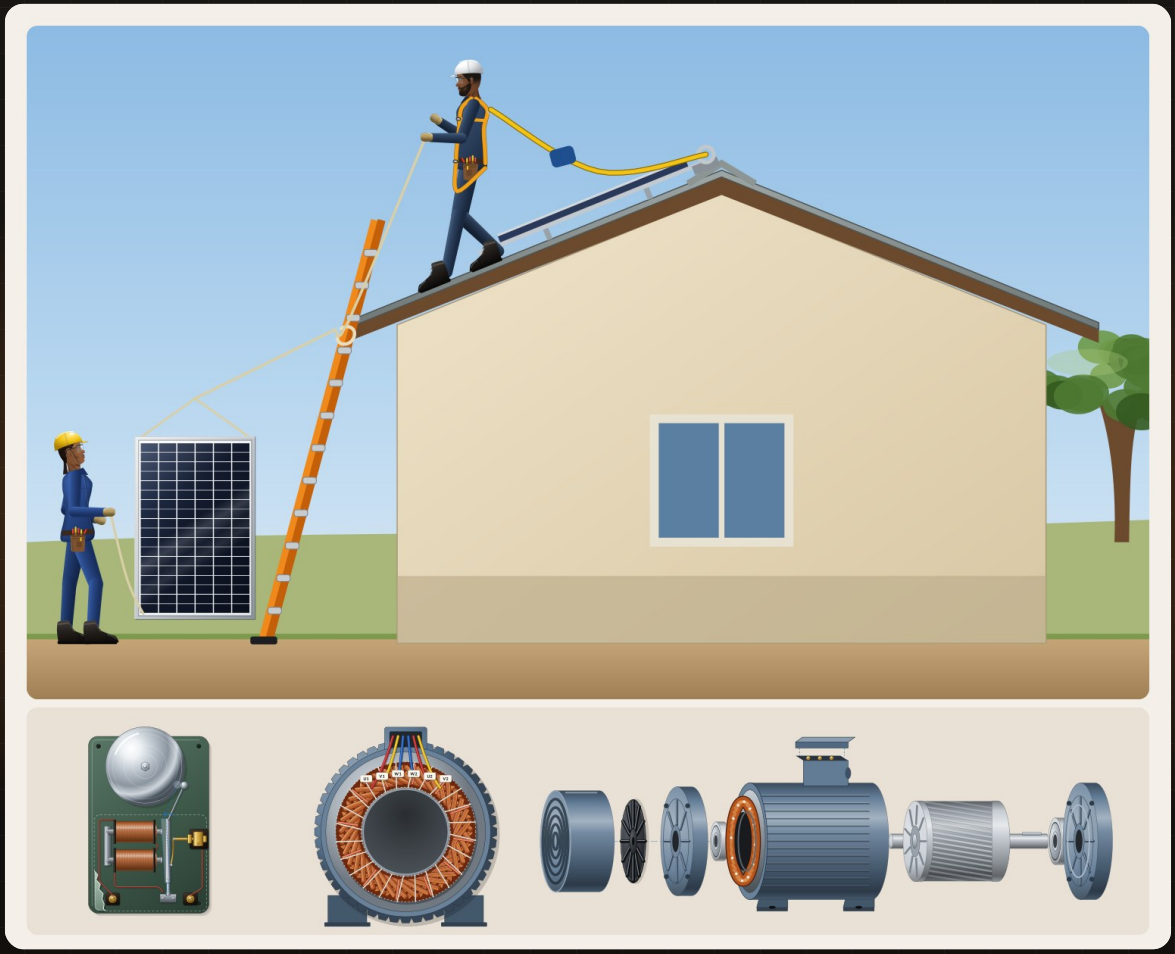
KNQF LEVEL 4 · TVET CDACC CYCLE 3

Electrical Installation

Level 4

A Practical Study Guide for Kenyan Trainees

Stand-alone solar PV · Bells and alarms · Motor rewinding · Industry training



Realistic pictures **Solar sizing** **Mock assessments**

For trainees, RPL candidates, trainers, solar technicians and rewinders

Alphonce Kimutai Kirui

Aligned to the TVET CDACC Competency-Based Modular Curriculum, Electrical Installation Technology KNQF Level 4

Electrical Installation Level 4

A Practical Study Guide for Kenyan Trainees

Stand-Alone Solar PV Systems · Bell and Alarm Systems · Electrical Machine Winding · Industry Training
Kenya National Qualifications Framework (KNQF) Level 4

Alphonce Kimutai Kirui

Electrical Installation Level 4: A Practical Study Guide for Kenyan Trainees
First edition, November 2026

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Published by the author. Website: alphoncekirui.com

About the curriculum

This book is an independent study guide. It follows the topics and units of the TVET CDACC Competency-Based Modular Curriculum and Occupational Standard for Electrical Installation Technology, KNQF Level 4 (Cycle 3, greened edition, programme code 0713 354B; standard edition 0713 354A), and the assessment documents for Electrical Worker Level 4. It covers the three Level 4 units (Module Two): Stand-Alone Solar PV Systems (ENG/CU/EI/CR/01/4/MB), Bell and Alarm Installation (ENG/CU/EI/CR/02/4/MB) and Electrical Machine Winding (ENG/CU/EI/CR/03/4/MB), together with the 320 hours of industry training. The three Level 3 units of the qualification (Module One: PVC sheathed cable, trunking and conduit systems) are covered in the companion book, *Electrical Installation Technology Level 3: A Practical Study Guide for Kenyan Trainees*, by the same author. Unit titles and codes are used for reference only. The book is not published, endorsed or approved by TVET CDACC, TVETA or the Ministry of Education. Always follow the current official curriculum and your trainer's guidance.

Safety and accuracy notice

Electricity can kill. Electric shock, DC arcs, battery explosions and acid burns, fire, falls from roofs and ladders, rotating machinery and harmful varnish fumes are real hazards in Level 4 work. The methods in this book are for training under the supervision of a qualified trainer. Never work on a live installation: isolate, lock off and prove dead first, and remember that a solar module makes voltage whenever light falls on it. Only a person licensed by the Energy and Petroleum Regulatory Authority (EPRA) for that class of work may design, install and certify solar PV systems or electrical installation work; trainees work under a licensed technician. Figures given as "typical" (sizing factors, cable sizes, protective device ratings, test values and prices) are general guidance only. Always follow the current Kenyan regulations, including the Energy (Solar Photovoltaic Systems) Regulations, 2012, the wiring regulations your trainer uses, the manufacturer's instructions, workplace rules and the Occupational Safety and Health Act 2007. Prices are approximate (2026) and vary by town.

Names of people, businesses, email addresses, websites and phone numbers used in examples are made up for teaching.

Illustrations and photographs

The illustrations in this book were drawn for it. They are realistic teaching illustrations and are not to scale unless dimensions are given. Charts marked "illustrative" show typical shapes, not measured data. Photographs come from Wikimedia Commons under free licences (public domain, CC0, CC BY or CC BY-SA). Each photograph is credited under the picture, and the full list of credits is at the back of the book.

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Preface

Kenya needs more people who can install a solar system that still works after five years, wire a school bell or a fire alarm that rings when it must, and bring a burnt-out motor back to life. These are the three skills of the Level 4 electrical worker, and they are skills that pay: in homes, schools, dispensaries, shops, farms and posho mills, in towns and in villages far from the grid.

This guide covers the three new units of the Electrical Installation Technology KNQF Level 4 course (Module Two): Stand-Alone Solar PV Systems, Bell and Alarm Installation and Electrical Machine Winding, together with the 320 hours of industry training and the assessments that lead to your certificates. The three Level 3 units of the qualification (Module One: PVC sheathed cable, trunking and conduit systems) are not repeated here. They are covered in the companion book, *Electrical Installation Technology Level 3: A Practical Study Guide for Kenyan Trainees*, which this book calls "the Level 3 guide". Where a Level 4 unit uses a Level 3 skill, such as cable joints, final circuits or insulation testing, this book gives a short reminder and points you to the right chapter of the Level 3 guide.

The book is written for trainees in vocational training centres and technical colleges, for candidates seeking recognition of prior learning, for trainers, and for working fundis who want to add solar, alarm and rewinding work to what they already do. Everything is explained in plain English, with realistic drawings, worked calculations using Kenyan prices and conditions, practical tasks and checklists matched to the way you will be assessed.

Above all, work safely. A solar array cannot be switched off, a battery can burn and explode, and a motor can start without warning. Learn the safety rules in Chapter 2 before you touch anything, and keep to them on every job.

Alphonce Kimutai Kirui
Bomet, November 2026

How to use this book

This book follows the Level 4 part of the Electrical Installation Technology course from start to finish. It covers the three Level 4 core units and the industry training, in the same order as your training. You can read it cover to cover, or study one unit at a time if you are taking a part qualification: the units are independent. Topics that all three units share, such as safety, electrical principles, calculations and test instruments, are taught once in Part 1, and the later chapters refer back to them. Level 3 topics are summarised and referred to the Level 3 guide.

The course at a glance

Part	What it covers	Training time
1. Getting started	The Level 4 worker and the course, assessment, safety for solar, alarm and motor work, electrical principles, calculations and instruments	Used throughout
2. Stand-alone solar PV systems	Unit 1: Stand-Alone Solar PV Systems (ENG/CU/EI/CR/01/4/MB)	120 hours
3. Bell and alarm systems	Unit 2: Bell and Alarm Installation (ENG/CU/EI/CR/02/4/MB)	120 hours
4. Electrical machine winding	Unit 3: Electrical Machine Winding (ENG/CU/EI/CR/03/4/MB)	120 hours
5. Industry training and assessment	Industry training, the mentoring tool and portfolio of evidence, starting out, and getting ready to be assessed	320 hours of industry training

The full Level 4 qualification also includes the three Level 3 units (Module One, 300 hours), covered in the Level 3 guide: 980 hours in all.

What is in each chapter

- **What you will learn:** the chapter's goals, with the unit, learning outcome and training hours it belongs to.
- **Key words:** the trade words you need, explained simply. More are in the Glossary at the back.
- **Explanations and drawings:** each topic explained step by step, with realistic labelled illustrations, circuit and wiring diagrams, charts and photographs.
- **Worked examples:** system sizes, battery banks, cable sizes and voltage drop, alarm battery standby, winding data, test readings and job prices worked through with real numbers.
- **Practical tasks:** real jobs with the tools, materials, steps and safety points. Do them with your trainer.
- **Check your competence:** a checklist of what an assessor will expect you to show. Tick each item when you can do it without help.
- **Practice questions:** answers, with full working for calculations, are at the back of the book.

Look out for these boxes

> **SAFETY FIRST**
>
> Hazards and how to stay safe. Never skip these.

GREEN TIP

Ways to save energy and materials, choose efficient equipment, and recycle batteries, e-waste, copper and varnish waste correctly.

TRAINER'S TIP

Advice from experienced trainers, solar technicians and rewinders to help you work faster and better.

COMMON MISTAKES

Errors trainees often make, and how to avoid them.

ON A KENYAN SITE

How the topic looks in real Kenyan homes, schools, dispensaries, farms, posho mills, rewinding workshops and county VTC workshops.

WORKED EXAMPLE

A calculation worked step by step with real numbers.

About the pictures and diagrams

This book uses realistic illustrations of real equipment and installations, circuit and wiring diagrams, charts and photographs. Labels and thin leader lines point to the parts that matter. On the DC side of a solar system, positive conductors are drawn red and negative conductors black. On the AC side, conductors are drawn in their insulation colours: brown for line, blue for neutral and green-and-yellow stripes for the protective (earth) conductor. Motor windings use the terminal marks U, V and W. Blue arrows show movement or direction. Red marks a danger or mistake; green marks the correct way. Some photographs show real places where people are not following every safety rule; the captions point this out. Always follow the isolation procedures in Chapter 2.

PART 1

Getting Started

What a Level 4 electrical worker and solar technician does, how the three Level 4 units are trained and assessed, how this book links to the Level 3 guide, safety for solar, alarm and motor work, and the electrical principles, calculations and instruments used in all three units.

Chapter 1: Becoming a Level 4 Electrical Worker and Solar Technician
Chapter 2: Safety for Solar, Alarm and Motor Work
Chapter 3: Electrical Principles, Calculations and Instruments

CHAPTER 1

Becoming a Level 4 Electrical Worker and Solar Technician

WHAT YOU WILL LEARN

- Describe the work of a Level 4 electrical worker and where such workers are employed in Kenya.
- Explain how EPRA licences control solar PV and electrical work, and why you must work under a licence holder until you are licensed.
- Plan your path from this certificate to further training, licences and specialist work.
- Explain how the course is organised: modules, units, hours, credits and industry training.
- Work out a unit score and rating from formative and summative marks.
- Behave professionally with clients, mentors and fellow workers.

Units 1–3 · Course overview, assessment, certification and industry training · Orientation

A farmer in a village far from the nearest Kenya Power line wants lights, a TV and a phone charger. A school wants a bell that rings on time and a fire alarm in its dormitories. A posho-mill owner's motor has burnt out. Each of them needs a Level 4 electrical worker. This chapter explains that job, the licences that control it, and how this course trains and assesses you.

Key words

Electrical worker
A person who carries out electrical work from a given design and the client's requirements; the title used in the Level 4 assessment papers.

Stand-alone solar PV system
A solar system with batteries that is not connected to the Kenya Power grid.

Unit of competency
A block of the course with its own certificate, such as Bell and Alarm Installation.

Element
One main task within a unit, such as "test the installation".

Performance criterion (PC)
A check the assessor uses to decide whether you did part of an element correctly. Each PC carries marks.

Range
The situations, equipment and materials the unit covers, such as the types of battery or cable.

Evidence
Proof of competence: observed tasks, finished work, test records, photos, oral answers.

Formative assessment
Assessment during training; 60% of the unit score.

Summative assessment
The final assessment of a unit; 40% of the unit score.

RPL
Recognition of prior learning: assessing skills you gained at work so they can count towards a qualification.

EPRA
Energy and Petroleum Regulatory Authority, which licenses electrical workers, solar technicians and contractors.

Mentor
An experienced worker who guides and assesses you during industry training.

