COURSE HANDBOOK

SOLAR PHOTOVOLTAIC INSTALLATION

European Union

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DEUTSCHE ZUSAMMENARBEIT

USAID
FROM THE AMERICAN PEOPLE

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Solar Photovoltaic Installation

Course Handbook for a 160-hours training course for technicians
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This manual is dedicated to
Walter Hunner,
the man who conceived NESP
and paved the way for this training course
and who lost his life in an accident
on Nigerian soil on June 3, 2012.

CONTENTS

1. THE SOLAR RESOURCE

About this module

The main input that enables solar panels to generate electricity is the sun. In this module, students are introduced to the concept of converting energy from the sun into electricity.

Learning outcomes

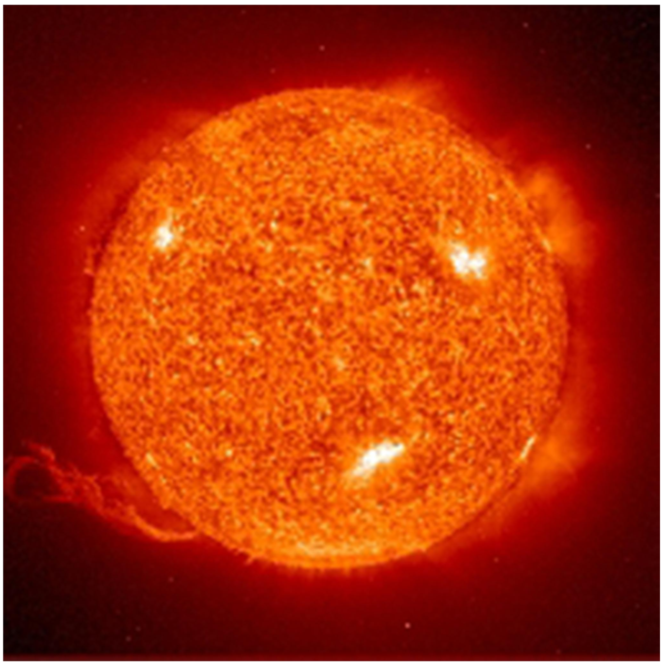
At the end of this module, the participant is able to

- Explain how the solar resource is distributed across Nigeria's climate zones
- Understand the basics of solar photovoltaics

1.1. The sun as a source of energy

We call energy from the sun "renewable", not because it can be refreshed or restored once burnt out, but because its supply is nearly endless. It has given us light on earth for more than 4,000 million years and will continue to brighten the lives of countless generations to come. Though it is terribly far away, it is also incredibly powerful and is the basis of all forms of life or energy on earth.

Energy from the sun



Our sun – Courtesy: NASA

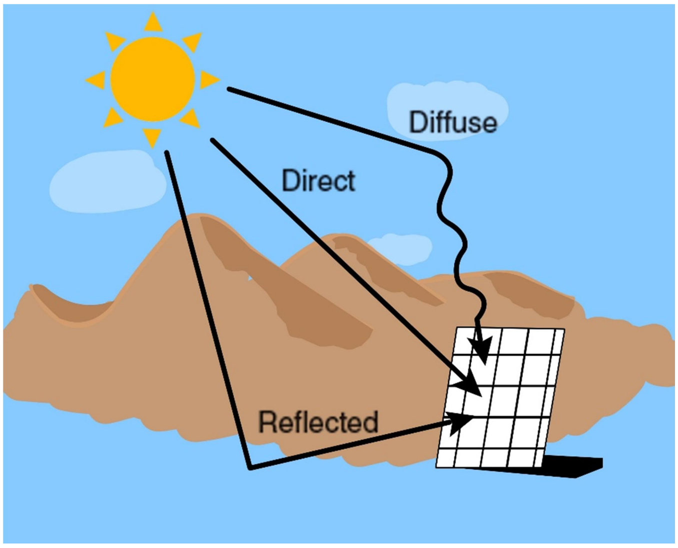
- Solar energy refers to rays from the sun (radiation) that reach earth. This energy can be converted into heat and electricity using different technologies.
- Solar power is energy from the sun. "Solar" is Latin and means "relating to the "sun". Without this powerful energy source, there would be no life. Solar energy is considered renewable due to its plentiful supply.

