch. One check can rule out several possible causes at once, and can also point you toward the NEXT check.**

One more habit matters before you troubleshoot anything: know what **normal** looks like. You cannot say output is 'low' unless you know what it should be. Your system's commissioning record (Chapter 18), its datasheet values, or a saved design in the app all tell you the expected numbers to compare against.

► *App tool: Know your baseline: check what your system should produce on a normal day*

### COMMON MISTAKE

**✗ Wrong:** Replacing parts one after another, hoping something works, without checking first.

**✓ Right:** Use the method: list possible causes, then do the cheapest and safest check before you buy or replace anything.

### ACTIVITY (HOME) — TROUBLESHOOT SOMETHING AT HOME

1. Find something small at home that is broken or not working well right now — a lamp, a charger, a toy, a remote control, anything safe to check.
2. Write down the symptom in your own words.
3. List at least two possible causes.
4. Pick the simplest, safest, cheapest check first, and do it.
5. Write down what you found, and whether you could fix it or it needs a new part.

*You need: Paper and pen, The broken item (unplugged first, if it uses electricity)*

## 19.2 Common Faults and Their Causes

Most calls for help fall into a small number of familiar families of problems. This lesson is your decision-tree reference for the four most common ones: low daytime production, a battery that empties faster than normal, inverter alarms, and loose or corroded connections. For each one, use the tables below the same way: match your symptom, check the possible causes in order, and apply the fix that matches what you actually find.

### Low daytime production

This is one of the most common complaints: 'my system used to make more power.' The table below lists the causes in a sensible checking order — cheapest and most common first.

#### Low daytime production — possible causes

| Possible cause                                          | How to check                                                                               | Typical fix                                                                                                                 |
|---------------------------------------------------------|--------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|
| Dust or dirt on the panels (soiling)                    | Look closely at the panel surface; compare output before and after cleaning one panel      | Clean the panels (safe methods are in Chapter 20)                                                                           |
| New or growing shading (a tree, a building, an antenna) | Watch the array through the day; look for shadows, especially morning and late afternoon   | Trim or move the shading object, or re-plan the array if the shade cannot be removed                                        |
| A failed or disconnected string or panel                | Measure each string's voltage and current in full sun; compare the strings with each other | Find and fix the broken connection, blown fuse, or tripped breaker; replace a failed panel                                  |
| Charge controller set to the wrong mode or battery type | Check the controller's settings and display against the battery type in use (Chapter 7)    | Reset the controller to the correct battery type and charging voltages                                                      |
| Very high panel temperature in extreme summer heat      | Compare output at midday with output in the cooler early morning, on the same clear day    | Improve airflow behind the panels; this is a normal, smaller loss in hot weather (Chapter 4), not usually a fault to repair |
| The inverter is limiting or reducing its own output     | Check the inverter's display or app for its own reported input power, and                  | See the inverter alarms table later in this lesson                                                                          |



| Possible cause | How to check                            | Typical fix |
|----------------|-----------------------------------------|-------------|
|                | compare with the array's expected power |             |

Before you go looking for a fault, it helps to put a number on 'low.' Comparing today's real output with what you expected turns a vague feeling into a clear decision.

#### EQUATION: PERCENT OF EXPECTED OUTPUT

$$R_{\text{output}} = \frac{E_{\text{actual}}}{E_{\text{expected}}} \times 100$$

*In words: Percent of expected output = (Actual energy ÷ Expected energy) × 100%*

| Symbol     | Meaning                                                                                 | Unit                              |
|------------|-----------------------------------------------------------------------------------------|-----------------------------------|
| R_output   | the percent of expected output — how close today's real result is to what was expected  | percent (%)                       |
| E_actual   | the energy actually measured or produced today                                          | kWh (or any matching energy unit) |
| E_expected | the energy expected for a similar day, from the system's commissioning record or design | kWh (same unit as E_actual)       |

*This is different from the performance ratio in Chapter 12, which compares real output to an ideal, calculated output under standard conditions. Here, you compare today's real output with YOUR OWN system's expected output from its commissioning record (Chapter 18) — a quick, practical daily check. Well-running systems normally land somewhere around 80–95% of this expected value, because of everyday weather changes; a result clearly below that range is worth investigating.*

#### WORKED EXAMPLE — IS THIS SYSTEM'S OUTPUT NORMAL, OR A FAULT?

A home system's commissioning record expected 12 kWh on a clear summer day. Today, also a clear day, the system produced 9.6 kWh. Is this within the normal range, or does it suggest a fault?

1. Write the equation:  $R_{\text{output}} = (E_{\text{actual}} \div E_{\text{expected}}) \times 100$
2. Put in the numbers:  $R_{\text{output}} = (9.6 \div 12) \times 100$
3. Calculate:  $R_{\text{output}} = 80\%$

**Answer: 80% — right at the edge of the normal 80–95% range, so this is probably normal (perhaps some extra dust, haze, or heat today). Keep watching it; if it drops further on similarly clear days, start working through the low-production table above.**

► [App simulation: Explore how dust and shading reduce output in the Shading & Dust simulation](#)

#### COMMON MISTAKE

**✗ Wrong:** Assuming low production always means a broken or worn-out panel.

**✓ Right:** Most 'low production' complaints have a simple cause, like dust or shading. These cost nothing to check and take only minutes — check them before assuming the panels themselves have failed.

**A battery that empties faster than normal**

This complaint feels alarming — 'the battery used to last all night, now it doesn't' — but it rarely means the battery has suddenly broken. Work through the table below in order.

**A battery that empties faster than normal — possible causes**

| Possible cause                                                     | How to check                                                                                                         | Typical fix                                                                                                     |
|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| A new or forgotten load left running (a parasitic load)            | List every device connected; measure the total load with nothing 'useful' running, using a multimeter or clamp meter | Unplug or switch off devices that are not needed; move flexible loads to daytime hours                          |
| Reduced daytime charging                                           | Check the array's daytime output against the low-production table above                                              | Fix the production problem — a battery that 'empties fast' is often really a charging problem                   |
| The battery bank is genuinely undersized for the current load      | Compare today's daily energy use against the original design's daily energy budget (Chapter 12)                      | Reduce the load, add more battery capacity, or manage use more carefully                                        |
| Sulfation, from being left at a low charge for a long time         | Check the charging history; watch whether the battery struggles to reach full voltage even after a long, good charge | A careful equalization charge may help some flooded batteries (Chapter 7); often the lost capacity is permanent |
| Simple aging — the battery has completed many cycles               | Compare its age and cycle count with its rated cycle life (Chapter 6)                                                | Plan and budget for battery replacement                                                                         |
| Charge controller or inverter settings wrong for this battery type | Check the settings against the battery manufacturer's recommended values                                             | Correct the settings to match the battery type in use                                                           |
| Self-discharge, faster in hot weather                              | Measure resting voltage after several days of no charging and no load, such as in storage                            | Store batteries somewhere cooler if possible; usually a smaller effect than the causes above                    |

**WORD TO KNOW**

**Parasitic load** — A small device or circuit that keeps drawing power all the time, even when it looks 'off' or is not doing useful work — for example, a charger left plugged in, or an inverter's own standby draw. Also called a phantom load.

**WORD TO KNOW**

**Self-discharge** — The slow loss of a battery's charge over time, even when nothing is connected to it and it is not being used. All batteries self-discharge a little; heat makes it faster.

**WORD TO KNOW**

**Sulfation** — A buildup of hard crystals on a lead-acid battery's plates, usually caused by leaving the battery at a low charge for too long. Sulfation reduces the battery's usable capacity, often permanently.

**WORKED EXAMPLE — HOW MUCH DOES A SMALL PARASITIC LOAD REALLY COST?**

An inverter's standby draw is 6 W, and it stays powered on all day and all night. Using  $E = P \times t$  from Chapter 1, how much energy does this waste in one day, and in 30 days?

1. Write the equation from Chapter 1:  $E = P \times t$
2. Daily energy:  $E = 6 \text{ W} \times 24 \text{ h} = 144 \text{ Wh}$
3. Convert to kWh:  $144 \div 1000 = 0.144 \text{ kWh per day}$
4. Monthly energy:  $0.144 \text{ kWh} \times 30 = 4.32 \text{ kWh per month}$

**Answer: About 4.3 kWh per month. This looks small compared to a big appliance, but it happens every single hour of every day — in an off-grid system, it quietly eats into the battery's charge every single night.**

► *App tool: Check whether your battery bank was sized correctly for your load*

#### COMMON MISTAKE

✗ **Wrong:** Immediately blaming a 'weak' or 'bad' battery when it empties faster than before.

✓ **Right:** First check for new or forgotten loads (parasitic loads) and reduced daytime charging. These are far more common than a battery suddenly failing on its own.

#### CASE STUDY — THE MYSTERY OF THE EARLY-EMPTY BATTERY • DUHOK, KURDISTAN REGION (EXAMPLE SCENARIO)

A small shop in Duhok had an off-grid solar system that had worked well for two years. Then, within one week, the owner noticed the battery was empty every night by 10 p.m. — much earlier than before. No new big appliance had been added, so the owner was ready to buy a whole new battery bank. A visiting technician used the method instead of guessing. Symptom: the battery empties much earlier than normal. Checks: daytime array output looked normal for the season. Looking at the load side, the technician found a new WiFi router and a security camera, installed that same week, both left on 24 hours a day. Together they drew about 15 W around the clock — small next to any single big appliance, but running every hour of every day. Over 24 hours, that alone used about  $15 \text{ W} \times 24 \text{ h} = 360 \text{ Wh}$ , more energy than an evening of lighting in that shop. The fix cost nothing: the router and camera were moved onto their own small daytime circuit. The shop owner saved the price of a whole new battery bank.

#### Inverter alarms

An inverter alarm is not the inverter 'breaking.' Most of the time, it is the inverter protecting itself, the battery, or you, by refusing to keep running in an unsafe condition.

#### WORD TO KNOW

**Fault code** — A short code, number, or message shown on an inverter's or controller's screen or lights, pointing to a specific type of problem. The exact codes are different for each brand, so always check the equipment's own manual.

#### WORD TO KNOW

**Ground fault** — A fault where electricity finds an unwanted path to earth, often through damaged insulation or a wiring mistake. Most inverters detect this automatically and shut down to protect people and equipment. Also called an earth fault (see 'earthing,' Chapter 9).

#### Common inverter alarms — possible causes

| Alarm type                                         | What it usually means                                                                                   | Typical fix                                                                                                                        |
|----------------------------------------------------|---------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| Low battery voltage                                | The battery has discharged below the inverter's safe cut-off point                                      | Let the battery recharge; check for a production problem or an oversized load; check the low-voltage disconnect setting            |
| Overload                                           | The connected loads are asking for more power than the inverter can safely supply                       | Switch off some loads; check for a motor's starting surge (Chapter 8); consider a bigger inverter if this happens often            |
| Over temperature                                   | The inverter itself has become too hot and is protecting itself                                         | Improve ventilation and airflow around the inverter; move it out of direct sun or a hot enclosed space; let it cool, then restart  |
| Ground fault / earth fault                         | The inverter has detected current leaking to earth somewhere in the system                              | Isolate the system safely; inspect cables and connections for damaged insulation or water; a qualified person is often needed      |
| Grid fault / no grid (grid-tie and hybrid systems) | The public grid's voltage or frequency is outside the inverter's safe range, or the grid is simply down | Often normal during a power cut — the inverter is protecting grid workers (anti-islanding, Chapter 8); wait for the grid to return |
| Fan fault                                          | The inverter's cooling fan is not working correctly                                                     | Check for dust blocking the fan; a stopped fan is a common reason for a follow-on over-temperature alarm                           |

► *App simulation: See how load and heat affect inverter behavior in the Inverter Performance simulation*

## SAFETY

Never clear a repeated alarm by pressing reset again and again — the inverter is protecting itself and you. If an alarm keeps returning, stop and work through the method instead. If your checks involve a flooded lead-acid battery bank, remember Chapter 6's warning: batteries release invisible, explosive hydrogen gas while charging, so keep sparks and open flames away, and make sure the battery space is ventilated.

## Loose or corroded connections

A connection problem can cause almost any of the symptoms above — low production, a battery that seems to empty fast, or an inverter alarm — because it quietly adds resistance somewhere current needs to flow.

## WORD TO KNOW

**Corrosion** — A crust or damage on a metal part, usually caused by moisture, dust, or chemical fumes reacting with the metal over time. Corrosion adds resistance to a connection, and can eventually break it completely.

## Loose or corroded connections — where to look

| Where to look        | What you might find                                                           | Typical fix                                                                 |
|----------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| MC4 panel connectors | Warm to the touch, a crusty residue, or a connector that is not fully clicked | Clean or replace the connector; make sure it clicks fully together, using a |

| Where to look                               | What you might find                                                         | Typical fix                                                                                                       |
|---------------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
|                                             | together                                                                    | proper MC4 tool (Chapter 9)                                                                                       |
| Battery terminals                           | White or greenish crust, or a terminal that wiggles instead of sitting firm | Disconnect safely, clean with the right method, tighten firmly, and consider a terminal protector spray or grease |
| Breaker and fuse terminals in the enclosure | Slightly darkened or discolored metal, or a screw that turns easily (loose) | Tighten to the correct torque; replace a badly discolored or pitted terminal                                      |
| Cable joints and crimped lugs               | A joint that feels warm under load, or a visible gap or looseness           | Redo the crimp or joint properly; do not use tape as a permanent fix                                              |
| Earthing (grounding) connections            | A rusty or loose earth clamp, or a broken earth wire                        | Repair immediately — this is a safety connection, not only a performance one (Chapter 9)                          |

► *App tool: Check whether your cable size matches your current and cable length*

#### SAFETY

A warm or discolored connector is a warning sign, not just a curiosity. Extra resistance turns electrical energy into heat, and a hot joint can damage insulation or even start a fire. Never leave a hot connector 'for later' — isolate that part of the system and deal with it. Lesson 3 shows you how to measure this heat with a multimeter, and Lesson 4 explains when a hot connection needs a professional.

## 19.3 Diagnosing With a Multimeter

The multimeter (Chapter 2) is a solar technician's most-used tool. This lesson teaches four specific tests, when to use each one, and — just as important — how to read the result safely and correctly.

#### SAFETY

A few habits keep you and your meter safe. Treat any solar array in daylight as always live, even if it looks disconnected at the inverter. Test one wire at a time, and keep your free hand away from metal parts. Wear safety glasses and remove metal jewelry before working near battery terminals — a dropped metal tool across a battery's terminals can create a dangerous short circuit in an instant. Always use a meter rated for your system's DC voltage.

#### WORD TO KNOW

**Load test** — A test where a measurement is taken while the circuit is doing real work, with current flowing, instead of at rest. A load test can reveal problems, like a weak battery or a bad connection, that do not show up in a simple resting measurement.

#### WORD TO KNOW

**Voltage drop test** — A multimeter test done on a working, powered circuit, measuring the voltage across one single connection or short section of cable while current flows through it. A good connection reads close to 0 V; a higher reading reveals hidden resistance, often from a loose or corroded joint.

#### EQUATION: FINDING A BAD CONNECTION'S RESISTANCE FROM A VOLTAGE-DROP TEST

$$R = \frac{V}{I}$$

In words: Resistance = Voltage drop ÷ Current

| Symbol | Meaning                                                                                             | Unit              |
|--------|-----------------------------------------------------------------------------------------------------|-------------------|
| R      | the resistance of the connection or joint being tested                                              | ohms ( $\Omega$ ) |
| V      | the voltage drop measured across the joint while current is flowing (the voltage-drop test reading) | volts (V)         |
| I      | the current flowing through the joint at the moment of the test                                     | amperes (A)       |

This is Ohm's law from Chapter 2 ( $V = I \times R$ ), rearranged to find resistance. You can also find the power being wasted as heat at the joint:  $P = V \times I$ . A widely used rule of thumb is that a voltage drop above about 0.5 V at one single connection is worth fixing.

#### WORKED EXAMPLE — HOW HOT IS THAT CONNECTOR GETTING?

While a system is running with 10 A flowing, a technician measures a voltage drop of 0.8 V across one MC4 connector, using the voltage-drop test. Find the connector's resistance and the power it is wasting as heat.

1. Write the equation:  $R = V \div I$
2. Put in the numbers:  $R = 0.8 \text{ V} \div 10 \text{ A}$
3. Calculate:  $R = 0.08 \Omega$
4. Find the wasted power:  $P = V \times I = 0.8 \text{ V} \times 10 \text{ A} = 8 \text{ W}$

**Answer: 0.08  $\Omega$  of resistance, wasting 8 W as heat — well above the 0.5 V guideline, and 8 W concentrated in one small connector is enough for it to feel hot. This connector should be cleaned or replaced soon.**

#### Four multimeter tests and what they tell you

| Test                      | Meter setting & circuit state                                                        | Good result                                                              | Bad result — what it suggests                                                    |
|---------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Continuity test           | Continuity/beep or resistance ( $\Omega$ ); circuit power OFF and isolated           | A beep, or a reading near 0 $\Omega$                                     | No beep, or a very high reading — a broken wire or open connection               |
| Voltage-drop test         | DC volts (V), across one connection; circuit power ON, current flowing (a load test) | A reading close to 0 V                                                   | A reading above about 0.5 V — hidden resistance, often a loose or corroded joint |
| Open-circuit voltage test | DC volts (V), across the source, with no load connected                              | Close to the expected $V_{oc}$ (Chapter 4) or resting battery voltage    | Zero — a broken source or an open connection; far too low — a real fault         |
| Resting voltage test      | DC volts (V), battery disconnected from charging and load for 1–2 hours              | Matches the expected value for its state of charge (see the table below) | Much lower than expected — a discharged, faulty, or old battery                  |

#### COMMON MISTAKE

**X Wrong:** Setting the multimeter to the current (A) setting, then touching the probes across a battery or panel's terminals, the way you would measure voltage.

**✓ Right:** This creates a short circuit straight through the meter, and can blow its internal fuse, damage it, or hurt you. Always start in DC voltage mode, on a high range, whenever you are not sure what you are measuring.

A multimeter can also answer a very practical question: how full is this battery, right now? The simplest way is to measure its resting voltage.

#### WORD TO KNOW

**Resting voltage** — A battery's voltage measured after it has had no charging and no load for at least one to two hours. Resting voltage gives a rough estimate of state of charge, especially for lead-acid batteries.

#### Typical 12 V lead-acid battery: resting voltage vs. state of charge (approximate)

| State of charge | Resting voltage (12 V battery) | What it means                                |
|-----------------|--------------------------------|----------------------------------------------|
| 100% (full)     | about 12.7 V                   | Fully charged                                |
| 75%             | about 12.4 V                   | Good — a normal, healthy range               |
| 50%             | about 12.2 V                   | Half full — getting low for daily use        |
| 25%             | about 12.0 V                   | Low — recharge soon                          |
| 0% (empty)      | about 11.8 V or below          | Fully discharged — damaging if left this way |

These numbers are typical examples for a flooded or AGM lead-acid battery at around 25°C, resting with no charging and no load for at least one to two hours. Real numbers vary a little by brand, age, and temperature — always check the battery's own data sheet when you can. For a 24 V or 48 V bank, simply multiply these voltages by 2 or 4. Lithium (LiFePO<sub>4</sub>) batteries behave very differently: their voltage stays much flatter across most of the charge range (Chapter 6), so voltage alone is a poor way to estimate their state of charge — rely on the battery's own battery management system (BMS) or a dedicated state-of-charge meter instead.

#### WORKED EXAMPLE — READING A BATTERY'S STATE OF CHARGE FROM ITS RESTING VOLTAGE

A 12 V battery has been resting, with no charging and no load, for 2 hours. The multimeter reads 12.4 V. About what state of charge is this, and should the owner be concerned?

1. Compare the reading with the typical 12 V table above: 12.4 V lines up with about 75% state of charge.
2. 75% is a healthy, normal reading for a battery that has been used, but not run all the way down.
3. Check again after the next full charge; a healthy system should return closer to 12.7 V (100%).

**Answer: About 75% state of charge — a normal, healthy reading, not a cause for concern.**

► *App simulation: Explore how voltage relates to charge and discharge in the Battery Storage simulation*

#### ACTIVITY (LABORATORY) — MULTIMETER PRACTICE

1. Set your multimeter to DC volts. Measure the resting voltage of a 12 V battery that has had no charging and no load for at least a few minutes. Record the reading.

2. Compare your reading with the state-of-charge table in this lesson. What is the approximate state of charge?
3. With the battery still disconnected from any circuit, switch the meter to continuity or resistance mode and test a length of wire or a fuse. Confirm you hear a beep, or read close to  $0\ \Omega$ .
4. With your teacher or technician supervising, and the circuit powered and safely working, try a voltage-drop test: measure the voltage across one connector while current is flowing. Is it close to  $0\text{ V}$ ?

*You need: A multimeter, A 12 V battery, A test wire or fuse, Teacher or technician supervision for the live test*

## 19.4 When to Call a Professional

Every lesson in this chapter has been building your troubleshooting skill and your confidence. This last lesson is about something just as important: knowing your limits. A good technician is not someone who can fix everything alone — it is someone who knows exactly when to stop and bring in help.

### WORD TO KNOW

**Qualified person** — Someone with the right training, certification, and hands-on experience to safely carry out a specific electrical or solar task. In this course, we often just call this person 'a professional' or 'a qualified technician.'

### Continue yourself, or call a professional?

| Situation                                                      | Continue yourself?               | Call a professional?                             |
|----------------------------------------------------------------|----------------------------------|--------------------------------------------------|
| Dusty or dirty panels                                          | Yes — simple and safe            | Not needed                                       |
| A cool, reachable, loose MC4 connector                         | Yes, after isolating the circuit | Not usually needed                               |
| Burning smell, melted plastic, sparks, or visible arcing       | No — stop immediately            | Yes — isolate safely first, then call            |
| Work on the grid-connection side, the meter, or utility wiring | No, in most places               | Yes — often required by local rules (Chapter 21) |
| Roof or height work without the right training or equipment    | No                               | Yes                                              |
| An alarm or fault that returns after honest, careful checking  | Maybe, with more experience      | Yes, once you are stuck                          |
| Equipment still under warranty that needs opening              | No — may void the warranty       | Yes — contact the installer or maker first       |

Two of these deserve a closer look. Work on the grid-connection side of a system often has legal and safety rules set by the local utility (Chapter 21 covers what is realistic and permitted here) — a mistake there can be dangerous for utility workers, not only for you. Roof and height work has its own safety training, equipment, and techniques (Chapter 17); do not improvise with a kitchen ladder and no one watching.

### WORD TO KNOW

**Arc fault** — A dangerous spark that jumps across a gap in a damaged or loose high-current connection. An arc fault can reach very high temperatures in a small space, and is a common cause of fires in electrical systems.



Think back to Lesson 3's connector example: 0.8 V and 10 A wasted 8 W as heat in a small space. Now imagine a worse connection, carrying more current, that has been getting hot for weeks without anyone checking it. A loose or corroded high-current connection is exactly the kind of fault that can turn into an arc fault — this is why this chapter has taken every 'warm connector' seriously, starting from Lesson 2's first table.

#### SAFETY

Never use water on an electrical fire — water conducts electricity. If you smell burning, see smoke, or see sparking, get everyone away from the area, switch off or isolate the system if you can do this safely and quickly, and call for help. If you are trained to use one safely, a CO<sub>2</sub> or dry-powder (Class C) fire extinguisher is appropriate for an electrical fire. When in doubt, prioritize people over equipment.

#### WORD TO KNOW

**Warranty** — A manufacturer's or installer's written promise to repair or replace equipment that fails within a certain time — usually only if the equipment was not opened, modified, or wired incorrectly by an untrained person.

#### COMMON MISTAKE

**✗ Wrong:** Opening a sealed inverter, or working on rooftop DC wiring, alone and without training, to save the cost of a technician.

**✓ Right:** Some jobs need a qualified person. A technician's fee is far smaller than the cost of an injury, a fire, or a warranty that no longer covers equipment because it was opened by an untrained person.

#### CASE STUDY — WHEN THE TECHNICIAN SAID NO • ERBIL, KURDISTAN REGION (EXAMPLE SCENARIO)

A university laboratory's solar-battery demonstration system began to smell faintly of hot plastic near the battery rack. A keen student, proud of the multimeter skills from this course, wanted to keep testing until the exact fault was found. Instead, the lab supervisor stopped the work immediately: everyone stepped back, the system was isolated at the main disconnect switches from a safe distance, and a qualified electrician was called. The electrician found a battery interconnect cable with damaged insulation, resting against a metal rack — a developing ground fault and an arc-fault risk. Because the team stopped early instead of pushing on, the damage stayed limited to one cable, and no one was hurt. The supervisor's lesson to the class: 'Multimeter skills are for finding a fault safely. The smell of hot plastic is not a symptom to diagnose — it is a stop sign.'

#### ACTIVITY (CLASSROOM) — FAULT-FINDING CHALLENGE

1. Work in pairs or small teams. While your team is out of the room, your teacher will secretly create ONE fault in a demonstration solar or battery circuit — for example, a loosened connector, a reversed wire, a switched-off breaker, or a wrongly set control.
2. Come back and use the full method. Write down the symptom exactly as you observe it, without touching anything yet.
3. List at least two possible causes before you touch anything.
4. Choose safe checks, using a multimeter where it helps, and record every result as you go.

5. State the root cause you believe you found, and the fix you would apply — but check with your teacher before actually changing anything.

6. Compare your process with another team. Did you both reach the same answer by different paths? Which checks wasted time, and which were the fastest way to the answer?

*You need: A small demonstration solar or battery circuit, A multimeter, This chapter's tables, for reference, A notebook to record each step*

## CHAPTER SUMMARY

- Troubleshooting is a method, not guessing: symptom → cause → check → fix, always in that order.
- A symptom can have more than one possible cause — list several before you start checking anything.
- Check the cheapest, safest, simplest cause first; do not replace expensive parts on a guess.
- Low production is most often dust, shading, or a wiring fault — check these before blaming the panels themselves.
- A battery that empties faster than before is often a new parasitic load or reduced daytime charging, not a sudden battery failure.
- Inverter alarms are the inverter protecting itself and you — read the alarm type before you reset and ignore it.
- A multimeter's continuity test, voltage-drop test, open-circuit test, and resting-voltage reading each answer a different question.
- A voltage drop above about 0.5 V at one connection, or a warm or corroded joint, wastes power as heat and can become a fire risk.
- Know when to stop: burning smells, sparks, grid-side work, roof work, and repeated unresolved faults are jobs for a qualified professional.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** On a clear, sunny afternoon, a home's solar array makes noticeably less power than it did last month. No new shade (trees, buildings) has appeared, and nothing else in the system has changed — except that the panels have not been cleaned in three months, during the dry season. (a) What is the most likely cause? (b) What simple check would help confirm it? (c) What is the fix?

**Problem 2 [Basic]** A family's off-grid battery used to last all night. This week, without any big new appliance added, it is nearly empty every morning. The only change: their son now leaves his laptop charger plugged into an inverter outlet all day and night, even when the laptop itself is not connected. (a) What is this kind of small, always-on drain called? (b) What is the simple, no-cost fix?

**Problem 3 [Basic]** While checking a solar array on a warm afternoon, a technician notices that one MC4 connector feels noticeably warmer than the others nearby, with a small white-green crust visible where the metal pins meet. (a) What is this crust most likely to be? (b) Why is a warm connector a warning sign, not just a curiosity? (c) What should the technician do?

**Problem 4 [Basic]** A technician wants to check whether a fuse has 'blown' (broken inside), using the multimeter's continuity/resistance setting, while the circuit is currently switched on and powered. Is it safe to test the fuse like this right now? What should be done instead?

**Problem 5 [Standard]** An off-grid inverter displays a 'Ground Fault' alarm and refuses to power the loads. (a) What does this alarm generally mean? (b) Name two realistic things a technician should check. (c) What must the technician do before touching any wiring to check it?

**Problem 6 [Standard]** A technician measures a 12 V flooded lead-acid battery at rest (no charging, no load, for 2 hours) and reads 12.0 V. Using the typical chart in Lesson 3, about what state of charge does this suggest? Should the technician be concerned yet?

**Problem 7 [Standard]** While a 12 V off-grid system is running with 8 A flowing, a technician measures a voltage drop of 0.6 V across one suspect MC4 connector, using the voltage-drop test. (a) What is the resistance of this connector? (b) How much power is it wasting as heat?

**Problem 8 [Standard]** An inverter's standby (parasitic) draw is 7 W, and it stays powered on 24 hours a day, every day. (a) How much energy does this waste in one month (30 days), in kWh? (b) At an example price of 100 IQD per kWh (as used in Chapter 1), how much does this cost per month? (c) How much per year (365 days)?

**Problem 9 [Standard]** A home's solar system was commissioned with an expected output of 12 kWh per day in summer (Chapter 18). This week, a technician measures actual output of 7.2 kWh on a similar clear, sunny day. (a) What percentage of expected output is the system producing? (b) Is this within the normal 80–95% day-to-day range, or does it point to a real fault? (c) Name two likely causes to check first.

**Problem 10 [Challenge]** A shop in Erbil has a small off-grid solar system. This month the owner reports two problems together: (1) the array produces less energy than usual on sunny days, and (2) the battery is empty earlier each night. A site visit finds a thin layer of dust on the panels, AND a new neighboring building now shades one corner of the array from about 3 p.m. onward. (a) Explain how these two site findings could cause BOTH symptoms. (b) List the findings using the method: symptom → possible causes → check → fix. (c) Which of the two fixes is simpler, and why?

**Problem 11 [Challenge]** During a voltage-drop test on a battery interconnect cable carrying 25 A, a technician measures 1.5 V across a single connector. (a) Calculate the connector's resistance and the power it is wasting as heat. (b) This chapter's rule of thumb flags voltage drops above about 0.5 V at one connection. Is this reading a serious concern? (c) The connector is too hot to touch comfortably, and there is a faint smell of hot plastic. What should the technician do right now, and why might this now need a qualified professional rather than a simple fix?

**Problem 12 [Challenge]** A family's off-grid home system was commissioned one year ago with an expected daily output of 10 kWh on a clear summer day (Chapter 18). This month a technician finds: (1) actual output on a similar clear day is 8.5 kWh; (2) the battery bank (nominal 24 V, 200 Ah) reads 25.0 V at rest one morning after a full day of good sun the day before; and (3) one battery interconnection cable feels slightly warm, with a 0.4 V drop across it while 15 A was flowing. (a) What percentage of expected output is the system achieving — is this normal? (b) A 24 V bank behaves like two 12 V batteries in series. Using the 12 V table from Lesson 3 (scaled ×2), is the 25.0 V morning reading normal? (c) Calculate the resistance and power wasted at the warm interconnection. (d) Overall, does this system need urgent professional attention, or can it be handled with routine care? Use (a)–(c) to justify your answer.

## CHAPTER TWENTY

# Maintenance

*Cleaning, inspection, battery care, and planning to keep a system healthy for years*

### IN THIS CHAPTER YOU WILL LEARN TO

- Explain why regular maintenance keeps a solar system safe and reliable, and describe the difference between preventive and corrective maintenance.
- Build a cleaning schedule for dusty conditions, and calculate the energy and money a system loses to soiling before cleaning compared with after.
- Carry out a visual inspection of a solar system, and describe how to check and care for batteries safely.
- Plan the seasonal tasks in a yearly maintenance calendar, and keep a clear maintenance log.
- Estimate a yearly maintenance budget for a small solar system.

## 20.1 Cleaning Schedules (Dust!)

A well-built solar system can work for twenty years or more. But it will not stay healthy by itself. This chapter is about **maintenance** — the ongoing care that keeps a system safe, efficient, and reliable for its whole life. We start with the single biggest everyday enemy of solar output in this region: dust.

### WORD TO KNOW

**Maintenance** — Work done regularly on a system to keep it safe, efficient, and working well, and to catch small problems before they become big ones.

Maintenance comes in two basic kinds, and every good plan uses both.

### WORD TO KNOW

**Preventive maintenance** — Planned maintenance done on a regular schedule, before anything breaks, to stop problems from happening in the first place. Example: cleaning panels every few weeks in the dusty season.