1.1 What a Level 4 Electrical Worker Does

At Level 3 you learned to wire a single-phase building with PVC-sheathed cable, trunking and conduit. At Level 4 you keep all of those skills and add three new kinds of work. The occupational standard describes the Level 4 electrical worker as someone who installs systems **from a design and the customer's requirements**: you read and interpret the drawings, and work to national and international standards. The designer or technician usually fixes the sizes and quantities of materials; you install, test and maintain to that design. Your main new tasks are:

- **Stand-alone solar PV systems:** mounting modules, controllers, batteries and inverters, wiring the DC and AC sides, testing, commissioning and maintaining them (Chapters 3–9).
- **Bells and alarms:** door and gate bells, school bells, hotel and hospital call systems, intruder alarms and small fire-alarm systems (Chapters 10–12).
- **Electrical machine winding:** dismantling a motor, recording winding data, rewinding the stator, reassembling and testing it (Chapters 13–15).
- **Safe and green practice** in all three: safety on roofs, with batteries and with machines (Chapter 2); efficient loads, correct cable sizes, recycling batteries and copper, and keeping records.

The Level 4 qualification also contains the three Level 3 units. **This book covers only the three Level 4 units.** The Level 3 units are taught in the companion book, *Electrical Installation Technology Level 3: A Practical Study Guide for Kenyan Trainees*, called "the Level 3 guide" in this book. Where a Level 4 unit repeats a Level 3 topic, such as joints, final circuits or insulation testing, this book summarises it and refers you to the right chapter of the Level 3 guide.

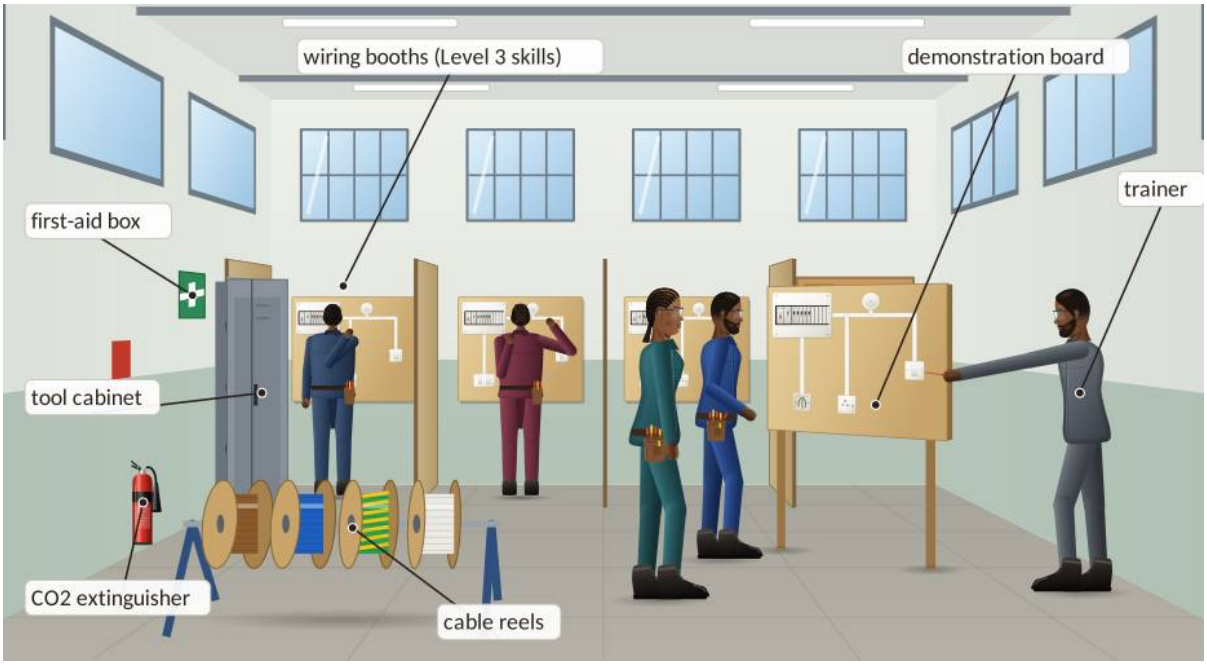


Figure 1.1 A county VTC electrical workshop. The wiring booths and demonstration board serve the Level 3 units; the Level 4 units add a solar training rig, an alarm board and a motor-rewind bench.



Figure 1.2 Solar technicians fixing mounting rails on a roof. Every worker wears a full-body harness: roof work is planned and protected (Chapter 2).

Photo: SAgbley, CC BY-SA 4.0, via Wikimedia Commons

1.2 Where Level 4 Workers Find Work

Kenya has made great progress with electricity: about 77% of people had access in 2024, but only about 67% in rural areas (World Bank). In the 2019 census, 19.3% of households already used solar as their main source of lighting. The Kenya Off-Grid Solar Access Project (KOSAP) is funding stand-alone solar home systems and mini-grids in 14 underserved counties. There is work for people who can install and repair solar systems properly. Typical employers are:

- **Solar companies and pay-as-you-go (PAYG) firms** that sell solar home systems on credit and need installers and repair technicians in every county.
- **Electrical contractors** who install solar back-up systems, bells, alarms and power for homes, schools, churches, clinics and offices.
- **Security and fire-alarm firms** that install and service intruder alarms in shops, banks and M-Pesa outlets, and fire alarms in schools, hotels and malls.
- **Maintenance departments** of hotels, hospitals, boarding schools, factories and county governments.
- **Motor-rewinding workshops** in towns and jua kali clusters, repairing pumps, posho mills, chaff cutters, milk coolers and workshop machines.
- **Water, irrigation and agro-processing projects:** solar and electric boreholes, irrigation pumps and processing plants.
- **Public projects** run by county governments and the Rural Electrification and Renewable Energy Corporation (REREC).
- **Self-employment**, once you hold the right licence (Chapter 16).

Pay depends on employer and experience. A reasonable expectation for an entry-level solar or alarm installer is about KSh 25,000–40,000 a month, or KSh 1,500–2,500 a day as a fundi (approximate, 2026). A Nairobi employer advertised a solar PV technician post at KSh 50,000 a month gross in late 2025.

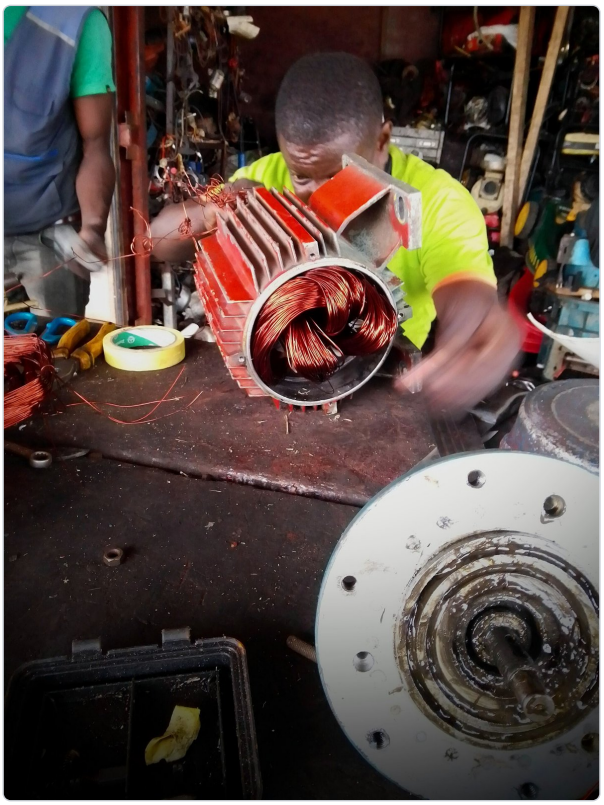


Figure 1.3 A motor rewinder at work on a stator. Rewinding gives a motor a second life and keeps copper in use.

Photo: Amuzujoe, CC BY-SA 4.0, via Wikimedia Commons

> **ON A KENYAN SITE**
>
> A boarding school in Bomet County may give one contractor three jobs in a single term: a solar back-up system for the laboratory and dormitory lights, an electric bell with a programmable timer, and a fire alarm for the dormitories. The same school's borehole pump motor may go to a rewinder in town. A Level 4 worker who can do all four, and who keeps proper records, gets called back.

1.3 The Law and EPRA Licences

Electricity can kill and burn buildings, and badly installed solar systems waste the money of families who can least afford it. Kenyan law therefore controls who may design and install them.

1.3.1 The laws and the regulator

The parent law is the **Energy Act, 2019**, and the regulator is **EPRA**. Solar PV work is controlled by the **Energy (Solar Photovoltaic Systems) Regulations, 2012**. EPRA confirmed in 2026 that these Regulations still provide for licensing solar firms and technicians. A draft replacement was published in 2019 but has not been gazetted, so follow the 2012 Regulations and watch EPRA's notices. Where AC wiring is involved, as on the output of an inverter, the **Electric Power (Electrical Installation Work) Rules, 2006** and the IET Wiring Regulations (BS 7671) also apply, as in the Level 3 guide.

In 2026 a separate Gazette notice changed how Kenya Power bills solar systems that export to the grid. It concerns grid-connected systems only. The stand-alone systems in this book are never connected to the grid.

1.3.2 Solar licence classes

No one may design or install a solar PV system without an EPRA licence. Technicians and firms are licensed in classes (Table 1.1).

Table 1.1 EPRA solar PV licence classes and fees (Solar PV Regulations, 2012; fees from EPRA's June 2026 notice, KSh)

Class	Who and what	Application / grant / yearly renewal
T1 technician	Small systems: one module and one battery, DC only, up to 100 Wp	250 / 1,000 / 500
T2 technician	Medium systems: several modules up to 300 Wp, several batteries, may include an inverter	500 / 2,000 / 750
T3 technician	Advanced systems, including grid-connected and hybrid systems	750 / 3,000 / 1,000
C1 firm	Contractor that designs and installs; must be or employ a T3 technician	500 / 1,000 / 1,000
V1 firm	Vendor that designs, sells or installs; must be or employ a T2 technician	1,000 / 2,500 / 1,000
V2 firm	Manufacturer or importer; must be or employ a T2 technician	2,000 / 5,000 / 2,000

Other rules worth knowing: a licence lasts **one year**; apply to renew at least 30 days before it expires; a technician must practise for at least **two years** before applying to move up a class. Each class also needs a set qualification and years of experience. EPRA has not published how the CBET Level 4 certificate maps onto those requirements, so ask EPRA or your trainer before you apply. **Your Level 4 certificate is not a licence.** Until you are licensed, you work **under the direction of** a licensed technician, usually a T2 or T3.

Electrical workers who wire buildings are licensed separately, in the classes C-2, C-1, B, A-1 and A-2 under the 2006 Rules; the Level 3 guide, Chapter 1, explains them.

1.3.3 Why a licence matters before you sign

For every solar installation the licensed vendor or contractor and the client both sign a **system design declaration**. When the work is finished, the licensed installer issues a **completion certificate** showing the date, installer, owner, location, system size and warranty, including confirmation that the user was trained. The client also receives the receipt and the user manuals. Records are kept for at least **five years**. Breaking the Regulations can bring a fine of up to KSh 1,000,000, a year in prison, or both. The Regulations also set minimum warranties, such as 20 years for modules and 10 years for controllers and inverters (Chapter 16).

SAFETY FIRST

Never sign a design declaration or completion certificate for a class of work your licence does not cover, and never let someone use your name to cover work you did not supervise. Your signature tells the client and EPRA that the system is safe. If it catches fire or injures someone, the person who signed answers for it.

1.4 Your Career Ladder

On the Kenya National Qualifications Framework (KNQF), Level 4 is the artisan level, Level 5 the craft certificate and Level 6 the national diploma. The trainers on this course must hold at least an Electrical Engineering Level 5 qualification, which shows the natural next step. Figure 1.4 shows the ladder, the licences beside it and the ways you can specialise.

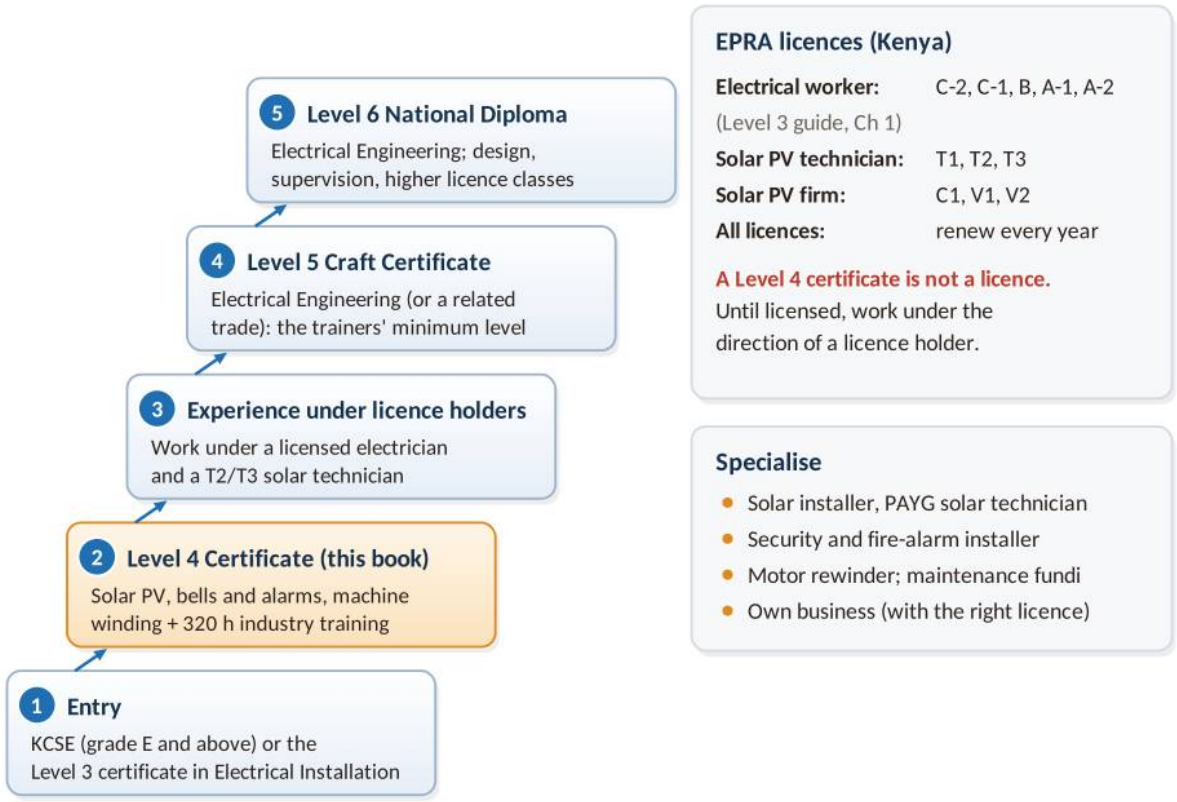


Figure 1.4 The career ladder. The Level 4 certificate is a qualification, not a licence: EPRA licences come with experience under licence holders.