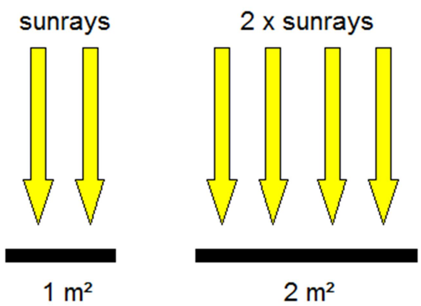
ADVANTAGES OF SOLAR ENERGY

1. Solar energy is virtually limitless and will not be exhausted in the lifetime of any human.
2. Technology used to convert sunlight into electricity does not produce smoke (carbon dioxide and other air pollutants).
3. Harnessing the sun's energy does not harm the environment.

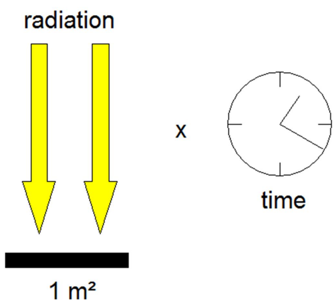
1.2. Estimating available solar energy

Radiation and irradiance





An area of 2 m² receives the double amount of solar power (W) than an area of 1 m²



When radiation hits a surface, more and more energy builds up on the surface over time. We call this accumulated energy irradiation.

SOLAR RADIATION

- The term solar radiation refers to energy emitted by the sun. It consists mostly of radioactive energy and light.
- Radiation that is not reflected or scattered but reaches the earth's surface directly is called direct radiation (G_B).
- Scattered radiation that reaches the earth's surface is called diffuse radiation (G_D).
- Reflected radiation (G_R) is the radiation reflected back into orbit on reaching the earth.
- Total global radiation (G) is the sum of three types above: $G = G_B + G_D + G_R$.
- Not all radiation from the sun is visible. Radiation can also come in the form of invisible infrared or ultraviolet radiation. Solar systems can even use parts of the invisible radiation to generate electricity.

IRRADIANCE

- Solar radiation carries power and the unit for measuring power is watt (W). Solar radiation power is called irradiance.
- However, the amount of power depends on the strength of the radiation (how strong the sun shines) and on the size of the surface it shines on. A larger surface receives more power. Therefore, irradiance is measured in watts per square metre (W/m^2).

- In Nigeria at noon the irradiance on 1 m^2 can be as strong as 1000 W. Therefore, we say it is 1000 W/m^2. As 1000 W is equal to 1 kW, we can also say the irradiance is 1 kW/m^2.

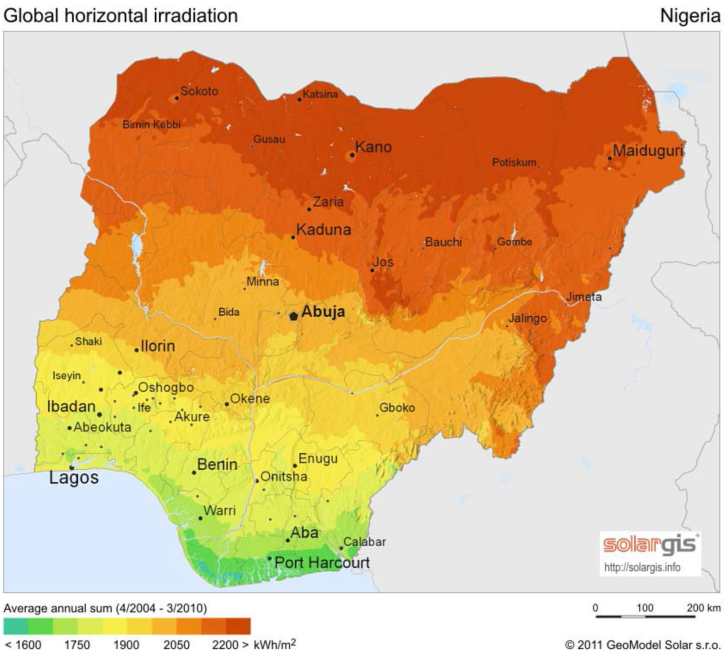
IRRADIATION

- Irradiation is a measure of solar energy.
- Energy is the impact of power for a period of time. Energy = power × time.
- Energy is measured in Wh or kWh. (watt hour or kilowatt hour).
- Solar energy is the product of solar power (irradiance) and time. Therefore, we measure it in Wh/m^2 or in kWh/m^2.
- Solar technicians need to know how much solar energy can be used during a day. Therefore, we measure the solar energy in $Wh/m^2/day$ or $kWh/m^2/day$.