### WORD TO KNOW

**Corrective maintenance** — Repair work done after something has already gone wrong.

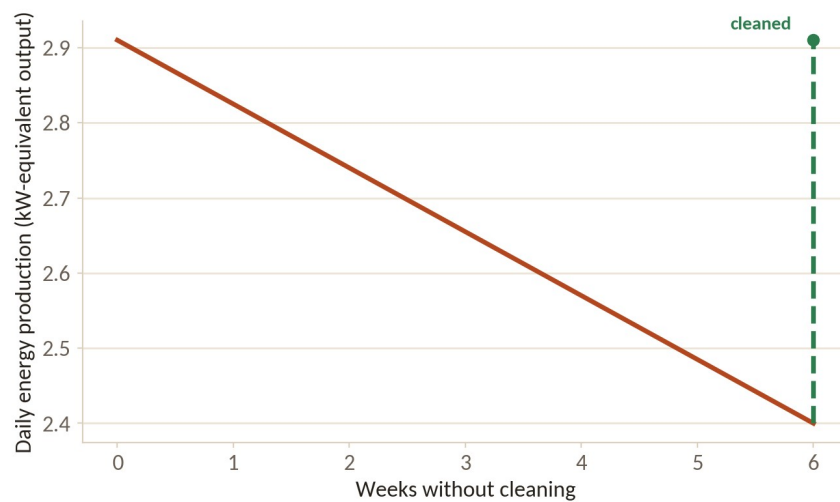
Chapter 19 gave you a systematic method for corrective work — symptom → cause → check → fix. This chapter focuses mostly on preventive maintenance: the steady, regular habits that mean Chapter 19's troubleshooting is needed far less often.

Chapter 5 already introduced **soiling** — power loss caused by dust, sand, or dirt sitting on a panel's glass. Soiling has one very good feature: it is completely reversible. Clean the glass, and the power comes back. A second kind of loss looks similar at first, but behaves very differently.

#### WORD TO KNOW

**Degradation** — The slow, permanent loss of a solar panel's power over many years, caused by the normal aging of its materials. Unlike soiling, degradation cannot be washed away.

A well-made panel loses only a small amount of power to degradation each year — often well under 1%, which is one reason panels commonly carry a performance warranty of 25 years or more (Chapter 5). Soiling can cost far more power, far faster than that — but a bucket of water and a soft cloth fixes it completely. This is exactly why cleaning is one of the most valuable, and easiest, maintenance tasks there is.



*Example chart: daily energy production slowly falling over several weeks as dust builds up, then jumping back up close to its normal level right after cleaning.*

#### WORD TO KNOW

**Cleaning schedule** — A written plan that says how often solar panels should be cleaned, based on local dust conditions and the season.

#### EQUATION: MONTHLY ENERGY FROM A SOILED OR CLEAN ARRAY

$$E_{\text{month}} = P_{\text{STC}} \times (1 - L_{\text{soil}}) \times \text{PSH} \times \text{days}$$

*In words: Monthly energy = Rated power × (1 – soiling loss) × peak sun hours × days*

| Symbol             | Meaning                                                         | Unit                                                        |
|--------------------|-----------------------------------------------------------------|-------------------------------------------------------------|
| $E_{\text{month}}$ | energy produced by the array in one month                       | kilowatt-hours per month (kWh/month)                        |
| $P_{\text{STC}}$   | the array's rated power at standard test conditions (Chapter 5) | kilowatts (kW)                                              |
| $L_{\text{soil}}$  | soiling loss for the array's current condition (Chapter 5)      | fraction (a percent written as a decimal, e.g., 20% = 0.20) |

|      |                                    |           |
|------|------------------------------------|-----------|
| PSH  | peak sun hours per day (Chapter 3) | hours (h) |
| days | number of days in the month        | days      |

*This equation joins two ideas you already know: the soiling-loss equation from Chapter 5, and the peak-sun-hour production idea from Chapter 3. It leaves out other losses (heat, wiring, and so on) on purpose, so the effect of dust alone is easy to see. Chapter 12's performance ratio combines every loss together for a full system design.*

#### WORKED EXAMPLE — WHAT DOES DUST COST THE SHOP FROM CHAPTER 5, IN A MONTH?

Recall the small shop with the 3 kW rooftop system from Chapter 5. In the dusty season, if it is left uncleaned for several weeks, it reaches the 'heavy dust' range from Chapter 5's soiling table — an example loss of 20%, matching the 'about a fifth' drop Chapter 5 described. Right after a good cleaning, a light layer of dust still returns within a week or two, giving a much smaller example loss of 3%. The shop's site gets an example 6.5 peak sun hours per day in the dusty season. Find the array's energy production in a 30-day month (a) while dusty and (b) right after cleaning, and (c) how much energy the dust cost the shop that month.

1. Before cleaning:  $P_{\text{actual}} = P_{\text{STC}} \times (1 - L_{\text{soil}}) = 3 \text{ kW} \times (1 - 0.20) = 2.4 \text{ kW}$
2. (a) Energy while dusty:  $E = 2.4 \text{ kW} \times 6.5 \text{ h} \times 30 \text{ days} = 468 \text{ kWh}$
3. After cleaning:  $P_{\text{actual}} = 3 \text{ kW} \times (1 - 0.03) = 2.91 \text{ kW}$
4. (b) Energy after cleaning:  $E = 2.91 \text{ kW} \times 6.5 \text{ h} \times 30 \text{ days} = 567.45 \text{ kWh}$
5. (c) Energy lost to dust:  $567.45 - 468 = 99.45 \text{ kWh}$

**Answer: About 99.45 kWh lost to dust in just one month — roughly 17–18% of what the freshly cleaned array would have produced.**

At the example electricity price of 100 IQD per kWh used in Chapter 1, that 99.45 kWh is worth about 9,945 IQD — close to 10,000 IQD — lost every single month the panels stay dusty. A little regular cleaning is one of the cheapest, most effective things anyone can do to protect a solar system's value.

#### An example cleaning schedule for the dust season (Iraq and the Kurdistan Region)

| Season                                              | Typical dust condition                                                                | Suggested cleaning interval                                                    |
|-----------------------------------------------------|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Spring and summer (dust season, dust storms common) | Fast dust buildup — can reach 'heavy' levels (Chapter 5) within weeks                 | Every 2–4 weeks, and again soon after any dust storm                           |
| Autumn and winter (cooler, some rain)               | Slower dust buildup; occasional rain helps a little but rarely cleans the glass fully | Every 6–10 weeks, or whenever panels look visibly dirty                        |
| Right after a dust storm (any season)               | A sudden, heavy layer of dust and sand                                                | Clean as soon as it is safely possible — do not wait for the next regular date |

Chapter 5 already explained how to clean safely: work in the cool morning or evening, use plenty of clean water with a soft cloth when water is available, or a soft dry brush when it is not, and never use sand, steel wool, or hard brushes. This lesson adds the missing piece — WHEN and HOW OFTEN. A **calendar-based** schedule cleans on fixed dates, like the table above. A **condition-based** schedule cleans whenever a trigger happens — a dust storm, or a visibly dusty panel — no matter what the calendar says. The best real plans use both together: the calendar as a safety net, and quick action after any trigger.

#### CASE STUDY — TWO SHOPS, ONE STREET, TWO CLEANING HABITS • KURDISTAN REGION (EXAMPLE FIGURES)

Two small shops on the same street installed identical 3 kW systems in the same month. Shop A's owner set a simple rule: clean every 3 weeks in spring and summer, and again right after any dust storm, no matter what. Shop B's owner cleaned only when he remembered, which in practice meant about twice a year. After one full dusty season, Shop A's system had produced close to its expected output all summer. Shop B's system had instead spent many weeks in the 'heavy dust' range of 15–25% soiling loss (Chapter 5), losing an example few hundred kWh that summer alone — worth tens of thousands of IQD at local electricity prices. Both shops had bought the exact same equipment. The only real difference was the schedule.

#### COMMON MISTAKE

**X Wrong:** If a panel's output has dropped, the panel itself must be wearing out or broken.

**✓ Right:** Check for dust first. A drop in output is very often simple soiling, which disappears completely after a good cleaning — not permanent damage. Chapter 19's method (symptom → cause → check → fix) can help if cleaning does not bring the output back.

#### SAFETY

Schedule cleaning for the cool early morning or evening — never the hottest part of a summer midday. This protects you from heat stress, and it protects the panels too: pouring cool water on glass that is very hot from midday sun can occasionally crack it from thermal shock. Always follow Chapter 5's full cleaning safety rules as well: use a stable ladder, keep dry footing where possible, and never work alone on a roof.

#### ACTIVITY (FIELD) — TRACK YOUR OWN SOILING RATE

1. Find a small solar panel that can be left outdoors, undisturbed, for at least four weeks (a garden light panel or a small demonstration panel works well).
2. Once a week, at the same time of day and in similar sunlight, measure the panel's short-circuit current (Isc) with a multimeter, without cleaning it.
3. Write down the date and the Isc reading each week, and calculate the percent drop from week 1 each time.
4. After four weeks, clean the panel and measure Isc one more time.
5. Use your own weekly numbers to suggest a sensible cleaning interval for that panel's location — this is exactly how a real cleaning schedule is built.

*You need: A small outdoor solar panel, A multimeter, A notebook for weekly readings*

► *App simulation: Explore again: change months since cleaning and watch the energy loss (Chapter 5's simulation, revisited)*

► *App tool: Try it: estimate your own site's monthly energy loss from dust*

## 20.2 Visual Inspections and Battery Care

Chapter 18 gave a system its first full check, at commissioning. Chapter 19 gave you a method for fixing problems once they appear. This lesson gives you the missing piece in between: a regular routine that finds small problems BEFORE they become failures, energy losses, or safety hazards.

## WORD TO KNOW

**Visual inspection** — A check done by carefully looking at equipment for damage, dirt, wear, or anything unusual — usually without opening, disconnecting, or electrically testing anything.

## A basic visual inspection checklist

| Part of the system         | What to look for                                                                                               | Possible warning sign                                                          |
|----------------------------|----------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Panels and glass           | Cracks, discoloration, dirt, bird droppings, and new shading (Chapter 5) from a growing tree or a new building | A cracked or badly discolored cell, or a shadow that was not there before      |
| Mounting structure         | Rust on the rack, loose or missing bolts, bent rails, movement when pushed gently                              | A rack that rocks or rattles, or visible rust on steel parts                   |
| Cables and connectors      | Cracked or sun-damaged insulation (Chapter 9), loose MC4 connectors, cables rubbing against metal edges        | Exposed copper, a connector not fully clicked together, a burnt smell          |
| Enclosures and electronics | Water stains inside a box, insect or bird nests blocking vents, warning lights on the controller or inverter   | A blocked cooling vent, a steady error light, an unusual noise                 |
| Battery area               | Clear ventilation, no leaks or swelling, clean and tight terminals                                             | A sour or rotten-egg smell, a swollen case, white or green powder on terminals |

Look closely at every metal connection — battery terminals, cable lugs, breaker terminals, earthing connections (Chapter 9). Moisture and air slowly attack unprotected metal.

## WORD TO KNOW

**Corrosion** — Slow damage to metal, often seen as rust or a white or greenish powder, caused by moisture or chemicals reacting with the metal over time. It weakens parts and increases resistance at electrical connections.

A corroded connection is a problem for two reasons. Chapter 2 taught that every material has resistance; corrosion adds extra, unwanted resistance exactly where a clean, low-resistance joint is needed. Chapter 9 then showed that resistance under load makes heat — so a badly corroded connection can grow hot enough to damage insulation, and in rare cases even start a fire.

## WORD TO KNOW

**Terminal** — The metal point on a battery, connector, or device where a wire is attached to complete an electrical connection.

Checking connections means looking for corrosion, and gently checking that each terminal is snug — neither loose (which causes sparking and heat) nor forced dangerously tight (which can crack a terminal or strip a thread). If a connection looks corroded or blackened, or feels warm during normal operation, treat it as a real warning sign, not a small detail.



## SAFETY

Battery terminal work needs extra care. Chapter 6 explained that flooded batteries release hydrogen gas while charging, and that a short circuit is dangerous — never let a metal tool touch both terminals at once, and remove rings and metal watches first. Always disconnect the load and the charging source, then disconnect the NEGATIVE terminal first; reconnect it LAST when the work is finished. Battery acid burns skin and eyes — wear gloves and eye protection, and keep clean water nearby. A paste of baking soda and water can help neutralize small acid spills and clean corrosion from lead-acid terminals; rinse and dry the area afterward.

Chapter 6 explained battery types, capacity, depth of discharge, and charging stages. Chapter 7 explained equalization charging for flooded batteries. This lesson turns that knowledge into a routine you can actually carry out on a real system.

## WORD TO KNOW

**Hydrometer** — A simple tool that measures the density (specific gravity) of a battery's liquid electrolyte, used to estimate the state of charge of a flooded lead-acid battery.

## WORD TO KNOW

**Specific gravity** — A number that compares the density of a battery's electrolyte to the density of plain water. A charged lead-acid cell has a higher specific gravity than a discharged one.

## Battery care tasks by type

| Battery type       | Regular care tasks                                                                                                                                                                                                                        |
|--------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Flooded lead-acid  | Check electrolyte level monthly (more often in summer heat); top up ONLY with distilled water, never tap water or acid; check specific gravity with a hydrometer; keep terminals clean and lightly greased; keep the area well ventilated |
| AGM / gel (sealed) | No water top-up — the battery is sealed; check the case for swelling, cracks, or leaks; check terminals for corrosion and tightness; check resting voltage from time to time                                                              |
| LiFePO4 (lithium)  | Rely on the battery management system (Chapter 6) for protection; check that the battery stays within its safe temperature range; check terminals for corrosion; no water or specific-gravity check is needed                             |

## WORKED EXAMPLE — HOW MUCH MORE ENERGY IS SAFE TO USE?

During a routine inspection, a technician uses a hydrometer to check the same 1000 Ah, 12 V flooded lead-acid battery bank sized in Chapter 6. The specific gravity reading corresponds to about 70% state of charge (SoC). The bank's maximum safe depth of discharge is 50%. How much more energy, in Wh, can safely be drawn from the bank before it reaches its 50% DoD limit?

1. Find the current depth of discharge:  $\text{DoD}_{\text{now}} = 100\% - \text{SoC} = 100\% - 70\% = 30\%$
2. Find the remaining safe DoD:  $50\% - 30\% = 20\%$  (as a fraction, 0.20)

3. Use Chapter 6's usable-energy equation:  $E_{\text{remaining}} = V \times C \times \text{DoD}$

4. Put in the numbers:  $E_{\text{remaining}} = 12 \text{ V} \times 1000 \text{ Ah} \times 0.20$

5. Calculate:  $E_{\text{remaining}} = 2400 \text{ Wh}$

**Answer: 2400 Wh (2.4 kWh) can still safely be drawn before the bank reaches its 50% DoD limit — after that, the load should be reduced or charging should start soon.**

#### COMMON MISTAKE

**✗ Wrong:** Top up a flooded battery's low electrolyte with ordinary tap water, or with acid, to be safe.

**✓ Right:** Always top up with distilled (or de-ionized) water only. Tap water carries minerals that damage the cells over time. Acid is almost never lost in normal use — only water evaporates — so adding acid without a confirmed reason usually makes things worse, not better.

#### ACTIVITY (FIELD) — INSPECTION WALK-THROUGH

1. Using this lesson's checklist table, walk around a real solar system (at school, home, or a local site) with a notebook.
2. Check the panels, the mounting structure, the cables and connectors, the enclosures and electronics, and the battery area, one at a time.
3. Write down anything unusual you find, even small things — a little dust, a slightly loose bolt.
4. For each item found, write what you would do about it: clean it, tighten it, keep watching it, or call a professional (Chapter 19).
5. Keep this sheet — Lesson 3 shows you how to turn it into a proper maintenance log.

*You need: Notebook and pen, A torch (flashlight) helps for enclosures, A real solar system, or clear photos of one*

► *App simulation: Revisit: see how a battery's state of charge changes as it charges and discharges*

► *App tool: Check the numbers for a battery bank like the one in this lesson*

## 20.3 Seasonal Tasks and Record Keeping

Not every maintenance task happens every week. Some tasks make real sense only at certain times of year. This lesson builds a full-year plan, and shows how to keep a proper record of everything done — the habit that turns good intentions into a system that really does get cared for.

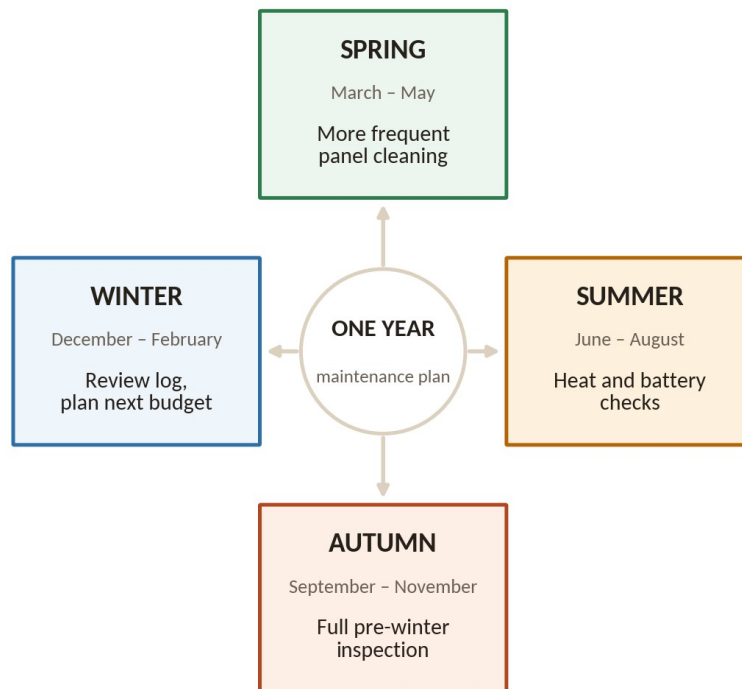
#### WORD TO KNOW

**Maintenance schedule** — A written plan listing every maintenance task for a system, how often each one should be done, and who is responsible for it.

#### A yearly maintenance calendar (example, for Iraq and the Kurdistan Region)

| Season                      | Typical months | Key maintenance tasks                                                                                                                                             |
|-----------------------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Spring — dust season begins | March–May      | Increase panel cleaning frequency (Lesson 1); check for winter storm or wind damage; inspect mounting bolts; check new plant growth for fresh shading (Chapter 5) |

| Season                                 | Typical months     | Key maintenance tasks                                                                                                                                                                                            |
|----------------------------------------|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Summer — peak heat and dust storms     | June–August        | Clean panels every 2–4 weeks (Lesson 1); check inverter and controller ventilation and cooling; check battery electrolyte level more often, since heat speeds up water loss; avoid maintenance work at midday    |
| Autumn — cooling down, less dust       | September–November | Full visual inspection before winter (Lesson 2); check cable insulation and every connection; clean panels once more before the winter rains; test any generator autostart (Chapter 13) before the outage season |
| Winter — rain, lower sun, shorter days | December–February  | Check enclosures for water leaks after rain; check earthing and earth electrode connections (Chapter 9); review the year's maintenance log and plan next year's budget (Lesson 4)                                |



*A year calendar showing one main maintenance focus for each season: spring cleaning increase, summer heat and battery checks, autumn pre-winter inspection, and winter review and budget planning.*

Not every task follows the seasons. Some are simply periodic, done on a fixed cycle all year round — for example, a full visual inspection (Lesson 2) every month or two. Others are condition-based, done only when a trigger happens — a dust storm, a heavy rainstorm, or an unusual reading on a monitoring app. A complete maintenance schedule mixes all three kinds: seasonal tasks, periodic tasks, and condition-based tasks.

## WORD TO KNOW

**Maintenance log** — A written or digital record of every maintenance visit, inspection, and repair on a system, including the date, what was found, and what was done.

A single inspection tells you how a system looks TODAY. A log, kept over months and years, tells you how a system is CHANGING — and change over time is often the earliest sign of a real problem, long before anything actually fails. A good log also supports a warranty claim, helps a new technician understand a system's history quickly, and builds trust with the system's owner. Many maintenance apps, including this course's own app, can send a reminder when a task is due — but the schedule and the log still need a real person to read them and act.

### What a good maintenance log entry includes

| Field             | Example entry                                                   |
|-------------------|-----------------------------------------------------------------|
| Date              | 14 June 2026                                                    |
| System / location | Family home, Ankawa, Erbil                                      |
| Task done         | Panel cleaning and full visual inspection                       |
| Findings          | Light dust layer; one loose mounting bolt found on the east row |
| Action taken      | Cleaned with soft cloth and water; bolt tightened by hand       |
| Next task due     | About 3 weeks, or sooner after a dust storm                     |
| Technician        | Initials or name                                                |

## WORKED EXAMPLE — HOW MANY INSPECTIONS HAPPEN IN A YEAR?

A maintenance schedule calls for a full visual inspection every 6 weeks. About how many inspections will happen in one year (52 weeks)?

1. Weeks in a year: 52
2. Divide by the interval:  $52 \div 6 \approx 8.7$
3. Round UP to a whole number of visits, so no gap is ever longer than planned: 9 inspections

**Answer: About 9 inspections a year. Always round scheduling numbers like this UP, not down — rounding down would leave a gap longer than the plan intended.**

## CASE STUDY — WHAT THE LOG SHOWED, TWO YEARS LATER • DUHOK, KURDISTAN REGION (EXAMPLE FIGURES)

A technician maintaining a school's solar system in Duhok kept a simple maintenance log for two years. Reading back through her notes, she noticed the flooded battery bank needed a water top-up after about 6 weeks in the first year, but only after about 4 weeks by the second year — the batteries were losing water faster over time, a common early sign of aging cells or of a charging voltage set a little too high. No single visit had looked unusual on its own; the pattern was only visible because every visit had been written down. She checked and slightly lowered the charge controller's absorption voltage (Chapter 7), and flagged the battery bank for likely replacement within the year — avoiding a surprise failure during the school's exam season.

### COMMON MISTAKE

**X Wrong:** Keep maintenance notes only in memory, or on scattered scraps of paper.

**✓ Right:** Use one dedicated notebook, spreadsheet, or the app's maintenance log feature, and record every visit — even the ones where nothing was wrong. 'Nothing wrong today' is still useful information later.

### ACTIVITY (CLASSROOM) — START YOUR OWN MAINTENANCE LOG

1. Design a simple log template with the fields from this lesson's table: date, system/location, task done, findings, action taken, next task due, technician.
2. Fill in one real entry, using the findings from Lesson 2's inspection walk-through activity, or a system you know.
3. Add one future date for the next cleaning and the next full inspection, using Lesson 1's schedule table and this lesson's calendar.
4. Compare your template with a classmate's. Is there any field you both agree is missing?

*You need: Notebook, spreadsheet, or phone app, Your Lesson 2 inspection notes, if you have them*

## 20.4 Planning a Maintenance Budget

Maintenance is not free. Even simple preventive care needs time, water, cleaning materials, occasional spare parts, and sometimes a paid technician. This lesson helps you plan and estimate a yearly maintenance budget, so it is never a surprise cost.

### WORD TO KNOW

**Maintenance budget** — A yearly estimate of the money needed for the regular and expected maintenance of a system, planned in advance.

A maintenance budget usually covers a few kinds of cost: cleaning materials, labor, and time; a professional inspection visit once or twice a year; distilled water and small spare parts, such as fuses or connectors; and money set aside for the day a major part — most often the battery bank — needs to be replaced.

### WORD TO KNOW

**Service life** — The number of years a piece of equipment is expected to keep working well, before it needs major repair or replacement.

### Typical example service life of the main components (planning figures — always check the real datasheet and warranty)

| Component                    | Typical example service life      | Notes                                                                                 |
|------------------------------|-----------------------------------|---------------------------------------------------------------------------------------|
| Solar panels                 | 25 years or more                  | Panels degrade slowly (Lesson 1); most keep producing well past their warranty period |
| Charge controller / inverter | About 10 years                    | Electronic parts; can fail earlier from heat, dust, or a voltage surge (Chapter 9)    |
| Flooded lead-acid battery    | Often 3–6 years in real solar use | Shorter with deep, frequent cycling                                                   |

| Component                     | Typical example service life | Notes                                                                                   |
|-------------------------------|------------------------------|-----------------------------------------------------------------------------------------|
|                               |                              | (Chapter 6); good care can push this higher                                             |
| LiFePO4 (lithium) battery     | Often 8–15 years or more     | Chapter 6 showed lithium tolerates far more cycles than lead-acid                       |
| Mounting structure and cables | 20–25 years or more          | Mainly limited by corrosion (this chapter) and UV aging of cable insulation (Chapter 9) |

These are general planning figures, not a promise for any specific product. Notice that batteries are almost always the shortest-lived major part of a system. This is exactly why a maintenance budget's biggest reserve is usually saved for battery replacement, not for panels.

#### WORD TO KNOW

**Contingency** — Extra money set aside in a budget for unexpected repairs, which cannot be predicted exactly but are likely to happen sometimes.

#### EQUATION: ANNUAL MAINTENANCE RESERVE FROM SYSTEM COST

$$C_{\text{reserve}} = C_{\text{capital}} \times r_{\text{maint}}$$

*In words: Annual maintenance reserve = System capital cost × maintenance rate*

| Symbol    | Meaning                                                                     | Unit                                                       |
|-----------|-----------------------------------------------------------------------------|------------------------------------------------------------|
| C_reserve | yearly money set aside for maintenance and eventual replacement             | currency per year (for example, IQD/year)                  |
| C_capital | the system's original capital cost (Chapter 15)                             | currency (for example, IQD)                                |
| r_maint   | an example maintenance rate — the share of capital cost set aside each year | fraction (a percent written as a decimal, e.g., 2% = 0.02) |

*This is a simple planning rule, not a fixed law. A common example range for solar systems is about 1% to 3% of capital cost set aside each year, mainly to prepare for eventual battery replacement. Add this reserve to routine yearly costs — cleaning materials, inspection visits — for the full annual maintenance budget.*

#### WORKED EXAMPLE — PLANNING A HOME SYSTEM'S YEARLY MAINTENANCE BUDGET

A home's off-grid solar system has an example capital cost of 12,000,000 IQD (Chapter 15 shows how a figure like this is built up). The owner plans an annual maintenance reserve of 2% of the capital cost, mainly to prepare for battery replacement later. Routine yearly costs — cleaning materials and a twice-yearly technician visit — add up to an example 300,000 IQD. Find the full yearly maintenance budget.

1. Annual maintenance reserve:  $C_{\text{reserve}} = C_{\text{capital}} \times r_{\text{maint}} = 12,000,000 \times 0.02 = 240,000$  IQD
2. Routine yearly cost (given):  $C_{\text{routine}} = 300,000$  IQD
3. Total yearly maintenance budget:  $B_{\text{annual}} = C_{\text{reserve}} + C_{\text{routine}} = 240,000 + 300,000 = 540,000$  IQD

**Answer: 540,000 IQD per year (example numbers) — about 4.5% of the original system cost, most of it set aside for the battery bank's eventual replacement.**

Compare this yearly figure with Lesson 1's dust example: neglecting cleaning for just one dusty month cost the shop from Chapter 5 about 9,945 IQD in lost energy alone — without counting any extra strain that neglect puts on other parts. A modest, planned budget, spent steadily throughout the year, is almost always cheaper in the end than the surprise cost of neglect.

#### COMMON MISTAKE

**✗ Wrong:** Assume a solar system needs no real ongoing money once it is bought and installed.

**✓ Right:** Even the best-built system needs a small, planned yearly budget. Skipping the plan does not remove the cost — it only turns a small, predictable cost into a bigger, surprise cost later, such as an early battery replacement or a repair that could have been prevented.

#### ACTIVITY (CLASSROOM) — BUILD A ONE-YEAR MAINTENANCE BUDGET

1. Choose a system size (for example, the 3 kW, 4 kW, 5 kW, or 6 kW examples used in this chapter) and an example capital cost for it.
2. Choose a maintenance rate between 1% and 3%, and calculate the annual reserve using this lesson's equation.
3. Estimate routine yearly costs — cleaning materials, water, and any technician visits — using local prices if you can find them, or clearly labeled example prices if you cannot.
4. Add the reserve and the routine costs together for a full annual maintenance budget.
5. Divide by 12 to find a monthly figure — this is often easier for a family to plan around.

*You need: Calculator or phone, Local price information, if available*

► *App tool: See how ongoing maintenance costs fit into a system's full lifetime cost and payback*

#### CHAPTER SUMMARY

- Maintenance keeps a solar system safe, efficient, and working well for its whole service life.
- Preventive maintenance is planned and regular; corrective maintenance repairs a problem after it happens (Chapter 19).
- Soiling (dust) is temporary and fully reversible by cleaning; degradation is slow, permanent aging that cannot be cleaned away.
- A cleaning schedule should be more frequent in the dusty season, and should react quickly after any dust storm.
- Even a single dusty month can cost real money in lost energy — cleaning is one of the cheapest, most valuable maintenance tasks there is.
- A visual inspection checks panels, mounting, cables, connectors, enclosures, and the battery area for damage, corrosion, and looseness.
- Battery care means checking electrolyte level and specific gravity for flooded types, watching temperature and terminals, and always following battery safety rules.
- A full maintenance plan mixes seasonal tasks, periodic tasks, and condition-based tasks, and every visit belongs in a written maintenance log.
- A yearly maintenance budget combines a capital-cost-based reserve (often 1–3%, mostly for eventual battery replacement) with routine yearly costs.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A 5 kW array has a soiling loss of 10% during a dusty week. What is its actual power output in strong, direct sunlight?

**Problem 2 [Basic]** A hydrometer reading on a flooded battery bank corresponds to 80% state of charge (SoC). What is its depth of discharge (DoD)?

**Problem 3 [Basic]** A solar system has an example capital cost of 10,000,000 IQD. The owner plans a 1% annual maintenance reserve. Find the yearly reserve.

**Problem 4 [Basic]** A technician inspects a system every 4 weeks. About how many inspections happen in one year (52 weeks)?

**Problem 5 [Standard]** A 4 kW array has a soiling loss of 12% before cleaning and 4% right after cleaning. The site's example peak sun hours are 6.5 hours per day. Find the extra energy cleaning gains in one day.

**Problem 6 [Standard]** A 6 kW rooftop array goes six weeks without cleaning during the dust season and reaches an 18% soiling loss (Chapter 5's 'heavy dust' range). Right after cleaning, the loss drops to 3%. The site's example peak sun hours are 7 hours per day. Find the energy lost to dust in one 30-day month, comparing the dusty condition with the freshly cleaned condition.

**Problem 7 [Standard]** A 12 V, 600 Ah flooded lead-acid battery bank has a maximum safe depth of discharge of 50%. A hydrometer check shows the bank is at 65% state of charge. How much more energy, in Wh, can safely be drawn before the bank reaches its 50% DoD limit?

**Problem 8 [Standard]** A home system has an example capital cost of 15,000,000 IQD. The owner sets aside a 2% annual maintenance reserve, plus example routine costs of 250,000 IQD per year for cleaning materials and an annual inspection visit. Find the total yearly maintenance budget.

**Problem 9 [Standard]** Two identical 4 kW systems sit in the same location, with the same example 6 peak sun hours per day. System A is cleaned regularly and has only a 4% soiling loss. System B is neglected and has a 20% soiling loss. Find the difference in their daily energy production.

**Problem 10 [Challenge]** A shop's 5 kW rooftop array is neglected for a full dusty-season month and reaches a 20% soiling loss (Chapter 5's 'heavy dust' range), compared with a 3% loss right after cleaning. The site's example peak sun hours are 7 hours per day, over a 30-day month. The example electricity value is 100 IQD/kWh (Chapter 1). (a) Find the energy lost to dust that month. (b) Find the money value of that lost energy. (c) A professional cleaning costs an example 40,000 IQD. Based on ONE month's loss alone, did the cleaning pay for itself, and by how much?

**Problem 11 [Challenge]** A 12 V, 800 Ah flooded lead-acid battery bank has a maximum safe depth of discharge of 50%. A technician's maintenance log shows that, for about the same daily load, the bank reached its 50% DoD limit after an average of 4 days in month 1, but after only an average of 3 days by month 6. (a) Find the bank's usable energy between full charge and the 50% DoD limit. (b) Using month 1's figure, roughly what was the daily energy draw? (c) What does the change from 4 days to 3 days most likely suggest, and what should the technician do?