GREEN TIP

Every job in this course is green work. A solar home system replaces kerosene lamps and diesel generators; an LED and an efficient TV make the system smaller; a long-life lithium battery lasts for years and contains no acid; a rewound motor stays in use instead of becoming scrap. Learn to explain these benefits to clients: it helps them and it wins you work.

1.5 How the Course Is Organised

The Level 4 course has three parts (Figure 1.5):

- **Module One**: the three Level 3 units (PVC sheathed cable, trunking and conduit), 300 hours, 30 credits. These are covered in the Level 3 guide. If you already hold Level 3 Certificates of Competency, ask your institution how they are recognised (credit transfer or RPL); do not assume you are exempt.
- **Module Two**: the three Level 4 units in this book, 120 hours each, 360 hours and 36 credits.
- **Industry training**: at least 320 hours in the electrical engineering sector, 32 credits (Chapter 16).

The course total is 980 hours and 98 credits (300 + 360 + 320 = 980 h; 30 + 36 + 32 = 98; one credit is 10 hours). The curriculum describes this as 24 weeks at 40 hours a week; 980 ÷ 40 = 24.5, so plan on about 24–25 weeks.

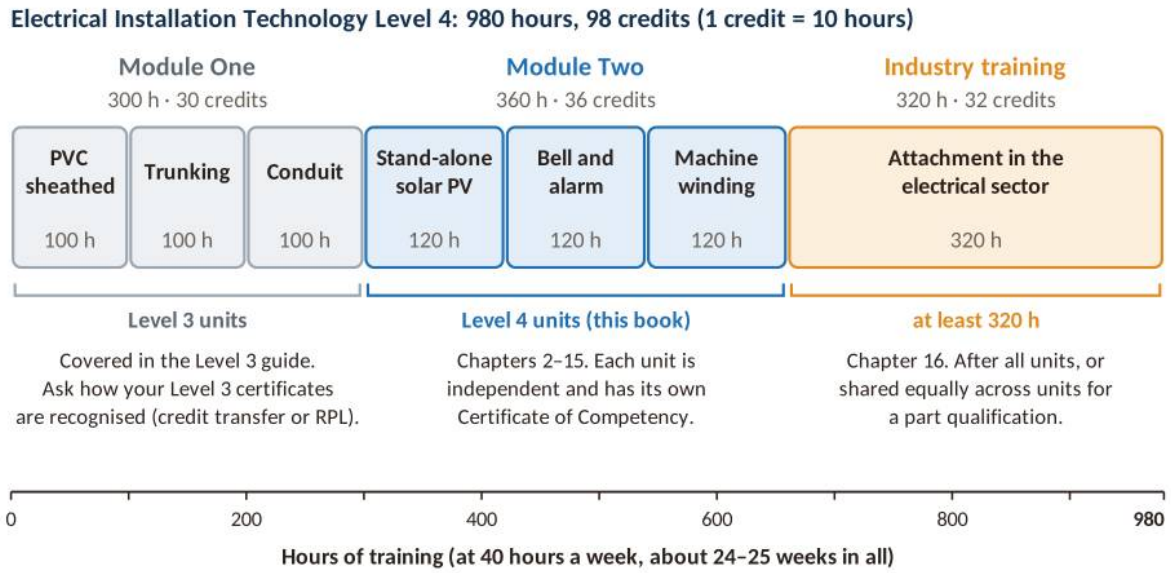


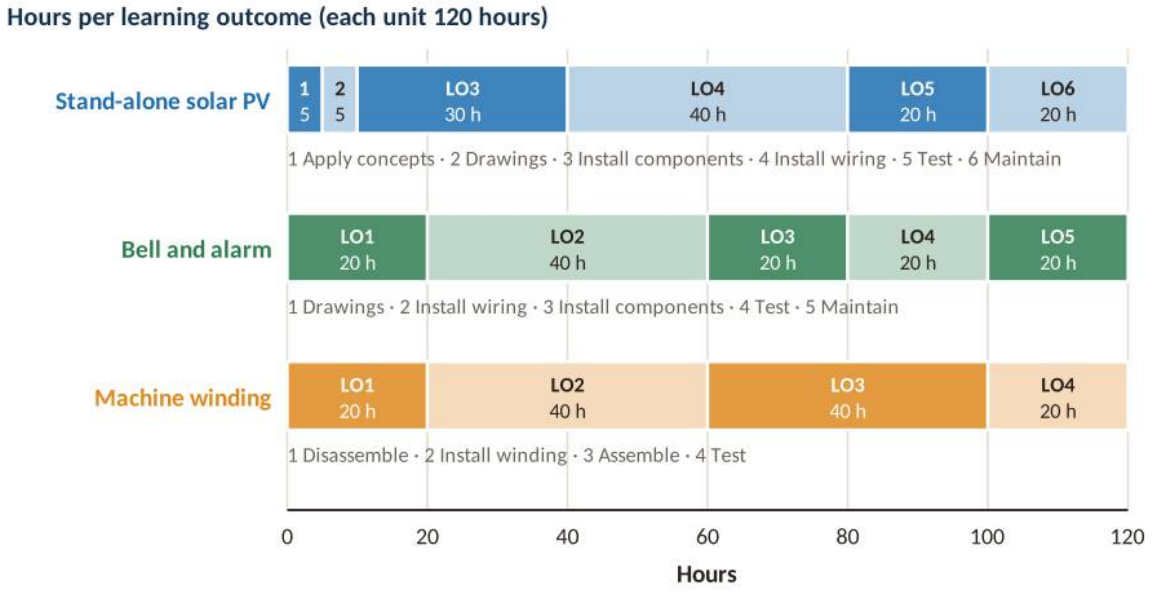
Figure 1.5 The course map, drawn to scale by hours. This book covers Module Two and prepares you for industry training.

The three Level 4 units are independent: you can take them in any order, or take one alone. Table 1.2 gives their TVET CDACC codes. (The summary table in the curriculum also prints ISCED codes, 0713 351 04B, 0714 351 05B and 0713 351 06B; other pages print different ISCED numbers, so this book uses the CDACC codes.)

Table 1.2 The Level 4 units

Unit	CDACC code	Hours	Chapters
Stand-Alone Solar PV Systems	ENG/CU/EI/CR/01/4/MB	120 (12 credits)	2–9
Bell and Alarm Installation	ENG/CU/EI/CR/02/4/MB	120 (12 credits)	2–3, 7, 10–12
Electrical Machine Winding	ENG/CU/EI/CR/03/4/MB	120 (12 credits)	2, 13–15

Each unit is divided into **learning outcomes**, which match the **elements** of the occupational standard. Figure 1.6 shows how the hours are shared. Notice where the time goes: wiring the solar system (40 h), wiring the bell and alarm system (40 h), and installing and assembling the machine winding (40 h each). These are the hands-on skills.



Source: TVET CDACC curriculum, Electrical Installation Technology Level 4 (unit summaries of learning outcomes).

Figure 1.6 Hours per learning outcome. Installing the wiring, the components and the winding take the most time.

1.5.1 Entry, trainers and industry training

To enter the course you need any one of: KCSE grade E or above; the Level 3 Certificate in Electrical Installation Technology; or an equivalent qualification accepted by TVETA. Your trainer must hold at least an Electrical Engineering Level 5 qualification (or one in a related trade), be licensed by TVETA, and be licensed by EBK/KETRB. Industry training of at least 320 hours may be taken after all units (full qualification) or shared equally between the units you take (part qualification). On the dual training model, follow the dual training policy.

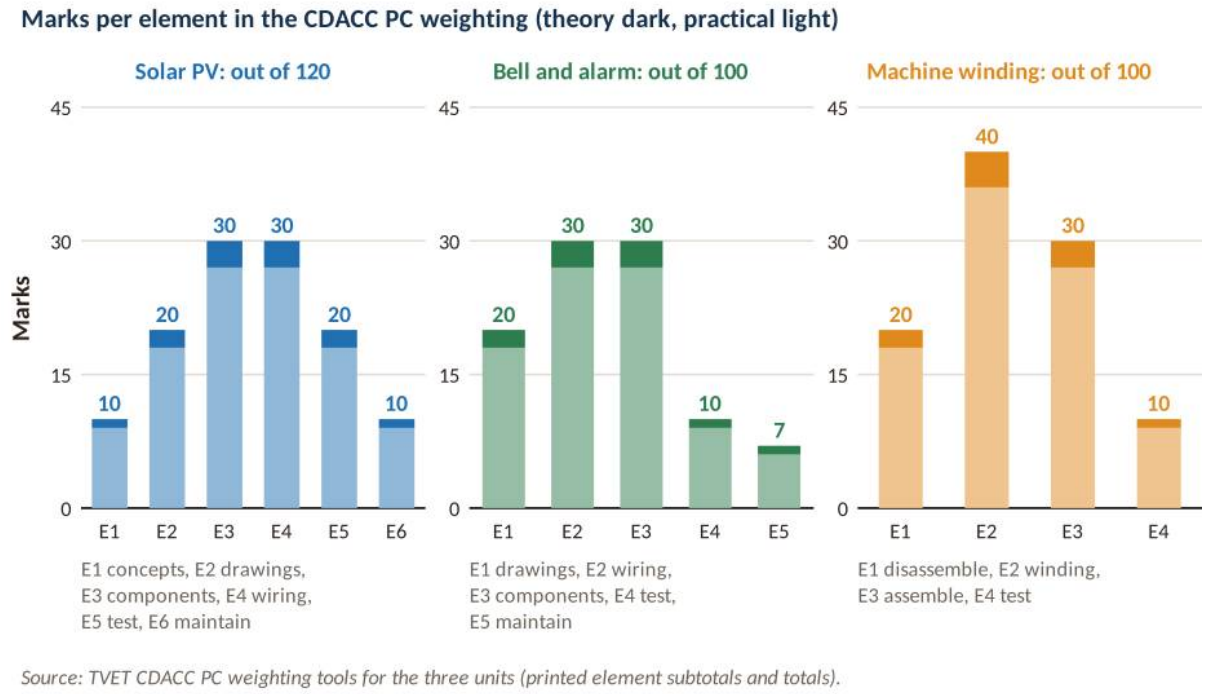
1.6 How You Are Assessed and Certified

Competency-based assessment asks: can you do the job to the standard, safely, every time? The rules are:

- Every unit is assessed **formatively** (during training) and **summatively** (at the end). There are at least as many formative assessments as there are elements in the unit.
- Every performance criterion is assessed, using the marks in the CDACC **PC weighting** tool.
- Theory is tested **orally**, during the practical. Theory and practical carry **10% and 90%** of the marks.
- The unit score is **60% formative plus 40% summative**.
- You are assessed **individually**, at a workplace or a simulated workplace such as the VTC rig. Solar and bell assessments use practical demonstrations, projects, written and oral tests; winding adds a portfolio of evidence and a third-party report.
- Assessors are TVETA-licensed trainers or industry experts registered by TVET CDACC and registered with EBK and KETRB.

1.6.1 Where the marks are

The PC weighting tool shares the marks among the elements (Figure 1.7). The solar unit is marked out of 120 and the bell and winding units out of 100. Table 1.3 lists the heaviest single performance criteria: practise these until they are automatic.



Source: TVET CDACC PC weighting tools for the three units (printed element subtotals and totals).

Figure 1.7 Where the marks are. Each element's marks are split about 1 : 9 between oral theory (dark) and practical (light).

Table 1.3 The heaviest performance criteria in each unit (marks)

Solar PV (of 120)	Bell and alarm (of 100)	Machine winding (of 100)
Components mounted (15)	Components installed (13)	Coils laid in stator slots (19)
Wiring mapped (10)	Power supply installed (11)	Winding data recorded (10)
Final circuits installed (8)	Systems installed (8)	Parts disassembled (10)
Components terminated (8)	Wiring mapped (8)	Bolts and nuts fastened (9)
Components identified (7)	Drawing interpreted (7)	Coils prepared (8)
Earth resistance test (7)	Cable management installed (7)	Bearings fitted (8)

1.6.2 Ratings and codes

Your unit score gives a rating: **80–100 Attained Mastery**, **65–79 Proficient**, **50–64 Competent**, and **49 and below Not Yet Competent**. Three codes are also used: **Y** for assessment malpractice or irregularity, **X** for absent, and **CRNM** for course requirement not met.

WORKED EXAMPLE 1.1: FROM MARKS TO A RATING

A trainee scores 92 out of 120 in the formative assessments of the solar unit and 58% in the summative assessment.

Step 1, formative percentage: 92 ÷ 120 × 100 = **76.7%**.

Step 2, weight each part: formative 0.6 × 76.7 = 46.0; summative 0.4 × 58 = 23.2.

Step 3, unit score: 46.0 + 23.2 = **69.2**.

Step 4, rating: 69.2 lies between 65 and 79, so the rating is **Proficient** (Figure 1.8). Had the summative mark been 30%, the score would be 46.0 + 12.0 = 58.0: Competent. A strong formative record protects you on a bad day.