SUMMARY

- Radiation is all sunlight that reaches the earth's surface. It includes direct, diffuse and reflected radiation.
- Irradiance is a measure of energy intensity. It describes how much power reaches a given surface.
- Irradiation is the solar energy as it collects over a period of time; it is the product of the irradiance (power) and time.

Received solar energy



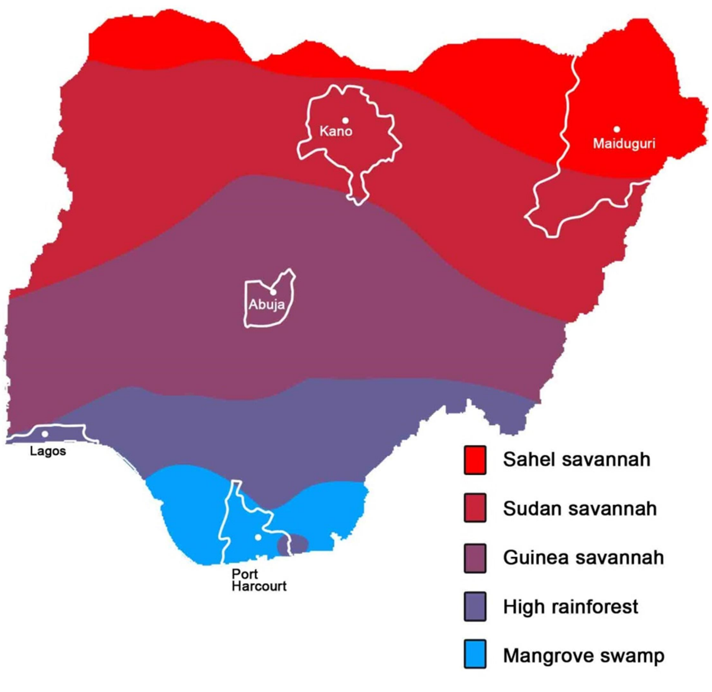
Solar irradiation levels in Nigeria, GHI

– Courtesy: GIZ, The Nigerian Energy Sector, 2015

SOLAR ENERGY IN NIGERIA

- Nigeria receives a lot of sunshine all year round due to its geographical location (close to the equator).
- On average, each square metre receives about 2,000 kWh per year. (Irradiation = 2,000 kWh/m²/year). This is more than enough to produce energy for all Nigerians.
- This energy can be used to generate electricity.

Solar resource distribution in Nigeria



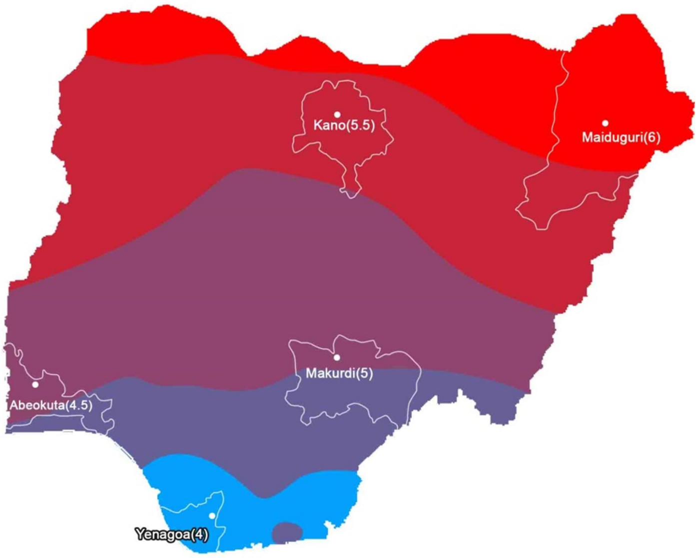
Climate zones in Nigeria

CLIMATE ZONES IN NIGERIA

Nigeria is divided into 5 distinct climatic zones based on vegetation, namely

- Sahel savannah
- Sudan savannah
- Guinea savannah
- High rainforest
- Mangrove swamp

Concept of peak sun hours



PSH of selected Nigerian cities

PEAK SUN HOURS (PSH)

The term "peak sun hours" is often used to describe the solar irradiation (the amount of solar energy) on a given day. If a day has five peak sun hours, this is equal to 5 kWh/m²/day.