**Problem 12 [Challenge]** A family's off-grid home system has an example capital cost of 20,000,000 IQD. They plan a 1.5% annual maintenance reserve, plus example routine costs of 400,000 IQD per year. (a) Find their total annual maintenance budget. (b) Express this as a monthly figure. (c) During the four-month dusty season, professional cleaning costs an example 15,000 IQD per visit, once a month. Does their planned monthly maintenance budget comfortably cover this cleaning cost?



PART FIVE

# OUR REGION AND REAL PROJECTS

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## CHAPTER TWENTY-ONE

# Solar Energy in Iraq and the Kurdistan Region

*The whole course applied to our own cities, homes, and projects — with example numbers until real local data is confirmed*

### IN THIS CHAPTER YOU WILL LEARN TO

- Describe the general solar resource pattern across major cities in Iraq and the Kurdistan Region, using clearly labeled example figures.
- Explain how summer heat, dust, and the local electricity situation affect solar system planning.
- List solar technologies and equipment commonly suited to the region, with example price ranges.
- Estimate example installation costs, savings, and payback time for a local solar system.
- Recognize that local rules and safety requirements vary by area and change over time, and must always be confirmed locally.
- Analyze representative local case studies and calculate the environmental benefits of a solar system.

## 21.1 The Solar Resource in Iraq and the Kurdistan Region, City by City

Chapters 1 to 20 gave you the full toolbox of solar energy: energy and power, electricity, sunlight, solar cells and panels, batteries, controllers, inverters, wiring, system design, installation, and maintenance. This chapter brings all of that home — to the cities, homes, farms, and businesses of Iraq and the Kurdistan Region. We start with the most basic question for any solar project: how much sun is there?

### WORD TO KNOW

**Governorate** — An administrative area of Iraq, similar to a province or state. Iraq is divided into 18 governorates.

This lesson compares eight cities: Duhok, Erbil, Sulaymaniyah, and Halabja in the Kurdistan Region, and Kirkuk, Mosul, Baghdad, and Basra elsewhere in Iraq.

### WORD TO KNOW

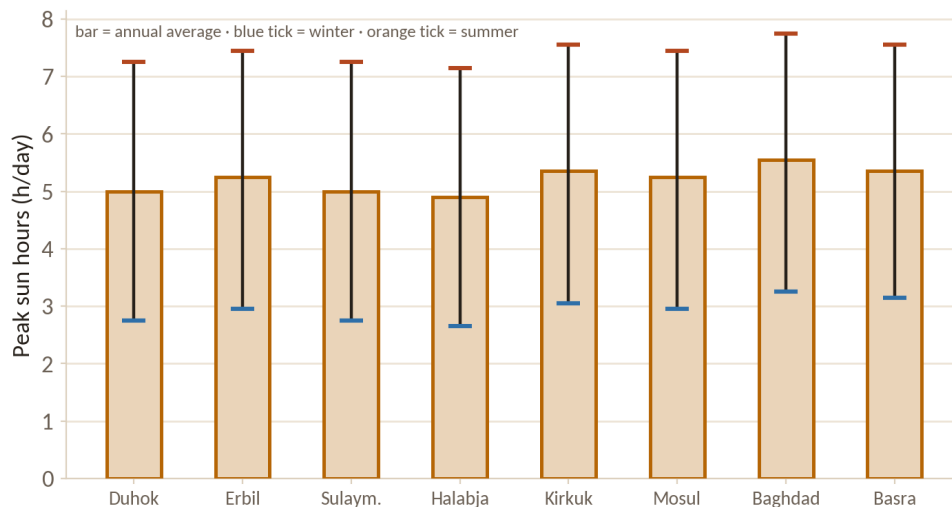
**Peak sun hour** — A simple way to measure how much sunlight a place gets in a day, as if the sun shone at one fixed strong brightness ( $1000 \text{ W/m}^2$ ) for that many hours, then stopped completely. More peak sun hours means more solar energy from the same size of array. Chapter 3 explains this fully.

**Example peak sun hours (PSH) by city — ILLUSTRATIVE numbers for practice, not verified measurements**

| City  | Governorate / area | Example annual average PSH | Example winter range (Dec-Jan) | Example summer range (Jun-Aug) |
|-------|--------------------|----------------------------|--------------------------------|--------------------------------|
| Duhok | Duhok              | ≈ 4.8–5.2 h/day            | ≈ 2.5–3.0 h/day                | ≈ 7.0–7.5 h/day                |
| Erbil | Erbil              | ≈ 5.0–5.5 h/day            | ≈ 2.7–3.2 h/day                | ≈ 7.2–7.7 h/day                |

| City         | Governorate / area | Example annual average PSH | Example winter range (Dec-Jan) | Example summer range (Jun-Aug) |
|--------------|--------------------|----------------------------|--------------------------------|--------------------------------|
| Sulaymaniyah | Sulaymaniyah       | ≈ 4.8–5.2 h/day            | ≈ 2.5–3.0 h/day                | ≈ 7.0–7.5 h/day                |
| Halabja      | Sulaymaniyah area  | ≈ 4.7–5.1 h/day            | ≈ 2.4–2.9 h/day                | ≈ 6.9–7.4 h/day                |
| Kirkuk       | Kirkuk             | ≈ 5.1–5.6 h/day            | ≈ 2.8–3.3 h/day                | ≈ 7.3–7.8 h/day                |
| Mosul        | Ninewa             | ≈ 5.0–5.5 h/day            | ≈ 2.7–3.2 h/day                | ≈ 7.2–7.7 h/day                |
| Baghdad      | Baghdad            | ≈ 5.3–5.8 h/day            | ≈ 3.0–3.5 h/day                | ≈ 7.5–8.0 h/day                |
| Basra        | Basra              | ≈ 5.1–5.6 h/day            | ≈ 2.9–3.4 h/day                | ≈ 7.3–7.8 h/day                |

These numbers are **examples for practice only**. Nobody has yet collected and verified them for this book — that data-collection work is a separate future task. Until then, use them only to practise the calculation method, never for a real design. A few general, well-known patterns are still worth understanding: - The whole region sits at a latitude with a strong sun resource — similar to much of the Middle East, North Africa, and other high-sun regions of the world. - Summers are sunny almost every day. Winters bring more cloud, especially in the northern mountains. - Mountain cities (Duhok, Sulaymaniyah, Halabja) can have more winter cloud and even snow, which lowers their winter sun hours a little compared with the plains. - Dust and haze, covered in Lesson 2, reduce sunlight everywhere in the region, in every city.



*Illustrative example comparison of peak sun hours across eight cities. These are example numbers for practice, not verified measurements.*

Once you know a location's peak sun hours, Chapter 12 taught you how to estimate an array's daily energy output.

#### WORD TO KNOW

**Performance ratio** — A single number that shows how much of a solar array's ideal output you actually get, once you include real losses like heat, dust, wiring, and inverter losses. A performance ratio of 0.80 means the system delivers about 80% of its ideal output. Chapter 12 explains this fully.

#### EQUATION: RECALL: DAILY ENERGY FROM AN ARRAY (CHAPTER 12)

$$E_{\text{array}} = P_{\text{array}} \times PSH \times PR$$

In words: Daily array energy = Array power × peak sun hours × performance ratio

| Symbol  | Meaning                                                          | Unit                             |
|---------|------------------------------------------------------------------|----------------------------------|
| E_array | energy produced by the array in one day                          | kilowatt-hours per day (kWh/day) |
| P_array | the array's rated power (nameplate, at standard test conditions) | kilowatts (kWp)                  |
| PSH     | peak sun hours for that location and period                      | hours per day (h/day)            |
| PR      | performance ratio                                                | ratio, no unit (0 to 1)          |

A typical example performance ratio used for practice in this book is about 0.75–0.85. Lesson 2 explains why heat and dust push it down in this region.

#### WORKED EXAMPLE — EXAMPLE ARRAY OUTPUT IN ERBIL

A 3 kWp array is installed in Erbil. Using the example annual-average peak sun hours for Erbil (midpoint of the illustrative 5.0–5.5 h/day range) and an example performance ratio of 0.80, estimate its average daily energy output.

1. Find the midpoint of the example range:  $(5.0 + 5.5) \div 2 = 5.25$ , which rounds to 5.3 h/day
2. Write the equation:  $E_{\text{array}} = P_{\text{array}} \times PSH \times PR$
3. Put in the numbers:  $E_{\text{array}} = 3 \text{ kW} \times 5.3 \text{ h} \times 0.80$
4. Calculate:  $E_{\text{array}} = 12.72$ , which rounds to about 12.7 kWh/day

**Answer: About 12.7 kWh/day, using example numbers. Lessons 3 and 4 use this same example system again.**

#### COMMON MISTAKE

**✗ Wrong:** Treating the numbers in the city table as confirmed, official measurements.

**✓ Right:** These are clearly labeled example numbers for practice. Before any real design, use verified data — for example, from a proper solar resource database or local measurements — which is a separate data-collection task for this project.

#### ACTIVITY (CLASSROOM) — COMPARE TWO CITIES

1. Pick two cities from the table above (for example, Duhok and Baghdad).
2. Write down which one has more sun hours in summer, and which has more in winter, using the example ranges.
3. Discuss: why might a mountain city have less sun in winter than a plains city, even at a similar latitude?
4. Discuss: why must we still confirm these numbers with real data before designing a real system?

You need: The city table from this lesson, Paper and pen

► App tool: Try it: explore peak sun hours for different cities and months

► App simulation: See it: watch how the sun's position changes through the day and year

## 21.2 Local Weather, Climate, and the Electricity Situation

Lesson 1 showed the region's strong sun resource, city by city. But the sun hours in a table are not exactly what your solar system will produce. Local weather and the local electricity situation both change the real picture — for the panels themselves, and for why people want solar power in the first place.

Iraq and the Kurdistan Region generally have a hot, dry, sunny climate, especially from late spring to early autumn. In many cities, summer daytime temperatures regularly climb past 40°C, and the hottest weeks of the year can go higher still. Winters are cooler and bring most of the year's rain; the northern mountains (around Duhok, Sulaymaniyah, and Halabja) are noticeably cooler and wetter in winter than the central and southern plains, and can see snow at higher elevations. Dust is a normal part of life across the region — from a light haze in the sky to full dust storms that can turn the sky orange or brown for hours or days.

### WORD TO KNOW

**Dust storm** — A strong wind that lifts a large amount of dust and sand into the air. It can block sunlight for hours or days, and leaves a layer of dust on anything outdoors, including solar panels.

Solar panels are usually dark, and dark surfaces absorb heat. On a sunny day, a panel's cell temperature commonly runs 20–30°C hotter than the surrounding air — this is well known and true almost everywhere panels are used, not only here. So on a hot regional summer day with an air temperature around 40°C, a cell temperature of roughly 65°C is a reasonable example for practice.

### WORD TO KNOW

**Temperature coefficient** — A number on a solar panel's datasheet that shows how much power the panel loses for every degree Celsius above its 25°C test temperature. Chapter 4 explains this fully.

### WORKED EXAMPLE — EXAMPLE EFFECT OF SUMMER HEAT ON PANEL OUTPUT

A panel is rated 400 W at 25°C. Using an example temperature coefficient of –0.4% per °C (a commonly cited typical value for crystalline silicon panels) and an example hot-summer cell temperature of 65°C, estimate its power output from heat alone, before any other losses.

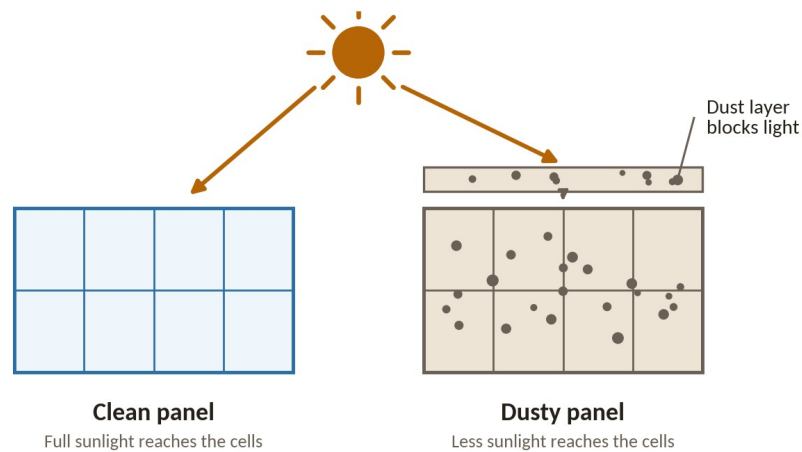
1. Find the temperature rise:  $\Delta T = 65^\circ\text{C} - 25^\circ\text{C} = 40^\circ\text{C}$
2. Find the percentage loss:  $0.4\% \times 40 = 16\%$
3. Apply the loss:  $\text{Output} = 400\text{ W} \times (1 - 0.16) = 400 \times 0.84$
4. Calculate:  $\text{Output} \approx 336\text{ W}$

**Answer: About 336 W from heat alone** — a real 400 W panel routinely works below its rated power on a hot regional summer day. This is one reason to design with a performance ratio (Lesson 1), not the nameplate rating.

### How regional weather affects a solar system (general patterns)

| Weather feature | General pattern in the region                                | Effect on a solar system                                                              |
|-----------------|--------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Hot summers     | Air temperatures often pass 40°C for weeks at a time         | Lower panel output (see the worked example); more stress on batteries and electronics |
| Dust and haze   | Common, especially spring and summer; occasional dust storms | Less sunlight reaches the cells; panels need regular cleaning                         |

| Weather feature      | General pattern in the region                                            | Effect on a solar system                                           |
|----------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------|
| Mild, wetter winters | More cloud and rain, especially in the north                             | Lower sun hours for weeks at a time (see Lesson 1's winter ranges) |
| Open, sunny sites    | Many flat roofs and open plots with little shade from trees or buildings | Good conditions for solar, once heat and dust losses are managed   |



*A layer of dust on a solar panel blocks some sunlight before it reaches the solar cells.*

#### COMMON MISTAKE

**X Wrong:** Assuming a panel will always produce its rated (nameplate) power, like 400 W, whenever the sun is out.

**✓ Right:** Real output is lower — often by 20% or more in regional summer conditions — once you include heat, dust, wiring, and inverter losses. Always design using a realistic performance ratio, never the nameplate number alone.

Now the other half of the local picture: the electricity supply itself. Across Iraq and the Kurdistan Region, the amount of power available from the public electricity system changes through the day and through the year — often falling furthest behind demand in the hottest summer months, exactly when air conditioners need the most power.

#### WORD TO KNOW

**National grid** — The network of power lines, substations, and power stations that carries electricity across a whole country, from power stations to homes, shops, and factories.

#### WORD TO KNOW

**Load shedding** — The planned switching off of electricity to different areas, at different times, because there is not enough power to supply everyone at once. Also called power rationing.

#### WORD TO KNOW

**Feeder** — A power line that carries electricity from a substation to one group of homes or businesses. Different feeders in the same city can be switched on and off at different times.

How many hours of national grid power does a household get? For many years, this varied a great deal by area, by season, and by year. In many areas, households received somewhere in the range of roughly 8 to 16 hours of national grid power a day, with the rest of the day's power, if any, coming from a neighborhood generator or a home solar-plus-battery system. Grid hours were usually worse in the hottest summer months, when demand for air conditioning is highest everywhere at once. That general pattern is still a fair description of many areas today, and it remains a useful example for practice. But in the Kurdistan Region, a major, real change is now under way — described next.

#### WORD TO KNOW

**Project Runaki** — A Kurdistan Regional Government (KRG) program, announced in May 2025, to give homes across the Kurdistan Region 24-hour national grid power under one new tiered tariff, instead of limited grid hours plus a separate paid generator subscription. Runaki (رووناکی) is the Kurdish word for light or brightness.

#### WORD TO KNOW

**Tiered tariff** — A pricing plan where the price for each kWh changes depending on how much energy is used in the billing period — a low price for the first block of energy, then a higher price for each higher block. Also called a progressive or scaled tariff.

In May 2025, the KRG Council of Ministers approved Project Runaki, a program to bring 24-hour national grid electricity to the whole Kurdistan Region, replacing the old system of limited grid hours plus a private generator subscription. The plan targets full coverage by the end of 2026. As of the most recently published figures at the time of writing, Runaki reports supplying more than 90% of the region — close to 5.5 million people — with round-the-clock power, supported by an announced \$200 million in government subsidies for the new tariff. **Coverage, timing, and exact figures are still changing as the rollout continues, and can differ from one city or neighborhood to another — always confirm the current situation for your own area rather than relying only on this book.**

**Real data: Project Runaki residential electricity tariff, Kurdistan Region (announced May 2025)**

| Monthly usage block | Price per kWh (IQD) |
|---------------------|---------------------|
| 1–400 kWh           | 72                  |
| 401–800 kWh         | 108                 |
| 801–1200 kWh        | 175                 |
| 1201–1600 kWh       | 265                 |
| Above 1600 kWh      | 350                 |

Notice the shape of the table: the price per kWh rises as a household uses more energy in the month, from 72 IQD for the first 400 kWh up to 350 IQD for any use above 1600 kWh — almost a five-times spread between the cheapest and most expensive block. Separate tariffs apply to shops, industry, and other sectors, and agricultural users generally pay a lower rate. Where Runaki has not yet reached full 24-hour coverage, or during

the transition, the older pattern of limited grid hours plus a neighborhood generator can still apply — so the general numbers earlier in this lesson remain a useful example for areas still waiting for full rollout.

#### CASE STUDY — A TOOL BUILT FOR THIS EXACT TARIFF: RUNAKI PRO • KURDISTAN REGION (REAL, CURRENT TOOL)

Because the new tariff has several price tiers instead of one flat rate, working out a real monthly bill by hand takes several steps — exactly the kind of calculation this book teaches in Chapters 1, 15, and 21. Runaki Pro, an Android app by this book's author, does this automatically: a household enters its monthly kWh usage, and the app calculates the bill under the new tiered Runaki system, and compares it with the old fixed tariff and with the standard Iraqi national grid rate, in English, Arabic, or Kurdish. Readers who want to try it can search for "Runaki Pro" on Google Play. It is a good real-world example of software supporting energy literacy — a small, focused calculator in the same spirit as the calculators built into the SEFE app.

#### WORD TO KNOW

**Neighborhood generator** — A shared diesel generator that supplies electricity to many homes or shops in one area, usually running during the hours when the national grid is off. Often paid for with a generator subscription — Chapter 1 explains this fully.

#### CASE STUDY — THE ERBIL FAMILY, ONE YEAR LATER • ERBIL, KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE, CONTINUING FROM CHAPTER 1)

In Chapter 1 you met a family in Erbil whose summer air conditioner used about five times as much energy as everything else in their home combined, and whose generator energy cost roughly four times more per kWh than grid energy in that chapter's example numbers. A year later, in this composite example, national grid hours in their area are shorter than ever in the hottest weeks of summer — exactly when their air conditioner needs power most. They are now looking seriously at a hybrid solar-plus-battery system, sized to cover as much of that summer afternoon and evening load as possible, so the generator only has to fill the gaps instead of carrying the whole burden.

#### SAFETY

Heat and dust bring their own safety risks, separate from electrical hazards. Working on a roof in full summer sun is dangerous — plan installation and maintenance work for early morning or late afternoon, drink plenty of water, and take shade breaks. During a dust storm, stop outdoor electrical work completely: visibility is poor, surfaces are slippery with fine dust, and dust can enter open equipment. Let panels and roofs cool before touching metal parts, which can become very hot in direct sun.

#### ACTIVITY (FIELD) — TRACK THE WEATHER FOR TWO WEEKS

1. Every day, write down the highest temperature and whether it was clear, hazy, or dusty.
2. If you have access to a small solar panel or a solar phone charger, note roughly how well it charges each day.
3. At the end of two weeks, compare the clearest days with the haziest or dustiest days.
4. Discuss: how big a difference did dust or haze seem to make?

*You need: Notebook or phone, A thermometer or weather app, A small solar panel or charger (optional)*



- App tool: Try it: see how heat, dust, and other losses add up
- App simulation: See it: watch how dust changes a panel's output

## 21.3 Suitable Solar Technologies and the Local Equipment Market

Lesson 1 showed a strong sun resource. Lesson 2 showed real losses from heat and dust, plus a grid that is often not enough on its own. Put these together, and a clear picture appears: this region is generally well suited to solar power, and especially to systems that include battery storage to cover the hours when the grid is weak or off. This lesson looks at which system types and equipment commonly fit the region, and what they typically cost in local markets.

### WORD TO KNOW

**Off-grid system** — A solar system that is not connected to the national grid at all. It must produce and store all the energy it needs itself, usually with a battery. Chapter 11 explains this fully.

### WORD TO KNOW

**Hybrid system** — A solar system that can use more than one power source together — usually solar, a battery, and the grid or a generator. Chapter 11 explains this fully.

### WORD TO KNOW

**Grid-tied system** — A solar system connected to the national grid, usually without a battery. It sends extra solar power to the grid, or draws grid power when the sun is not enough. Also called an on-grid system. Chapter 11 explains this fully.

### Which system type usually fits, and why (recall Chapter 11)

| System type | Typical local fit                                                                                                      | Needs a battery?                          |
|-------------|------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| Off-grid    | Sites with no practical grid connection at all — remote farms, remote villages, some telecom towers                    | Yes, usually with a backup generator too  |
| Hybrid      | Homes and businesses with a grid connection that is not available all day — the most common regional situation today   | Yes                                       |
| Grid-tied   | Sites with a reliable grid connection and supportive local rules, where the goal is only to lower the electricity bill | No — but it needs the grid to work at all |

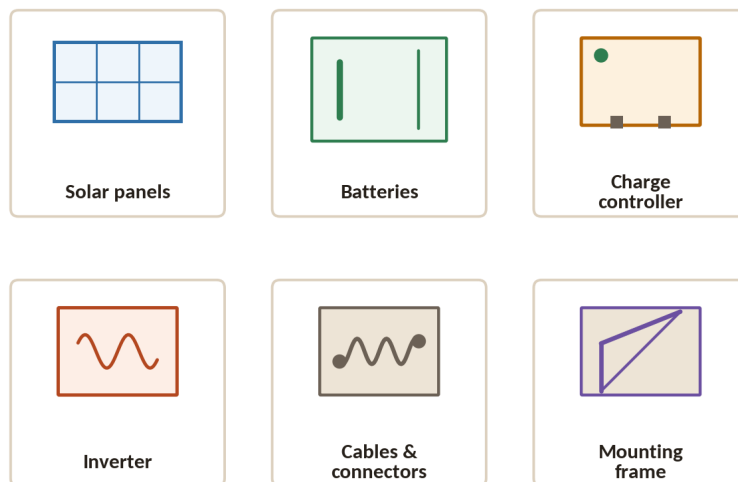
Chapters 4 to 8 covered how panels, batteries, controllers, and inverters work. In local markets across the region, you will typically find: monocrystalline panels as the common modern choice; both lead-acid and lithium (LiFePO<sub>4</sub>) batteries, with lithium becoming more common as prices fall; both PWM and MPPT charge controllers; and off-grid or hybrid inverters, often combined as one inverter-charger unit.

**Example equipment and price ranges — ILLUSTRATIVE, for practice only**

| Equipment                                  | Common type in local markets            | Example price range (illustrative)                |
|--------------------------------------------|-----------------------------------------|---------------------------------------------------|
| Solar panel (module)                       | Monocrystalline, roughly 350–550 W each | example \$0.20–0.40 per watt                      |
| Battery — lead-acid (flooded, AGM, or gel) | 12 V, roughly 100–200 Ah                | example \$80–150 per kWh of capacity              |
| Battery — lithium (LiFePO <sub>4</sub> )   | 12 V, 24 V, or 48 V packs               | example \$250–450 per kWh of capacity             |
| Charge controller — PWM                    | Smaller systems                         | example \$15–40                                   |
| Charge controller — MPPT                   | Medium and large systems                | example \$60–300, depending on current rating     |
| Inverter (off-grid or hybrid)              | Modified or pure sine wave              | example \$0.15–0.35 per watt of continuous rating |
| Mounting, cables, connectors, breakers     | Balance of system                       | example 15–25% of the other equipment's cost      |

#### WORD TO KNOW

**Balance of system** — All the parts of a solar system besides the panels, batteries, controller, and inverter — for example, the mounting frame, cables, connectors, and circuit breakers. Often shortened to BOS.



*Typical solar equipment types found in local markets: panels, batteries, a charge controller, and an inverter.*

#### WORKED EXAMPLE — EXAMPLE TOTAL COST OF A SMALL HYBRID SYSTEM

Using the example price ranges above, estimate the total cost of a small 3,000 W (3 kW) hybrid system with these example choices: panels at \$0.30/W, a 5 kWh lithium battery at \$350/kWh, one MPPT controller at \$150, and a 3,000 W inverter at \$0.25/W. Balance of system is an example 20% of the other equipment's cost.

1. Panels:  $3000 \text{ W} \times \$0.30/\text{W} = \$900$

2. Battery:  $5 \text{ kWh} \times \$350/\text{kWh} = \$1,750$
3. Controller: \$150 (example flat price)
4. Inverter:  $3000 \text{ W} \times \$0.25/\text{W} = \$750$
5. Subtotal:  $900 + 1750 + 150 + 750 = \$3,550$
6. Balance of system:  $20\% \times 3,550 = \$710$
7. Total:  $3,550 + 710 = \$4,260$

**Answer: About \$4,260 in this example (roughly 5,580,000 IQD at an example exchange rate of 1 USD  $\approx$  1,310 IQD). Lessons 4 and 5 use this same example system again.**

#### COMMON MISTAKE

**X Wrong:** Buying from the first supplier you find, or trusting a price with no written details.

**✓ Right:** Get at least two or three written quotations, compare the exact equipment (brand, power rating, warranty), and ask for the datasheet of the main components before you decide.

#### SAFETY

Poor-quality or wrongly rated electrical parts — fake breakers, undersized cables, uncertified batteries — are a common cause of fires in solar installations everywhere, not only here. Paying a little more for parts that are correctly rated and from a known brand is a safety decision, not just a money decision. When in doubt, ask a qualified electrician to check the plan before you buy.

A few general, practical habits help in any local market: compare at least two or three suppliers; ask for the datasheet, not just a price; ask what the warranty covers and for how long; and remember that the cheapest quotation is not always the best value once quality and warranty are considered.

► *App tool: Try it: size an array for your own example load*

► *App simulation: See it: compare off-grid, hybrid, and grid-tied system diagrams*

## 21.4 Installation and Maintenance Challenges, Costs, Savings, and Local Rules and Safety Requirements

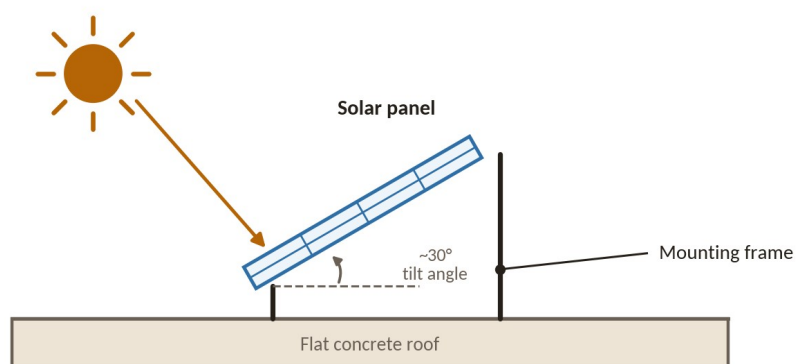
A solar system is not finished at the moment of design. This lesson looks at three practical questions every real project in this region must answer: What makes installation and maintenance harder here? What will it realistically cost and save, in example numbers? And what rules and safety requirements apply?

Chapter 17 covered installation step by step. In this region, a few challenges come up again and again. Summer heat makes rooftop work slow and dangerous during the hottest hours (see Lesson 2's safety note). Flat roofs are the most common roof type in many towns and cities, so panels almost always need a tilted mounting frame rather than lying flat, and roof waterproofing around any fixing point needs special care. Fine dust can work its way into poorly sealed enclosures and connectors over time, so equipment rated for outdoor, dusty conditions is worth the extra cost. Finally, importing certain equipment can take time, so realistic project planning should allow for delivery delays.

#### Installation and maintenance challenges, and practical responses

| Challenge                                    | Practical response                                  |
|----------------------------------------------|-----------------------------------------------------|
| Extreme summer heat during installation work | Work early morning or late afternoon; keep the crew |

| Challenge                                                      | Practical response                                                                           |
|----------------------------------------------------------------|----------------------------------------------------------------------------------------------|
|                                                                | hydrated and shaded                                                                          |
| Flat roofs, needing a tilt frame                               | Use a mounting frame rated for local wind loads; check the roof's structural condition first |
| Dust entering equipment                                        | Use enclosures and connectors with a good outdoor dust rating; seal cable entries            |
| Dust build-up on panels over time                              | Set a regular cleaning schedule (Chapter 20); clean more often in dusty seasons              |
| Extra heat stress on batteries                                 | Keep batteries in a shaded, ventilated space, away from direct sun (Chapter 6)               |
| Loose connections from repeated heat expansion and contraction | Check and re-tighten connections at each maintenance visit (Chapter 19)                      |



*A tilted mounting frame on a flat roof — the most common roof type in the region.*

#### COMMON MISTAKE

**✗ Wrong:** Skipping maintenance visits because the system still seems to be working.

**✓ Right:** A system can lose a real share of its output to dust and small faults long before it stops working completely. Regular checks (Chapter 20) catch small problems before they become expensive ones.

#### WORD TO KNOW

**Payback period** — The time it takes for the money saved by a solar system to equal the money it cost to buy and install. Chapter 15 explains this fully.

#### EQUATION: RECALL: SIMPLE PAYBACK PERIOD (CHAPTER 15)

$$T_{\text{payback}} = \frac{C_{\text{system}}}{S_{\text{annual}}}$$

*In words: Payback period = System cost ÷ Annual savings*

| Symbol    | Meaning                                                                  | Unit                               |
|-----------|--------------------------------------------------------------------------|------------------------------------|
| T_payback | the time until the savings equal the system cost                         | years                              |
| C_system  | the total cost of the system                                             | currency (for example, USD or IQD) |
| S_annual  | the money saved each year by using solar instead of other energy sources | currency per year                  |

*This simple version ignores financing interest, rising fuel prices, and maintenance cost — Chapter 15 covers a fuller version. It is still a good first estimate.*

#### WORKED EXAMPLE — EXAMPLE PAYBACK FOR THE LESSON 3 SYSTEM

Recall the example 3 kW hybrid system from Lesson 3, costing about \$4,260 ( $\approx 5,580,000$  IQD). Using Erbil's example output from Lesson 1 (about 12.7 kWh/day) and this chapter's example generator energy cost recalled from Chapter 1 (about 380 IQD per kWh), estimate: (a) the system's annual energy production, and (b) its simple payback period, assuming for this example that all the solar energy replaces generator energy.

1. Monthly production:  $12.7 \text{ kWh/day} \times 30 = 381 \text{ kWh/month}$
2. Annual production:  $381 \text{ kWh/month} \times 12 = 4,572 \text{ kWh/year}$
3. Annual savings:  $4,572 \text{ kWh} \times 380 \text{ IQD/kWh} \approx 1,737,000 \text{ IQD/year}$
4. Payback:  $T = C \div S = 5,580,000 \text{ IQD} \div 1,737,000 \text{ IQD/year} \approx 3.2 \text{ years}$

**Answer: About 3.2 years in this example — well inside a typical 20-plus-year system life. Real payback depends on real prices, real usage, and how much of the solar energy actually replaces generator energy rather than grid energy.**

#### COMMON MISTAKE

**X Wrong:** Treating every price, rate, and time period in this chapter as a fixed, current, real-world fact.

**✓ Right:** Every number in this chapter is a clearly labeled example for practice. Prices, exchange rates, and electricity costs change often — always confirm current numbers before a real design or purchase.