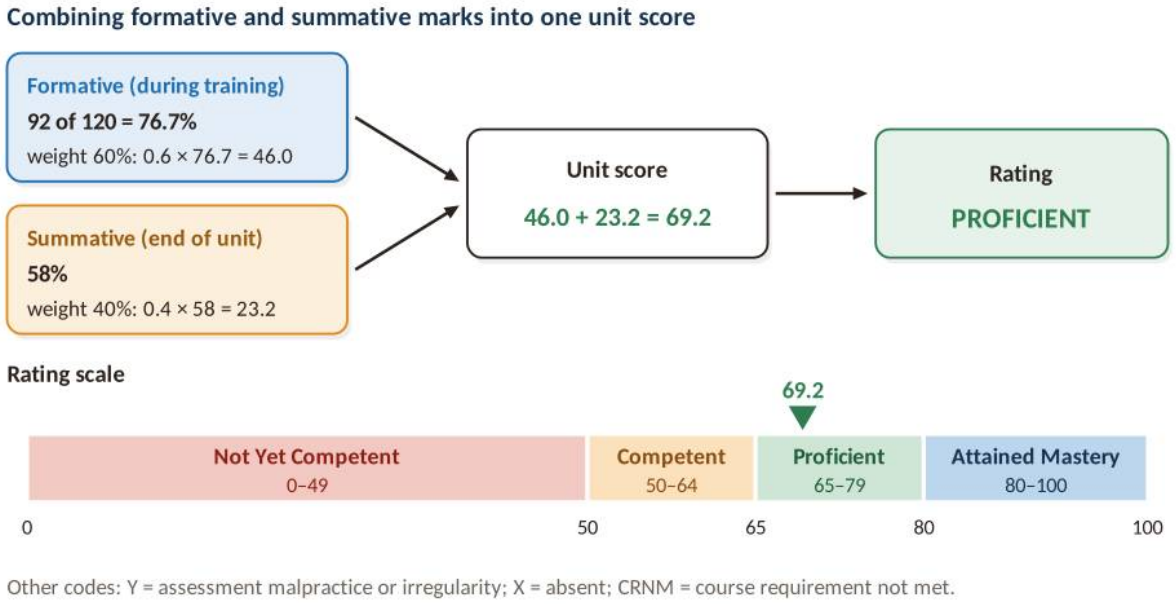


Figure 1.8 Worked example 1.1 on the rating scale: 60% formative plus 40% summative gives 69.2, Proficient.

1.6.3 Certificates and RPL

TVET CDACC issues the certificates. You receive a **Certificate of Competency** for each unit you pass, and a **Statement of Attainment** may be awarded for a certifiable element within a unit. When you have passed **all** the units in the qualification pack, you receive the **Kenya National Certificate in Electrical Installation Technology Level 4**. Experienced workers without certificates can apply for **RPL**, which may lead to part or all of the qualification.

COMMON MISTAKES

- Believing the Level 4 certificate is a licence and signing for solar work alone.
- Assuming a Level 3 certificate automatically exempts you from Module One. Ask how it is recognised.
- Treating formative assessments as practice that "does not count": they are 60% of the unit score.
- Studying theory alone. Theory is only 10% and is asked orally while you work.
- Losing evidence. Photograph and file every assessed task, drawing and test record.

1.7 How to Use This Book

Each chapter opens with its outcomes, unit and key words, and contains:

- **Worked examples** with every step and unit shown. Cover the answer, try it yourself, then check.
- **Figures:** realistic drawings, technical diagrams with standard symbols, and data charts whose notes say whether the data are measured, from a datasheet or illustrative.
- **Boxes:** Safety first (read every one), Green tip, Trainer's tip, Common mistakes and On a Kenyan site.
- **Practical task cards**, **Check your competence** lists and **practice questions** (answers at the back).

Prices are given in Kenya shillings as "approximate, 2026"; always check current prices before quoting a client. Where a topic is already taught in the Level 3 guide, you will see a short summary and a reference such as "the Level 3 guide, Chapter 16".

> **TRAINER'S TIP**
>
> Start your portfolio of evidence on the first day. Buy a strong file, label a section for each unit and each element, and add photos, drawings, sizing sheets, test records and winding data sheets as you go. At assessment time and during industry training, a full portfolio speaks for you.

1.8 Professional Behaviour and Customer Care

During industry training your mentor rates not only your skills but your behaviour as a worker. The mentoring tool lists 17 qualities, and you must meet at least 75% of them. In plain terms, a good Level 4 worker:

- **communicates** clearly, works in a team and treats everyone fairly and with respect;
- is **tolerant, trustworthy and emotionally intelligent**, staying calm with difficult clients;
- **solves problems**, is open to correction, knows his or her own strengths and weaknesses, and looks for better ways of working;
- is **thorough**, **environmentally conscious**, on time and **presentable**;
- is **resilient and self-driven**, **disciplined** in following the organisation's code of conduct, and keen to grow.

With clients, professional behaviour means honest advice. Explain what a solar system can and cannot power before they pay; a client who expects a 150 W system to run a fridge, an iron and a water heater will be angry, however neat your work. Give written quotations, use genuine KEBS-marked products, hand over the documents and manuals, train the user, and come back when you promise. Respect the client's home and take your waste away.

Practical task 1.1: Workshop orientation and portfolio start

Tools and equipment

- Notebook and pen; phone camera
- PPE issued by the VTC: overall, safety boots, safety glasses

Materials

- Curriculum unit summaries (from your trainer)
- A ring file with dividers
- The VTC solar rig, alarm board and rewind bench (observe only)

Steps

1. Tour the workshop with your trainer. Record where the first-aid box, fire extinguishers, emergency stop or main isolator and exits are.
2. At the solar rig, list the main components you can see without touching anything. Do the same at the alarm board and the rewind bench.
3. Copy the learning outcomes and hours of each unit into your file (Figure 1.6) and mark the three heaviest PCs of each unit (Table 1.3).
4. Set up your portfolio: one section per unit, one divider per element, and a log page for hours of practice.
5. Write a short personal plan: which unit you expect to find hardest, and two worker behaviours you want to improve.
6. Show your file to your trainer and agree the date of your first formative assessment.

Safety

- Observe only: do not switch, connect or touch any rig, panel or machine during the tour.
- Wear the PPE you have been issued.

Chapter summary

- A Level 4 electrical worker installs, tests and maintains stand-alone solar PV systems and bell and alarm systems, and rewinds and tests motors, working from a given design.
- Jobs are found with solar and PAYG firms, contractors, alarm firms, maintenance departments, rewind workshops, water and agro-processing projects, and in self-employment.
- Solar work is licensed by EPRA under the Energy (Solar PV Systems) Regulations, 2012: technicians T1–T3, firms C1, V1, V2. The certificate is not a licence; work under a licence holder until you are licensed.
- The course is 980 hours and 98 credits: Module One 300 h (Level 3 guide), Module Two 360 h (this book) and industry training 320 h.
- Assessment: every PC, theory 10% and practical 90%, formative 60% and summative 40%; ratings Mastery 80+, Proficient 65+, Competent 50+.
- Certificates: Certificate of Competency per unit, Statement of Attainment per element, and the National Certificate when all units are passed.
- Professional behaviour and honest customer care count in your industry training and in your future business.

Check your competence

- [ ] I can describe the work of a Level 4 electrical worker and name five places that employ one.
- [ ] I can name the EPRA solar technician and firm classes and say what each covers.
- [ ] I can explain why I must work under a licence holder until I am licensed.
- [ ] I can state the hours and credits of each part of the course.
- [ ] I can name the heaviest performance criteria of each unit.
- [ ] I can calculate a unit score and rating from formative and summative marks.
- [ ] I can name the certificates CDACC awards and explain RPL.
- [ ] I can describe professional behaviour towards clients and mentors.

Practice questions

1. List four kinds of work a Level 4 electrical worker does that are not part of Level 3.
2. Name five types of employer for Level 4 workers in Kenya, with one example task for each.
3. State the hours and credits of Module One, Module Two and industry training, and the course total. About how many weeks is this at 40 hours a week?
4. Name the three EPRA solar technician classes and what each may install. Which firm class must be, or employ, a T3 technician?
5. A technician takes out a T2 licence and renews it each year. Using Table 1.1, calculate the total fees paid for the first three years.
6. A trainee scores 78 out of 120 in the formative assessments of the solar unit and 70% in the summative assessment. Calculate the unit score and give the rating.
7. In the bell and alarm unit a trainee has a formative score of 61% and a summative score of 45%. Calculate the unit score and rating. What would the rating be if the summative score were 30%?
8. Name the heaviest single performance criterion in each of the three units. Why should you practise these most?
9. (Oral) Explain the difference between a Certificate of Competency, a Statement of Attainment and the Kenya National Certificate Level 4. What do the codes Y, X and CRNM mean?
10. (Oral) What documents should a client receive when a solar installation is handed over, and for how long must the installer keep records?
11. (What is wrong?) A newly certified Level 4 trainee installs a solar system for a neighbour, signs the completion certificate in his own name, leaves without explaining how to use the system, and throws the old car battery into the bush. List everything that is wrong and what should have been done.
12. (Practical) Carry out Practical task 1.1 and present your portfolio file and personal plan to your trainer.

PART 2

Stand-Alone Solar PV Systems

Unit 1: Install Stand-Alone Solar PV Systems. Modules, charge controllers, batteries and inverters; drawings, the site survey and sizing a system; mounting the array and the equipment; wiring, terminating and earthing; testing and commissioning; and maintaining and troubleshooting a system so it keeps working for years.

Chapter 4: Solar PV System Components
Chapter 5: Solar Drawings, Site Survey and System Sizing
Chapter 6: Mounting Solar PV Components
Chapter 7: Wiring, Terminating and Earthing a Solar PV System
Chapter 8: Testing and Commissioning a Solar PV System
Chapter 9: Maintaining and Troubleshooting Solar PV Systems

CHAPTER 5

Solar Drawings, Site Survey and System Sizing

WHAT YOU WILL LEARN

- Recognise solar drawing symbols and agree a scope of work.
- Read and draw block, single-line, wiring and layout drawings, and map a wiring route.
- Explain irradiance, irradiation and peak sun hours, and use Kenyan solar data to choose a design value.
- Carry out a site survey: orientation, tilt, shading, roof, routes, battery location and security.
- Size a complete stand-alone system: loads, array, battery, controller, inverter, cables and protection.
- Prepare a bill of quantities and a quotation in Kenya shillings.

Unit: Stand-Alone Solar PV Systems · ENG/CU/EI/CR/01/4/MB · Learning outcome 2, with the calculations of learning outcome 1 · About 5 hours plus design practice

Mrs Chebet lives near Sigor in Bomet County. The Kenya Power line is more than a kilometre away, her house was wired years ago "for when the power comes", and she now wants solar for lights, a TV, a small fridge, phone charging, her son's laptop and the pump that fills her water tank. This chapter follows her job from the first conversation to the quotation. The drawings in Section 5.2 are the finished result; Sections 5.3 to 5.6 show where every number on them comes from.

Key words

Scope of work
A written list of what the installer will do and supply, and what is not included.

Block diagram
A simple drawing of boxes and arrows showing which parts are connected and which way energy flows.

Single-line diagram
A schematic in which one line stands for all the conductors of a circuit.

Layout drawing
A scale plan showing where equipment, points and cable routes are.

Irradiance
The power of sunlight falling on a surface at one moment, in watts per square metre (W/m²).

Irradiation
The energy of sunlight received over a period, usually a day, in kWh/m².

Peak sun hours (PSH)
The day's irradiation expressed as hours of full 1,000 W/m² sun. 5.2 kWh/m² a day = 5.2 PSH.

Days of autonomy
How many days the battery can run the loads with no sun at all.

Loss factor
The number (1.3 in this book) the daily load is multiplied by to allow for all system losses.

Bill of quantities (BoQ)
A list of every item needed for the job, with quantities, rates and amounts.

5.1 The Design Job and the Scope of Work

The steps of a design are always the same: talk to the client, survey the site, list the loads, size the parts, draw, price, agree the scope, then install. The **scope of work**, in plain words that the client reads before you start, protects both sides. It states:

- **What the client wants**: loads, hours, autonomy and planned loads.
- **What is included**: components with ratings, mounting, cabling, protection, earthing, testing, commissioning and client training.
- **What is not included**: for the Chebet home, rewiring the existing house wiring (it will be tested), the pump itself, building work and transport beyond an agreed distance.
- **Handover**: drawings, datasheets and manuals, test results, warranty terms and a simple user guide.

The Energy (Solar Photovoltaic Systems) Regulations, 2012 add a **system design declaration**, signed by the vendor or contractor and by the customer, and an **installation completion certificate** issued on completion. The installer keeps copies for at least five years. You prepare drawings and calculations, but a licensed technician of the right class signs the design (Chapter 1).

5.2 Symbols and Drawings

5.2.1 Symbols

Figure 5.1 shows the symbols you will meet on solar drawings. The schematic symbols follow the style of IEC 60617, the international standard for graphical symbols. Converters (controllers and inverters) are squares with a diagonal, with the kind of current marked in the corners. The layout symbols are those of house wiring (Level 3 guide, Chapter 7). Drawing offices vary, so always read the key on the drawing.

5.2.2 The four drawings of a solar job

Table 5.1 Drawings used on a stand-alone PV job

Drawing	What it shows	Who uses it, and when
Block diagram	Main parts as boxes, arrows for energy flow. No ratings.	Explaining to the client; first sketch.
Single-line (schematic) diagram	Every device with symbol, designation (Q1, F2 …) and rating; cable sizes and lengths.	Designer and installer; the design record.
Wiring diagram	Every conductor and terminal: + and − drawn separately, in red and black, with terminal names.	Installer at the board and battery; fault finding.
Layout drawing (plan)	The building to scale: array, routes, equipment, battery, earth rod, points.	Marking out; cable lengths; mapping the wiring.

Read the single-line diagram of the Chebet system (Figure 5.2 B) from left to right, as the energy flows: module PV1, 12 m of 6 mm² PV cable, PV isolator Q1, surge protective device F1, MPPT controller U1, DC breaker Q2, the DC busbars, then battery fuse F2 to the battery G1 and a branch to inverter U2, whose AC output feeds the consumer unit. Which battery post each cable lands on is shown only on the **wiring diagram**, which Chapter 7 draws for a 24 V system like this one.