When we talk about peak sun hours, we can imagine that the sun rises immediately to its maximum power (as if it were switched on to "high noon" like a lamp). It stays there for the number of peak sun hours and is then suddenly "switched off" again.

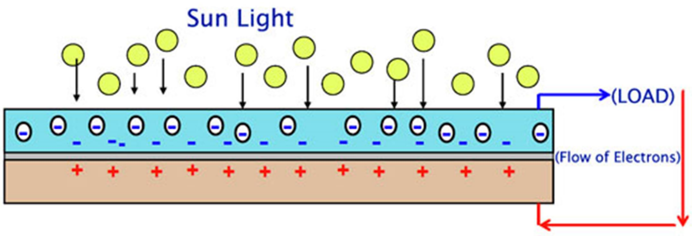
Climate	*PSH*	*Example location*
Mangrove swamp	4	Yenegoa
High rain-forest	4.5	Abeokuta
Guinea savannah	5	Makurdi
Sudan savannah	5.5	Kano
Sahel savannah	6	Maiduguri

1.3. Photovoltaic principles and solar cells

Raw crystalline silicon

SEMICONDUCTORS

- A semiconductor is a material or substance that is capable of transmitting electricity (conductor) under certain conditions. It also possesses the ability to restrict the flow of electricity under other conditions (insulator).
- The semiconductor provides the basis for the design and manufacture of solar panels.



Movement of electrons in a solar cell

A solar cell

- The most frequently used semiconductor material used to manufacture solar cells is silicon, which is found abundantly in the form of quartz sand.

PHOTOVOLTAIC PRINCIPLE

The photovoltaic principle refers to how light is converted into electricity. In certain types of semiconductors, electrons start to flow when exposed to light. The flow of electrons creates an electric current.

SOLAR CELL

- A solar cell (also known as a photovoltaic cell) is an electronic device that converts light to electricity.
- Solar cells can be made from a variety of semiconductor materials. However, for commercial use, silicon-based solar cells are commonly employed.
- Solar cells are used in a variety of applications such as calculators, wristwatches and in larger applications, e.g. for pumping water or generating domestic electricity.

HOW DO SOLAR CELLS WORK?

- When light strikes a solar cell, direct current (DC) is generated.
- When the solar cell is connected to an electrical load via cables, this direct current can be used to power devices.
- Current cannot flow without sunlight.

2. WORKPLACE SAFETY

About this module

Accidents can happen during the installation of solar systems. This module provides students with necessary information to work safely and provide first aid in the event of injuries during installation.

Learning outcomes

At the end of this module, the participant is able to

- Demonstrate familiarity with common workplace safety rules and regulations
- Assess possible health and safety threats and describe how to avoid them
- Identify the different types of protective clothing and equipment
- Identify the different methods of extinguishing fires
- Recognise the signs and symbols for work safety

2.1. Risks and dangers

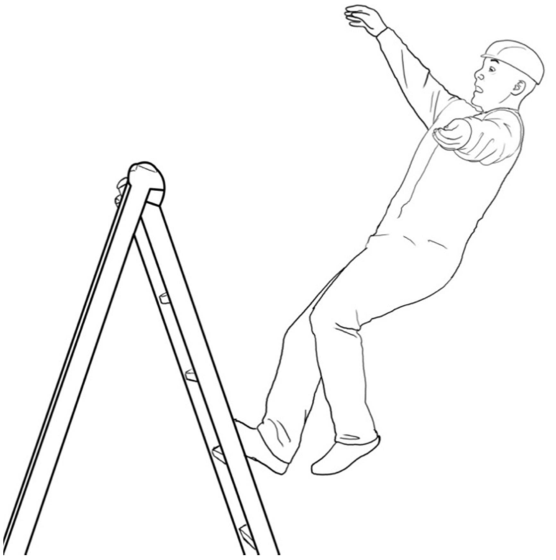
General risks

When working with electrical equipment and appliances, the most immediate and obvious danger is electrocution or electric shocks. Electric shock occurs when current flows through your body, offering a path of little resistance to the current while your body is connected to ground.