The payback method above treats the avoided energy cost as one single number, like the example 380 IQD/kWh generator cost. Under a real tiered tariff like Project Runaki's (Lesson 2), the story is more interesting: since the price per kWh rises with total monthly usage, the value of the kWh that solar panels replace first depends on which tier a household normally reaches by the end of the month.

#### WORD TO KNOW

**Marginal cost** — The cost of one more unit of something — here, the price of the NEXT kWh a household would use, not the average price of all the kWh it has already used. Under a tiered tariff, the marginal cost is the price of the highest tier a household reaches that month.

#### WORKED EXAMPLE — REAL RUNAKI TARIFF AND PAYBACK: DOES THE TIER MATTER?

Recall the Lesson 3 example system: a 3 kW hybrid system costing about 5,580,000 IQD, producing about 4,572 kWh/year (from the Lesson 1 Erbil example, 12.7 kWh/day). Using Project Runaki's real residential tariff table (Lesson 2), find the simple payback period if this solar energy replaces (a) top-tier grid energy at

350 IQD/kWh, for a high-usage household, and (b) second-tier grid energy at 108 IQD/kWh, for a lower-usage household.

1. (a) High-usage household, top tier: Annual savings =  $4,572 \text{ kWh} \times 350 \text{ IQD/kWh} = 1,600,200 \text{ IQD/year}$
2. (a) Payback:  $T = C \div S = 5,580,000 \div 1,600,200 \approx 3.5 \text{ years}$
3. (b) Lower-usage household, second tier: Annual savings =  $4,572 \text{ kWh} \times 108 \text{ IQD/kWh} = 493,776 \text{ IQD/year}$
4. (b) Payback:  $T = C \div S = 5,580,000 \div 493,776 \approx 11.3 \text{ years}$

**Answer: About 3.5 years for the high-usage household, but about 11.3 years for the lower-usage household — the same system and the same price, but more than three times the payback time, only because of which tariff tier each household's last kWh comes from. This uses real, sourced data from Project Runaki's announced tariff (Lesson 2); always confirm the current tariff and a household's real usage before estimating a real payback.**

#### COMMON MISTAKE

**X Wrong:** Using one single "electricity price" for every household when estimating solar payback.

**✓ Right:** Under a tiered tariff, first check which price tier a household's usage normally reaches. Solar panels effectively remove kWh from the TOP of that household's usage first, so high-usage households in the top tier generally see the fastest payback.

Every real installation must also follow local rules, not just good engineering practice. Iraq and the Kurdistan Region are still developing clear, consistent rules for solar installations, and requirements can differ between governorates and cities, and can change from year to year.

#### WORD TO KNOW

**Quotation** — A written offer from a supplier or installer that lists the equipment, the work, and the price for a job.

Some safety requirements are essentially universal, wherever local rules stand: correct earthing/grounding (Chapter 9), correctly rated breakers and fuses, and — most importantly — never connecting a generator or a solar inverter to the grid without a proper changeover switch or an approved grid-tie inverter with anti-islanding protection. This protects electricity workers who may be repairing lines during an outage, thinking the line is safely switched off. Some places also allow net metering — sending extra solar power back to the grid for a bill credit — but this is not available everywhere, and where it does exist, the rules can change.

#### SAFETY

Before starting any real project: confirm current permit, inspection, and grid-connection rules with your local electricity directorate or municipality, and involve a licensed local engineer. Do not rely only on this textbook for legal or regulatory requirements — rules vary by area and change over time.

#### ACTIVITY (FIELD) — GET A REAL QUOTATION

1. Contact one real local solar supplier or installer, in person, by phone, or online.
2. Ask for a written quotation for a small example system (for example, similar in size to Lesson 3's 3 kW example).

3. Compare their real prices with this chapter's example price ranges.

4. Discuss in class: what was different? What was similar?

*You need: Contact details for a local supplier, Notebook or phone*

► *App tool: Try it: estimate payback for your own example numbers*

► *App simulation: See it: explore how costs and savings add up over time*

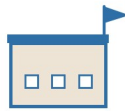
## 21.5 Real Solar Energy Projects in Iraq and the Kurdistan Region

This lesson looks at the kinds of solar projects that are common across Iraq and the Kurdistan Region.

**Important:** the examples below are illustrative composite case studies. Each one is representative of a common project type, built from typical patterns and this chapter's example numbers — they are not citations of specific, verified, named real installations. Chapter 22 lets you design a complete project of your own, checked against your own real local data.



Homes



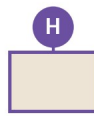
Schools



Farms



Shops



Health centers



Remote sites

*Some common types of local solar projects: homes, schools, farms, shops, health centers, and remote sites.*

### CASE STUDY — A FAMILY HOME — HYBRID SYSTEM • ERBIL, KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)

This composite example continues the Erbil family from Chapter 1 and Lesson 2 of this chapter. Their biggest single load is a summer air conditioner. They install a hybrid system like Lesson 3's 3 kW example (about \$4,260, roughly a 3.2-year example payback from Lesson 4), sized to cover as much of their daytime and early-evening load as possible. The result, in this example: fewer hours depending on the neighborhood generator, a quieter home in the evening, and a lower monthly generator subscription bill. The battery keeps essential loads — lights, fridge, phone charging, and internet — running through short evening outages.

### CASE STUDY — A SCHOOL BUILDING — GRID-TIED OR HYBRID SYSTEM • A TOWN IN THE REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)

Schools are a strong natural match for solar power, because they mostly operate during daylight hours —

exactly when panels produce the most energy. A composite example school with a large, flat, unshaded roof installs a system sized to cover most of its daytime electricity use: lighting, fans, computers, and printers. Where local rules and a supportive grid connection allow it, a grid-tied design (no battery) keeps costs lower. Where the school also needs power during outages, for example to protect computer equipment or run laboratory instruments, a smaller hybrid design with a modest battery is a common local choice instead.

#### **CASE STUDY — A FARM AND GREENHOUSE — SOLAR WATER PUMPING • RURAL KURDISTAN REGION OR IRAQ (ILLUSTRATIVE COMPOSITE EXAMPLE)**

A composite example farm replaces a diesel water pump with a solar-powered pump for irrigation. The pump runs mainly through the day, which matches irrigation needs well: crops and greenhouses typically need watering during the day anyway. Benefits in this example: no more diesel fuel trips to the farm, much lower running cost once the system is paid for, and less noise. The main limitation: on a cloudy day, or if watering is needed very early or late, the farm may still need a small backup — either a storage tank filled during sunny hours, or, in some designs, a battery or a backup generator.

► *App tool: Try it: estimate the energy a solar water pump needs (see the Practice Problems for a worked pumping example)*

#### **CASE STUDY — A SHOP OR SMALL BUSINESS • A CITY MARKET AREA (ILLUSTRATIVE COMPOSITE EXAMPLE)**

A composite example shop uses solar power mainly for lighting, a drinks refrigerator, and a fan during opening hours — again, a good match with daylight hours. A small battery lets the shop stay open a little past sunset without depending fully on the neighborhood generator. In this example, the shop owner's main motivation is not environmental — it is simply a lower, more predictable monthly energy cost compared with an unpredictable generator subscription.

#### **CASE STUDY — A HEALTH CENTER — RELIABILITY FIRST • A RURAL CLINIC (ILLUSTRATIVE COMPOSITE EXAMPLE)**

For a health center, reliability matters more than cost savings alone — losing power can mean losing vaccines or medicine that must stay cold, or losing light and equipment during a medical procedure. A composite example clinic installs a hybrid system with a generous battery (extra autonomy, well beyond a typical home system) and keeps its old generator as a backup, not a replacement. The design goal here is not the fastest payback; it is the smallest realistic chance of ever losing power completely.

#### **CASE STUDY — A REMOTE VILLAGE, TELECOM SITE, OR STREETLIGHT • A REMOTE AREA OF IRAQ OR THE KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)**

Some sites have no practical grid connection at all: a small remote village, an isolated telecommunications tower, or a standalone streetlight beside a rural road. These composite examples typically use fully off-grid solar designs. A remote telecom site or streetlight often has a small, steady, well-known load and its own dedicated battery, since running a diesel generator out to a very remote site is expensive and inconvenient. A remote village project is more like many small home systems side by side, or, in some designs, a small shared mini-grid — an idea explored further in Chapter 22.



Beyond money, every one of these examples shares an environmental benefit. Each kWh produced by the sun is a kWh not produced by burning diesel or fuel oil — which means less carbon dioxide (CO<sub>2</sub>) released into the air, and locally, less noise and fewer diesel fumes from generators.

#### WORD TO KNOW

**Emission factor** — A number that shows how much CO<sub>2</sub> is released for each kWh of energy from a certain fuel or power source, like a diesel generator or a national grid. Chapter 15 explains this fully.

#### EQUATION: RECALL: CO<sub>2</sub> AVOIDED (CHAPTER 15)

$$M_{CO_2} = E_{\text{annual}} \times EF$$

*In words: CO<sub>2</sub> avoided per year = Annual solar energy × emission factor*

| Symbol   | Meaning                                                                   | Unit                                                                     |
|----------|---------------------------------------------------------------------------|--------------------------------------------------------------------------|
| M_CO2    | the mass of CO <sub>2</sub> avoided per year                              | kilograms of CO <sub>2</sub> per year (kg/year)                          |
| E_annual | the solar energy produced, or the generator/grid energy avoided, per year | kilowatt-hours per year (kWh/year)                                       |
| EF       | an emission factor for the energy being replaced                          | kilograms of CO <sub>2</sub> per kilowatt-hour (kg CO <sub>2</sub> /kWh) |

*The real emission factor depends on exactly what the solar energy replaces — grid power, a diesel generator, or a mix of both — and on the fuels used. A commonly cited illustrative planning figure for fuel oil, gas, or diesel-based electricity is roughly 0.6–0.8 kg CO<sub>2</sub>/kWh; this book uses 0.7 kg CO<sub>2</sub>/kWh as an example.*

#### WORKED EXAMPLE — EXAMPLE CO<sub>2</sub> AVOIDED BY THE LESSON 3-4 SYSTEM

Using the example system's annual production from Lesson 4 (about 4,572 kWh/year) and an example emission factor of 0.7 kg CO<sub>2</sub>/kWh, estimate how much CO<sub>2</sub> this one example system avoids in a year.

1. Write the equation:  $M_{CO_2} = E_{\text{annual}} \times EF$
2. Put in the numbers:  $M_{CO_2} = 4,572 \text{ kWh/year} \times 0.7 \text{ kg/kWh}$
3. Calculate:  $M_{CO_2} \approx 3,200 \text{ kg/year}$
4. Convert to tonnes:  $3,200 \div 1000 = 3.2 \text{ tonnes/year}$

**Answer:** About 3,200 kg, or 3.2 tonnes, of CO<sub>2</sub> avoided per year in this example — and if 100 similar homes did the same thing, that is roughly 320 tonnes of CO<sub>2</sub> a year, from a single neighborhood.

#### Other environmental and local benefits (general, not numbered examples)

| Benefit                                 | Why it matters locally                                                             |
|-----------------------------------------|------------------------------------------------------------------------------------|
| Less diesel fume and noise              | Fewer running hours for neighborhood and backup generators                         |
| Less fuel transport                     | Fewer diesel delivery trips to homes, farms, and remote sites                      |
| No water use for generating electricity | Unlike some large power plants, solar panels need no water to generate electricity |
| Long equipment life                     | Panels commonly keep working for 20–25 years or more                               |

| Benefit | Why it matters locally       |
|---------|------------------------------|
|         | with basic care (Chapter 20) |

### ACTIVITY (CLASSROOM) — CHOOSE YOUR PROJECT TYPE

1. Pick one project type from this lesson (or your own idea) that is closest to your own situation.
2. List the three biggest challenges you would expect for that project in your own area.
3. List the three biggest benefits you would expect.
4. Keep your notes — Chapter 22 lets you design a complete version of this project.

*You need: Notebook or phone*

► *App tool: Try it: estimate CO2 avoided for your own example system*

► *App simulation: See it: explore financial and environmental results together*

### CHAPTER SUMMARY

- Iraq and the Kurdistan Region generally have a strong solar resource, similar to much of the Middle East — but every specific city number in this chapter is a clearly labeled example, not verified data.
- Hot summers reduce panel output through heat (temperature derating); dust and haze reduce it further. Real design must use a realistic performance ratio, not the nameplate rating.
- Limited national grid hours, load shedding, and expensive neighborhood generator subscriptions are major reasons solar-plus-battery systems are attractive here.
- Hybrid systems usually fit the region best; pure off-grid suits remote sites with no grid at all; grid-tied fits sites with reliable grid and supportive local rules.
- Local markets typically offer monocrystalline panels, both lead-acid and lithium batteries, PWM and MPPT controllers, and off-grid or hybrid inverters — always at example, not confirmed, price ranges.
- Installation and maintenance challenges here include extreme heat, flat roofs, dust ingress, and dust build-up on panels, alongside the same wiring and safety rules taught throughout this course.
- Simple payback period = system cost ÷ annual savings; this chapter's fully worked example gives about 3.2 years, using example numbers only.
- Local rules for permits, inspection, and grid connection vary by area and change over time — always confirm them locally before a real project, alongside universal safety practices like correct earthing and changeover switches.
- Real local projects generally fall into recognizable types: homes, schools, farms and irrigation, shops, health centers, and remote or off-grid sites — each with its own priorities.
- Every kWh from the sun avoids CO2 emissions from burning fuel, plus local benefits like less generator noise and fewer fuel deliveries.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** This chapter's example summer peak sun hours for Sulaymaniyah are about 7.0–7.5 h/day. Find the midpoint of this range, and find the energy a 1 kW array would produce in one day at that midpoint, ignoring all losses (performance ratio = 1, for this simple practice question).

**Problem 2 [Basic]** This chapter uses an example exchange rate of 1 USD  $\approx$  1,310 IQD. Convert an example solar panel price of \$0.30 per watt into IQD per watt.

**Problem 3 [Basic]** A shop uses: 4 LED lamps (10 W each) for 10 hours, a small refrigerator (120 W) running effectively 8 hours, and a fan (60 W) for 10 hours during opening hours. Find the shop's daily energy use, in kWh.

**Problem 4 [Basic]** A panel is rated 300 W at 25°C. Using an example temperature coefficient of  $-0.4\%$  per °C, estimate its power output when its cell temperature reaches 55°C.

**Problem 5 [Standard]** A family in Duhok wants their example hybrid system to produce about 10 kWh per day. Using Duhok's example annual-average peak sun hours of 5.0 h/day (midpoint of the illustrative 4.8–5.2 range) and an example performance ratio of 0.80, what array size do they need, in kWp?

**Problem 6 [Standard]** A remote clinic needs 6 kWh per day of backup energy and wants 2 days of autonomy (no sun and no generator). Using an example lithium battery depth of discharge (DoD) of 90% — the fraction of the battery's energy that can safely be used — and a system voltage of 48 V, find (a) the required battery energy capacity, in kWh, and (b) the required capacity, in Ah.

**Problem 7 [Standard]** Using this chapter's example generator energy cost recalled from Chapter 1 (about 380 IQD per kWh) and an example solar system that produces 12.7 kWh per day, how much money does a family save, in IQD per month (30 days), by using that solar energy instead of generator energy?

**Problem 8 [Standard]** An example off-grid system for a small shop costs 3,200,000 IQD in total. It saves the shop owner an example 90,000 IQD per month by reducing generator use. What is the simple payback period, in years?

**Problem 9 [Standard]** A school's example solar system produces 8,000 kWh per year. Using an example emission factor of 0.7 kg CO<sub>2</sub> per kWh, how much CO<sub>2</sub> does the school avoid per year, in kg and in tonnes?

**Problem 10 [Standard]** An array would produce 20 kWh per day with no losses. Using example estimates for practice — dust reduces output by 8%, and summer heat reduces the remaining output by another 10% — apply the two losses one after another to find the actual daily output.

**Problem 11 [Challenge]** A farmer needs to lift 40 m<sup>3</sup> of water per day through a total head of 25 m for irrigation. (a) Using the standard water-lifting relation, Hydraulic energy (Wh) =  $2.725 \times \text{Head (m)} \times \text{Volume (m}^3\text{)}$ , find the ideal hydraulic energy needed per day. (b) If the pump and motor together are 45% efficient, find the actual electrical energy the solar pump system must supply per day. (c) Using an example peak sun hours value of 6.0 h/day for the pumping season, and assuming the array's full rated output is used while the sun shines (performance ratio = 1, for this simple pump example), what array size is needed, in kW?

**Problem 12 [Challenge]** A design needs an array that produces at least 15 kWh per day on average, using an example performance ratio of 0.78. Using this chapter's example annual-average peak-sun-hour midpoints — Basra  $\approx$  5.35 h/day (from the 5.1–5.6 range) and Sulaymaniyah  $\approx$  5.0 h/day (from the 4.8–5.2 range) — find the required array size for each city, and state how much bigger, in percent, the Sulaymaniyah array must be compared with the Basra array to produce the same energy.

**Problem 13 [Challenge]** A small health center needs reliable power. Its daily load is: lighting (8 LED lamps, 12 W each, 10 hours), a vaccine refrigerator (100 W, effectively running 12 hours), and small medical equipment and fans (250 W average, 8 hours). (a) Find the daily energy demand, in kWh. (b) Using an example peak sun hours value of 5.2 h/day and performance ratio 0.75, find the required array size, in kWp. (c) The clinic wants 1.5 days of battery autonomy at 90% depth of discharge, at a system voltage of 48 V. Find the required battery capacity, in kWh and in Ah. (d) If the whole system (array, battery, and the rest) costs an example 9,000,000 IQD, and

saves the clinic an example 500,000 IQD per month versus its old generator-only setup, what is the simple payback period, in years?

**Problem 14 [Challenge]** An example hybrid system costs 5,580,000 IQD and saves its owner about 1,737,000 IQD per year by reducing generator use. The system has a design life of 20 years. Ignoring maintenance costs and battery replacement (a simplification for this practice problem), what are the total lifetime savings over 20 years, and how many times bigger is that than the original system cost?

## CHAPTER TWENTY-TWO

# Capstone Design Projects

*Nine complete design projects — apply the whole course to real problems*

### IN THIS CHAPTER YOU WILL LEARN TO

- Apply the complete design chain from Chapter 12 — loads, sun data, array, battery, controller, and inverter — to nine different real project types.
- Choose a suitable system type (off-grid, hybrid, or grid-tied) and battery autonomy or backup strategy for a given site, load, and reliability need.
- Carry out full hand calculations for each project, then check the results against the app's calculators and Design wizard.
- Compare design choices across project types — for example, why a health center needs more autonomy than a shop, or why a streetlight needs no inverter at all.
- Recognize the safety priorities that change from project to project, such as reliability for a health center, roadside electrical safety for streetlights, and isolation procedures for remote telecom sites.
- Write a clear, well-organized engineering report for a solar design, using a marking rubric to check its quality.

### 22.1 Project 1 — A Family House (Off-Grid and Hybrid Versions)

Welcome to the capstone chapter. Chapters 1 to 21 taught you the ideas, the equations, and the safety rules of solar energy, one piece at a time. This chapter has nine projects, and each one is a complete, realistic design case — a real kind of building or site, with example load and site data, sized by hand using the SAME design chain you learned in Chapter 12: **energy demand → sun data → array → battery → controller → inverter**, adjusted for each project's own needs. Every price, every load, and every site number in this chapter is a clearly labeled example for practice, in the same style as Chapter 21.

For every project, you will: read the scenario, follow a full worked example by hand, then write a short engineering report — checked against a simple marking rubric, just like a real client or teacher would check it. Keep a notebook or spreadsheet open as you work through this chapter; you will reuse the design-chain method nine times, and it gets faster and more natural each time.

**Project 1: A family house.** A family house is the most common solar project anywhere, including Iraq and the Kurdistan Region — it is also where Chapter 12 built its own full worked example. This project asks a sharper question: for the SAME family, with the SAME appliances, how does the design change if the house has no grid at all, compared with a house that has a grid connection but loses power for part of each day? You will size BOTH versions and compare them directly, the same way Chapter 13, Lesson 3 compared a 'grid-lean' and a 'self-reliant' hybrid array.

**The family's daily loads (example data, same for both versions)**

| Appliance    | Power (W)          | Hours per day | Energy (Wh) |
|--------------|--------------------|---------------|-------------|
| 10 LED lamps | $10 \times 8 = 80$ | 5             | 400         |

| Appliance                        | Power (W)           | Hours per day | Energy (Wh) |
|----------------------------------|---------------------|---------------|-------------|
| Television                       | 100                 | 5             | 500         |
| Refrigerator (effective run)     | 150                 | 8             | 1200        |
| 2 ceiling fans                   | $2 \times 60 = 120$ | 8             | 960         |
| Router and phone/laptop chargers | 30                  | 6             | 180         |
| Washing machine                  | 500                 | 1             | 500         |
| Small water pressure pump        | 260                 | 1             | 260         |
| Total                            | —                   | —             | 4000        |

#### WORKED EXAMPLE — STEP 1: THE FAMILY'S TOTAL DAILY ENERGY NEED

Add up the table above to find the household's daily energy need, in Wh and kWh.

1. Add every appliance's energy:  $400 + 500 + 1200 + 960 + 180 + 500 + 260 = 4000$  Wh
2. Convert to kWh:  $4000 \div 1000 = 4.0$  kWh

**Answer: E<sub>daily</sub> = 4000 Wh = 4.0 kWh per day — the SAME starting point for both versions of this project**

**Version A — the off-grid house.** This family lives on a remote farm outside Erbil, with no national grid line anywhere nearby. Chapter 12's rule applies in full: size the array for the design month (winter), and size the battery bank for full autonomy, because there is no other backup at all.

#### WORKED EXAMPLE — STEP 2-3: SIZING THE OFF-GRID ARRAY

Using E<sub>daily</sub> = 4000 Wh, Erbil's example winter (design-month) peak sun hours PSH = 3.0 h/day, and this book's standard performance ratio PR = 0.80, find the minimum array size and choose real panels.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH} \times \text{PR})$
2. Put in the numbers:  $P_{\text{array}} = 4000 \div (3.0 \times 0.80) = 4000 \div 2.4 \approx 1666.7$  W
3. This matches Chapter 12, Lesson 2's own worked example exactly — a useful check that the method is being applied correctly
4. Choose panels: with the example 400 W panel used throughout this book ( $V_{\text{oc}} = 49$  V,  $I_{\text{sc}} = 10.5$  A,  $V_{\text{mp}} = 40$  V,  $I_{\text{mp}} = 10$  A),  $1666.7 \div 400 \approx 4.17 \rightarrow$  round up to 5 panels = 2000 W

**Answer: At least 1.67 kWp needed; five 400 W panels (2000 W total) chosen**

Wiring: five panels in parallel keeps array  $V_{\text{oc}}$  at one panel's value (49 V), safely below almost any MPPT controller's input limit. Array as wired:  $V_{\text{oc}} = 49$  V,  $I_{\text{sc}} = 5 \times 10.5 = 52.5$  A,  $V_{\text{mp}} = 40$  V,  $I_{\text{mp}} = 5 \times 10 = 50$  A, giving  $40 \times 50 = 2000$  W (matches  $5 \times 400$  W ✓).

#### WORKED EXAMPLE — STEP 4: SIZING THE OFF-GRID BATTERY BANK

This remote home has no other backup, so the design uses 3 days of autonomy (Chapter 12, Lesson 3's upper 'remote home' guide), a 24 V system voltage (the 2 kWp array sits in the 'medium' 1–3 kW range), and flooded lead-acid batteries with DoD = 0.5. Find the required capacity and a real battery count.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (4000 \times 3) \div (24 \times 0.5) = 12,000 \div 12 = 1000$  Ah

3. Batteries in series for 24 V:  $24 \div 12 = 2$  per string
4. Strings in parallel for capacity, using 200 Ah batteries:  $1000 \div 200 = 5$  strings exactly
5. Total batteries: 2 in series  $\times$  5 strings = 10 batteries (a '2S5P' bank), giving 24 V, 1000 Ah

**Answer: 1000 Ah at 24 V required; ten 12 V, 200 Ah batteries (2S5P) chosen — exactly matching the requirement, so autonomy =  $(24 \times 1000 \times 0.5) \div 4000 = 3.0$  days exactly**

#### WORKED EXAMPLE — STEP 5: SIZING THE OFF-GRID CONTROLLER

Using the array's  $I_{sc} = 52.5$  A and rated power 2000 W at 24 V, apply both checks from Chapter 12, Lesson 4.

1. Check 1 — short-circuit current rule:  $I_{controller} \geq 52.5 \times 1.25 = 65.6$  A  $\rightarrow$  round up to 80 A
2. Check 2 — power check at 24 V:  $I_{battery} \approx 2000 \div 24 = 83.3$  A  $\rightarrow$  round up to 100 A
3. Compare: Check 2 (100 A) is larger, so Check 2 governs

**Answer: Choose a 100 A MPPT controller, rated for at least 60 V PV input ( $V_{oc} = 49$  V, so a 100 V-rated model gives a safe cold-morning margin)**

#### WORKED EXAMPLE — STEP 6: SIZING THE OFF-GRID INVERTER

The biggest simultaneous loads happen in two different moments of the day: an evening with lamps, TV, fridge, fans, and router running together (480 W), and a daytime laundry session with the fridge, fans, and washing machine running together (770 W). Find the minimum continuous and surge ratings.

1. Continuous, evening:  $80 + 100 + 150 + 120 + 30 = 480$  W
2. Continuous, daytime laundry:  $150 + 120 + 500 = 770$  W — this is the larger of the two, so it governs
3. Add a 25% margin:  $770 \times 1.25 = 962.5$  W  $\rightarrow$  round up to a 1000 W continuous inverter
4. Surge, washing machine starting (surge factor about  $3\times$  for this size of motor): other loads on (fridge + fans) = 270 W; washing machine surge =  $500 \times 3 = 1500$  W; total = 1770 W
5. Compare with the fridge starting alone in the evening: other loads (lamps + TV + fans + router) = 330 W; fridge surge ( $4\times$ ) = 600 W; total = 930 W — smaller than the washing machine case
6. Minimum surge rating: 1770 W (the larger of the two surge checks)

**Answer: Choose a 1000 W continuous / 2000 W surge, pure sine wave inverter, 24 V DC input**

#### Version A — off-grid — final component list

| Component                                        | Specification                                                                             |
|--------------------------------------------------|-------------------------------------------------------------------------------------------|
| Solar array                                      | 5 $\times$ 400 W panels, wired in parallel — 2000 W total, $V_{oc}$ 49 V, $I_{sc}$ 52.5 A |
| Charge controller                                | 100 A MPPT, rated for at least 100 V PV input                                             |
| Battery bank                                     | 10 $\times$ 12 V, 200 Ah flooded lead-acid, wired 2S5P — 24 V, 1000 Ah                    |
| Inverter                                         | 1000 W continuous / 2000 W surge, pure sine wave, 24 V DC input                           |
| Example cost (Chapter 21 price ranges, BOS +20%) | $\approx$ \$4,160 (about 5,450,000 IQD at an example rate of 1,310 IQD/\$)                |

**Version B — the hybrid house.** Same family, same appliances — but this time the house is in town, connected to the national grid, which is typically available about 10–14 example hours a day (Chapter 21), with the rest covered by a neighborhood generator. Chapter 13's hybrid method applies: size the array to a consumption OFFSET using the ANNUAL AVERAGE peak sun hours, and size the battery to cover a typical daily outage, not multiple days of full autonomy.

#### WORKED EXAMPLE — STEP 2-3: SIZING THE HYBRID ARRAY FOR AN 80% OFFSET

The family wants their array to offset about 80% of their average annual use. Using Erbil's example annual average peak sun hours (5.3 h/day) and  $PR = 0.80$ , find the minimum array size and choose real panels.

1. Write the equation:  $P_{\text{array}} = (\text{Offset} \times E_{\text{daily}}) \div (\text{PSH}_{\text{avg}} \times PR)$
2. Put in the numbers:  $P_{\text{array}} = (0.80 \times 4000) \div (5.3 \times 0.80) = 3200 \div 4.24 \approx 754.7 \text{ W}$
3. Choose panels: with 400 W panels,  $754.7 \div 400 \approx 1.89 \rightarrow$  round up to 2 panels = 800 W
4. Check the real offset:  $E_{\text{array}} = 800 \times 5.3 \times 0.80 = 3392 \text{ Wh/day}$ ; offset =  $(3392 \div 4000) \times 100 \approx 84.8\%$

**Answer: At least 754.7 W needed; two 400 W panels (800 W total) chosen, giving about an 84.8% offset — comfortably above target because whole panels must be bought**

Compare the two arrays so far: 2000 W (off-grid) vs. 800 W (hybrid) — the off-grid array is 2.5 times bigger, for the exact same family, because it alone must survive the whole winter with no help at all. This is precisely the trade-off Chapter 13, Lesson 3 called 'self-reliant' vs. 'grid-lean.'

#### WORKED EXAMPLE — STEP 4: SIZING THE HYBRID BATTERY BANK FOR A DAILY OUTAGE

The neighborhood's typical evening grid outage is 6 hours (Chapter 21). During an outage, the family only needs to keep its critical loads running: lamps, fridge, fans, and router — 380 W in total (the TV, washing machine, and water pump are treated as non-critical and stay off the backup circuit). Using a 24 V system and LiFePO<sub>4</sub> batteries (DoD = 0.8, chosen here because this battery cycles once almost every single day, and lithium tolerates many more cycles than lead-acid — Chapter 6), find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (P_{\text{critical}} \times t_{\text{backup}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (380 \times 6) \div (24 \times 0.8) = 2280 \div 19.2 \approx 118.75 \text{ Ah}$
3. Choose real batteries: two 12 V, 150 Ah LiFePO<sub>4</sub> batteries in series give 24 V, 150 Ah — already above the 118.75 Ah required, with no parallel string needed

**Answer: At least 118.75 Ah at 24 V; two 12 V, 150 Ah LiFePO<sub>4</sub> batteries (24 V, 150 Ah) chosen**

Compare the batteries: 1000 Ah (off-grid) vs. 150 Ah (hybrid) at the same 24 V — the off-grid bank is more than six times bigger. Sizing the array and battery from the load ONWARD, not from a fixed budget, is exactly Chapter 12, Lesson 1's warning against buying components separately and hoping they fit.

#### WORKED EXAMPLE — STEP 5-6: CONTROLLER AND INVERTER FOR THE HYBRID HOUSE

Size the controller and inverter for the hybrid array and critical-load backup circuit.

1. Array (2 panels in parallel):  $V_{\text{oc}} = 49 \text{ V}$ ,  $I_{\text{sc}} = 2 \times 10.5 = 21 \text{ A}$ ,  $V_{\text{mp}} = 40 \text{ V}$ ,  $I_{\text{mp}} = 2 \times 10 = 20 \text{ A}$ ,  $P = 800 \text{ W}$
2. Controller check 1:  $21 \times 1.25 = 26.25 \text{ A} \rightarrow$  round up to 30 A
3. Controller check 2:  $800 \div 24 = 33.3 \text{ A} \rightarrow$  round up to 40 A — this governs
4. Inverter continuous:  $380 \text{ W (critical loads)} \times 1.25 = 475 \text{ W} \rightarrow$  round up to a 500 W continuous inverter



5. Inverter surge: fridge starting — other critical loads on (230 W) + fridge surge ( $150 \times 4 = 600$  W) = 830 W

**Answer: Choose a 40 A MPPT controller and a 500 W continuous / 1000 W surge hybrid inverter-charger, 24 V DC input, wired only to the critical loads panel (Chapter 10)**

#### Version A vs. Version B — full comparison (example numbers)

| Feature            | Version A: off-grid                         | Version B: hybrid                                     |
|--------------------|---------------------------------------------|-------------------------------------------------------|
| Array              | $5 \times 400$ W = 2000 W                   | $2 \times 400$ W = 800 W                              |
| Battery bank       | $10 \times 200$ Ah lead-acid, 24 V, 1000 Ah | $2 \times 150$ Ah LiFePO <sub>4</sub> , 24 V, 150 Ah  |
| Controller         | 100 A MPPT                                  | 40 A MPPT                                             |
| Inverter           | 1000 W / 2000 W surge                       | 500 W / 1000 W surge (critical loads only)            |
| Design basis       | Design-month PSH, full autonomy             | Annual average PSH, offset target, daily backup hours |
| Example total cost | ≈ \$4,160 (≈ 5,450,000 IQD)                 | ≈ \$2,070 (≈ 2,710,000 IQD)                           |

The off-grid version costs about twice as much — but it is also the ONLY option where it is installed, since there is no grid to fall back on at all. The hybrid version costs less because the grid quietly does most of the hard work; solar and battery only need to cover the gaps. Neither version is 'wrong' — the site decides which method applies, exactly as Chapter 11 taught.