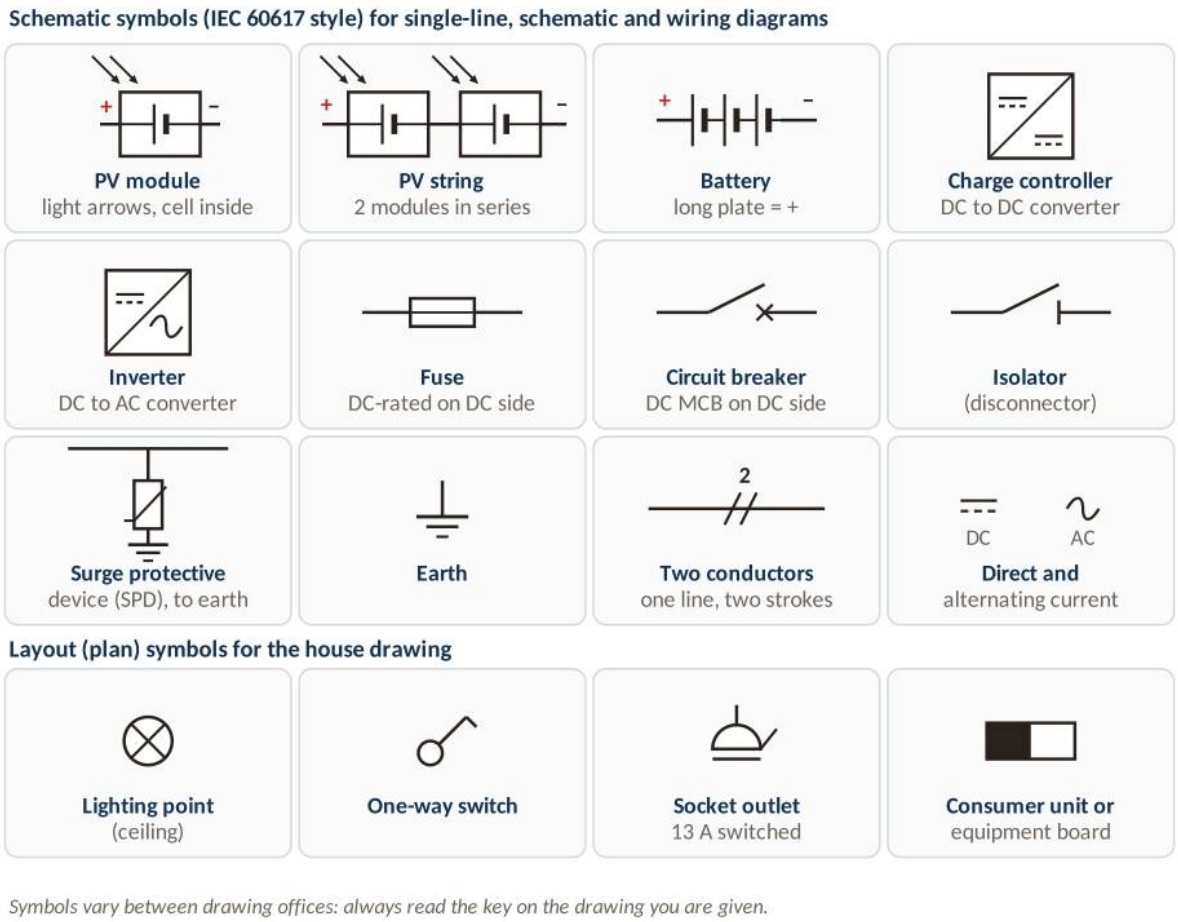


Figure 5.1 Symbols for stand-alone PV drawings. Rows 1–3: schematic symbols in IEC 60617 style; row 4: layout symbols used on house plans.

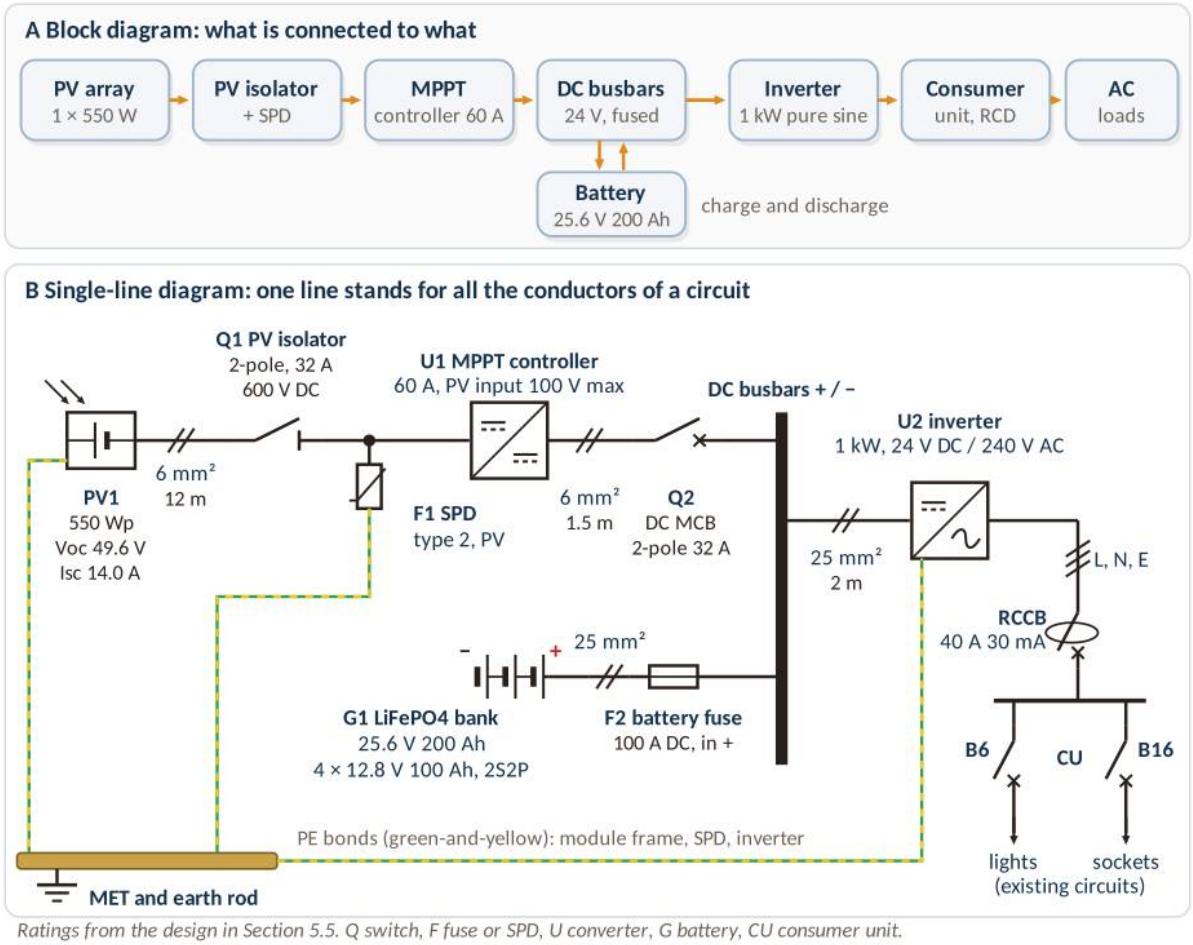


Figure 5.2 The Chebet design. A: block diagram. B: single-line diagram with designations, ratings and cable sizes, the information an installer needs.

5.2.3 The layout drawing and mapping the wiring

The single-line diagram says *what* is connected; the **layout drawing** (Figure 5.3) says *where*. At 1:100, 1 cm on paper is 1 m on site, so you can measure cable lengths from it. Mapping the wiring means planning every cable route on it before you drill. On the Chebet plan the module is on the north slope near the east end, so the PV cable is short (12 m including drops and spare). It runs under the rails, over the fascia and down the wall in UV-resistant conduit, never across a roof valley where water runs. The board and battery cabinet are side by side in a lockable room, so the battery cables are only about 2 m long, and the earth rod is just outside. Keep routes straight and inspectable, and label both ends.

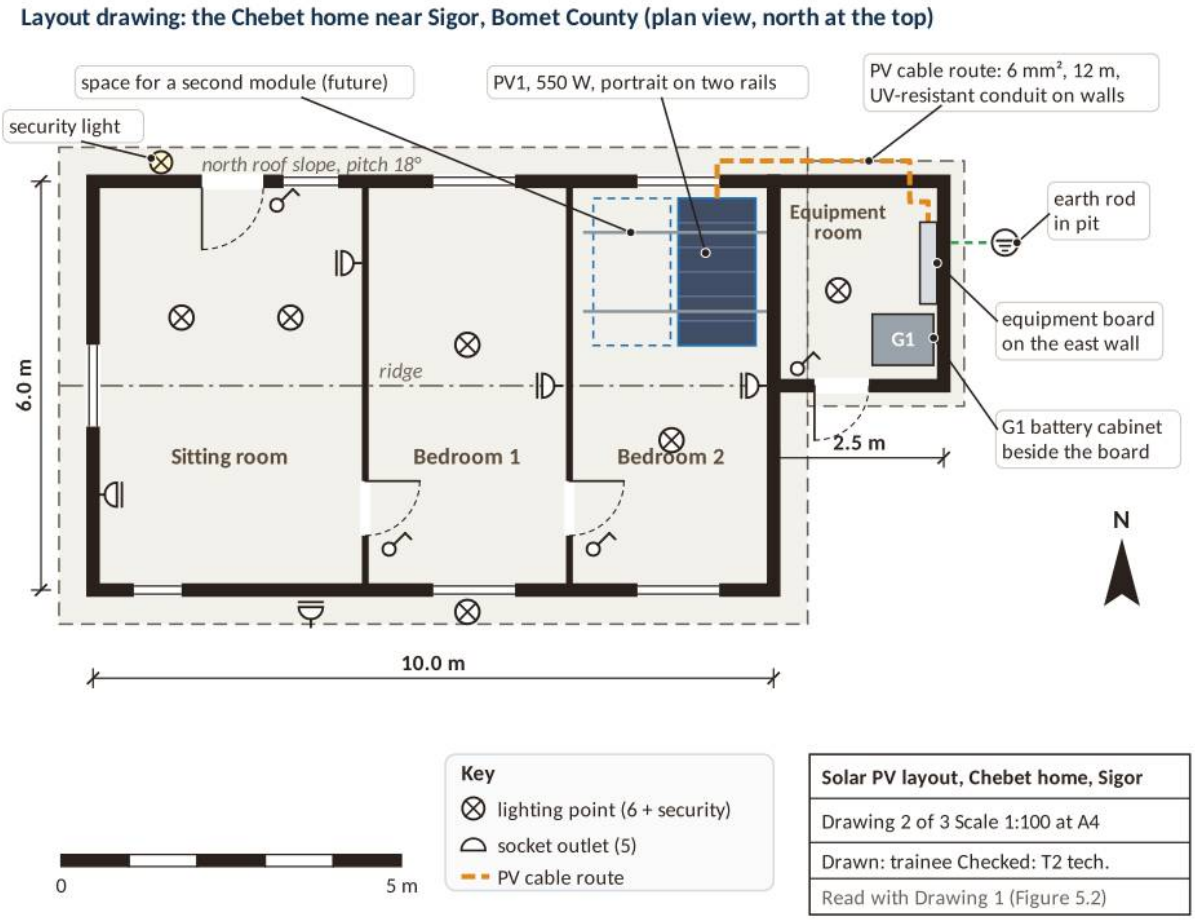


Figure 5.3 Layout drawing of the Chebet home: where the module, cable route, equipment, battery, earth rod and points are. Read it with Figure 5.2.

> **TRAINER'S TIP**
>
> Use the same designation (Q1, F2, U1 …) on every drawing and board label, so that a fundi opening the board in five years can find any breaker on your drawing in seconds.

5.3 Sunlight in Kenya

5.3.1 Irradiance, irradiation and peak sun hours

Irradiance is how strong the sunlight is *now*, in W/m² (Chapter 3). On a clear day it reaches about 1,000 W/m² at most, the standard test condition for modules. **Irradiation** is the solar *energy* received over a day, in kWh/m². In Figure 5.4 the shaded area under the clear-day curve, 6.5 kWh/m², equals the blue box of 1,000 W/m² for 6.5 hours: that is the idea of **peak sun hours**. Numerically, PSH and kWh/m² per day are the same number, so a 550 W module in 6.5 PSH makes about 550 × 6.5 = 3,575 Wh before losses.

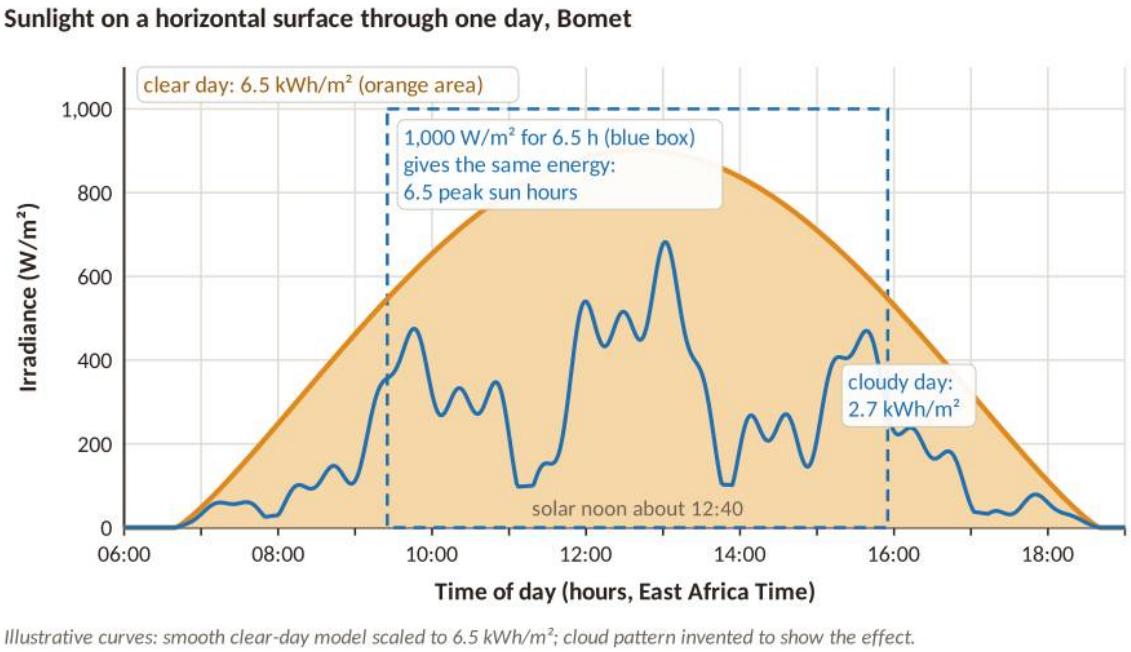


Figure 5.4 Irradiance through one day at Bomet. The blue box of 1,000 W/m² for 6.5 hours holds the same energy, so the clear day gives 6.5 peak sun hours.