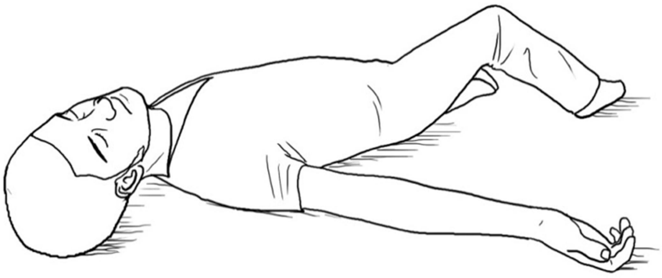
Skin burn

Electric shocks occur when you work on live electric circuits. These shocks could be minor (when working with lower voltages) but could lead to other more serious injuries such as:

1. Skin burn on affected areas
2. Falling from a ladder when working at heights
3. Loss of consciousness
4. Vision, hearing and speech impediments



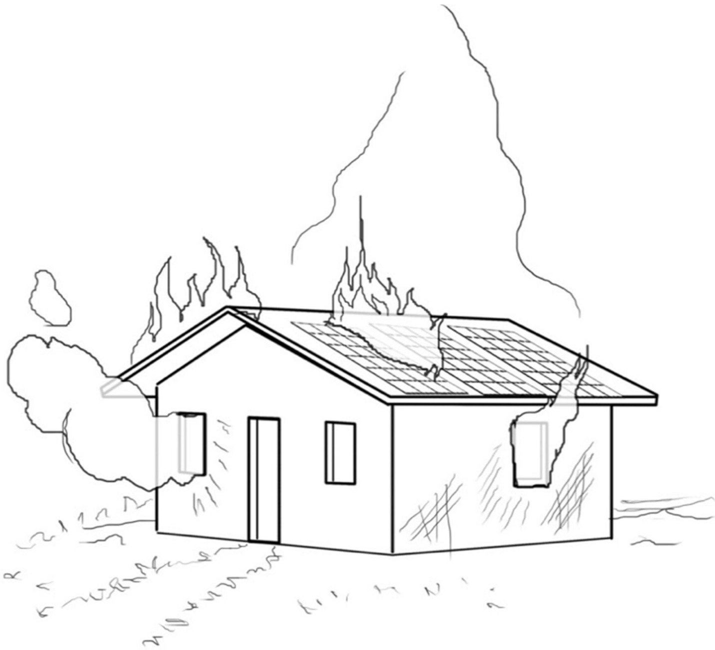
Falling from ladder



Loss of consciousness

Vision, hearing and speech impediments

Another major risk associated with electrical installations is the outbreak of fire. This could occur if there is an electrical spark near a combustible substance. When connecting to a solar battery bank, for instance, a nearby bucket of petrol could lead to an explosion and subsequently fire.



Minimising electrical hazards

In order to minimise the possibility of electric shocks or other hazards associated with installation, carry out these steps before beginning installation work:

1. Evaluate and identify electrical hazards.
2. Eliminate electrical hazards.
3. Ensure controlled environments/locations where hazards cannot be eliminated in order to reduce risks.
4. Ask yourself: What steps will I take in the event of a hazard?

2.2. Personal safety

Safety equipment

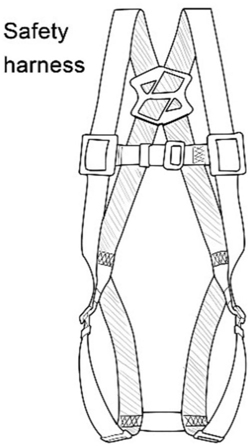
This basic equipment is required to ensure the safety of installers while at work.

Solar PV installers wearing all required PPE
– Courtesy: www.thesolarplanner.com

PPE	Importance
Hard hat	Essential
Goggles	Essential
Earmuffs	Desirable
Gloves	Essential
Safety boots	Essential
Body harness	Essential
Emergency first aid kit	Essential
Fire extin-guisher	Essential

Helmet/hard hat for protection against falling objects.

Gloves to protect the hands from cuts and insulation.



Body harness to protect against falls when working at heights.

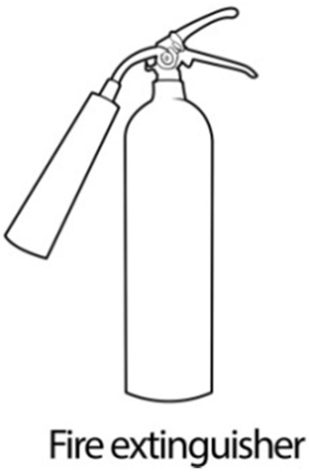
Safety goggles for protecting the eyes against sparks and flints.