#### COMMON MISTAKE

**✗ Wrong:** Assume the same family, in the same climate, always needs the same size of solar system.

**✓ Right:** System size depends on the SITE'S access to backup power just as much as on the family's loads. The same 4.0 kWh/day family needed a 2000 W off-grid array with no other option, but only an 800 W array once a grid connection was available to share the load. Always ask 'what backup already exists here?' before sizing anything.

#### SAFETY

Whichever version is built, never mix the two designs' parts casually. A 1000 Ah, 24 V lead-acid bank meant for the off-grid house must never be connected to hardware sized and rated for the smaller hybrid system, and a hybrid inverter-charger must never be wired to accept the grid and a generator on the same input at once without the correct changeover protection (Chapter 11, Chapter 13). Confirm every DC voltage matches before connecting anything (Chapter 12).

#### WORD TO KNOW

**Engineering report** — A clear written document that explains an engineering design: the problem, the data used, every calculation, the equipment chosen, and the reasons behind each choice. Every project in this chapter ends with writing one.

#### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 1

1. Choose ONE version (off-grid or hybrid) — or, for extra practice, do both.
2. Write a short report with these sections: (1) Scenario and load table, (2) Sun data and array sizing, (3) Battery sizing, (4) Controller and inverter sizing, (5) Final component list and example cost, (6) One safety note specific to this project.
3. Show every equation, every substitution, and every rounding step — not just final answers.
4. Check your hand-calculated array and battery numbers against the Design wizard in the app, using the same inputs.
5. Trade reports with a classmate and mark each other's work using the rubric below, before handing both in.

*You need: Calculator or phone, Notebook or word processor, This lesson's tables*

### Marking rubric — Project 1 report (20 points)

| Criteria                                                                                                                 | Points |
|--------------------------------------------------------------------------------------------------------------------------|--------|
| Load table is clear, complete, and the daily energy total is correct                                                     | 4      |
| Sun data is correctly chosen (design-month for off-grid; annual average for hybrid) and the array calculation is correct | 4      |
| Battery calculation uses the correct method (autonomy days for off-grid; backup hours for hybrid) and is correct         | 4      |
| Controller and inverter are correctly matched to the array and loads, with both required checks shown                    | 4      |
| Final component list, example cost, and at least one safety note are included and clearly presented                      | 4      |

► *App tool: Check both array sizes with the PV Array Sizing calculator*

► *App tool: Check both battery banks with the Battery Bank Sizing calculator*

► *App simulation: Compare off-grid and hybrid energy flow for this same family in the System Types simulation*

## 22.2 Project 2 — A School or University Building

**Project 2: a school building.** Schools are one of the best natural matches for solar power. Classes run mainly in daylight hours — exactly when an array produces the most energy — so a school can use most of its solar power directly, with little need for a large, expensive battery. This project designs a GRID-TIED system using Chapter 13's offset method, then adds a small hybrid backup for the school's most sensitive loads.

### The school's daily loads (example data)

| Load group                          | Power (W)             | Hours per day | Energy (Wh) |
|-------------------------------------|-----------------------|---------------|-------------|
| Classroom lighting (40 tube lights) | $40 \times 18 = 720$  | 6             | 4320        |
| Classroom and office fans (30 fans) | $30 \times 60 = 1800$ | 7             | 12,600      |
| Computer lab (15 computers)         | $15 \times 80 = 1200$ | 4             | 4800        |

| Load group                                                    | Power (W) | Hours per day | Energy (Wh) |
|---------------------------------------------------------------|-----------|---------------|-------------|
| Lab printer                                                   | 300       | 0.5           | 150         |
| Office equipment<br>(photocopier, router, admin<br>computers) | 500       | 5             | 2500        |
| Water pump (fills the<br>rooftop tank)                        | 550       | 1             | 550         |
| Gate and security lighting<br>(overnight)                     | 60        | 10            | 600         |
| Total                                                         | —         | —             | 25,520      |

#### WORKED EXAMPLE — STEP 1: THE SCHOOL'S TOTAL DAILY ENERGY NEED

Add up the table above to find the school's daily energy need, in Wh and kWh.

1. Add every load group's energy:  $4320 + 12,600 + 4800 + 150 + 2500 + 550 + 600 = 25,520$  Wh
2. Convert to kWh:  $25,520 \div 1000 = 25.52$  kWh

**Answer:  $E_{\text{daily}} = 25,520$  Wh = 25.52 kWh per day — about six times the family house in Project 1, which fits a much bigger building with concentrated daytime equipment**

The school has a reliable enough grid connection and supportive conditions for a grid-tied array (Chapter 11, Chapter 13). Because the grid always covers any shortfall, the array is sized using the ANNUAL AVERAGE peak sun hours, not the design month, and a target offset instead of 100% of the load.

#### WORKED EXAMPLE — STEP 2-3: SIZING THE GRID-TIED ARRAY FOR AN 85% OFFSET

The school wants to offset about 85% of its average annual use — a high target, reasonable here because daytime use lines up so well with solar production. Using Erbil's example annual average peak sun hours (5.3 h/day) and  $PR = 0.80$ , find the minimum array size and choose real panels.

1. Write the equation:  $P_{\text{array}} = (\text{Offset} \times E_{\text{daily}}) \div (\text{PSH}_{\text{avg}} \times PR)$
2. Put in the numbers:  $P_{\text{array}} = (0.85 \times 25,520) \div (5.3 \times 0.80) = 21,692 \div 4.24 \approx 5117$  W
3. Choose panels: with 400 W panels,  $5117 \div 400 \approx 12.8 \rightarrow$  round up to 13 panels = 5200 W
4. Check the real offset:  $E_{\text{array}} = 5200 \times 5.3 \times 0.80 = 22,048$  Wh/day; offset =  $(22,048 \div 25,520) \times 100 \approx 86.4\%$

**Answer: At least 5117 W (5.12 kWp) needed; thirteen 400 W panels (5200 W, 5.2 kWp total) chosen, giving about 86.4% offset**

This array has no battery — it is a plain grid-tied system. During class hours, the array's power goes to classroom loads first (self-consumption); on a very bright day with light loads, any extra can be exported (Chapter 13, Lesson 2, where the local rule allows it). At night and on cloudy days, the school simply draws normal grid power, exactly as before.

#### WORKED EXAMPLE — CHOOSING THE GRID-TIE INVERTER

Following Chapter 13, Lesson 1's guidance, choose a grid-tie inverter rated close to the array's DC power, about 90–110% of its rated wattage.

1. Array rated power: 5200 W
2. 90% of 5200 W = 4680 W; 110% of 5200 W = 5720 W
3. A common commercial size inside this window is a 5000 W grid-tie inverter

**Answer: Choose a 5000 W grid-tie inverter — always check its maximum DC input power and voltage window against the array's real Voc and Vmp before ordering**

One problem remains: a plain grid-tied array gives NO power at all the instant the grid goes down — Chapter 8's anti-islanding rule switches it off automatically for safety. But Chapter 21's case study noted that some school equipment, especially computer lab machines and lab instruments, is worth protecting from a sudden outage. This is exactly the situation Chapter 21, Lesson 5 described: 'a smaller hybrid design with a modest battery' added on top of the main grid-tied array.

#### WORKED EXAMPLE — ADDING A SMALL HYBRID BACKUP FOR THE COMPUTER LAB

The school wants the 15 computers (1200 W) plus a few emergency lights (100 W) — 1300 W together — to stay powered for 2 hours during a daytime outage, long enough to save work and shut down safely. Using a 48 V system (matched to the size of the main array) and LiFePO4 batteries (DoD = 0.8), find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (P_{\text{critical}} \times t_{\text{backup}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (1300 \times 2) \div (48 \times 0.8) = 2600 \div 38.4 \approx 67.7 \text{ Ah}$
3. Choose real batteries: four 12 V, 100 Ah LiFePO4 batteries in series give 48 V, 100 Ah — comfortably above the 67.7 Ah required

**Answer: At least 67.7 Ah at 48 V; four 12 V, 100 Ah LiFePO4 batteries in series (48 V, 100 Ah) chosen, feeding a small hybrid inverter wired only to the computer lab's critical circuit**

#### Final component list — school project

| Component                            | Specification                                                                    |
|--------------------------------------|----------------------------------------------------------------------------------|
| Solar array                          | 13 × 400 W panels — 5200 W (5.2 kWp) total                                       |
| Grid-tie inverter                    | 5000 W, rated for the array's Voc and Vmp window                                 |
| Optional computer-lab backup battery | 4 × 12 V, 100 Ah LiFePO4 in series — 48 V, 100 Ah, on a small hybrid inverter    |
| Mounting                             | Tilted rack, sized for the flat roof and local wind load (Chapter 5, Chapter 21) |

#### CASE STUDY — CHOOSING BETWEEN GRID-TIED AND HYBRID FOR A SCHOOL • A TOWN IN THE REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)

Two similar schools considered solar power. The first had a very reliable grid connection and no equipment sensitive to short outages, so its committee chose the simpler, cheaper, plain grid-tied design — like the main array in this project. The second school ran a small science laboratory with equipment that could be damaged by a sudden, uncontrolled power loss, so its committee added the computer-lab-style hybrid backup on top of the same grid-tied array. Same building type, same offset target, two different backup decisions — both reasonable once the equipment sensitivity was properly considered.

### COMMON MISTAKE

**✗ Wrong:** Size a school's grid-tied array using the design-month peak sun hours, the same rule used for the off-grid house in Project 1.

**✓ Right:** A grid-tied array should use the ANNUAL AVERAGE peak sun hours (Chapter 13, Lesson 1), because the grid — not the array — covers the shortfall in winter. Using the design month here would make the array roughly 75% bigger than needed, wasting a large part of the school's budget.

### SAFETY

A school roof sees many feet during installation, maintenance, and even student activities. Any array on a school roof needs secure fencing or signage to keep students away from live DC wiring and the edge of the roof, clearly labeled disconnect switches (Chapter 9) for staff and maintenance crews, and a documented lock-out procedure before anyone works on the system. Treat a school installation with at least the same care as a public building, because it is one.

### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 2

1. Write a short report with these sections: (1) Load table by group, (2) Offset target and array sizing, (3) Grid-tie inverter choice, (4) Whether a hybrid backup is needed, and for which loads, (5) Final component list, (6) One safety note specific to a school site.
2. Justify your chosen offset target in one or two sentences — why not 100%? why not 50%?
3. If you include a hybrid backup, show its battery sizing calculation in full.
4. Check your array sizing against the Design wizard, using the same inputs.
5. Present your report to the class as if to a school head teacher deciding whether to approve the project.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 2 report (20 points)

| Criteria                                                                                           | Points |
|----------------------------------------------------------------------------------------------------|--------|
| Load table is grouped clearly and the daily energy total is correct                                | 4      |
| Offset target is chosen and justified, and the array calculation uses annual average PSH correctly | 4      |
| Grid-tie inverter choice is reasonable and explained                                               | 3      |
| Hybrid backup decision is reasonable, with correct battery sizing if included                      | 4      |
| Final component list and a school-specific safety note are included                                | 3      |
| Report is clear enough for a non-technical reader (a head teacher) to follow the main decisions    | 2      |

► *App tool: Check the offset-based array sizing with the PV Array Sizing calculator*

► *App tool: Estimate the array's daily and monthly production*

► *App simulation: Compare grid-tied and hybrid energy flow for this school in the System Types simulation*

## 22.3 Project 3 — A Farm and Greenhouse

**Project 3: a farm and greenhouse.** Project 4 studies a full irrigation pump design using Chapter 14's method — this project is different. It looks at a greenhouse's OTHER electrical needs: ventilation, circulation, climate control, and a small cold-storage room for the harvest. These loads bring a genuinely new design question: what happens when a load itself changes with the seasons, alongside the sun?

**The greenhouse's loads — two very different seasons (example data)**

| Load                               | Power (W)            | Winter hours/day | Winter energy (Wh) | Summer hours/day | Summer energy (Wh) |
|------------------------------------|----------------------|------------------|--------------------|------------------|--------------------|
| 2 exhaust ventilation fans         | $2 \times 150 = 300$ | 0 (closed up)    | 0                  | 6                | 1800               |
| 4 circulation fans                 | $4 \times 40 = 160$  | 4                | 640                | 10               | 1600               |
| Climate controller and electronics | 20                   | 24               | 480                | 24               | 480                |
| Packing shed lighting              | 60                   | 3                | 180                | 3                | 180                |
| Cold storage room (effective run)  | 200                  | 8                | 1600               | 8                | 1600               |
| Total                              | —                    | —                | 2900               | —                | 5660               |

### WORKED EXAMPLE — STEP 1: TWO VERY DIFFERENT DAILY ENERGY TOTALS

Add up the winter and summer columns separately.

1. Winter:  $0 + 640 + 480 + 180 + 1600 = 2900$  Wh
2. Summer:  $1800 + 1600 + 480 + 180 + 1600 = 5660$  Wh

**Answer: Winter  $E_{\text{daily}} \approx 2900$  Wh (2.9 kWh); summer  $E_{\text{daily}} \approx 5660$  Wh (5.66 kWh) — almost twice as much energy in summer, mainly from ventilation**

Chapter 14, Lesson 3 taught that a load which only exists in a sunny season — like irrigation — should be sized using THAT season's peak sun hours, not the worst winter month, or the array becomes needlessly large. It would be easy to assume the same shortcut applies here: size for summer, using summer's strong sun. But this greenhouse ALSO has a real winter load (cold storage and basic electronics never stop). The only safe way to know which season truly governs is to check BOTH.

### WORKED EXAMPLE — STEP 2-3: CHECKING WINTER AND SUMMER ARRAY SIZES

Using Erbil's example winter peak sun hours (3.0 h/day) and summer peak sun hours (7.5 h/day), with PR = 0.80 in both cases, find the minimum array power required for EACH season's own load, then compare them.

1. Winter:  $P_{\text{array}} = 2900 \div (3.0 \times 0.80) = 2900 \div 2.4 \approx 1208.3$  W
2. Summer:  $P_{\text{array}} = 5660 \div (7.5 \times 0.80) = 5660 \div 6.0 \approx 943.3$  W
3. Compare: winter needs MORE array power (1208.3 W) than summer (943.3 W), even though summer uses almost twice the energy

4. This happens because summer's much stronger sun (7.5 h vs. 3.0 h — 2.5× more) more than makes up for its bigger load; winter's small load still needs real panel area because winter's sun is so much weaker

**Answer: Winter is the governing (tighter) case here:  $P_{\text{array}} \approx 1208.3 \text{ W}$ . Choosing panels for summer alone, as Chapter 14 does for a pump used only in the growing season, would have UNDER-sized this array — always check every season a real load exists, never assume the sunniest month is always safest**

#### COMMON MISTAKE

**✗ Wrong:** Copy Chapter 14's rule directly: 'this load is bigger in summer, so size the array using summer's peak sun hours.'

**✓ Right:** Chapter 14's rule works when the load exists ONLY in the sunny season, like seasonal irrigation. Here, a smaller load continues through winter, when the sun is much weaker — so winter can still be the tighter design case even though it uses less energy. Calculate BOTH seasons and use the bigger array requirement, every time a load does not disappear completely outside its peak season.

#### WORKED EXAMPLE — CHOOSING PANELS AND SIZING THE BATTERY

Using the governing winter requirement (1208.3 W), choose real panels. Then, because losing ventilation for several cloudy days in summer could damage the crop, size the battery bank on the SUMMER load (5660 Wh) with 2 days of autonomy, a 24 V system, and lead-acid batteries (DoD = 0.5).

1. Panels: with 400 W panels,  $1208.3 \div 400 \approx 3.02 \rightarrow$  round up to 4 panels = 1600 W
2. Battery:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD}) = (5660 \times 2) \div (24 \times 0.5) = 11,320 \div 12 \approx 943.3 \text{ Ah}$
3. Choose real batteries: with 200 Ah batteries,  $943.3 \div 200 \approx 4.72 \rightarrow$  round up to 5 strings; 2 in series  $\times$  5 strings = 10 batteries (2S5P), giving 24 V, 1000 Ah

**Answer: 1600 W array (4  $\times$  400 W panels); 1000 Ah battery bank at 24 V (10 batteries, 2S5P) — sized on the bigger, more time-sensitive summer load, giving about 2.12 days of real autonomy at that load**

#### WORKED EXAMPLE — CONTROLLER AND INVERTER FOR THE GREENHOUSE

Wire the 4 panels in parallel and size the remaining components.

1. Array:  $V_{\text{oc}} = 49 \text{ V}$ ,  $I_{\text{sc}} = 4 \times 10.5 = 42 \text{ A}$ ,  $V_{\text{mp}} = 40 \text{ V}$ ,  $I_{\text{mp}} = 4 \times 10 = 40 \text{ A}$ ,  $P = 1600 \text{ W}$
2. Controller check 1:  $42 \times 1.25 = 52.5 \text{ A} \rightarrow$  round up to 60 A
3. Controller check 2:  $1600 \div 24 = 66.7 \text{ A} \rightarrow$  round up to 80 A — this governs
4. Inverter continuous (summer daytime peak): exhaust fans 300 + circulation fans 160 + controller 20 + cold storage 200 = 680 W;  $\times 1.25 = 850 \text{ W} \rightarrow$  round up to 1000 W
5. Surge, cold storage compressor starting (4×): other loads on (480) + surge ( $200 \times 4 = 800$ ) = 1280 W

**Answer: Choose an 80 A MPPT controller and a 1000 W continuous / 2000 W surge inverter, 24 V DC input**

#### Final component list — farm and greenhouse project

| Component   | Specification                                                                  |
|-------------|--------------------------------------------------------------------------------|
| Solar array | 4 $\times$ 400 W panels, parallel — 1600 W, sized for the winter baseline load |

| Component         | Specification                                                                     |
|-------------------|-----------------------------------------------------------------------------------|
| Charge controller | 80 A MPPT                                                                         |
| Battery bank      | 10 × 12 V, 200 Ah lead-acid, 255P — 24 V, 1000 Ah, sized for the summer peak load |
| Inverter          | 1000 W continuous / 2000 W surge, pure sine wave, 24 V DC input                   |

#### CASE STUDY — A GREENHOUSE THAT LOST ITS VENTILATION · RURAL KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)

A neighboring farm sized its greenhouse's solar system using only the summer load and summer sun hours, following what it remembered as 'the pumping season rule' from a short course. Its array was smaller than the one in this project — enough for a sunny summer day, but not enough to keep the cold-storage room and basic controls running through three cloudy winter days in a row. The family lost part of a stored harvest before adding extra panels the following year. The lesson matches this lesson's own mistake box exactly: check every season a load actually exists, not just the season with the biggest number.

#### SAFETY

Greenhouse ventilation is not just a comfort setting — on a hot, still day, a greenhouse with no working ventilation can reach temperatures that damage or kill crops within hours. Treat the ventilation fan circuit as a near-critical load, protected by its own breaker, and check it first on every maintenance visit (Chapter 20). Also remember Chapter 6 and Chapter 21's warning: batteries in a farm building should sit in a shaded, ventilated space, away from chemical stores and direct summer sun.

#### ACTIVITY (FIELD) — WRITE YOUR ENGINEERING REPORT — PROJECT 3

1. If possible, visit a real greenhouse, farm building, or cold-storage room and list its actual loads and seasonal pattern; otherwise use this lesson's example data.
2. Write a short report with these sections: (1) Winter and summer load tables, (2) Array sizing calculation for BOTH seasons, with a clear statement of which one governs and why, (3) Battery sizing, with your reasoning for which season's load you used, (4) Controller and inverter sizing, (5) Final component list and one safety note.
3. Check your array sizing against the Design wizard for both seasons.
4. Discuss with a partner: could a smart controller that runs ventilation fans only during the sunniest midday hours reduce the array size needed? Write one sentence with your idea.

*You need: Calculator or phone, Notebook or word processor*

#### Marking rubric — Project 3 report (20 points)

| Criteria                                                                                             | Points |
|------------------------------------------------------------------------------------------------------|--------|
| Winter and summer load tables are both clear and correctly totaled                                   | 4      |
| Array sizing is checked for BOTH seasons, with the governing case correctly identified and explained | 5      |
| Battery sizing is correct, with a stated reason for the                                              | 4      |



| Criteria                                                                   | Points |
|----------------------------------------------------------------------------|--------|
| chosen season and autonomy                                                 |        |
| Controller and inverter sizing is correct, with both required checks shown | 4      |
| Final component list and a greenhouse-specific safety note are included    | 3      |

► *App tool: Check both seasons' array sizes with the PV Array Sizing calculator*

► *App tool: Check the battery bank with the Battery Bank Sizing calculator*

► *App simulation: See how performance ratio affects both seasons' array requirement in the System Energy Losses simulation*

## 22.4 Project 4 — A Water Pump and Irrigation System

**Project 4: a water pump and irrigation system.** This project follows Chapter 14's own design chain exactly: head and flow → hydraulic power → electrical energy → array → storage. Unlike every other project in this chapter, there is no battery bank at all — the water tank itself is the energy store, exactly as Chapter 14, Lesson 4 explained.

**Scenario.** A vegetable farm needs water from a borehole for its drip irrigation system through the summer growing season. The farmer currently rents a diesel pump for the season — expensive, noisy, and dependent on fuel deliveries — and wants a solar-powered submersible pump instead.

**Site data (example numbers for practice)**

| Quantity                                                                          | Value                                  |
|-----------------------------------------------------------------------------------|----------------------------------------|
| Daily water need, $V_{\text{daily}}$                                              | 12 m <sup>3</sup> (12,000 liters)      |
| Static head (borehole water level while pumping, plus rise to the delivery point) | 25 m                                   |
| Friction head loss (estimated as 10% of static head, Chapter 14, Lesson 2)        | 2.5 m                                  |
| Pump-and-motor efficiency, $\eta_{\text{pump}}$                                   | 40% (0.40)                             |
| Pumping season peak sun hours, PSH                                                | 7.5 h/day (Erbil example summer value) |
| Performance ratio, PR                                                             | 0.80                                   |

### WORKED EXAMPLE — STEP 1: TOTAL DYNAMIC HEAD

Find the total dynamic head,  $H$ , from the static head and the friction head loss.

1. Write the equation:  $H = H_{\text{static}} + H_{\text{friction}}$
2. Put in the numbers:  $H = 25 + 2.5 = 27.5 \text{ m}$

**Answer:  $H = 27.5 \text{ m}$**

### WORKED EXAMPLE — STEP 2: DAILY HYDRAULIC ENERGY

Using the shortcut form of Chapter 14, Lesson 3's equation, find the daily hydraulic energy needed to lift 12 m<sup>3</sup> of water through 27.5 m.

1. Write the equation:  $E_{\text{hyd}} = 2.725 \times V_{\text{daily}} \times H$
  2. Put in the numbers:  $E_{\text{hyd}} = 2.725 \times 12 \times 27.5$
  3. Multiply:  $2.725 \times 12 = 32.7$ ;  $32.7 \times 27.5 \approx 899.25 \text{ Wh}$
- Answer:  $E_{\text{hyd}} \approx 899.25 \text{ Wh}$  (about 0.90 kWh) per day**

#### WORKED EXAMPLE — STEP 3: DAILY ELECTRICAL ENERGY

Divide the hydraulic energy by the pump-and-motor efficiency to find the electrical energy the pump must actually draw.

1. Write the equation:  $E_{\text{elec}} = E_{\text{hyd}} \div \eta_{\text{pump}}$
2. Put in the numbers:  $E_{\text{elec}} = 899.25 \div 0.40$
3. Calculate:  $E_{\text{elec}} \approx 2248.1 \text{ Wh}$

**Answer:  $E_{\text{elec}} \approx 2248.1 \text{ Wh}$  (about 2.25 kWh) per day — notice how much energy is 'lost' to only 40% pump-and-motor efficiency: the electrical energy needed is 2.5 times the hydraulic energy actually delivered to the water**

#### WORKED EXAMPLE — STEP 4: SIZING THE ARRAY

Using the pumping-season peak sun hours (7.5 h/day) and  $PR = 0.80$ , find the minimum array size and choose real panels and wiring.

1. Write the equation:  $P_{\text{array}} = E_{\text{elec}} \div (PSH \times PR)$
2. Put in the numbers:  $P_{\text{array}} = 2248.1 \div (7.5 \times 0.80) = 2248.1 \div 6.0 \approx 374.7 \text{ W}$
3. Choose panels: with an example 200 W panel ( $V_{\text{oc}} = 36 \text{ V}$ ,  $I_{\text{sc}} = 7.5 \text{ A}$ ,  $V_{\text{mp}} = 29 \text{ V}$ ,  $I_{\text{mp}} = 6.9 \text{ A}$ ),  $374.7 \div 200 \approx 1.87 \rightarrow$  round up to 2 panels = 400 W
4. Wire the 2 panels in SERIES, not parallel, to raise the voltage for the DC pump's input window: array  $V_{\text{oc}} = 2 \times 36 = 72 \text{ V}$ ,  $I_{\text{sc}} = 7.5 \text{ A}$ ,  $V_{\text{mp}} = 2 \times 29 = 58 \text{ V}$ ,  $I_{\text{mp}} = 6.9 \text{ A}$ ,  $P = 58 \times 6.9 \approx 400.2 \text{ W}$

**Answer: At least 374.7 W needed; two 200 W panels (400 W total) wired in series, feeding a DC solar pump controller (Chapter 14, Lesson 1) directly into the submersible pump — no separate battery and no inverter**

Even for this small array, the pump controller still needs a current check, the same idea as Chapter 12's charge controller check, just applied to a pump controller instead.

#### WORKED EXAMPLE — CHECKING THE PUMP CONTROLLER'S CURRENT RATING

Using the array's  $I_{\text{sc}} = 7.5 \text{ A}$ , apply the short-circuit current rule.

1.  $I_{\text{controller}} \geq I_{\text{sc}} \times 1.25 = 7.5 \times 1.25 = 9.375 \text{ A}$
2. Round up to a real product size

**Answer: Choose a solar pump controller rated for at least 10 A, matched to the pump motor's voltage window (around 72 V here)**

#### WORKED EXAMPLE — STEP 5: SIZING THE STORAGE TANK

The farmer wants 2 days of water storage, enough to smooth out one or two cloudy or low-production

days without stopping irrigation. Find the minimum tank capacity.

1. Write the equation:  $V_{\text{tank}} = V_{\text{daily}} \times N_{\text{store}}$
2. Put in the numbers:  $V_{\text{tank}} = 12 \times 2 = 24 \text{ m}^3$  (24,000 liters)

**Answer:  $V_{\text{tank}} = 24 \text{ m}^3$  — ideally elevated on a stand or high ground, so the field is supplied afterward by gravity, with no second pump needed (Chapter 14, Lesson 4)**

#### Final component list — water pump and irrigation project

| Component       | Specification                                                                             |
|-----------------|-------------------------------------------------------------------------------------------|
| Solar array     | 2 × 200 W panels, wired in series — 400 W total, Voc 72 V                                 |
| Pump controller | 10 A DC solar pump controller, matched to the pump's voltage window                       |
| Pump            | DC submersible pump, rated for at least 27.5 m total dynamic head at the design flow rate |
| Storage tank    | 24 m <sup>3</sup> (24,000 liters), elevated where possible for gravity-fed delivery       |
| Battery         | None — the storage tank replaces it (Chapter 14, Lesson 4)                                |

#### COMMON MISTAKE

**X Wrong:** Assume a solar pumping system needs a battery bank, the same as a home or shop system, to run overnight or on cloudy days.

**✓ Right:** Most solar pumping systems store WATER, not electricity. A correctly sized tank is usually cheaper, simpler, and longer-lasting than a battery bank doing the same reserve job (Chapter 14, Lesson 4). A small separate battery is sometimes still added for something else entirely, like a security light at the wellhead — but not for the pump itself.

#### SAFETY

Never let the pump run dry — always fit and test dry-run protection (Chapter 14, Lesson 1) before leaving the system unattended. Before filling any new tank, especially an elevated one, have a qualified person confirm its stand or tower can safely bear the full weight of water — 1 m<sup>3</sup> of water has a mass of 1000 kg, so this 24 m<sup>3</sup> tank will weigh about 24 tonnes when full (Chapter 14, Lesson 4).

#### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 4

1. Choose your own example (or a real local) daily water need and total dynamic head, different from this lesson's numbers.
2. Write a short report with these sections: (1) Site data and total dynamic head, (2) Hydraulic and electrical energy calculations, (3) Array sizing, with panels and wiring choice, (4) Pump controller sizing, (5) Storage tank sizing, (6) One safety note.
3. Explain in one or two sentences why this project has no battery bank and no inverter, using your own words.
4. Check your full calculation chain against the Solar Water Pump calculator in the app.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 4 report (20 points)

| Criteria                                                                                               | Points |
|--------------------------------------------------------------------------------------------------------|--------|
| Total dynamic head is correctly found from static and friction head                                    | 3      |
| Hydraulic energy calculation is correct, with units shown at every step                                | 4      |
| Electrical energy calculation correctly divides by pump efficiency                                     | 3      |
| Array sizing uses the pumping-season peak sun hours correctly, with a sensible panel and wiring choice | 4      |
| Storage tank sizing is correct, and the 'no battery, no inverter' design choice is clearly explained   | 4      |
| A relevant safety note is included                                                                     | 2      |

► *App tool: Check the full pump-to-array calculation with the Solar Water Pump calculator*

► *App tool: Explore why series wiring raises array voltage in the String Configuration calculator*

► *App simulation: See the difference between series and parallel wiring in the Series & Parallel simulation*

## 22.5 Project 5 — A Shop or Small Business

**Project 5: a shop or small business.** For a shop owner, solar power is rarely about the environment first — it is about a smaller, more predictable monthly cost than an unpredictable generator subscription (Chapter 21, Lesson 5). This project designs a small hybrid system: an offset-based array for daytime savings, plus a modest battery to stay open through a short evening outage.

### The shop's daily loads (example data)

| Load                                | Power (W)          | Hours per day | Energy (Wh) |
|-------------------------------------|--------------------|---------------|-------------|
| 8 LED lamps                         | $8 \times 10 = 80$ | 10            | 800         |
| Drinks refrigerator (effective run) | 150                | 8             | 1200        |
| Ceiling fan                         | 70                 | 8             | 560         |
| Point-of-sale system and router     | 40                 | 10            | 400         |
| Security light (overnight)          | 15                 | 10            | 150         |
| Total                               | —                  | —             | 3110        |

### WORKED EXAMPLE — STEP 1: THE SHOP'S TOTAL DAILY ENERGY NEED

Add up the table above.

1. Add every load's energy:  $800 + 1200 + 560 + 400 + 150 = 3110$  Wh

**Answer:  $E_{\text{daily}} = 3110$  Wh (3.11 kWh) per day**

#### WORKED EXAMPLE — STEP 2-3: SIZING THE ARRAY FOR AN 80% OFFSET

The shop wants its array to offset about 80% of its average annual use. Using Erbil's example annual average peak sun hours (5.3 h/day) and  $PR = 0.80$ , find the minimum array size and choose real panels.