5.3.2 Monthly variation and the design value

Figure 5.5 uses NASA POWER satellite data averaged over 25 years. Bomet averages 5.78 PSH, with the best month February (6.57) and the worst June and July (5.17). Nairobi averages 5.82 but falls to 4.74 in June, when the highlands and coast are cloudy. So design for the **worst month**. This book uses **5.0 PSH** for most of Kenya and **4.5 PSH** for Nairobi, Central and the Coast if the system must work fully in June and July. For other sites, use NASA POWER or the Global Solar Atlas (both free online).

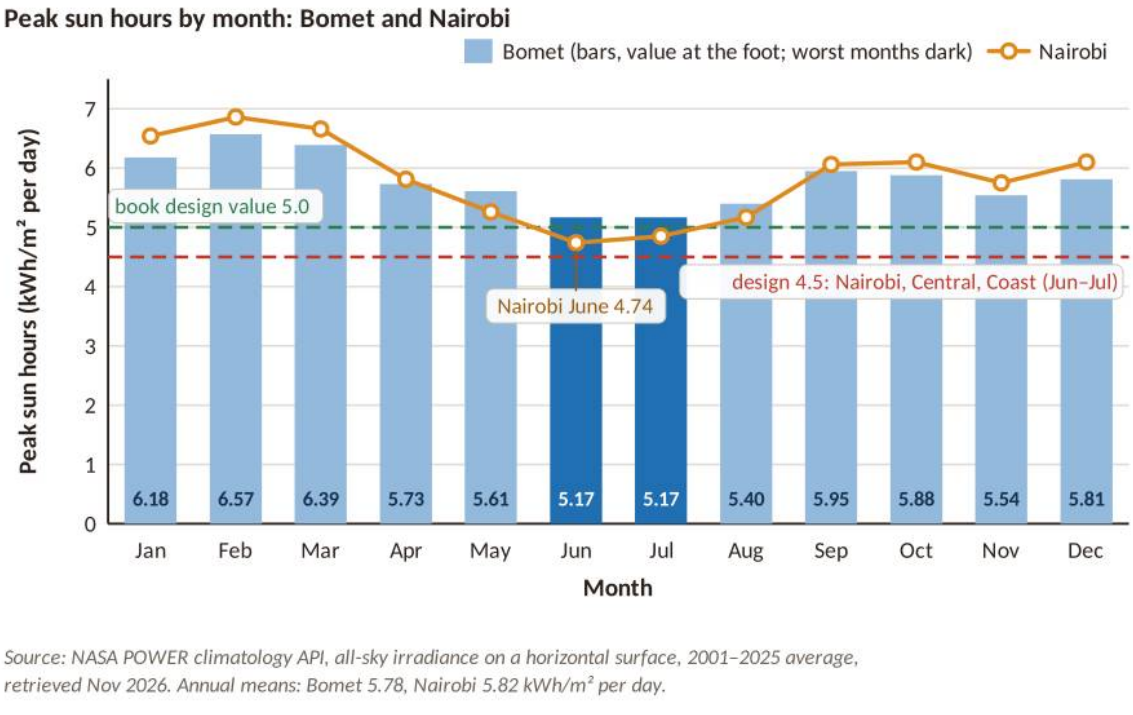


Figure 5.5 Monthly peak sun hours at Bomet and Nairobi. Design for the worst month, not the yearly average.

WORKED EXAMPLE 5.1: WHAT ONE MODULE GIVES THROUGH THE YEAR

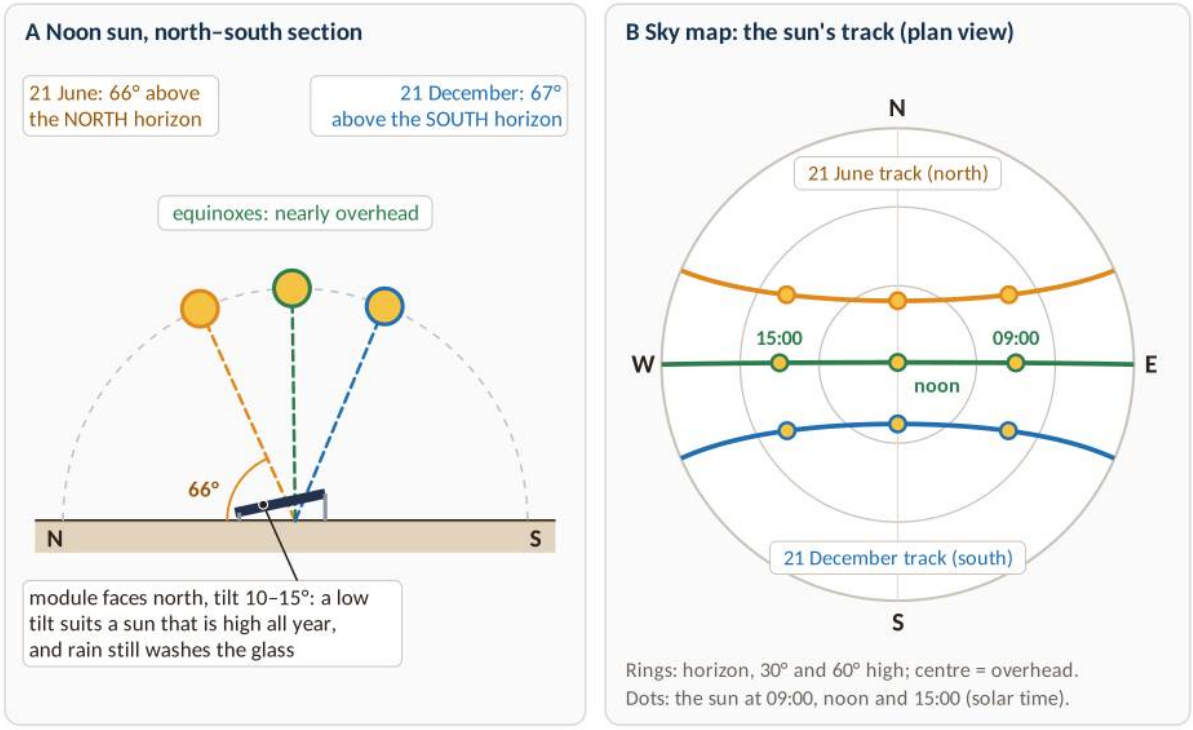
A 550 W module, all losses allowed for by the loss factor 1.3. **Bomet, February:** 550 × 6.57 ÷ 1.3 = **2,780 Wh** a day. **Bomet, June:** 550 × 5.17 ÷ 1.3 = **2,187 Wh**, 21% less (2,187 ÷ 2,780 = 0.79). **Nairobi, June:** 550 × 4.74 ÷ 1.3 = **2,005 Wh**. Size for June and the system works all year.

5.3.3 The sun's path near the equator: orientation and tilt

Bomet lies about 0.8° south of the equator, so the noon sun is always high, between about 66° and nearly 90°: north of overhead from late March to late September, south of it otherwise (Figure 5.6).

- **Tilt.** Almost flat gives the most energy but collects dust and water, so this book uses **10–15°**, enough for rain to wash the glass; a 15–20° mabati roof is fine as it is.
- **Orientation.** South of the equator, face the modules roughly **north**; north of it, roughly **south**. At a low tilt near the equator the direction matters little (Chapter 6 gives the numbers), so use the roof slope that is free of shade and nearest the equipment room.

In Kenya a compass points very close to true north; keep it away from steel. Solar noon at Bomet is about 12:40 East Africa Time.

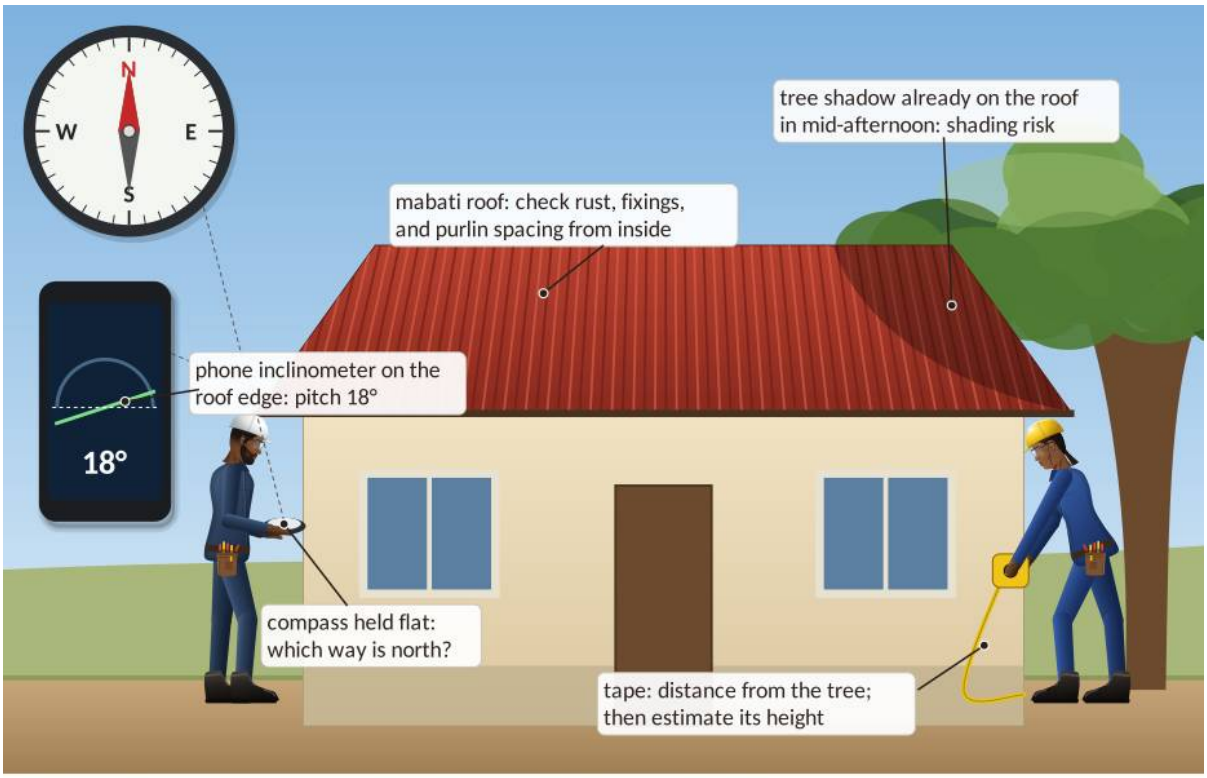


Calculated for latitude 0.78° S with the standard sun-position formulas (declination ±23.44°). At 09:00 and 15:00 the sun is only 40–45° high and lies to the east or west: trees and buildings on those sides cause most shading.

Figure 5.6 The sun's path at Bomet. A: the noon sun is high all year, north of overhead in June and south of it in December. B: its daily track seen from above.

5.4 The Site Survey

The survey is where the design is won or lost. Take the survey form (Table 5.2), a compass, a phone with an inclinometer app, a 30 m tape, a torch, a camera and a ladder. Talk to the client first, then walk the site with them.



Art library (site-survey). Record every reading on the survey form (Table 5.2) with photos.

Figure 5.7 A site survey. The technicians find north, measure the roof pitch and check the tree that will shade part of the roof.

5.4.1 The client interview and the load list

Ask what the client wants to run, how many, for how long and at what time of day. Read every rating plate, or measure the current with a clamp meter. Ask about future loads, daytime use (it needs less storage), budget and theft risk. This is also the moment to **cut the load**: LED lamps, an efficient fridge, phones and pumping in the daytime. Every watt-hour saved here saves modules and batteries.

5.4.2 Roof or ground?

Check the roof from outside and, with a torch, from inside: sound purlins and rafters (Chapter 6 fixes the rails to them), sheets not rusted through, and enough free area. A 550 W module is 2.27 m by 1.13 m and weighs 28.9 kg. Record the pitch, the purlin spacing and the sheet type. Never walk on or drill asbestos; refer that roof to a specialist. If the roof is weak, shaded or faces the wrong way, a ground frame (Chapter 6) may be better.



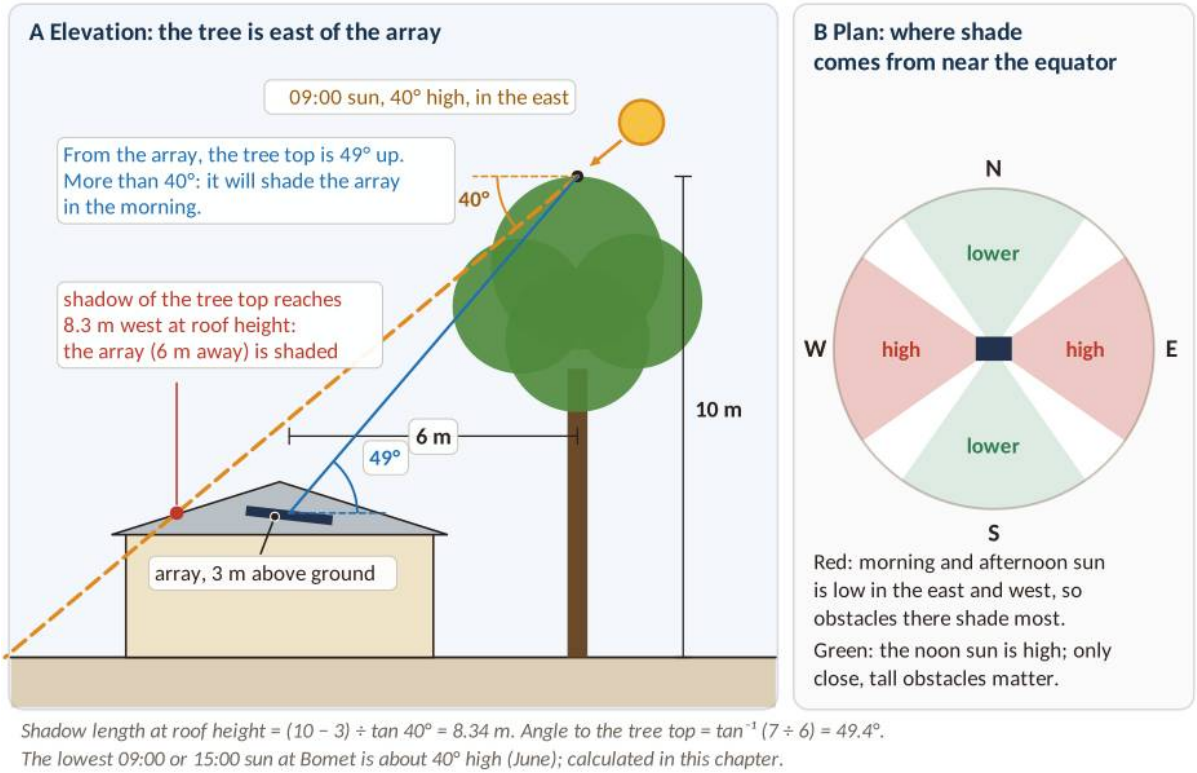
Figure 5.8 A rural home with a small module and a satellite dish. What would you record here? Look at the patched sheets, the trees close to the roof and the space for more modules.