Air mask to protect from fumes and dust.

Safety boots to protect the feet from impacts and for insulation.

Always wear when working on site.

Earmuffs to protect the ears against loud sounds.



Class E fire extinguisher to extinguish fires.

Emergency first aid kit to treat injuries that may occur while at work.

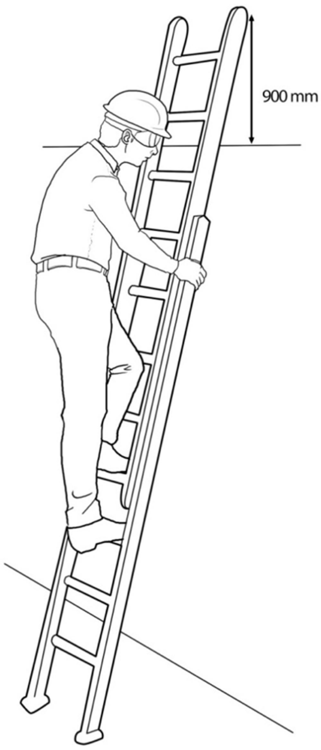
2.3. Rooftops and facades

Solar PV installer in Hawaii with fall protection

When working on rooftops and facades, it is important that maximum care is taken to avoid accidents.

Whenever you work at a height more than two metres (2 m) above ground, you must you use **fall protection**.

This could be a body harness.



When working with a ladder:

1. Ensure that the ladder you are using is a non-conductive ladder equipped with a non-slip base.
2. Ensure that there is ample space to set up the ladder.
3. Ensure you have a ladder in good condition and someone else to assist you.
4. Always secure the ladder to a fixed position before climbing. If there is none, ensure there is someone to hold the ladder.
5. There should never be more than one person on a ladder at any given time.

6. Always face the ladder; never climb up or down facing away from the ladder.
7. Always use both hands when climbing up and down a ladder.
8. Ensure that the ladder rests on a stable base.
9. Ensure that the ladder is long enough to enable you reach the level at which you want to work.
10. Never work while on the topmost four rungs of the ladder.
11. Keep at least 3 metres away from any power lines.
12. If you are using an extension ladder:
    - Ensure that the top of the ladder extends up to 900 mm above the ladder support point.
    - Ensure that the bottom of the overlap is at least three rungs away from the top of the base.

2.4. Fire hazards

Before you attempt to put out a fire, remember the three cardinal rules:

Rules for fighting fires

The three rules:

Inform people on site of the fire and activate the fire alarm.

Assist persons who require support to escape the danger.

Attempt to extinguish only after activating and assisting.

Remember: Only attempt to put out a fire if:

- The fire is small and contained.
- You are safe from toxic smoke.
- You have a means of escape.
- Your instincts tell you it's OK.

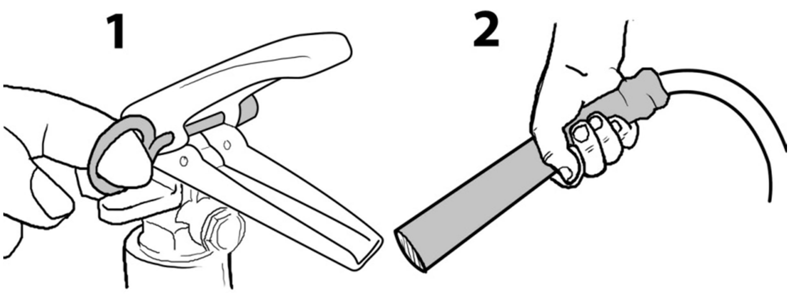
Types of fires and fire extinguishers

Class and type	*Symbol*	*Extinguisher type*
Class A fires Fires in common items such as wood, paper, cloth, plastic, etc.		Water and foam
Class B fires Fires in flammable fluids such as petrol or kerosene		Carbon dioxide, dry chemical
Class C fires Fires in flammable gases such as cooking gas		Carbon dioxide, dry chemical