1. Write the equation:  $P_{\text{array}} = (\text{Offset} \times E_{\text{daily}}) \div (\text{PSH}_{\text{avg}} \times PR)$
2. Put in the numbers:  $P_{\text{array}} = (0.80 \times 3110) \div (5.3 \times 0.80) = 2488 \div 4.24 \approx 586.8 \text{ W}$
3. Choose panels: with an example 200 W panel,  $586.8 \div 200 \approx 2.93 \rightarrow$  round up to 3 panels = 600 W
4. Check the real offset:  $E_{\text{array}} = 600 \times 5.3 \times 0.80 = 2544 \text{ Wh/day}$ ; offset =  $(2544 \div 3110) \times 100 \approx 81.8\%$

**Answer: At least 586.8 W needed; three 200 W panels (600 W total) chosen, giving about 81.8% offset**

#### WORKED EXAMPLE — STEP 4: SIZING THE BACKUP BATTERY

The shop closes soon after sunset and wants its lights, fridge, and point-of-sale system — 270 W together — to keep running through a typical 4-hour evening outage. Using a 12 V system (this array is under 1 kW) and LiFePO<sub>4</sub> batteries (DoD = 0.8), find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (P_{\text{critical}} \times t_{\text{backup}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (270 \times 4) \div (12 \times 0.8) = 1080 \div 9.6 = 112.5 \text{ Ah}$
3. Choose a real battery: one 12 V, 150 Ah LiFePO<sub>4</sub> battery — already above the 112.5 Ah required, with no series or parallel wiring needed at all

**Answer: At least 112.5 Ah at 12 V; one 12 V, 150 Ah LiFePO<sub>4</sub> battery chosen**

#### WORKED EXAMPLE — STEP 5-6: CONTROLLER AND INVERTER FOR THE SHOP

Wire the 3 panels in parallel and size the remaining components. For the inverter, use the shop's full connected load (all loads that could run together during opening hours), not only the backup circuit.

1. Array (3 panels in parallel):  $V_{\text{oc}} = 36 \text{ V}$ ,  $I_{\text{sc}} = 3 \times 7.5 = 22.5 \text{ A}$ ,  $V_{\text{mp}} = 29 \text{ V}$ ,  $I_{\text{mp}} = 3 \times 6.9 = 20.7 \text{ A}$ ,  $P = 29 \times 20.7 = 600.3 \text{ W}$  (matches  $3 \times 200 \text{ W}$  ✓)
2. Controller check 1:  $22.5 \times 1.25 = 28.1 \text{ A} \rightarrow$  round up to 30 A
3. Controller check 2:  $600.3 \div 12 \approx 50.03 \text{ A} \rightarrow$  just above the 50 A standard size, so round up to 60 A — this governs
4. Inverter continuous: lamps 80 + fridge 150 + fan 70 + POS 40 + security light 15 = 355 W;  $\times 1.25 = 443.75 \text{ W} \rightarrow$  round up to a 500 W continuous inverter
5. Inverter surge, fridge starting (4×): other loads on (205 W) + fridge surge ( $150 \times 4 = 600 \text{ W}$ ) = 805 W

**Answer: Choose a 60 A MPPT controller and a 500 W continuous / 1000 W surge hybrid inverter, 12 V DC input**

#### Final component list — shop project

| Component         | Specification                                                  |
|-------------------|----------------------------------------------------------------|
| Solar array       | 3 × 200 W panels, parallel — 600 W total                       |
| Charge controller | 60 A MPPT                                                      |
| Battery           | 1 × 12 V, 150 Ah LiFePO <sub>4</sub>                           |
| Inverter          | 500 W continuous / 1000 W surge, pure sine wave, 12 V DC input |

| Component                                        | Specification                                                      |
|--------------------------------------------------|--------------------------------------------------------------------|
| Example cost (Chapter 21 price ranges, BOS +20%) | ≈ \$1,300 (about 1,700,000 IQD at an example rate of 1,310 IQD/\$) |

This is a good moment to compare Project 5 with Project 1's hybrid house (Lesson 1). Both use the same offset method and the same backup-hours battery method — but the shop's array, battery, and inverter are all noticeably smaller, because its total daily energy need (3110 Wh) is a little lower and its critical backup load (270 W) is smaller too. The METHOD stays identical from project to project; only the numbers change. This is the real payoff of learning one design chain well.

#### CASE STUDY — WHY THE PAYBACK MATTERS MORE THAN THE TECHNOLOGY, FOR A SHOP OWNER • A CITY MARKET AREA (ILLUSTRATIVE COMPOSITE EXAMPLE)

A shop owner comparing quotations was not especially interested in panel brands or battery chemistry — she wanted to know one thing: how many months until this pays for itself, compared with what she is already paying? Using this project's example cost (≈ 1,300 USD) and an example saving of about 400,000 IQD a year from reduced generator subscription costs (illustrative numbers), a simple payback calculation (Chapter 15) gave her the answer in a form she could compare directly with her monthly rent and other business costs — a far more useful number to her than any technical specification alone.

#### COMMON MISTAKE

**✗ Wrong:** Size a shop's backup battery for the WHOLE shop's connected load, the same way the inverter is sized.

**✓ Right:** A backup battery only needs to cover the CRITICAL loads the owner truly wants to keep running during an outage (Chapter 10) — here, lights, the fridge, and the till, not the full connected load. Sizing the battery for everything wastes money on capacity that is rarely needed.

#### SAFETY

A shop's battery and inverter are often installed in a back room or under a counter, among stock and packaging. Keep them in a ventilated space, away from flammable stock, with a clear 1-meter working space in front of any disconnect switch or breaker panel (Chapter 9). Label the DC disconnect clearly, in a language your staff reads, so anyone can isolate the system quickly in an emergency.

#### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 5

1. Visit or imagine a real local shop, and list its actual loads and opening hours, or use this lesson's example data.
2. Write a short report with these sections: (1) Load table, (2) Offset target and array sizing, (3) Backup battery sizing for critical loads only, (4) Controller and inverter sizing, (5) Final component list and example cost, (6) One safety note.
3. Add one paragraph estimating the shop's simple payback period, using an example annual saving of your choice (state your assumption clearly).
4. Check your array and battery sizing against the Design wizard.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 5 report (20 points)

| Criteria                                                                                      | Points |
|-----------------------------------------------------------------------------------------------|--------|
| Load table is clear and the daily energy total is correct                                     | 3      |
| Offset target is stated and the array calculation is correct                                  | 4      |
| Backup battery correctly covers only the stated critical loads                                | 4      |
| Controller and inverter sizing is correct, with both required checks shown for the controller | 4      |
| Payback estimate is included, with assumptions clearly stated                                 | 3      |
| Final component list and a relevant safety note are included                                  | 2      |

► *App tool: Check the backup battery sizing with the calculator*

► *App tool: Estimate the shop's simple payback period with the calculator*

► *App simulation: Explore how different savings assumptions change the payback time*

## 22.6 Project 6 — A Health Center (Reliability-First Design)

**Project 6: a rural health center.** Every project so far has balanced cost against performance. This project changes the priority order completely: for a clinic, losing power can mean losing vaccines, medicine, light during a procedure, or a working diagnostic device. Chapter 21, Lesson 5 called this 'reliability first' — the design goal is not the fastest payback, but the smallest realistic chance of ever losing power completely.

### The health center's daily loads (example data)

| Load                                              | Power (W) | Hours per day | Energy (Wh) | Priority tier (Chapter 13)     |
|---------------------------------------------------|-----------|---------------|-------------|--------------------------------|
| Vaccine and medicine refrigerator (effective run) | 100       | 10            | 1000        | Tier 1 — must never lose power |
| Exam room and corridor lighting                   | 100       | 8             | 800         | Tier 1                         |
| Autoclave (sterilizer)                            | 900       | 0.5           | 450         | Tier 2                         |
| Medical equipment and diagnostic devices          | 60        | 6             | 360         | Tier 1                         |
| Fans                                              | 120       | 8             | 960         | Tier 2                         |
| Water pump (clinic water supply)                  | 200       | 0.5           | 100         | Tier 2                         |
| Total                                             | —         | —             | 3670        | —                              |

### WORKED EXAMPLE — STEP 1: TOTAL DAILY ENERGY NEED, PLUS A DESIGN MARGIN

Add up the table, then add a 15% design margin (Chapter 12, Lesson 1) to allow for new equipment the clinic may add later.

1. Add every load's energy:  $1000 + 800 + 450 + 360 + 960 + 100 = 3670 \text{ Wh}$

2. Add the design margin:  $3670 \times 1.15 \approx 4220.5 \text{ Wh}$

**Answer:  $E_{\text{daily}}$  (base) = 3670 Wh;  $E_{\text{daily}}$  (design, with margin) = 4220.5 Wh — this is the number used for every step from here on**

Reliability-first design uses Chapter 12's off-grid method — design-month sun hours and full autonomy — even where a grid connection exists, because a clinic cannot simply 'wait for the grid to come back.' Chapter 12, Lesson 3's guide places critical sites like health centers and telecom relays at 3–5 days of autonomy; this design uses 4 days.

#### WORKED EXAMPLE — STEP 2-3: SIZING THE ARRAY

Using Erbil's example winter (design-month) peak sun hours (3.0 h/day) and  $PR = 0.80$ , find the minimum array size and choose real panels.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (PSH \times PR)$

2. Put in the numbers:  $P_{\text{array}} = 4220.5 \div (3.0 \times 0.80) = 4220.5 \div 2.4 \approx 1758.5 \text{ W}$

3. Choose panels: with 400 W panels,  $1758.5 \div 400 \approx 4.40 \rightarrow$  round up to 5 panels = 2000 W

**Answer: At least 1758.5 W needed; five 400 W panels (2000 W total) chosen**

#### WORKED EXAMPLE — STEP 4: SIZING THE BATTERY BANK FOR 4 DAYS OF AUTONOMY

Using a 24 V system and LiFePO<sub>4</sub> batteries (DoD = 0.8, chosen for reliability and long cycle life — Chapter 6), find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$

2. Put in the numbers:  $C_{\text{bank}} = (4220.5 \times 4) \div (24 \times 0.8) = 16,882 \div 19.2 \approx 879.3 \text{ Ah}$

3. Choose real batteries: with 200 Ah batteries,  $879.3 \div 200 \approx 4.40 \rightarrow$  round up to 5 strings; 2 in series  $\times$  5 strings = 10 batteries (2S5P), giving 24 V, 1000 Ah

**Answer: At least 879.3 Ah at 24 V; ten 12 V, 200 Ah LiFePO<sub>4</sub> batteries (2S5P) chosen, giving real autonomy of  $(24 \times 1000 \times 0.8) \div 4220.5 \approx 4.55$  days**

#### WORD TO KNOW

**Redundancy** — Building extra, independent backup capacity into a design — such as two smaller devices instead of one big one — so that if one part fails, the system does not lose everything at once.

#### WORKED EXAMPLE — STEP 5: CONTROLLER SIZING, WITH A REDUNDANCY OPTION

Wire the 5 panels in parallel and apply both controller checks, then compare a single-controller design with a redundant two-controller design.

1. Array:  $V_{oc} = 49 \text{ V}$ ,  $I_{sc} = 5 \times 10.5 = 52.5 \text{ A}$ ,  $V_{mp} = 40 \text{ V}$ ,  $I_{mp} = 5 \times 10 = 50 \text{ A}$ ,  $P = 2000 \text{ W}$

2. Controller check 1:  $52.5 \times 1.25 = 65.6 \text{ A} \rightarrow$  round up to 80 A

3. Controller check 2:  $2000 \div 24 = 83.3 \text{ A} \rightarrow$  round up to 100 A — this governs

4. Single-controller option: one 100 A MPPT controller for the whole array

5. Redundant option: split the array into two sub-arrays of about 1000 W (2–3 panels) each, with two



separate 50–60 A controllers — if one controller fails, the other half of the array keeps charging the battery

**Answer: Either a single 100 A MPPT controller, or two smaller MPPT controllers on separate sub-arrays for redundancy — the clinic's committee should weigh the extra cost of two controllers against the value of never losing ALL charging capacity to one failed part**

#### WORKED EXAMPLE — STEP 6: SIZING THE INVERTER

The design assumes, conservatively, that the fridge, lighting, medical equipment, fans, AND the autoclave could all be needed at once during a busy clinic day.

1. Continuous, all loads together:  $100 + 100 + 60 + 120 + 900 = 1280 \text{ W}$
2. Add a 25% margin:  $1280 \times 1.25 = 1600 \text{ W} \rightarrow$  round up to a 2000 W continuous inverter
3. Surge, autoclave starting (surge factor about 1.5 $\times$ , mostly a resistive heating element): other loads on (380 W) + autoclave surge ( $900 \times 1.5 = 1350 \text{ W}$ ) = 1730 W

**Answer: Choose a 2000 W continuous / 4000 W surge, pure sine wave inverter, 24 V DC input — generously sized on purpose, reflecting this project's reliability-first priority**

#### Final component list — health center project

| Component         | Specification                                                                                  |
|-------------------|------------------------------------------------------------------------------------------------|
| Solar array       | 5 $\times$ 400 W panels, parallel — 2000 W total (or split into two sub-arrays for redundancy) |
| Charge controller | 100 A MPPT (or two smaller controllers, redundant design)                                      |
| Battery bank      | 10 $\times$ 12 V, 200 Ah LiFePO <sub>4</sub> , 2S5P — 24 V, 1000 Ah, 4 days design autonomy    |
| Inverter          | 2000 W continuous / 4000 W surge, pure sine wave, 24 V DC input                                |
| Backup generator  | Existing diesel generator kept as a last-resort backup, not replaced (Chapter 13, Chapter 21)  |

#### CASE STUDY — A CLINIC'S SECOND LINE OF DEFENSE • A RURAL CLINIC (ILLUSTRATIVE COMPOSITE EXAMPLE)

A rural clinic installed a hybrid system like this project's, sized for 4 days of autonomy, and deliberately kept its old diesel generator connected as a backup, rather than removing it. In its first year, the system covered every single grid outage on its own. Then, during an unusually long stretch of dust-storm-darkened days (Chapter 21), the battery dropped low enough to trigger the generator's autostart (Chapter 13, Lesson 4) for the first time — and the clinic never lost power at all, because the two backup layers worked exactly as designed, one after another. The lesson: reliability-first design is not about eliminating risk completely; it is about making sure no single failure, however unlikely, can take the whole system down.

#### COMMON MISTAKE

**✗ Wrong:** Design a health center's solar system the same way as a shop or home — sized mainly to save money, with autonomy chosen to fit the budget.

**✓ Right:** For a critical site, choose autonomy and design margin FIRST, based on what a power failure would cost in health and safety terms — then find the budget to match. Chapter 12, Lesson 3 places health

centers and telecom relays at 3–5+ days of autonomy for exactly this reason. A cheaper system that fails during a medical emergency is not a saving.

### SAFETY

Tier 1 loads (the vaccine refrigerator, essential lighting, and medical equipment) must be wired on their own dedicated critical loads panel (Chapter 10), completely separate from any non-essential circuit, so a fault or overload elsewhere in the building can never take down the loads that matter most. Label this panel clearly, train clinic staff on its purpose, and test the full backup path — battery, inverter, and generator autostart — on a regular schedule, not only when something has already gone wrong.

### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 6

1. Write a short report with these sections: (1) Load table with priority tiers, (2) Design margin and array sizing, (3) Battery sizing with your chosen autonomy and its justification, (4) Controller sizing — compare the single-controller and redundant options and recommend one, (5) Inverter sizing, (6) Final component list, (7) A Tier 1 critical loads panel safety note.
2. Write one paragraph explaining, in plain language a clinic manager could understand, why this design costs more than a shop or home system of a similar daily energy total.
3. Check your array and battery sizing against the Design wizard.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 6 report (20 points)

| Criteria                                                                                     | Points |
|----------------------------------------------------------------------------------------------|--------|
| Load table correctly identifies priority tiers, and the design-margin calculation is correct | 3      |
| Array sizing uses design-month peak sun hours correctly                                      | 3      |
| Battery sizing is correct, with autonomy choice clearly justified for a critical site        | 4      |
| Controller redundancy option is discussed and a clear recommendation is made                 | 3      |
| Inverter sizing is correct, with both required checks shown                                  | 3      |
| Explanation of extra cost is clear and reasonable for a non-technical reader                 | 2      |
| Critical loads panel safety note is included                                                 | 2      |

► *App tool: Check the 4-day autonomy battery bank with the calculator*

► *App tool: Compare the single and redundant controller options with the calculator*

► *App simulation: See how depth of discharge and autonomy affect a critical-site battery bank*

## 22.7 Project 7 — Solar Streetlights

**Project 7: a solar streetlight.** This is the smallest system in the whole chapter — but do not mistake 'small' for 'simple.' A streetlight is unattended, often beside a road, and expected to work every single night without

anyone checking it. This project also brings a genuinely new idea for this book: a load that automatically switches itself on and off, and a system with no inverter at all.

#### WORD TO KNOW

**Dusk-to-dawn control** — A control method that automatically switches a light on when it gets dark and off again when it gets light, usually using a small light sensor. Common on solar streetlights, so nobody needs to switch them by hand every evening and morning.

#### Streetlight data (example numbers)

| Quantity                                                | Value                                                                                 |
|---------------------------------------------------------|---------------------------------------------------------------------------------------|
| LED fixture power                                       | 30 W                                                                                  |
| Operating hours per night (dusk-to-dawn control)        | 11 h                                                                                  |
| Design-month peak sun hours, PSH (Erbil winter example) | 3.0 h/day                                                                             |
| Performance ratio, PR                                   | 0.80                                                                                  |
| Days of autonomy, $N_{\text{auto}}$                     | 3 days (an unlit road is a safety hazard, so this is treated as a near-critical load) |
| System voltage, $V_{\text{sys}}$                        | 12 V                                                                                  |
| Battery depth of discharge, DoD (LiFePO <sub>4</sub> )  | 0.8                                                                                   |

#### WORKED EXAMPLE — STEP 1: NIGHTLY ENERGY NEED

Find the energy the fixture uses each night.

1. Write the equation:  $E_{\text{daily}} = P \times t$
2. Put in the numbers:  $E_{\text{daily}} = 30 \text{ W} \times 11 \text{ h} = 330 \text{ Wh}$

**Answer:  $E_{\text{daily}} = 330 \text{ Wh}$  per night — about twelve times smaller than the family house in Project 1, and this is the biggest single load in the whole chapter's comparison to the smallest**

#### WORKED EXAMPLE — STEP 2-3: SIZING THE ARRAY

Using the design-month peak sun hours (3.0 h/day, the same rule Chapter 12 uses for any load that runs every single day of the year, not just a season) and  $PR = 0.80$ , find the minimum array size.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (PSH \times PR)$
2. Put in the numbers:  $P_{\text{array}} = 330 \div (3.0 \times 0.80) = 330 \div 2.4 \approx 137.5 \text{ W}$
3. Choose a real panel: a single example 150 W panel ( $V_{\text{oc}} = 22.5 \text{ V}$ ,  $I_{\text{sc}} = 8.8 \text{ A}$ ,  $V_{\text{mp}} = 18.5 \text{ V}$ ,  $I_{\text{mp}} = 8.1 \text{ A}$ ) already exceeds 137.5 W

**Answer: At least 137.5 W needed; one 150 W panel chosen — a streetlight's small, steady load rarely needs more than a single panel**

#### WORKED EXAMPLE — STEP 4: SIZING THE BATTERY

Using 3 days of autonomy, a 12 V system, and  $DoD = 0.8$ , find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times DoD)$

2. Put in the numbers:  $C_{\text{bank}} = (330 \times 3) \div (12 \times 0.8) = 990 \div 9.6 \approx 103.1 \text{ Ah}$

3. Choose a real battery: a 100 Ah battery falls just short ( $100 < 103.1$ ), so round up to a 150 Ah LiFePO4 battery

**Answer: At least 103.1 Ah at 12 V; one 12 V, 150 Ah LiFePO4 battery chosen, giving real autonomy of  $(12 \times 150 \times 0.8) \div 330 \approx 4.36$  days — extra margin, because whole batteries must be bought, not fractions of one**

#### WORKED EXAMPLE — STEP 5: SIZING THE CONTROLLER — AND THE MISSING STEP 6

This is a small, single-panel, cost-sensitive product, so a PWM controller is a common, practical choice (Chapter 7) — unlike the larger MPPT controllers used in every other project in this chapter. Apply both checks anyway, to confirm.

1. Check 1:  $I_{\text{controller}} \geq I_{\text{sc}} \times 1.25 = 8.8 \times 1.25 = 11.0 \text{ A} \rightarrow$  round up to 20 A

2. Check 2:  $I_{\text{battery}} \approx P_{\text{array}} \div V_{\text{sys}} = 150 \div 12 = 12.5 \text{ A} \rightarrow$  round up to 20 A — both checks agree here

3. Step 6 (inverter): NOT NEEDED. The LED fixture is a DC load, wired directly to the controller's load output. This is the same DC-load idea Chapter 14 used for a DC water pump — no inverter, no AC conversion losses, and one less component to fail in the dark, unattended pole

**Answer: Choose a 20 A PWM (or small MPPT) controller with a built-in load output and dusk-to-dawn control — and no inverter at all**

#### Final component list — solar streetlight project

| Component          | Specification                                                                                               |
|--------------------|-------------------------------------------------------------------------------------------------------------|
| Solar array        | 1 × 150 W panel                                                                                             |
| Controller         | 20 A PWM/small MPPT, with load output and dusk-to-dawn (light sensor) control                               |
| Battery            | 1 × 12 V, 150 Ah LiFePO4                                                                                    |
| Fixture            | 30 W DC LED streetlight head — no inverter needed                                                           |
| Pole and enclosure | Weatherproof battery box (often pole-mounted), rated for outdoor dust and rain (Chapter 9's IP rating idea) |

Notice the pattern across this chapter so far: Project 4's pump needed no battery (a tank replaced it); this streetlight needs no inverter (a DC fixture replaced the need for AC). A good designer does not add components out of habit — every part of the design chain earns its place, or it is left out.

#### WORD TO KNOW

**Lock-out/tag-out** — A safety procedure: disconnect and lock a power source before working on equipment, and attach a tag showing who is working and why, so nobody reconnects it by accident while work is still underway.

#### COMMON MISTAKE

**✗ Wrong:** Assume a small, cheap streetlight system does not need the same careful sizing as a bigger project, because 'it's only a light.'

✓ **Right:** An unlit street is a real safety hazard for pedestrians, drivers, and cyclists — every night, for years, with nobody nearby to notice a fault quickly. Apply the SAME design chain, with real autonomy margin, exactly as this lesson did. Small does not mean unimportant.

### SAFETY

Streetlight batteries and controllers sit inside a pole, often near a busy road — always park a service vehicle safely off the road, use hazard signs, and never open a pole's access panel without first following lock-out/tag-out: switch off and physically isolate the battery and array connections, and label the pole as 'being serviced,' before touching any wiring. If the fixture itself must be reached, follow safe working-at-height procedures and never work on a live circuit while on a ladder.

### ACTIVITY (FIELD) — WRITE YOUR ENGINEERING REPORT — PROJECT 7

1. If possible, find a real streetlight (solar or grid-powered) and note its approximate fixture power and nightly operating hours; otherwise use this lesson's example data.
2. Write a short report with these sections: (1) Nightly load, (2) Array sizing, (3) Battery sizing, (4) Controller choice and why no inverter is needed, (5) Final component list, (6) A lock-out/tag-out safety note for pole servicing.
3. In one sentence, explain why this project used 3 days of autonomy instead of the shorter backup-hours method used for the shop in Project 5.
4. Check your array and battery sizing against the calculators in the app.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 7 report (20 points)

| Criteria                                                                                              | Points |
|-------------------------------------------------------------------------------------------------------|--------|
| Nightly energy calculation is correct                                                                 | 3      |
| Array sizing uses design-month peak sun hours correctly                                               | 4      |
| Battery sizing is correct, with autonomy choice justified for a safety-related load                   | 4      |
| Controller sizing is correct (both checks shown), and the 'no inverter' decision is clearly explained | 4      |
| Lock-out/tag-out safety note is specific and practical                                                | 3      |
| Final component list is complete and clearly presented                                                | 2      |

► *App tool: Check the streetlight's small battery bank with the calculator*

► *App tool: Practice converting between Wh and Ah at different voltages*

► *App simulation: See how a small PWM controller manages charging in the Charge Controller simulation*

## 22.8 Project 8 — A Remote Village (Mini-Grid Thinking)

**Project 8: a remote village.** Chapter 21, Lesson 5 raised a question this lesson now answers properly: when a whole village has no grid connection at all, should every home get its own small off-grid system, or should the

village share ONE larger system through its own local network? This project sizes BOTH approaches for the same village and compares them honestly — there is no single correct answer, only trade-offs.

#### WORD TO KNOW

**Mini-grid** — A small, local electricity network that generates and shares power among a group of nearby homes or buildings — like a tiny version of the national grid, but standing alone, not connected to it.

#### The village: 20 households plus one community building (example data)

| Load                                           | Power (W)         | Hours per day | Energy (Wh) |
|------------------------------------------------|-------------------|---------------|-------------|
| 6 LED lamps (per household)                    | $6 \times 8 = 48$ | 5             | 240         |
| TV or radio (per household)                    | 60                | 4             | 240         |
| Phone chargers (per household)                 | 20                | 3             | 60          |
| Fan (per household)                            | 60                | 6             | 360         |
| Household total (each of 20 homes)             | 188               | —             | 900         |
| Community building (lighting, PA system, fans) | —                 | —             | 1500        |

#### WORKED EXAMPLE — STEP 1: TOTAL VILLAGE DAILY ENERGY

Find one household's daily energy, then the whole village's daily energy (20 households plus the community building).

1. One household:  $240 + 240 + 60 + 360 = 900$  Wh
2. 20 households:  $900 \times 20 = 18,000$  Wh
3. Add the community building:  $18,000 + 1500 = 19,500$  Wh

**Answer: Total village  $E_{\text{daily}} = 19,500$  Wh (19.5 kWh) per day**

**Approach A — individual solar home systems (SHS).** Each household gets its own small off-grid system, sized exactly the way Project 1 sized the off-grid family house — just smaller.

#### WORKED EXAMPLE — APPROACH A: SIZING ONE HOUSEHOLD'S SYSTEM

Using design-month PSH = 3.0 h/day, PR = 0.80, 2 days of autonomy, a 12 V system, and lead-acid batteries (DoD = 0.5), size one household's array and battery.

1. Array:  $P_{\text{array}} = 900 \div (3.0 \times 0.80) = 900 \div 2.4 = 375$  W → two 200 W panels = 400 W
2. Battery:  $C_{\text{bank}} = (900 \times 2) \div (12 \times 0.5) = 1800 \div 6 = 300$  Ah → two 12 V, 150 Ah batteries in parallel = 300 Ah exactly
3. Repeat this SAME calculation, unchanged, for all 20 households — and once more, scaled up, for the community building ( $P_{\text{array}} \approx 625$  W → two 400 W panels;  $C_{\text{bank}} \approx 500$  Ah → three 200 Ah batteries in parallel)

**Answer: Each household: 400 W array, 300 Ah at 12 V. Community building: 800 W array, 600 Ah at 12 V. Example total cost for all 21 systems (Chapter 21 prices, BOS +20%):  $\approx \$15,640$  (about 20,490,000 IQD)**

**Approach B — a shared mini-grid.** Instead of 21 separate systems, the village builds ONE central array and battery bank, with a local low-voltage network of poles and cable carrying power to every home and the community building — plus a meter at each connection, so every household's use can be tracked fairly (Chapter 15's tariff idea, applied at village scale).

#### WORKED EXAMPLE — APPROACH B: SIZING THE SHARED ARRAY AND BATTERY

Using the SAME design-month PSH (3.0 h/day) and PR (0.80), size ONE array and battery bank for the village's full 19,500 Wh/day, with 2 days of autonomy. Because the array is now well over 3 kW, use a 48 V system; because this is still a cost-sensitive rural project, use lead-acid batteries (DoD = 0.5).

1. Array:  $P_{\text{array}} = 19,500 \div (3.0 \times 0.80) = 19,500 \div 2.4 = 8125 \text{ W} \rightarrow$  with 400 W panels,  $8125 \div 400 \approx 20.3 \rightarrow$  round up to 21 panels = 8400 W (8.4 kWp)
2. Battery:  $C_{\text{bank}} = (19,500 \times 2) \div (48 \times 0.5) = 39,000 \div 24 = 1625 \text{ Ah} \rightarrow$  with 200 Ah batteries: 4 in series (48 V)  $\times$  9 strings ( $1625 \div 200 \approx 8.13 \rightarrow$  round up to 9) = 36 batteries (4S9P), giving 48 V, 1800 Ah

**Answer: 8.4 kWp array (21  $\times$  400 W panels, built as several sub-arrays); 48 V, 1800 Ah battery bank (36 batteries) — notice the TOTAL daily energy required is exactly the same 19,500 Wh either way; grouping the village together does not change how much energy is needed, only how it is generated and shared**

The array and battery scale directly with total energy — no surprise there. But the INVERTER is a different story. Not every home runs its fan, TV, and lights at the exact same second; Chapter 10's demand factor idea (peak load  $\div$  connected load) applies here at village scale, not just inside one building.

#### WORKED EXAMPLE — SIZING THE SHARED INVERTER USING A VILLAGE DEMAND FACTOR

Find the village's full connected load (everything switched on at once), then apply an example demand factor of 0.6 (typical for a village where evening usage times cluster together) to estimate a more realistic peak.

1. Connected load: 20 households  $\times$  188 W + community building peak ( $\approx$ 300 W) = 3760 + 300 = 4060 W
2. Apply the demand factor: peak load = 4060  $\times$  0.6 = 2436 W
3. Add a 25% margin: 2436  $\times$  1.25 = 3045 W

**Answer: Minimum inverter continuous rating  $\approx$  3045 W. For a shared community asset, installers often choose several smaller inverters working together instead of one unit at the exact minimum — for example, three 3 kW hybrid inverters, giving both enough headroom for future growth AND redundancy (Project 6's idea, applied here: if one inverter fails, the village does not lose everything at once)**

#### Approach A vs. Approach B — full comparison (example numbers)

| Feature       | Approach A: 21 individual SHS                                 | Approach B: shared mini-grid                                                                                 |
|---------------|---------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------|
| Total array   | 21 small arrays, same total capacity as a single 8+ kWp array | One 8.4 kWp array, in several sub-arrays                                                                     |
| Total battery | 21 small banks                                                | One 1800 Ah, 48 V bank                                                                                       |
| Distribution  | None needed — each home is self-contained                     | Local low-voltage network: poles, cable, and a meter per connection                                          |
| Redundancy    | If one home's system fails, only that home loses power        | If the shared array or battery fails badly, MANY homes could lose power at once — unless the design includes |

| Feature            | Approach A: 21 individual SHS                                  | Approach B: shared mini-grid                                                                           |
|--------------------|----------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|
|                    |                                                                | redundancy (several controllers and inverters)                                                         |
| Maintenance        | 21 separate systems for families to maintain themselves        | One system, professionally maintained — but needs a clear payment/tariff plan to fund that maintenance |
| Future growth      | Adding a new appliance means upgrading ONE home's small system | Extra headroom can be built in once, benefiting the whole village as it grows                          |
| Example total cost | ≈ \$15,640 (≈ 20,490,000 IQD)                                  | ≈ \$17,960 (≈ 23,530,000 IQD), including an example 3,000 USD for the distribution network             |

In this example, the two approaches cost about the same — Approach A is not automatically cheaper just because it needs no shared infrastructure, and Approach B is not automatically cheaper just because of economies of scale on the battery and controllers. The honest answer is: it depends on what the village values most — full independence per household (Approach A), or shared reliability, easier professional maintenance, and room to grow together (Approach B). A real village committee should weigh this table, not just the two bottom-line prices.

#### CASE STUDY — TWO NEARBY VILLAGES, TWO DIFFERENT CHOICES • REMOTE AREAS OF IRAQ OR THE KURDISTAN REGION (ILLUSTRATIVE COMPOSITE EXAMPLE)

One remote village chose individual solar home systems: fast to install household by household as money became available, with no need for village-wide agreement on cost-sharing or a metering system. A second village, slightly larger and with strong local leadership, chose a shared mini-grid: it took longer to plan and needed an agreed tariff so every household paid its fair share of maintenance, but it let the community add streetlights (Project 7) and a small health post's refrigerator (Project 6) to the SAME system later, without every household needing its own separate upgrade. Both villages ended up with reliable power — they simply valued different trade-offs along the way.

#### COMMON MISTAKE

**✗ Wrong:** Assume that grouping 20 households onto one shared mini-grid automatically reduces the TOTAL daily energy they need, because 'sharing saves energy.'