Photo: ROYMUNENE, CC BY-SA 4.0, via Wikimedia Commons

5.4.3 Checking for shade

A module partly covered by a branch can lose a third or more of its output. Look for trees (which grow), tanks, chimneys, poles and dishes. Near the equator the main risk is from obstacles to the east and west (Figure 5.9 B). Three hours either side of solar noon the sun at Bomet is never lower than about 40° (on 21 June). So, with the inclinometer app:

1. Stand at the array position (or on a ladder at the same height).
2. Measure the angle up to the top of each obstacle to the east and west.
3. If the angle is **more than 40°**, the obstacle will shade the array during the main generating hours. If it is less, it shades only early or late, when there is little energy anyway.



Shadow length at roof height = (10 − 3) ÷ tan 40° = 8.34 m. Angle to the tree top = $\tan^{-1}$ (7 ÷ 6) = 49.4°.
The lowest 09:00 or 15:00 sun at Bomet is about 40° high (June); calculated in this chapter.

Figure 5.9 Checking shade from a tree. A: the 09:00 sun at 40° puts the shadow of a 10 m tree 6 m away across the array. B: near the equator, obstacles to the east and west matter most.

WORKED EXAMPLE 5.2: WILL THE TREE SHADE THE ARRAY?

A tree 10 m high stands 6 m east of an array that is 3 m above the ground. The lowest morning sun to allow for is 40°.

Height above the array: 10 − 3 = 7 m. **Angle to the top:** tan θ = 7 ÷ 6 = 1.167, θ = **49.4°**, more than 40°: the tree shades the array in the morning.

Shadow length at roof height: 7 ÷ tan 40° = 7 ÷ 0.839 = **8.34 m**, so the array would need to be at least 8.3 m from the tree.

Or trim it below 3 + 6 × 0.839 = **8.0 m**, with the owner's agreement.

5.4.4 Equipment, battery, earthing and security

Put the equipment and battery together near the array, in a dry, shaded, ventilated, lockable place, never in a bedroom, kitchen or exit route. Table 5.2 lists what to record.

Table 5.2 Site survey checklist, completed for the Chebet home

Item	Check and record	Chebet home
Client and site	Name, phone, GPS location, access	Near Sigor; grid over 1 km away
Loads	Appliances, watts, hours, time of use, plans	Table 5.3; second module later
Roof	Type, condition, pitch, slope directions, purlins	Mabati, sound; 18°; N and S slopes; 50 × 75 mm purlins
Shading	Angle to the top of each obstacle east and west	Cypress 15 m west, top at 31°: acceptable
Equipment room	Size, ventilation, heat, lock, distance to array	Store room on the east end, 2.5 × 3 m, lockable
Cable routes	PV, battery and AC run lengths; wall entries	PV 12 m; battery–inverter 2 m
Earthing and wiring	Rod position; existing circuits	New rod; two circuits, to be tested
Security; photos	Theft, children, exits; photos of roof, route, plates	Lockable room; 12 photos

SAFETY FIRST

A survey involves ladders and roofs. Follow Chapter 2: ladder footed and tied at 1 : 4, extending 1 m above the eaves; walk only on the purlin (screw) lines of mabati; never step on fragile sheets, skylights or asbestos; no roof work in rain, wind or lightning. Treat any existing solar system as live.

5.5 Sizing Step by Step: the Chebet Home

We now size the Chebet system with the book constants: design PSH 5.0, loss factor 1.3, autonomy 2 days, and the battery, controller and inverter rules of Chapter 4.

5.5.1 Step 1: the load table

List every load: watts × hours = watt-hours a day. A fridge's compressor switches on and off, so use its energy label (kWh per year ÷ 365) instead of watts × 24 h; its starting surge, like a pump's, matters for the inverter, not for the energy.

Table 5.3 Load table of the Chebet home (all loads on the 240 V inverter output)

Load	Qty	W each	Total W	Hours a day	Wh a day
LED lamps (rooms)	6	9	54	4	216
LED security light	1	10	10	11	110
TV, 32-inch LED	1	50	50	5	250
Satellite decoder	1	15	15	5	75
Radio	1	10	10	6	60
Phone chargers	3	10	30	2	60
Laptop	1	45	45	3	135
Fridge, 120 L, A-rated	1	80	80	label	400
Surface water pump 0.5 hp	1	370	370	1	370
Totals			**664**		**1,676**

The fridge label says 146 kWh a year: 146,000 Wh ÷ 365 = 400 Wh a day. The daily total is **1,676 Wh**, and everything at once would draw **664 W**. Figure 5.10 shows when: the pump runs at midday, straight from the sun; the evening peak must come from the battery.

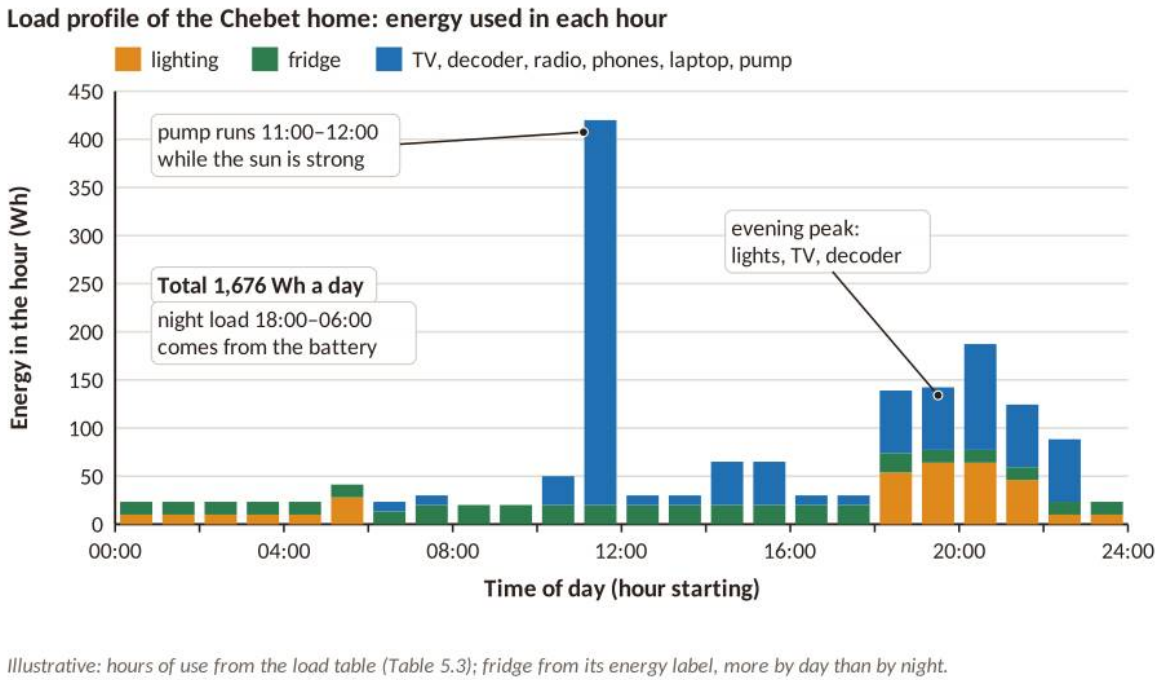


Figure 5.10 Load profile of the Chebet home: a midday peak (the pump, in full sun) and the evening, when it must come from the battery.

5.5.2 Step 2: the system voltage

The book guide is 12 V for loads up to about 600 W, 24 V up to about 1.5 kW and 48 V above. The Chebet loads total 664 W, so the system is **24 V**, which also halves the currents compared with 12 V.

5.5.3 Step 3: the PV array

> **WORKED EXAMPLE 5.3: ARRAY FOR THE CHEBET HOME**
>
> **Energy the array must supply:** 1,676 Wh × 1.3 = **2,178.8 Wh** a day.
>
> **Array power:** 2,178.8 Wh ÷ 5.0 h = **435.8 W**.
>
> **Number of modules:** 435.8 ÷ 550 = 0.79, rounded **up** to **one 550 W module**.
>
> **Check:** 550 × 5.0 ÷ 1.3 = 2,115 Wh a day, 26% more than needed; in Bomet's worst month (5.17 PSH) 2,187 Wh.

Always round up. The spare 26% covers a bad week, ageing and growth; the rails take a second module later.

5.5.4 Step 4: the battery bank

Battery capacity (Ah) = daily Wh × days of autonomy ÷ (battery efficiency × DoD × battery voltage), with 0.95 and 80% for LiFePO4 and 0.85 and 50% for lead-acid.

> **WORKED EXAMPLE 5.4: BATTERY BANK, LIFEPO4 AGAINST LEAD-ACID**
>
> **Energy for two days:** 1,676 × 2 = 3,352 Wh.
>
> **LiFePO4 at 25.6 V:** 0.95 × 0.8 × 25.6 = 19.456. Capacity = 3,352 ÷ 19.456 = **172.3 Ah**, so **200 Ah**: four 12.8 V 100 Ah batteries, two in series and two such strings in parallel (**2S2P**). Usable 25.6 × 200 × 0.8 = 4,096 Wh (2.4 days). Cost 4 × KSh 30,000 = **KSh 120,000**.
>
> **Gel lead-acid at 24 V:** 3,352 ÷ (0.85 × 0.5 × 24) = 3,352 ÷ 10.2 = **328.6 Ah**, so **400 Ah** (four 12 V 200 Ah, 2S2P). Cost 4 × KSh 38,000 = **KSh 152,000**, and it wears out several times sooner (Chapter 4).
>
> LiFePO4 is cheaper here and lasts longer (prices approximate, 2026). Check that the maker allows series and parallel connection.

Figure 5.11 checks the design hour by hour: on a design day the battery is full by about 14:00, and after a whole cloudy day it still ends at about 73%, far above the 20% lowest level.

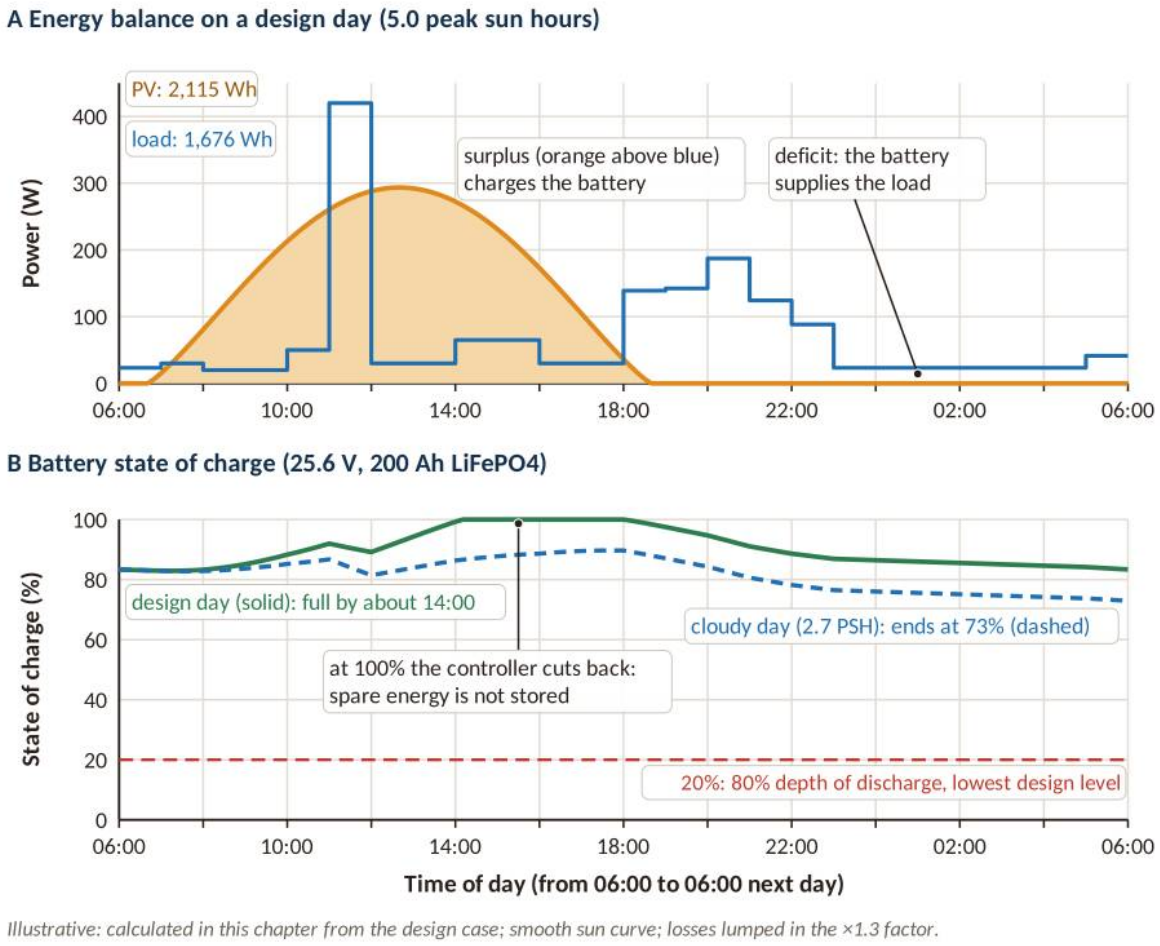


Figure 5.11 Energy balance. A: on a design day the module gives more than the home uses. B: the battery fills by early afternoon; after a cloudy day it still holds most of its charge.