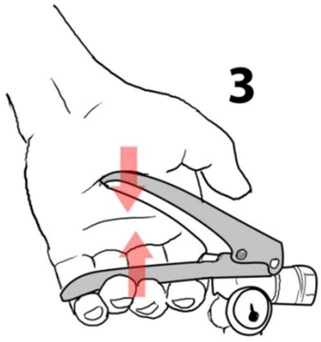
Class D fires Fires in combustible metals		Dry powder
Class E fires Electrical fires		Carbon dioxide, dry chemical
Class F fires Fires in cooking oils and greases		Wet chemical

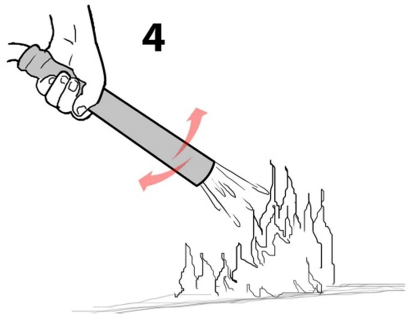
	Water	Foam	Dry Powder	CO2 Carbon Dioxide	Wet Chemical
Solids (wood, paper cloth etc)	✓	✓	✓	✗	✓
For Flammable Liquids	✗	✓	✓	✓	✗
For Flammable gasses	✗	✗	✓	✗	✗
For Electrical equipement	✗	✗	✓	✓	✗
For Cooking oils and fats	✗	✓	✗	✗	✓
For Use on all risks	✗	✗	✓	✗	✗

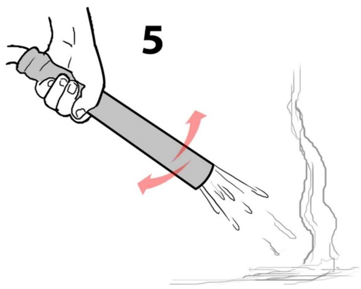
Using a fire extinguisher



- Pull the pin.
- Aim the nozzle at the base of the fire.
- Squeeze the operating lever to release the extinguishing agent.
- In a sweeping motion, move the hose from side to side until the fire is completely put out.







2.5. Site safety

Site safety is a very important but often neglected aspect of installation. On a construction site, safety symbols are generally classified according to their colours. The colours used in safety signs are:

Red – prohibited (never do these)

For example, the symbol below tells you never to put out a fire with water.

A red sign signifies dangerous behaviour. This behaviour should be avoided at all costs.

Yellow – hazard

For example, the symbol below means that there are live electrical connections.

A yellow sign is a warning sign. It advises you to take extreme cautions.

Blue – compulsory (must be obeyed at all times)

For example, the symbol below signifies that a safety helmet must be worn at all times.

A blue sign indicates a specific behaviour to be obeyed.

It mostly refers to **mandatory PPE**.

Green – no danger

For example, the symbol below shows that there is a first aid box or clinic on site.

A green sign signifies that there is no danger. It mostly refers to opportunities to escape from or treat hazards.

Symbols for marking obstacles and dangerous locations. These symbols are used to mark barriers or hazardous areas (slippery areas or falling objects).

2.6. Lifting

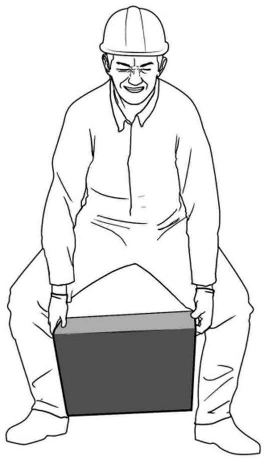
Worker lifting a load manually

In a solar system, equipment to be lifted includes:

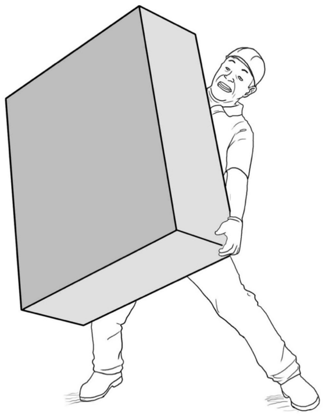
- Solar panels
- Batteries
- Inverter
- Mounting systems

Factors that make manual lifting dangerous

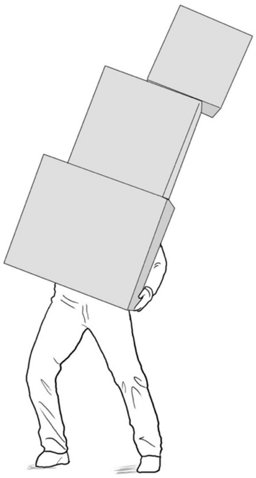
Injuries associated with manual lifting of heavy loads are predominantly back-related. The worker could also sustain cuts if appropriate gloves are not worn.