**✓ Right:** Total daily ENERGY (kWh) stays the same either way — 20 homes still use 20 homes' worth of lamps, fans, and chargers. What a shared mini-grid can reduce is the PEAK POWER (kW) needed for the inverter, through the demand factor, because not everyone runs everything at the exact same instant. Never confuse a demand-factor saving on power with a saving on total energy.

#### SAFETY

A shared mini-grid's local distribution network is a small version of the national grid, and it deserves the same respect: correctly rated cable and poles for the local wind and weather, breakers at the powerhouse AND at each household connection, clear earthing throughout (Chapter 9), and a single, well-known changeover point if the village ever gains a real grid connection later — never let two power sources feed the same wires without a proper changeover switch (Chapter 11).



### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 8

1. Choose your own example village size (number of households) and per-household load, different from this lesson's numbers.
2. Write a short report with these sections: (1) Village load table and total daily energy, (2) Approach A sizing for one household, scaled to the whole village, (3) Approach B sizing, including the demand-factor inverter calculation, (4) A comparison table like this lesson's, (5) Your own recommendation, with reasons, (6) One safety note for the distribution network.
3. In your recommendation, name at least two things that matter besides price.
4. Check your Approach B array and battery sizing against the Design wizard.

*You need: Calculator or phone, Notebook or word processor*

### Marking rubric — Project 8 report (20 points)

| Criteria                                                                                         | Points |
|--------------------------------------------------------------------------------------------------|--------|
| Village load table and total daily energy are correct                                            | 3      |
| Approach A sizing is correct and properly scaled to the whole village                            | 3      |
| Approach B array and battery sizing is correct                                                   | 3      |
| Demand-factor inverter calculation is correct and clearly explained                              | 4      |
| Comparison table fairly presents both approaches, not just cost                                  | 4      |
| Recommendation is reasoned, not just a guess, and a distribution-network safety note is included | 3      |

- *App tool: Check both approaches' array sizes with the PV Array Sizing calculator*
- *App tool: Compare the two approaches' example costs against estimated savings*
- *App simulation: Explore off-grid energy flow at village scale in the System Types simulation*

## 22.9 Project 9 — A Telecommunications Site

**Project 9: a telecommunications relay site.** The last project in this chapter shares one thing with the health center (Project 6): it is critical, and it must survive long stretches with no help nearby. It differs in an important way: its main load runs at a constant, unchanging power, 24 hours a day, every day of the year — there is no 'evening peak' or 'growing season' to plan around, just a steady, continuous draw.

### The telecom site's daily loads (example data)

| Load                                                                | Power (W) | Hours per day | Energy (Wh) |
|---------------------------------------------------------------------|-----------|---------------|-------------|
| Radio/transmission equipment (runs on 48 V DC plant power directly) | 150       | 24            | 3600        |
| Equipment shelter cooling fan                                       | 40        | 12            | 480         |
| Shelter lighting                                                    | 20        | 1             | 20          |

| Load                               | Power (W) | Hours per day | Energy (Wh) |
|------------------------------------|-----------|---------------|-------------|
| (maintenance visits)               |           |               |             |
| Site security lighting (overnight) | 15        | 10            | 150         |
| Total                              | —         | —             | 4250        |

#### WORKED EXAMPLE — STEP 1: TOTAL DAILY ENERGY, PLUS A DESIGN MARGIN

Add up the table, then add a 10% design margin, because telecom sites often add equipment over the years and a technician may not visit again for months.

1. Add every load's energy:  $3600 + 480 + 20 + 150 = 4250 \text{ Wh}$
2. Add the design margin:  $4250 \times 1.10 = 4675 \text{ Wh}$

**Answer: E<sub>daily</sub> (base) = 4250 Wh; E<sub>daily</sub> (design, with margin) = 4675 Wh**

Telecom equipment shelters commonly standardize on 48 V DC — a telecom industry convention, not one of Chapter 12's general size-based voltage guesses. Matching the EXISTING equipment's fixed voltage matters more here than the usual 'array size decides system voltage' guideline, so this design uses 48 V even though a smaller general-purpose system near this array size might otherwise use 24 V. Chapter 12, Lesson 3 itself calls its voltage table 'a general guide, not a fixed rule' — a fixed equipment voltage like this is exactly the kind of real-world reason to move away from it.

#### WORKED EXAMPLE — STEP 2-3: SIZING THE ARRAY

Using the design-month peak sun hours (3.0 h/day — this load never takes a season off) and PR = 0.80, find the minimum array size.

1. Write the equation:  $P_{\text{array}} = E_{\text{daily}} \div (\text{PSH} \times \text{PR})$
2. Put in the numbers:  $P_{\text{array}} = 4675 \div (3.0 \times 0.80) = 4675 \div 2.4 \approx 1947.9 \text{ W}$
3. Choose panels: with 400 W panels,  $1947.9 \div 400 \approx 4.87 \rightarrow$  round up to 5 panels = 2000 W

**Answer: At least 1947.9 W needed; five 400 W panels (2000 W total) chosen**

#### WORKED EXAMPLE — STEP 4: SIZING THE BATTERY FOR EXTREME REMOTENESS

This site may go weeks between technician visits, so the design uses 5 days of autonomy — the top of Chapter 12, Lesson 3's range for critical sites. Using the 48 V system and LiFePO<sub>4</sub> batteries (DoD = 0.8, chosen for their long cycle life with no nearby technician to replace a worn-out bank), find the required battery capacity.

1. Write the equation:  $C_{\text{bank}} = (E_{\text{daily}} \times N_{\text{auto}}) \div (V_{\text{sys}} \times \text{DoD})$
2. Put in the numbers:  $C_{\text{bank}} = (4675 \times 5) \div (48 \times 0.8) = 23,375 \div 38.4 \approx 608.7 \text{ Ah}$
3. Choose real batteries: with 200 Ah batteries, 4 in series (48 V)  $\times$  4 strings ( $608.7 \div 200 \approx 3.04 \rightarrow$  round up to 4) = 16 batteries (4S4P), giving 48 V, 800 Ah

**Answer: At least 608.7 Ah at 48 V; sixteen 12 V, 200 Ah LiFePO<sub>4</sub> batteries (4S4P) chosen, giving real autonomy of  $(48 \times 800 \times 0.8) \div 4675 \approx 6.57$  days**

#### WORKED EXAMPLE — STEP 5: CONTROLLER SIZING — A CONTRAST WITH PROJECT 6

Wire the 5 panels in parallel and apply both controller checks. Compare the result with Project 6's health center, which used the same 5-panel, 2000 W array but a 24 V system.

1. Array:  $V_{oc} = 49 \text{ V}$ ,  $I_{sc} = 5 \times 10.5 = 52.5 \text{ A}$ ,  $V_{mp} = 40 \text{ V}$ ,  $I_{mp} = 5 \times 10 = 50 \text{ A}$ ,  $P = 2000 \text{ W}$
2. Check 1:  $52.5 \times 1.25 = 65.6 \text{ A} \rightarrow$  round up to 80 A
3. Check 2:  $2000 \div 48 = 41.7 \text{ A} \rightarrow$  round up to 50 A
4. Compare: here, Check 1 (80 A) governs — the OPPOSITE of Project 6, where Check 2 governed at 24 V. The higher 48 V system voltage in this project keeps the battery-side current low, so the array-side short-circuit current rule becomes the deciding check instead

**Answer: Choose an 80 A MPPT controller — and note how the SAME array, at a different system voltage, changes which check governs. Always calculate both, every time (Chapter 12, Lesson 4)**

#### WORKED EXAMPLE — STEP 6: A SMALL INVERTER FOR AC LOADS ONLY

The main radio/transmission equipment runs directly on 48 V DC — no inverter needed for it at all, the same DC-load idea as Project 7's streetlight. Only the shelter light and an occasional maintenance socket (a laptop charger or a power tool) need AC power:  $20 \text{ W} + 100 \text{ W}$  (maintenance provision) = 120 W.

1. Continuous:  $120 \text{ W} \times 1.25 = 150 \text{ W}$
2. No large motor is present, so no significant surge check is needed

**Answer: Choose a small 300 W continuous off-grid inverter, pure sine wave, 48 V DC input — used only occasionally, for maintenance visits and shelter lighting**

#### Final component list — telecommunications site project

| Component         | Specification                                                                                    |
|-------------------|--------------------------------------------------------------------------------------------------|
| Solar array       | 5 × 400 W panels, parallel — 2000 W total                                                        |
| Charge controller | 80 A MPPT                                                                                        |
| Battery bank      | 16 × 12 V, 200 Ah LiFePO <sub>4</sub> , 4S4P — 48 V, 800 Ah, 5 days design autonomy              |
| Main telecom load | Powered directly from the 48 V DC battery bus — no inverter involved                             |
| Small inverter    | 300 W continuous, pure sine wave, 48 V DC input, for shelter lighting and maintenance tools only |

#### SAFETY

Telecom –48 V DC power is unusual: by industry convention, the POSITIVE terminal is normally connected to earth, not the negative terminal most solar equipment assumes by default. Before connecting any new solar charge controller or battery to an existing telecom plant, always confirm the site's grounding convention with the equipment's documentation or a qualified telecom technician — connecting new solar equipment with the 'usual' negative-grounded assumption to a positive-grounded telecom plant can cause a short circuit or damage sensitive equipment instantly.

A technician servicing a remote telecom site is very often working ALONE, far from help, sometimes after climbing a tower or driving hours on a rough road. This is exactly the situation lock-out/tag-out (Project 7) was designed for: before touching any wiring, isolate and lock every relevant disconnect switch, and tag it with your name and the time — so that even if someone else arrives at the unattended site while you are still working, they cannot reconnect power by mistake.

#### COMMON MISTAKE

**✗ Wrong:** Treat a telecom site's solar system as 'just another off-grid system,' using general-purpose assumptions for voltage, grounding, and battery type.

**✓ Right:** Telecom sites often have their own fixed conventions — a 48 V DC standard, a positive-grounded plant, and a genuine need for very long, unattended reliability. Confirm the SITE'S existing standards first, and design the solar addition to match them, rather than assuming the site will adapt to a textbook default.

#### ACTIVITY (CLASSROOM) — WRITE YOUR ENGINEERING REPORT — PROJECT 9

1. Write a short report with these sections: (1) Load table and design margin, (2) Array sizing, (3) Battery sizing, with your reasoning for the chosen autonomy, (4) Controller sizing, with both checks shown and a comparison to Project 6's result, (5) Inverter sizing for AC-only loads, (6) Final component list, (7) A DC-grounding safety note and a lock-out/tag-out note for solo remote work.
2. In one paragraph, explain why this project's main load needed no inverter, referring back to Project 7's streetlight for comparison.
3. Check your array and battery sizing against the Design wizard.

*You need: Calculator or phone, Notebook or word processor*

#### Marking rubric — Project 9 report (20 points)

| Criteria                                                                                             | Points |
|------------------------------------------------------------------------------------------------------|--------|
| Load table and design-margin calculation are correct                                                 | 3      |
| Array sizing uses design-month peak sun hours correctly                                              | 3      |
| Battery sizing is correct, with autonomy choice justified for extreme remoteness                     | 4      |
| Controller sizing is correct, with both checks shown and compared to Project 6                       | 4      |
| Small inverter sizing is correct, and the 'no inverter for the main load' point is clearly explained | 3      |
| DC-grounding and lock-out/tag-out safety notes are specific and correct                              | 3      |

► *App tool: Compare the controller check results at 24 V and 48 V with the calculator*

► *App tool: Size the cable run from the array to the shelter, checking both current rating and voltage drop*

► *App simulation: Review the complete design chain, start to finish, for this site in the System Sizing simulation*

#### CHAPTER SUMMARY

- Every project in this chapter uses the SAME design chain from Chapter 12 — energy demand → sun data

→ array → battery → controller → inverter — adapted, not replaced, for each project's own needs.

- System TYPE follows the site's access to backup power, not the building type: the same family house needed a 2000 W off-grid array with no grid at all (Project 1A), but only an 800 W hybrid array once a grid connection existed to share the load (Project 1B).
- Grid-tied and hybrid arrays (schools, shops, Project 1B) use ANNUAL AVERAGE peak sun hours and an offset target, because the grid covers any shortfall; off-grid and reliability-critical arrays (Project 1A, health center, streetlight, telecom) use the DESIGN-MONTH peak sun hours, because nothing else will cover a shortfall.
- Battery sizing has two different jobs: days-of-autonomy for systems with no other backup (Projects 1A, 3, 6, 7, 9), and backup-hours for systems bridging a typical daily outage while the grid or generator stands ready (Projects 1B, 2's lab backup, 5).
- Reliability-critical sites (health center, telecom) deliberately use more autonomy, extra design margin, and sometimes redundancy — two smaller controllers or inverters instead of one — because a power failure there costs far more than the extra equipment.
- Not every project needs every component: a water pump (Project 4) stores WATER in a tank instead of electricity in a battery; a streetlight (Project 7) and a telecom site's main load (Project 9) run on DC and need no inverter at all.
- A load that changes with the seasons (the greenhouse, Project 3) must be checked in EVERY season it exists, not just its peak season — the season with the smaller load can still need the bigger array, if its sun hours are weaker by an even larger factor.
- At village scale (Project 8), total daily ENERGY is the same whether 20 homes are wired separately or shared on one mini-grid — only the PEAK POWER for a shared inverter can shrink, through a demand factor, because not every home uses everything at the same instant.
- Safety priorities shift with the project: dedicated critical-loads panels and redundancy for a health center; roadside lock-out/tag-out for streetlights; confirming DC grounding conventions before connecting new equipment to an existing telecom plant.
- A complete design is not finished until it is written up clearly — an engineering report with a load table, every calculation step, a final component list, and a safety note lets someone else check, trust, and build from your work.

## Practice Problems

*Try each problem on paper first. Full step-by-step solutions are in the companion Teacher's Guide.*

**Problem 1 [Basic]** A streetlight uses 25 W and runs for 12 hours each night, controlled by a dusk-to-dawn sensor. How much energy does it use in one night, in Wh?

**Problem 2 [Basic]** A telecom relay's radio equipment draws a steady 120 W and runs 24 hours a day, every day. Find its daily energy use, in Wh and kWh.

**Problem 3 [Basic]** A shop's drinks refrigerator is rated 140 W. Its compressor effectively runs about 9 hours a day. Find its daily energy use, in Wh.

**Problem 4 [Basic]** A solar pump's datasheet gives its flow rate as 50 liters per minute (L/min). Convert this to cubic meters per second ( $\text{m}^3/\text{s}$ ), the unit needed for the hydraulic power equation.

**Problem 5 [Basic]** A family's washing machine uses 500 W and runs for 45 minutes each day. Find its daily energy use, in Wh. (Careful: convert minutes to hours first.)

**Problem 6 [Standard]** A solar streetlight needs 275 Wh of energy each night. The design uses 2 days of autonomy, a 12 V system, and LiFePO<sub>4</sub> batteries with a maximum depth of discharge of 0.8. Find the required battery bank capacity, in Ah.

**Problem 7 [Standard]** A rural clinic wants a small emergency lighting circuit, totaling 250 W, to keep working for 3 hours during any power interruption. Using a 24 V system and lithium batteries with DoD = 0.8, find the required battery capacity, in Ah.

**Problem 8 [Standard]** A small telecom array has a short-circuit current ( $I_{sc}$ ) of 21 A. Using the 1.25 safety factor, find the minimum charge controller current rating, then round up to the nearest standard size (10, 20, 30, 40, 50, 60, 80, 100 A).

**Problem 9 [Standard]** A greenhouse's exhaust fan uses 250 W and runs for 5 hours on a summer afternoon. (a) Find its energy use for that day, in Wh. (b) Using summer peak sun hours of 7.2 h/day and a performance ratio of 0.80, find the minimum array power needed to cover this fan alone.

**Problem 10 [Standard]** A pump delivers a flow rate of 40 L/min against a total dynamic head of 18 m. Find the hydraulic power, in W. (Convert the flow rate to m<sup>3</sup>/s first, and use  $\rho = 1000 \text{ kg/m}^3$ ,  $g = 9.81 \text{ m/s}^2$ .)

**Problem 11 [Standard]** A shop wants its array to offset 70% of its average daily use of 2800 Wh. Using an annual average peak sun hours of 5.3 h/day and a performance ratio of 0.80, find the minimum array power, in W.

**Problem 12 [Challenge]** A remote cluster of 15 similar homes each need 850 Wh per day. A shared community pump house needs another 1200 Wh per day. (a) Find the total daily energy for the whole group. (b) Using a design-month peak sun hours of 3.2 h/day and a performance ratio of 0.78, find the minimum shared array size, in kWp.

**Problem 13 [Challenge]** A school uses an average of 18,000 Wh per day. It wants a 75% consumption offset, using an annual average peak sun hours of 5.1 h/day and a performance ratio of 0.80. (a) Find the minimum array power, in W. (b) Using 350 W panels, find how many panels are needed, rounded up, and the actual array power.

**Problem 14 [Challenge]** A telecom site's daily electrical need, including its design margin, is 3800 Wh. The design uses 4 days of autonomy, a 48 V system, and LiFePO<sub>4</sub> batteries with DoD = 0.8. (a) Find the required battery bank capacity, in Ah. (b) Using 12 V, 150 Ah batteries wired 4 in series (for 48 V), find how many parallel strings are needed, and the actual battery bank capacity.

# Glossary

*Every important term used in this book, in one place.*

**Absorption stage** — The second charging stage. The charger holds the voltage steady at a set maximum, while the current slowly falls as the battery finishes filling.

**AC pump** — A pump whose motor runs on alternating current (AC) — the same kind of motor used in ordinary mains-powered pumps. In a solar system, something must first change the array's DC power into AC power for the motor.

**Acceptance** — The formal step where the system's owner, or a responsible engineer, agrees — based on the test results — that a finished system meets its design and is ready for regular use.

**AGM battery** — AGM stands for Absorbed Glass Mat. The acid is soaked into a fiberglass mat, so the battery is sealed and needs no water top-up.

**Alternating current** — Electric current that keeps changing direction, back and forth, many times every second. Short name: AC. The electricity grid and generators supply AC.

**Ambient temperature** — The temperature of the air around a piece of equipment, not the temperature inside it. A hot room gives equipment a hot ambient temperature to work in, even if the equipment itself is working normally.

**Ampere** — The unit of electric current. Written A. Generator subscriptions are often sold by the ampere.

**Ampere-hour** — The unit used to measure battery capacity. Written Ah. 1 Ah means the battery can supply 1 ampere of current for 1 hour.

**Anchor point** — A strong, fixed structural point used to attach a safety harness's lanyard. It must be able to hold a falling person's weight safely.

**Anti-islanding** — A safety feature that makes a grid-tie inverter switch off automatically as soon as it senses that the public grid has gone down.

**Appliance** — A machine at home that uses electricity, like a fridge, fan, or washing machine.

**Arc fault** — A dangerous spark that jumps across a gap in a damaged or loose high-current connection. An arc fault can reach very high temperatures in a small space, and is a common cause of fires in electrical systems.

**Array** — Two or more modules — often connected in strings — working together as one power-producing unit.

**As-built drawing** — A final drawing that shows exactly how a system was actually built, including any changes made during installation.

**Axial tilt** — The tilt of Earth's spin axis, about 23.5° from straight up. This tilt is the real cause of the seasons.

**Azimuth** — The compass direction of something, measured in degrees. Due north is 0°, east is 90°, south is 180°, and west is 270°.

**Backup hours** — The number of hours a hybrid system's battery must supply backup power by itself during a typical grid outage, before the grid returns or a generator is needed.

**Balance of system** — All the parts of a solar system except the panels and batteries — for example, the charge controller, inverter, cables, mounting structure, and protection devices. Often shortened to BOS.

**Ballast** — Heavy weight, such as concrete blocks, placed on a mounting rack to hold it down without drilling into the roof.

**Battery** — A device that stores electrical energy using a chemical reaction, and releases it later as electric current.

**Battery bank** — Two or more batteries connected together, in series, parallel, or both, to give the voltage and capacity a system design needs.

**Battery management system (bms)** — An electronic circuit built into a lithium battery that protects it — for example, by stopping charging if the battery is too cold, too hot, too full, or too empty.

**Battery parallel connection** — Connecting all the positive terminals together, and all the negative terminals together. This adds up the capacity (Ah), while the voltage stays the same as one battery.

**Battery series connection** — Connecting the positive terminal of one battery to the negative terminal of the next. This adds up the voltage, while the capacity (Ah) stays the same as one battery.

**Bill of materials** — A complete list of every part needed for a project, with the quantity of each. Often shortened to BOM.

**Bonding** — Connecting all the metal parts of a system together with a conductor, so they are all at the same electrical potential (voltage). Bonding is usually done together with earthing, so nothing metal is ever left 'floating' at a different voltage from everything around it.

**Borehole** — A narrow, deep hole drilled into the ground to reach groundwater, usually lined with a pipe casing. Boreholes are a common water source for farms, orchards, and rural homes across Iraq and the Kurdistan Region.

**Bulk stage** — The first charging stage. The charger sends as much safe current as it can. The battery voltage slowly rises while it fills up.

**Bypass diode** — A small electronic part inside a panel's junction box that lets current skip around a shaded or faulty group of cells, instead of that group blocking the whole panel's current.

**C-rate** — The speed of charging or discharging, compared to a battery's capacity. C20 means fully discharging over 20 hours; C100 means over 100 hours. The same battery shows a bigger Ah number at a slower rate.

**Cable** — An insulated conductor, or a group of conductors together, made to carry electric current safely from one point to another. People often just say 'wire' for the same thing.

**Cable gland** — A fitting that lets a cable pass into an enclosure or conduit while sealing tightly around it, keeping out water and dust, and holding the cable firmly.

**Cable tray** — An open metal channel, like a ladder or tray, that supports and protects many cables running together along the same route.

**Capacity** — How much electric charge a battery can store, measured in ampere-hours (Ah). A 100 Ah battery can, in theory, give 100 A for 1 hour, or 10 A for 10 hours, or 5 A for 20 hours.

**Capital cost** — The one-time money paid to buy and install a system. Also called the upfront cost.

**Carbon dioxide** — A gas released when fuels like diesel, petrol, or coal are burned. It is the main gas causing climate change.

**Carbon footprint** — The total amount of greenhouse gas, mainly CO<sub>2</sub>, produced by a person's, family's, or system's activities.

**Centrifugal pump** — The most common type of pump. A spinning part called an impeller throws water outward with force, creating flow. Most solar surface and submersible pumps use this design. It gives a steady flow, but that flow changes with head.

**Changeover switch** — A switch that connects only one power source to a building's wiring at a time — for example, the grid or a generator, never both together. Also called a transfer switch. An automatic version is called an automatic transfer switch (ATS).

**Charge controller** — The device between the solar array and the battery. It controls how the battery is charged, and protects it from overcharge, over-discharge, and reverse current. Also called a charge regulator.



**Charging stage** — A step in the charging process. Controllers use different stages, one after another, to charge a battery quickly and safely, then keep it topped up without stress.

**Circuit** — A complete, unbroken path that lets electric current flow, from the source, through the load, and back again. If the path breaks, current stops.

**Circuit breaker** — A protection device with a mechanical switch inside that trips (switches off) automatically when too much current flows. Unlike a fuse, a breaker can simply be reset and used again.

**Clamp** — A metal bracket that fixes a panel's edge to a mounting rail. A mid clamp holds two panels where they meet; an end clamp holds the outer edge of a row.

**Clamp meter** — A test tool that measures electric current by clamping around a single wire, without breaking the circuit open. It can safely measure higher currents than most multimeters, and is a common choice for testing a solar array's current.

**Cleaning schedule** — A written plan that says how often solar panels should be cleaned, based on local dust conditions and the season.

**Clearance** — The empty space that must be kept open around a piece of equipment, for safe airflow, access, and repair.

**Clinometer** — A small tool used to measure an angle above the horizontal — for example, a roof's pitch, or the height angle of a nearby obstruction. Many phone apps work as a clinometer.

**Commissioning** — The process of checking, testing, and officially confirming that a newly installed system is safe and working correctly, before it is used normally or handed to its owner.

**Commissioning checklist** — A written, ordered list of every test and check that must be completed, in the right order, before a newly installed system is accepted as working correctly. Chapter 17 covers the pre-power-up part of this list — wiring, torque, and safety. Chapter 18 covers the testing part, once the system is running.

**Conductor** — A material with very low resistance that lets electric current flow easily. Copper and aluminium are common conductors, used to make wires.

**Conduit** — A pipe or tube, made of plastic or metal, that protects a cable running through or along a wall, floor, or roof.

**Connected load** — The sum of the nameplate (rated) power of every appliance in a building, as if every single one were switched on at the same time.

**Consumption offset** — The target share of a home's average yearly energy use that a solar array is designed to produce. An offset of 70% means the array is sized to produce about 70% of the home's average annual consumption, not necessarily 70% every single day.

**Contingency** — Extra money added to a budget or quotation to cover unexpected costs or problems.

**Continuity test** — A quick multimeter test that checks if a wire or connection is complete, with no break. The meter usually beeps if current can pass through.

**Continuous power rating** — The steady AC power an inverter can supply non-stop, for as long as needed, without overheating or shutting down.

**Corrective maintenance** — Repair work done after something has already gone wrong.

**Corrosion** — A crust or damage on a metal part, usually caused by moisture, dust, or chemical fumes reacting with the metal over time. Corrosion adds resistance to a connection, and can eventually break it completely.

**Cost per watt** — The price of a panel divided by its rated power. It helps compare the value of different panels, in money per watt (for example, \$/W).

**Critical load** — An appliance or circuit that must keep working during a power cut — for example, lights for safety, a refrigerator to stop food spoiling, or a medical device.

**Critical loads panel** — A separate electrical panel that carries only the most important circuits, like lights and the refrigerator. During a power cut, the backup system (battery and inverter) only needs to power this smaller panel — not the whole building.

**Cross-sectional area** — The area of the metal conductor's cut face, seen if you sliced straight through the cable. Measured in square millimetres (mm<sup>2</sup>). A bigger number means a thicker, more capable conductor.

**Current** — The flow of electricity through a wire. Measured in amperes (A).

**Current at maximum power** — The panel's current exactly at the maximum power point. Written Imp. Always a little less than Isc.

**Current rating** — The maximum current a cable can carry continuously without getting too hot. Also called ampacity. A bigger cross-sectional area gives a higher current rating.

**Cycle life** — The number of full charge-and-discharge cycles a battery can complete before its capacity drops too low to be useful. A deeper DoD each cycle gives a shorter cycle life.

**Daily solar energy** — The total amount of sunlight energy that falls on one square meter of surface in one day. Measured in kilowatt-hours per square meter per day (kWh/m<sup>2</sup>/day).

**Datasheet** — A document from the manufacturer that lists a product's technical numbers, such as a solar panel's power, voltage, and current ratings.

**Days of autonomy** — The number of days a battery bank must supply a home's full energy need by itself, with little or no help from the sun — for example, during a run of cloudy days.

**Days of water storage** — The number of days a full tank can supply a system's daily water need by itself, with little or no help from the pump — the water version of the 'days of autonomy' idea used for batteries.

**DC pump** — A pump whose motor runs directly on direct current (DC). It usually connects straight to a solar array through a small pump controller, with no separate inverter needed.

**Deep-cycle battery** — A battery built to be discharged deeply and recharged many hundreds or thousands of times, unlike a car battery which is built for short bursts.

**Degradation** — The slow, permanent loss of a solar panel's power over many years, caused by the normal aging of its materials. Unlike soiling, degradation cannot be washed away.

**Demand factor** — The ratio of the peak load to the connected load. It shows what fraction of all appliances are typically running at the same time.  $DF = \text{peak load} \div \text{connected load}$ .

**Depth of discharge** — How much of a battery's capacity has already been used, shown as a percentage. Written DoD.  $\text{DoD} = 100\% - \text{SoC}$ . A deeper discharge puts more stress on the battery.

**Derating** — Reducing a cable's safe current rating below its normal table value, to allow for tough conditions such as high ambient temperature or several cables bundled together.

**Derating factor** — A number less than 1 that reduces an ideal value to a more realistic one, to account for one specific real-world loss, such as heat or dust. A performance ratio is built by multiplying several derating factors together.

**Design chain** — The ordered series of calculations that turns a home's daily energy need into a complete, correctly sized solar system: array, battery bank, charge controller, inverter, and cables — each step built on the step before it.

**Design margin** — Extra size added to a component beyond the bare minimum calculation, to leave room for cloudy years, future loads, or ageing equipment.

**Design month** — The month used to size an off-grid array — usually the month with the fewest peak sun hours (often winter here) — so the system still meets the load even in the hardest month of the year.

**Diffuse radiation** — Sunlight that is scattered by clouds, dust, and air before it reaches the ground. It comes from all parts of the sky, not just from the Sun's direction.

**Direct current** — Electric current that flows in only one direction and does not change. Short name: DC. Batteries and solar panels produce DC electricity.

**Direct radiation** — Sunlight that travels straight from the Sun to the ground without changing direction. It makes sharp, clear shadows.

**Disconnect switch** — A manual switch used to safely turn off part of a solar system on purpose, for testing, maintenance, or in an emergency. Also called an isolator.

**Drawing scale** — The ratio between a distance on a drawing and the real distance it represents — for example, 1:100, where 1 cm on the drawing equals 100 cm in real life.

**Drip loop** — A downward loop left in a cable just before it enters a connector or enclosure, so that any water running down the cable drips off at the bottom of the loop instead of flowing inside.

**Dusk-to-dawn control** — A control method that automatically switches a light on when it gets dark and off again when it gets light, usually using a small light sensor. Common on solar streetlights, so nobody needs to switch them by hand every evening and morning.

**Dust storm** — A strong wind that lifts a large amount of dust and sand into the air. It can block sunlight for hours or days, and leaves a layer of dust on anything outdoors, including solar panels.

**Duty cycle** — The share of time a fast switch spends 'on' during each on/off cycle. A high duty cycle means more current flows on average; a low duty cycle means less.

**Earth electrode** — A metal rod or plate driven or buried in the ground, connected to a system's earthing wire, giving fault current a safe path into the earth. Also called an earth rod.

**Earthing** — Connecting the metal parts of a system — panel frames, racks, enclosures — to the ground with a wire, so that if a fault happens, dangerous voltage flows safely into the earth instead of staying on metal that a person could touch. Also called grounding.

**Efficiency** — The percentage of sunlight energy that a solar cell or module changes into electrical energy.  $\text{Efficiency} = \text{electrical power out} \div \text{sunlight power in} \times 100\%$ .

**Electricity meter** — The device that counts how many kilowatt-hours (kWh) your home uses. Your bill is based on its reading.

**Electrolyte** — The liquid, mat, or gel inside a battery that carries the chemical reaction. In lead-acid batteries, the electrolyte is a mix of sulfuric acid and water.

**Emission factor** — A number that shows how much CO<sub>2</sub> (or another pollutant) is released for each unit of energy — for example, kilograms of CO<sub>2</sub> per kWh.

**Enclosure** — A protective box or cabinet that holds electrical parts — such as breakers, fuses, or connectors — safely away from weather, dust, and accidental touch.

**Energy** — The ability to do work — to move, heat, light, or change things. Measured in joules (J) or kilowatt-hours (kWh).

**Energy efficiency** — Getting the same useful result — light, cooling, washing, ironing — while using less electrical energy. This is different from a solar cell's efficiency (Chapter 4), which is about how much sunlight a panel converts to electricity — energy efficiency here is about the appliances using that electricity.

**Energy storage** — Keeping energy now so it can be used later, at a different time. A battery is the main way solar systems store energy.

**Energy-loss waterfall** — A chart or table that shows power or energy being reduced step by step, from the panel's ideal rating down to what actually reaches the load, so you can see exactly where each loss happens.

**Engineering report** — A clear written document that explains an engineering design: the problem, the data used, every calculation, the equipment chosen, and the reasons behind each choice. Every project in this chapter ends with writing one.

**Equalization** — A controlled overcharge, done on purpose sometimes for flooded lead-acid batteries. It mixes the acid and helps prevent a problem called sulfation. It must never be done to sealed (AGM, gel) or lithium batteries.

**Equinox** — One of the two days in the year when day and night are about equal length everywhere on Earth, and the Sun rises due east and sets due west.