5.5.5 Step 5: the charge controller

The module's Vmp of 40.9 V is far above the battery voltage, so the controller must be **MPPT**. (A small 12 V system with a matched "12 V" module can use PWM, sized at 1.3 × Isc: Chapter 4.)

WORKED EXAMPLE 5.5: MPPT CONTROLLER

Current: (550 ÷ 24) × 1.2 = 22.9 × 1.2 = **27.5 A**. We choose a **60 A** unit (KSh 15,000), which also covers a second module: (1,100 ÷ 24) × 1.2 = 55 A.

Voltage on a cold morning: at 10 °C the cells are 15 °C below STC, and Voc rises 0.28% per °C: 49.6 × (1 + 0.0028 × 15) = 49.6 × 1.042 = **51.7 V**, well below the controller's 100 V maximum.

The second module: two in series would give 2 × 51.7 = 103.4 V, **above 100 V**, which can destroy the controller. With this controller it must go **in parallel**.

5.5.6 Step 6: the inverter

WORKED EXAMPLE 5.6: INVERTER RATING AND BATTERY CURRENT

Continuous: 664 W × 1.25 = 830 W, so a **1,000 W, 24 V pure sine** inverter.

Surge: the pump may need 3 × 370 = 1,110 W at start. With everything else running (664 − 370 = 294 W) the peak is 1,110 + 294 = **1,404 W**. The inverter's 2,000 W surge rating covers it.

DC current at full output: 1,000 ÷ (0.9 × 24) = **46.3 A**; during the 2,000 W surge, 2,000 ÷ (0.9 × 24) = 92.6 A for a few seconds.

5.5.7 Step 7: cables and protection

Choose each cable for its current, then check the voltage drop with Vd = 2 × L × I × r (Chapter 3), aiming for 3% or less. Rate each protective device at least 1.25 × the normal current but small enough to protect its cable, DC-rated on the DC side. Add a PV SPD, bond the frame, rails, SPD and inverter to the earth rod, and fit a 30 mA RCCB on the AC output (Chapter 7).

WORKED EXAMPLE 5.7: CABLES, FUSES AND BREAKERS

PV cable, 12 m, Imp 13.45 A, Vmp 40.9 V. 4 mm²: Vd = 2 × 12 × 13.45 × 0.00461 = 1.49 V = **3.6%**, too much. 6 mm²: Vd = 2 × 12 × 13.45 × 0.00308 = 0.99 V = **2.4%**. Use **6 mm²**.

PV isolator Q1: at least 1.25 × 14.0 = 17.5 A, and above the cold Voc of 51.7 V: a 2-pole 32 A, 600 V DC isolator. (A second module would need 35 A: note it.)

Controller to battery: about 550 ÷ 24 = 22.9 A; Q2 at least 1.25 × 22.9 = 28.6 A, so a **32 A 2-pole DC MCB**. On 6 mm² for 1.5 m: Vd = 2 × 1.5 × 22.9 × 0.00308 = 0.21 V = **0.9%**.

Battery to inverter: 46.3 A, 2 m. On 25 mm²: Vd = 2 × 2 × 46.3 × 0.000727 = 0.135 V = **0.6%**. Fuse F2 at least 1.25 × 46.3 = 57.9 A but not blowing on the 92.6 A surge: a **100 A DC fuse** in the positive, close to the battery.

5.6 Bill of Quantities and Quotation

The bill of quantities (BoQ) lists every item from the drawings with a quantity, a rate and an amount. Count from the drawings, not from memory: each device on the single-line diagram, each metre of cable on the layout (plus about 10% spare), each L-foot on the roof plan. Table 5.4 uses the book prices of Chapter 4, Level 3 book prices for AC parts and labour, and retail listings for the rest; two items are estimates.

Table 5.4 Bill of quantities for the Chebet home (KSh, approximate, 2026). Basis: B book price, R retail listing, L3 Level 3 book price, E estimate

No.	Item	Qty	Rate	Amount	Basis
1	PV module, 550 W mono (Vmp 40.9 V)	1 no.	13,000	13,000	B
2	Mounting kit: 2 rails 4.2 m, clamps, 8 L-feet	1 set	11,740	11,740	R
3	MPPT controller 60 A, 12/24 V, 100 V input	1 no.	15,000	15,000	B
4	LiFePO4 battery 12.8 V 100 Ah (2S2P bank)	4 no.	30,000	120,000	B
5	Inverter-charger 1 kW pure sine, 24 V	1 no.	30,000	30,000	B
6	PV cable 6 mm² red and black, 30 m; 2 MC4 pairs	1 lot	6,200	6,200	B
7	PV DC isolator, 2-pole, 32 A, 600 V DC	1 no.	2,000	2,000	R
8	DC surge protective device (PV)	1 no.	5,500	5,500	B
9	DC MCB 2-pole 32 A	1 no.	3,500	3,500	B
10	Battery fuse 100 A with holder	1 no.	4,500	4,500	R
11	Battery cable 25 mm², red and black	8 m	850	6,800	R
12	Consumer unit 4-way, RCCB 40 A 30 mA, MCBs B6 and B16	1 set	6,800	6,800	L3
13	Earth rod 1.2 m, clamp, 10 m of 10 mm² earth cable	1 set	5,000	5,000	L3
14	UV-resistant PVC conduit 20 mm and fittings	1 lot	1,450	1,450	L3
15	Sundries: lugs, heat-shrink, busbars, labels, board	1 lot	6,000	6,000	E
16	Battery shelf or cabinet, made locally	1 no.	8,000	8,000	E
17	Labour: technician	3 day	2,000	6,000	L3
18	Labour: helper	3 day	1,000	3,000	L3
	Materials			**245,490**	
	Labour			**9,000**	
	Total (VAT included in retail prices)			**254,490**	

The batteries are about 47% of the total and the module only about 5%, which is typical: the load list and the autonomy drive the cost. With one day of autonomy the battery would be 1,676 ÷ 19.456 = 86.1 Ah, so 100 Ah at 25.6 V, saving KSh 60,000 at the price of less reserve. Offer such choices in writing; do not decide for the client.

The **quotation** is built from the BoQ. It adds transport, overheads and profit, and states the validity (often 14 or 30 days), payment terms, scope and warranties (under the 2012 regulations at least 20 years for modules, 10 years for controllers and inverters and 1 year for batteries). Prices in this book are approximate, 2026: always get current prices before you quote.

GREEN TIP

Size the loads before the system. An old fridge using 400 Wh a day more would push the battery past 200 Ah (2,076 × 2 ÷ 19.456 = 213 Ah): two more batteries, about KSh 60,000, and more to recycle later.

ON A KENYAN SITE

A school bursar shows you another firm's quotation: "3 kW solar", with one 300 W module and a 3 kW inverter. The energy comes from the module and battery, and one 300 W module makes only about 300 × 5 ÷ 1.3 = 1,150 Wh a day. Your load table and a clear explanation of watts against watt-hours protect the client from a bad buy.

COMMON MISTAKES

- Sizing on the yearly average sun instead of the worst month, so the system fails every June and July.
- Taking a fridge as rated watts × 24 hours, or forgetting the starting surge of fridges and pumps.
- Rounding the number of modules or batteries down "to save money".
- Forgetting the cold-morning rise in Voc, and exceeding the controller's maximum input voltage.
- Choosing cable by current only and ignoring voltage drop on long low-voltage runs.
- Single-line diagrams without ratings or cable sizes.
- Surveying at noon only and missing the tree that shades the roof every morning.

Practical task 5.1: Survey a site and complete a load table

Tools and equipment

- Hand-bearing compass
- Phone with inclinometer app, or angle finder
- 30 m tape measure
- Clamp meter (AC/DC) and multimeter
- Ladder, helmet, gloves, safety boots
- Camera or phone; torch

Materials

- Survey form (copy of Table 5.2)
- Load table form (copy of Table 5.3)
- Clipboard, pencil, squared paper
- Monthly PSH data for your town (Figure 5.5 or NASA POWER)

Steps

1. Interview the "client" (the VTC, a staff house or a neighbour) about loads, hours, time of use and plans.
2. Read every rating plate; clamp two appliances and compare with the plate.
3. Find north, away from steel; sketch the roof slopes, measure pitch, free area and purlins, and photograph the roof.
4. From the array position, measure the angle to every obstacle east and west; record any above 40°.
5. Choose the equipment, battery and earth rod positions and measure the cable runs.
6. Complete the load table and suggest two ways to reduce the load.

Safety

- Ladder footed and tied at 1 : 4, 1 m above the eaves; stay on the purlin lines; no roof access in rain or wind.
- Do not open or touch any existing solar or electrical equipment unless your trainer has isolated it.

Practical task 5.2: Size the system and draw the design

Tools and equipment

- Calculator or spreadsheet
- Scale rule, set squares, symbol template
- Coloured pencils (red, black, brown, blue, green)

Materials

- Your survey and load table from Practical task 5.1
- Module, controller, battery and inverter datasheets
- A3 drawing paper or a free drawing app
- Price list (Chapter 4 and Table 5.4)

Steps

1. Choose the system voltage and size the array, battery, controller (check the cold Voc) and inverter, showing every step with units.
2. Size every cable for voltage drop (3% or less) and choose every fuse, breaker and isolator.
3. Draw the block and single-line diagrams, the DC wiring diagram (red and black, every terminal named) and the layout drawing to scale with cable lengths.
4. Prepare the BoQ and a one-page scope of work, and present the design to your trainer as if to the client.

Safety

- On every drawing, show the battery fuse close to the battery positive and use only DC-rated devices on the DC side.
- Have a licensed technician check the design before anything is bought or installed.

Chapter summary

- A solar job runs: interview, survey, load table, sizing, drawings, BoQ, scope, installation; the design is declared and signed (2012 regulations).
- Block diagrams show what connects to what; single-line diagrams add ratings and cable sizes; wiring diagrams show every conductor; layout drawings show where, to scale.
- Irradiance is W/m² now; irradiation is kWh/m² per day, which equals peak sun hours. Design for the worst month: 5.0 PSH for most of Kenya, 4.5 for Nairobi, Central and the Coast.
- Near the equator, tilt modules 10–15° for self-cleaning, facing away from the equator; obstacles east and west cause most shade.
- Array Wp = daily Wh × 1.3 ÷ PSH; battery Ah = daily Wh × days ÷ (efficiency × DoD × V); round up.
- MPPT current = (Wp ÷ V) × 1.2, with the cold Voc below the maximum input; inverter = total W × 1.25 with enough surge for motors.
- Size cables for 3% drop or less and protective devices at 1.25 × current, DC-rated on the DC side.
- Batteries are often half the cost: cut the load and agree the autonomy.

Check your competence

- [ ] I can identify and draw the symbols used on solar PV drawings.
- [ ] I can write a scope of work and explain the declaration and certificate.
- [ ] I can read and draw block, single-line, wiring and layout diagrams, and map a wiring route on a plan.
- [ ] I can explain peak sun hours and choose a design value from monthly data.
- [ ] I can carry out a site survey, including orientation, tilt and a shading check.
- [ ] I can size the array, battery, controller and inverter of a stand-alone system.
- [ ] I can size cables for voltage drop and choose DC-rated protective devices.
- [ ] I can prepare a bill of quantities and explain the quotation to a client.

Practice questions

1. Draw the symbols for a PV module, a battery, a charge controller, an inverter, a fuse, a circuit breaker, an isolator and an SPD. How do you show the positive plate of a battery?
2. List four things a scope of work should state. Which two documents do the 2012 solar regulations require the installer to give the owner, and how long must records be kept?
3. Explain the difference between a block diagram, a single-line diagram and a wiring diagram. Which one would you take to the battery to make the connections, and why?
4. Explain the difference between irradiance and irradiation. A clear day gives 6.2 kWh/m². How many peak sun hours is that, and what energy would a 550 W module give the loads (loss factor 1.3)?
5. Using Figure 5.5, explain why a designer in Nairobi should not use the annual mean of 5.82 PSH. What design value does this book recommend there?
6. A water tank 4 m high stands 3 m west of a ground-mounted array whose modules are 1 m above the ground. Will it shade the array at 15:00? Show your working.

7. A home uses 6 LED lamps of 7 W for 5 h, a 30 W DC TV for 4 h and 3 phones at 5 W for 3 h. Calculate the daily Wh and size a 12 V system: array (PSH 5.0), LiFePO4 battery for 2 days, and a PWM controller if the module's Isc is 9.4 A.
8. A school dormitory has 16 LED tubes of 18 W used 5 h and 4 security lights of 20 W used 12 h. Size a 24 V system with 550 W modules and LiFePO4 batteries for 2 days of autonomy. What MPPT rating is needed, and can the modules be in series on a controller with a 100 V maximum input?
9. An inverter of 1,500 W runs from a 24 V battery at 90% efficiency. Calculate the DC current at full output and the minimum battery fuse rating. Why must the fuse be DC-rated?
10. A PV cable run is 18 m; the string gives 13.45 A at 40.9 V. Calculate the voltage drop and percentage drop for 6 mm² and 10 mm² cable. Which would you choose?
11. (What is wrong?) A drawing handed to you shows: the battery fuse in the negative at the inverter end; an AC MCB between the controller and the battery; the inverter supplied from the controller's LOAD terminals; two 550 W modules in series on a controller rated 100 V maximum; no cable sizes. Explain each fault and correct it.
12. (Practical) Carry out Practical tasks 5.1 and 5.2 for a site chosen by your trainer, and present the design, drawings and bill of quantities.

Enjoyed this sample?

This free sample has the front matter, Chapter 1 and the full Chapter 5 on solar drawings, site survey and system sizing. The complete guide has **16 chapters** and **336 pages**. It covers all three Level 4 units (Stand-Alone Solar PV Systems, Bell and Alarm Systems and Electrical Machine Winding) plus the 320-hour industry training: components, sizing, mounting, wiring, testing, commissioning and maintenance of solar systems; bell, intruder and fire alarm circuits; and rewinding, reassembling and testing motors.

It also includes 145+ realistic illustrations, diagrams, charts and photos, practical tasks, practice questions with full answers, filled test certificates and reports, a mock assessment, a 200-term glossary, a symbols reference and logbook pages.

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