**Fault** — Something wrong in a system that stops it from working correctly, or makes it work worse than it should.

**Fault code** — A short code, number, or message shown on an inverter's or controller's screen or lights, pointing to a specific type of problem. The exact codes are different for each brand, so always check the equipment's own manual.

**Feeder** — A power line that carries electricity from a substation to one group of homes or businesses. Different feeders in the same city can be switched on and off at different times.

**Fill factor** — A number (0 to 1, or a %) that shows how close a solar cell's real maximum power is to the largest possible value ( $V_{oc} \times I_{sc}$ ). A higher fill factor means a better-quality cell.

**Financing** — A way to pay for something over time, in smaller regular payments, instead of paying the whole cost at once.

**Float stage** — The third charging stage. The charger holds a lower, gentle voltage to keep a full battery topped up, without overcharging it.

**Flooded battery** — A lead-acid battery with a free liquid electrolyte. The cheapest and most common type, but it needs regular water top-up and good ventilation.

**Flow rate** — The volume of water a pump moves in a given time. Written  $Q$ . Common units include liters per minute (L/min), liters per second (L/s), and cubic meters per hour ( $m^3/h$ ).

**Frequency** — How many times AC current completes a full back-and-forth cycle every second. Measured in hertz (Hz).

**Friction head loss** — The extra equivalent height 'lost' as water rubs against the inside of pipes, valves, and fittings on its way to its destination. It depends on pipe length, pipe width, and flow rate.

**Fuse** — A simple protection device with a thin metal strip inside. If too much current flows, the strip heats up, melts, and breaks the circuit. A fuse must be replaced after it operates — people say it has 'blown.'

**Galvanic corrosion** — Faster rusting that happens when two different metals touch each other and stay wet, such as an aluminum rail against a plain steel bolt. Using matched metals, or a barrier between them, prevents it.

**Gel battery** — A lead-acid battery where the acid is mixed with silica to form a thick gel. Sealed, and handles heat and deep cycling better than a flooded battery.

**Generator** — A machine that burns fuel, such as diesel or petrol, to produce electricity. Often used as backup power during grid outages. Chapter 1 introduced the generator subscription — the payment for using a shared one.

**Generator autostart** — A hybrid system feature that starts the generator automatically once the battery's state of charge drops to a chosen threshold, and stops it again once the battery is recharged or the grid returns — without anyone needing to start it by hand.

**Generator subscription** — A monthly payment to a neighborhood generator for a fixed number of amperes during power cuts.

**Governorate** — An administrative area of Iraq, similar to a province or state. Iraq is divided into 18 governorates.

**Gravity-fed system** — A water system where an elevated tank supplies water to fields or taps using only gravity, with no extra pump needed for delivery.

**Greenhouse gas** — A gas in the air that traps heat from the sun, like a blanket around the Earth. Carbon dioxide (CO<sub>2</sub>) is the most common greenhouse gas produced by human activities.

**Grid** — The public network of power lines and power stations that supplies electricity to homes, shops, and factories. Also called the public grid or the national grid. Chapter 21 looks at Iraq's grid in detail.

**Grid export** — Electrical energy flowing FROM a home or building's solar system OUT TO the public grid, usually because the array is producing more than the home needs at that moment.

**Grid import** — Electrical energy flowing FROM the public grid INTO a home or building. Measured in kWh, usually shown on a bill as normal electricity use.

**Grid-tie inverter** — An inverter designed to connect to the public grid. It synchronizes with the grid's voltage and frequency and feeds solar power directly to the home or the grid.

**Grid-tied system** — A solar system connected to the national grid, usually without a battery. It sends extra solar power to the grid, or draws grid power when the sun is not enough. Also called an on-grid system. Chapter 11 explains this fully.

**Ground fault** — A fault where electricity finds an unwanted path to earth, often through damaged insulation or a wiring mistake. Most inverters detect this automatically and shut down to protect people and equipment. Also called an earth fault (see 'earthing,' Chapter 9).

**Handover documents** — The complete set of papers and records given to a system's owner when installation and testing are finished, including test results, datasheets, warranty papers, and basic operating instructions. Also called a handover pack.

**Hertz** — The unit of frequency. One hertz (1 Hz) means one complete cycle every second. Iraq's grid frequency is 50 Hz.

**Horizon profile** — A record of the height, in degrees, of every obstruction around a site, matched to its compass direction, as seen from the array's own position.

**Hot spot** — A dangerously hot area on a solar cell, caused when a shaded or damaged cell is forced to absorb power as heat instead of producing it. Bypass diodes exist mainly to prevent hot spots.

**Hybrid inverter** — An inverter that can work with solar panels, a battery, AND the grid or a generator, all in the same system. It can send power between sources automatically.

**Hybrid system** — A system that combines two or more power sources — usually solar, a battery, and the grid and/or a generator — and can switch between them, often automatically.

**Hydraulic power** — The real, useful power delivered to the water itself — the power needed, in theory, to lift a certain flow of water through a certain head. Written P<sub>hyd</sub>. This is the pump's OUTPUT in terms of water, not the electrical power it draws from the array.

**Hydrogen gas** — An invisible, explosive gas released by lead-acid batteries while they charge. It has no smell, and can explode if it collects in a closed space and meets a spark or flame.

**Hydrometer** — A simple tool that measures the density (specific gravity) of a battery's liquid electrolyte, used to estimate the state of charge of a flooded lead-acid battery.

**I-v curve** — A graph of a solar panel's current (I) against its voltage (V), from short circuit ( $I_{sc}$ ) to open circuit ( $V_{oc}$ ). It shows how the panel behaves at every possible operating point.

**Installation plan** — A written plan that lists the tasks, the order of work, the people, the tools, and the time needed to install a solar system safely.

**Insulator** — A material with very high resistance that blocks electric current. Plastic, rubber, and glass are common insulators, used to cover wires and protect people.

**Inter-row shading** — One row of panels casting a shadow onto the row behind it, usually when the sun is low in the sky. Rows need enough space between them to avoid this.

**Inverter** — A device that changes DC electricity into AC electricity, so that solar panels and batteries can power normal AC appliances.

**Inverter efficiency** — The percentage of DC input energy that comes out as usable AC output energy. The rest is lost as heat inside the inverter.

**Inverter-charger** — A device that both changes DC to AC for the loads AND changes AC from the grid or a generator back into DC to recharge the battery, automatically.

**Ip rating** — A code, such as IP65, that shows how well an enclosure protects against dust and water. A higher number means better protection.

**Irradiance** — The power of sunlight falling on one square meter of surface at a single moment. Measured in watts per square meter ( $W/m^2$ ).

**Irradiance meter** — A tool that measures the power of sunlight falling on a surface, in watts per square meter ( $W/m^2$ ). Some models also add up (integrate) readings over time to give the total irradiation, in  $kWh/m^2$ , for a chosen period. Also called a solar meter, or, in scientific use, a pyranometer.

**Irrigation** — Supplying water to crops or land on purpose, instead of relying only on rain. Common methods include flooding a field, spraying water through sprinklers, or dripping water slowly at each plant's roots.

**Irrigation scheduling** — Planning WHEN and HOW MUCH to irrigate, based on the crop's water needs, the weather, and — for solar pumping — the hours of strong sunlight and the water already sitting in storage.

**Joule** — The basic scientific unit of energy. One joule is a very small amount — lifting a small apple by one meter takes about one joule.

**Kilowatt** — 1000 watts. Written kW. Used for bigger appliances like water heaters and air conditioners.

**Kilowatt-hour** — The energy of 1000 watts working for one hour. Written kWh. This is the unit on your electricity bill.

**Latitude** — A location's distance from the equator, measured in degrees, from  $0^\circ$  at the equator to  $90^\circ$  at the poles.

**Levelized cost of energy** — The average cost of one kWh of energy from a system over its whole working life. Found by dividing the total cost by the total energy produced. Often shortened to LCOE.

**Lifepo4 battery** — A lithium battery using lithium iron phosphate chemistry. Written  $LiFePO_4$ . It costs more today, but lasts far more cycles than lead-acid and can be discharged much deeper.

**Lifetime savings** — The total money saved by a system over its whole working life, after subtracting what the system cost.

**Live** — Carrying electric current, or connected to a voltage source, so that touching it could give a dangerous shock. The opposite is de-energized (dead) — safely disconnected, but only after this has been tested and confirmed, never just assumed.

**Load** — Anything that uses electrical energy — a lamp, a fridge, a television. Also the total power all these things use together.

**Load audit** — A complete, organized list of every electrical device in a building, with its power, how it is used, and how often. A load audit is the first step of every solar system design.

**Load profile** — A table or chart that shows how much power a building uses at each hour (or period) of the day. It shows when energy is used, not only how much.

**Load shedding** — The planned switching off of electricity to different areas, at different times, because there is not enough power to supply everyone at once. Also called power rationing.

**Load test** — A test where a measurement is taken while the circuit is doing real work, with current flowing, instead of at rest. A load test can reveal problems, like a weak battery or a bad connection, that do not show up in a simple resting measurement.

**Load-bearing capacity** — How much extra weight a roof or structure can safely carry, including the solar panels, the mounting rack, wind, and people working on it.

**Lock-out/tag-out** — A safety procedure: disconnect and lock a power source before working on equipment, and attach a tag showing who is working and why, so nobody reconnects it by accident while work is still underway.

**Lockout-tagout** — A safety procedure where a switch or disconnect is physically locked in the OFF position, and labeled with a tag, so nobody can switch it back on while a person is working on that circuit.

**Low-voltage disconnect** — A safety feature on many controllers. It disconnects small DC loads (like lights) from the battery if the battery voltage drops too low, to stop over-discharge. Short form: LVD.

**Magnetic declination** — The small difference between the direction a compass needle points (magnetic north) and true north. It must be corrected for when using a simple compass to find true south for solar panels.

**Maintenance** — Work done regularly on a system to keep it safe, efficient, and working well, and to catch small problems before they become big ones.

**Maintenance budget** — A yearly estimate of the money needed for the regular and expected maintenance of a system, planned in advance.

**Maintenance log** — A written or digital record of every maintenance visit, inspection, and repair on a system, including the date, what was found, and what was done.

**Maintenance schedule** — A written plan listing every maintenance task for a system, how often each one should be done, and who is responsible for it.

**Margin** — The extra amount a supplier adds on top of their own costs, to cover profit and business expenses, when preparing a quotation price.

**Marginal cost** — The cost of one more unit of something — here, the price of the NEXT kWh a household would use, not the average price of all the kWh it has already used. Under a tiered tariff, the marginal cost is the price of the highest tier a household reaches that month.

**Maximum power point** — The one point on a solar panel's I-V curve where it produces the most electrical power ( $V \times I$  is largest). Written MPP.

**Mc4 connector** — A weatherproof, locking plug-and-socket connector used to join solar panel cables safely. The name comes from 'Multi-Contact,' the original maker, and its 4 mm pin size. Once clicked together, it should only be unplugged with a proper tool, not pulled apart by hand.

**Mini-grid** — A small, local electricity network that generates and shares power among a group of nearby homes or buildings — like a tiny version of the national grid, but standing alone, not connected to it.

**Modified sine wave** — A middle-quality inverter waveform. It moves in rough, flat-topped steps that only roughly copy the smooth shape of a true sine wave.

**Module** — A group of solar cells connected together, usually in series, and sealed in glass and a frame as one unit. Also called a solar panel.

**Monocrystalline** — A solar cell made from one single, pure silicon crystal. It usually has the highest efficiency and a uniform dark blue or black color.

**Mounting rail** — A straight metal bar fixed to a rack or roof, that solar panels are clamped onto in a row.

**MPPT** — Maximum power point tracking. A smart charging method that constantly finds the array's best operating point, and converts extra voltage into extra current, so more of the panel's power reaches the battery.

**Multimeter** — A tool that measures electrical quantities — usually voltage, current, and resistance — in one device. It is the most important test tool for solar work.

**Nameplate rating** — The power (or other values) printed by the manufacturer on an appliance's label. It is measured under standard test conditions — the value in daily use can be a little different. (Chapter 5 covers a solar panel's own version of this idea, its rated power in watt-peak.)

**National grid** — The network of power lines, substations, and power stations that carries electricity across a whole country, from power stations to homes, shops, and factories.

**Neighborhood generator** — A shared diesel generator that supplies electricity to many homes or shops in one area, usually running during the hours when the national grid is off. Often paid for with a generator subscription — Chapter 1 explains this fully.

**Net billing** — A billing arrangement where energy exported to the grid is credited at a DIFFERENT (often lower) rate than the price charged for energy imported. This is different from true net metering, where both directions use the same rate.

**Net metering** — A billing arrangement where solar energy sent to the grid reduces the electricity bill, sometimes by running the meter backward. Rules are different in every country and area — Chapter 13 looks at what is realistic here.

**Nominal operating cell temperature** — The cell temperature a panel reaches under a more realistic outdoor test: 800 W/m<sup>2</sup> sunlight, 20°C air temperature, and 1 m/s wind, with the panel at open circuit. Written NOCT. It helps estimate real operating temperature.

**Nominal voltage** — The standard "name" voltage of a battery or cell, such as 2 V, 6 V, 12 V, or 24 V. The real voltage moves a little above and below this as the battery charges and discharges.

**Non-critical load** — An appliance that can wait until grid or generator power returns, without real harm — for example, a washing machine, a water heater, or an iron.

**Obstruction** — Anything on or near a site that blocks sunlight or takes up space where panels could go — for example, a water tank, a chimney, a satellite dish, or a vent pipe.

**Obstruction angle** — The angle, measured upward from the horizontal, from the array to the top of a nearby obstruction.

**Off-grid inverter** — An inverter that is not connected to the public grid at all. It takes DC power from a battery bank and supplies AC power to the loads.

**Off-grid system** — A solar system that is not connected to the public grid at all. It produces and stores all the energy it needs by itself, usually with a battery bank.



**Ohm** — The unit of electrical resistance. Written with the Greek letter  $\Omega$  (omega). A high number of ohms means the material blocks current strongly.

**On-grid system** — A solar system connected to the public grid, usually without a battery. It uses solar power first and draws any extra power it needs from the grid. Also called a grid-tied system.

**Open-circuit voltage** — The voltage of a solar panel measured when no current is flowing (the circuit is open). Written Voc. It is the panel's maximum possible voltage.

**Operating cost** — The ongoing money needed to run a system after it is installed — for example, fuel, repairs, and maintenance.

**Operating current** — The real current measured at a point in a solar system while it is running normally, connected to its load. Different from  $I_{sc}$ , which is measured with the two terminals connected directly together.

**Operating voltage** — The real voltage measured at a point in a solar system while it is running normally, connected to its load. Different from Voc, which is measured with no current flowing at all.

**Orientation** — The compass direction that a solar panel faces.

**Overcharge** — Charging a battery past its safe voltage. It can boil away the water in a flooded battery, damage its plates, and in a lithium battery it can cause serious, even dangerous, damage.

**Overcurrent** — Any current higher than a circuit or cable is designed to carry safely. It covers two situations: an overload and a short circuit.

**Overload** — Too much current flowing for too long, usually because too many loads are switched on together, or a motor is struggling. Gentler than a short circuit, but still dangerous over time because it slowly overheats a cable.

**P-v curve** — A graph of a solar panel's power (P) against its voltage (V). It rises to one peak at the maximum power point, then falls.

**Parallel circuit** — A circuit where components are connected across the same two points, each on its own branch. Every branch gets the full supply voltage.

**Parallel connection** — Connecting panels side by side, positive to positive and negative to negative. In parallel, current adds up and voltage stays the same.

**Parapet** — A low wall built around the edge of a flat roof. It can be a useful place to fix an anchor point, but it is not always strong enough to bear heavy loads.

**Parasitic load** — A small device or circuit that keeps drawing power all the time, even when it looks 'off' or is not doing useful work — for example, a charger left plugged in, or an inverter's own standby draw. Also called a phantom load.

**Payback period** — The time needed for the money saved by a system to equal the money it cost to buy and install.

**Peak load** — The highest power drawn at any single moment of the day. It is usually much less than adding up every appliance's rated power, because not everything runs at the same time.

**Peak sun hour** — The number of hours in a day when sunlight would need to shine at the standard strength of  $1000 \text{ W/m}^2$  to give the same total daily energy as the real sunlight. Written PSH.

**Performance ratio** — A single number that shows how much of a solar array's ideal output you actually get, once real losses like heat, dust, wiring, and equipment inefficiency are included. A performance ratio of 0.80 means the system delivers about 80% of its ideal output. Written PR.

**Personal protective equipment (ppe)** — Equipment worn by a worker to reduce the risk of injury, such as gloves, safety glasses, a helmet, and non-slip boots.

**Photon** — A tiny packet of light energy from the sun. Photons hit a solar cell and knock electrons loose, starting the flow of electricity.

**Photovoltaic effect** — The way certain materials make electricity directly when light shines on them. 'Photo' means light; 'voltaic' means electricity.

**Plane-of-array irradiation** — The total sunlight energy that falls on a solar array's own tilted surface over a period of time, usually one day. It uses the same idea as daily solar energy (Chapter 3), measured directly in the array's own mounting plane. Written H\_POA. Numerically equal to that period's peak sun hours, in hours.

**Polarity** — Which terminal or wire is positive (+) and which is negative (–) in a DC circuit. Getting this wrong is called reverse polarity, and it can damage equipment instantly.

**Polycrystalline** — A solar cell made from many small silicon crystals melted together. It usually costs less than monocrystalline but has slightly lower efficiency.

**Power** — How fast energy is used or produced. Measured in watts (W).

**Preventive maintenance** — Planned maintenance done on a regular schedule, before anything breaks, to stop problems from happening in the first place. Example: cleaning panels every few weeks in the dusty season.

**Project Runaki** — A Kurdistan Regional Government (KRG) program, announced in May 2025, to give homes across the Kurdistan Region 24-hour national grid power under one new tiered tariff, instead of limited grid hours plus a separate paid generator subscription. Runaki (ڕووناکی) is the Kurdish word for light or brightness.

**Pump** — A machine that moves a fluid — in this course, always water — from one place to another. A pump adds energy to water, usually to lift it higher or push it further through a pipe.

**Pump controller** — The device between a solar array and a pump. It matches the array's changing DC power to what the pump motor needs at that moment, and it protects the pump. For an AC pump, it also changes DC into AC, similar to an inverter, but built specially for a pump motor.

**Pump curve** — A graph or table from a pump's manufacturer showing how much flow (Q) the pump delivers at each possible head (H). For most pumps, flow drops as head rises.

**Pump efficiency** — The share of a pump's electrical (or shaft) input power that becomes useful hydraulic power in the water; the rest is lost as heat and friction inside the pump and motor. This is different from a solar panel's efficiency (Chapter 4) or general energy efficiency (Chapter 10).

**Pumping season** — The months of the year when a pump actually needs to run — for example, the dry growing season for crop irrigation. A pump array is often sized using the peak sun hours of the pumping season itself, not the worst month of the whole year.

**Punch list** — A written list of small items still to finish or fix — found during testing — before a system receives final, unconditional acceptance.

**Pure sine wave** — The highest-quality inverter waveform. It is a smooth curve that closely matches the AC power from the public grid.

**PV cable** — A special cable made for solar panel and array wiring. It has extra-strong insulation that resists sunlight (UV), rain, and heat for years outdoors — ordinary indoor cable cannot survive on a roof.

**PWM** — Pulse width modulation. A way of switching a connection on and off very fast to control the average current. PWM controllers use this trick to control battery charging.

**Qualified person** — Someone with the right training, certification, and hands-on experience to safely carry out a specific electrical or solar task. In this course, we often just call this person 'a professional' or 'a qualified technician.'

**Quotation** — A written offer from a supplier or installer that lists the equipment, the work, and the price for a job.

**Rack** — The metal frame that holds solar panels in place at the chosen tilt angle and orientation.

**Rated power** — The panel's power output at standard test conditions, in watts (W) or watt-peak (Wp). Written P<sub>max</sub>. This is the number used in a panel's name, like a '450 W panel'.

**Redundancy** — Building extra, independent backup capacity into a design — such as two smaller devices instead of one big one — so that if one part fails, the system does not lose everything at once.

**Residual current device (rcd)** — A safety switch that constantly compares the current going out on the live wire with the current coming back on the neutral wire. If even a small amount is missing — for example, leaking to earth through a person's body — it switches the circuit off in a fraction of a second. Also called an ELCB (earth leakage circuit breaker), or in some countries a GFCI.

**Resistance** — The property of a material that opposes (pushes back against) the flow of electric current. Measured in ohms ( $\Omega$ ). More resistance means less current flows for the same voltage.

**Resistivity** — A property of a material that shows how strongly it resists current flow, for a standard size and length. Its symbol is  $\rho$  (the Greek letter rho). Copper has low resistivity, so it is a good conductor. This is different from resistance (Chapter 2), which depends on a specific object's size and shape as well as its material.

**Resting voltage** — A battery's voltage measured after it has had no charging and no load for at least one to two hours. Resting voltage gives a rough estimate of state of charge, especially for lead-acid batteries.

**Reverse current** — Current that flows backward, from the battery into the solar panel, when there is no sunlight. Without a charge controller, this slowly drains the battery every single night.

**Roof penetration** — A hole made through a roof's surface, for example to bolt down a mounting frame. Every penetration must be sealed well, or it can leak for years.

**Roof pitch** — The steepness of a roof's slope, often given in degrees. A flat roof has a pitch close to 0°.

**Root cause** — The real, underlying reason for a fault. Fixing only the symptom without finding the root cause often means the same problem comes back.

**Safety harness** — A set of straps worn around the body and legs, connected by a lanyard to a secure anchor point, to stop a person falling a dangerous distance if they slip at height.

**Scope of work** — A clear, written list of exactly what work a supplier or installer will do — and will not do — for a project.

**Self-consumption** — The part of a solar system's energy that a home uses directly, instead of sending it out to the grid.

**Self-discharge** — The slow loss of a battery's charge over time, even when nothing is connected to it and it is not being used. All batteries self-discharge a little; heat makes it faster.

**Semiconductor** — A material that conducts electricity better than an insulator (like rubber) but worse than a metal (like copper). Silicon is the semiconductor used in most solar cells.

**Series circuit** — A circuit where components are connected one after another, in a single path. The same current flows through every component.

**Series connection** — Connecting panels one after another, the positive terminal of one to the negative terminal of the next. In series, voltage adds up and current stays the same.

**Service life** — The number of years a piece of equipment is expected to keep working well, before it needs major repair or replacement.

**Setback** — A strip of clear space, required by safety and fire rules, that must be kept free of panels near the edges of a roof or array.

**Shading** — Something blocking direct sunlight from reaching part or all of a solar panel, such as a building, a tree, or a water tank.

**Shading survey** — A careful check of everything that blocks, or could block, sunlight from a solar array — done at different times of the day and across the seasons of the year.

**Short circuit** — An unwanted direct connection between a battery's positive and negative terminals, letting a very large, dangerous current flow suddenly.

**Short-circuit current** — The current that flows when a solar panel's two terminals are connected directly together, so the voltage is zero. Written  $I_{sc}$ . It is the panel's maximum possible current.

**Single-line diagram** — A simplified drawing of a solar system that shows its main components and how they connect, using one line for each circuit instead of every real wire. Often shortened to SLD.

**Site plan** — A drawing, seen from above, that shows a site's layout — a roof or piece of ground, buildings, and the solar array — drawn to scale.

**Site survey** — A visit to a building or piece of land to check, measure, and record everything needed before designing or installing a solar system. Also called a site assessment.

**Soiling** — A loss of solar panel performance caused by dust, sand, dirt, or other material settling on the panel's surface and blocking some sunlight.

**Solar altitude** — The height of the Sun above the horizon, measured in degrees.  $0^\circ$  means the Sun is on the horizon;  $90^\circ$  means it is straight overhead.

**Solar cell** — The basic building block that changes sunlight into electricity. Most solar cells are made from a thin slice of silicon. Also called a photovoltaic (PV) cell.

**Solar constant** — The power of sunlight on one square meter, measured just outside Earth's atmosphere, facing straight at the Sun. About 1360 watts per square meter ( $W/m^2$ ).

**Solar map** — A map that uses colors to show how much solar energy different places receive, usually averaged over a year.

**Solar noon** — The moment during the day when the Sun is at its highest point in the sky. It is not always exactly 12:00 on the clock.

**Solar radiation** — Energy that travels from the Sun as light and heat. It is the source of almost all energy on Earth, including solar power.

**Solar resource** — The amount of useful sunlight energy available at a place. A 'strong' solar resource means a place is a good location for solar power.

**Solstice** — One of the two days in the year when the Sun reaches its highest or lowest noon position in the sky, giving the longest or shortest day of the year.

**Source priority** — The order in which a hybrid system chooses where to draw power from at each moment — usually solar first, then the battery, then the grid, and the generator last.

**Specific gravity** — A number that compares the density of a battery's electrolyte to the density of plain water. A charged lead-acid cell has a higher specific gravity than a discharged one.

**Square wave** — The simplest and lowest-quality inverter waveform. It jumps sharply between two fixed levels, with no smooth curve at all.

**Standard test conditions** — The fixed conditions used to test and rate every solar panel:  $1000 W/m^2$  of sunlight,  $25^\circ C$  cell temperature, and a standard sunlight spectrum (AM1.5). Written STC.

**Standby consumption** — The small amount of power an inverter uses just to stay switched on, even when no appliance is drawing power from it. Also called idle consumption.

**Standby power** — The small amount of power a device uses even when switched off but still plugged in — sometimes called phantom load. A charger left plugged in with no phone attached might still use 0.3–0.5 W. (Chapter 8 covers an inverter's own idle draw, called standby consumption — the same idea, for a different device.)

**State of charge** — How full a battery is right now, shown as a percentage. Written SoC. 100% SoC means full; 0% SoC means empty.

**Static head** — The real vertical height water must be lifted, measured straight up from the water source's surface to the point where the water is delivered — for example, the top of a storage tank. Measured in meters (m).

**Storage tank** — A container that holds pumped water for later use — for drinking, irrigation, or livestock. It lets a solar pump run only while the sun shines, while water is still available at any hour.

**Strain relief** — A fitting or method that stops the weight or pulling force on a cable from being carried by its electrical connection, protecting the connection from damage over time.

**String** — A group of modules connected together in series (one after another) so their voltages add up.

**Submersible pump** — A pump built to work fully underwater. It is sealed so water cannot damage its motor, and it is lowered into a borehole, well, or tank, where it PUSHES water up and out through a pipe, instead of pulling it from above.

**Suction lift** — The vertical distance a surface pump pulls water upward by suction, before pushing it onward. Limited by air pressure to about 10 m in theory, and to about 6–7 m in real, practical systems.

**Sulfation** — A buildup of hard crystals on a lead-acid battery's plates, usually caused by leaving the battery at a low charge for too long. Sulfation reduces the battery's usable capacity, often permanently.

**Sun path diagram** — A chart that shows the Sun's altitude and compass direction for every hour of the day, across the months of the year, for one latitude.

**Surface pump** — A pump that stays above the water, usually on the ground or a platform, and pulls water up into itself through a suction pipe. Also called a suction pump.

**Surge power** — The higher power an inverter can supply for a few seconds only. Also called peak power. Mainly used to start motors.

**Surge protection device** — A device that senses a dangerous voltage surge and instantly diverts the extra energy safely to earth, protecting the equipment connected after it. Also called an SPD or a surge arrester.

**Symptom** — A sign that something is wrong — what you notice or measure, like 'the lights are dim' or 'the battery is empty by midnight.' A symptom points toward a cause, but it is not the cause itself.

**System record book** — A notebook or file, kept with the system, that starts with its as-built drawing (Chapter 16) and commissioning test results, and then keeps a complete, dated history of every later test, repair, and maintenance visit — Chapter 19 and Chapter 20 both rely on it.

**System voltage** — The DC voltage that the battery bank, the charge controller's output, and the inverter's input all share in one system — commonly 12 V, 24 V, or 48 V. Written  $V_{sys}$ .

**Tariff** — The price charged for each unit of energy, usually in currency per kWh. Electricity bills and generator subscriptions are both based on a tariff.

**Temperature coefficient** — A number, usually a small negative percentage per °C, that shows how much a solar panel's power drops for every 1°C rise in cell temperature above 25°C.

**Temperature compensation** — Automatically adjusting the charging voltage based on the battery's temperature, so it is not overcharged when hot or undercharged when cold. Many charge controllers do this with a temperature sensor.

**Terminal** — The metal point on a battery, connector, or device where a wire is attached to complete an electrical connection.

**Thermal runaway** — A dangerous chain reaction inside a battery, where rising heat makes the chemical reaction go faster, which then makes even more heat. It can end in fire. It is rare, especially in LiFePO<sub>4</sub> batteries, but becomes more likely if a battery is damaged, overcharged, or allowed to overheat badly.

**Thin-film** — A solar cell made by putting a very thin layer of light-absorbing material on a backing, using much less material than crystalline cells. It has lower efficiency but can be light and flexible.

**Tiered tariff** — A pricing plan where the price for each kWh changes depending on how much energy is used in the billing period — a low price for the first block of energy, then a higher price for each higher block. Also called a progressive or scaled tariff.

**Tilt angle** — The angle between a solar panel's surface and the flat, horizontal ground. A panel lying flat has a tilt angle of 0°; a panel standing straight up has a tilt angle of 90°.

**Tilt frame** — A rack built to lift the back edge of a panel on a flat roof, so the panel sits at a chosen tilt angle instead of lying flat.

**Torque** — The turning force used to tighten a nut or bolt. Bolts need the correct torque — not too loose, which can work loose over time, and not too tight, which can crack the material.

**Total dynamic head** — The full height-equivalent a pump must overcome: the static head plus the friction head loss. Written H, or TDH. This is the head used in the hydraulic power equation.

**Troubleshooting** — Finding and fixing the reason something is not working, using a logical method instead of guessing.

**True south** — The compass direction that points exactly toward the geographic South Pole. It is different from magnetic south, the direction a simple compass needle points to (Chapter 5).

**Usable area** — The part of a roof or site that is actually free for solar panels, after removing the space lost to obstructions and setbacks.

**Ventilation** — The movement of fresh air through a space, which carries away heat and any gas that has collected there.

**Visual inspection** — A check done by carefully looking at equipment for damage, dirt, wear, or anything unusual — usually without opening, disconnecting, or electrically testing anything.

**Volt** — The unit of voltage. Written V.

**Volt-ampere** — A unit sometimes used on inverter and UPS nameplates instead of watts. Written VA. For simple loads like lamps, VA and W are about the same number. For loads with motors, VA is usually higher than W.

**Voltage** — The electrical pressure that pushes current through a wire. Measured in volts (V). Home electricity in Iraq is about 220 V.

**Voltage at maximum power** — The panel's voltage exactly at the maximum power point. Written Vmp. Always a little less than Voc.

**Voltage drop** — The loss of voltage along a cable, caused by the cable's own resistance. The voltage arriving at the load is always a little lower than the voltage that left the source.

**Voltage drop percentage** — The voltage drop written as a percentage of the system's voltage, instead of in volts. This is the number designers compare against a recommended limit, because the same voltage loss matters more on a lower-voltage system.

**Voltage drop test** — A multimeter test done on a working, powered circuit, measuring the voltage across one single connection or short section of cable while current flows through it. A good connection reads close to 0 V; a higher reading reveals hidden resistance, often from a loose or corroded joint.

**Voltage surge** — A short, sudden increase in voltage, far above the normal level, usually lasting a tiny fraction of a second. Common causes are lightning and the switching of heavy equipment nearby. Do not confuse this with an inverter's surge power rating (Chapter 8) — a different idea that just happens to share the word 'surge.'

**Warranty** — A manufacturer's or installer's written promise to repair or replace equipment that fails within a certain time — usually only if the equipment was not opened, modified, or wired incorrectly by an untrained person.

**Watt** — The unit of power. One watt means one joule of energy every second.

**Watt-hour** — A unit of energy. The energy used when one watt works for one hour. Written Wh.

**Waveform** — The shape you get when you draw a graph of AC voltage over time. Different inverters produce different waveform shapes.

**Wind load** — The force that wind puts on a mounted panel and its rack. Racks and roofs must be strong enough to handle the local wind load safely.