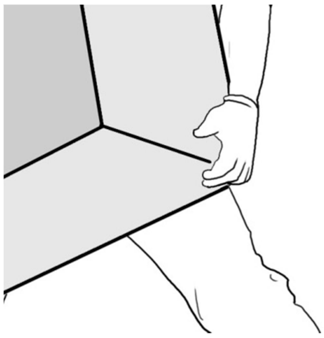
Some loads are too heavy to be carried alone.



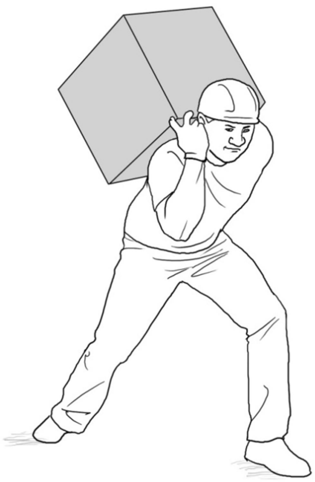
Some loads are too large and bulky for an individual to carry alone.



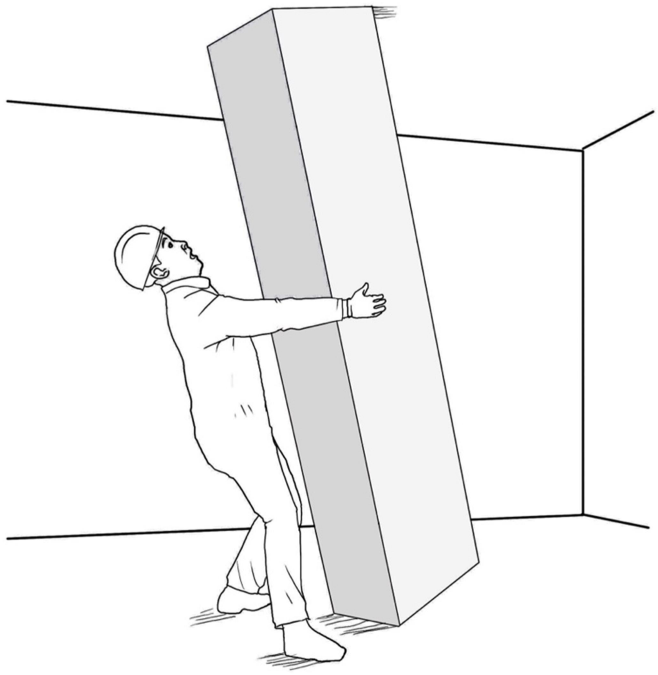
Some loads are unbalanced or unstable.



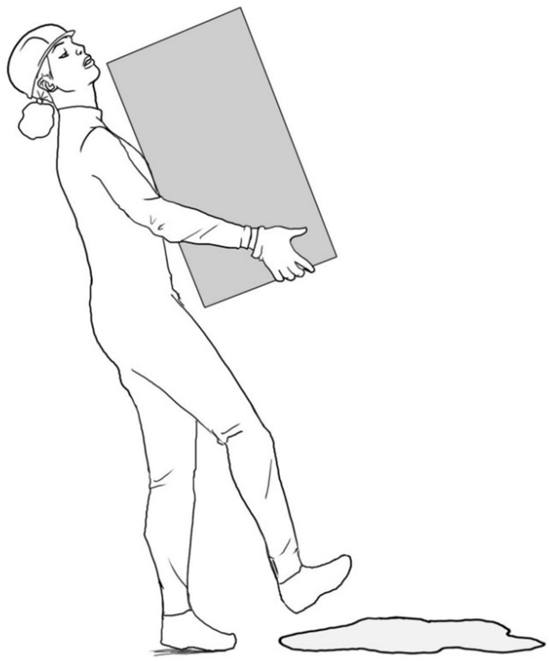
Some loads are difficult grasp firmly in your hands.



Other loads may require you to assume an awkward position to lift the load.



Sometimes, there is not enough space to lift a load.



Or the floor might be wet, slippery or uneven.

SAFE LIFTING PRACTICES

When lifting loads manually, keep in mind:

- Never lift heavy loads by bending forward from your back. Bend your hips and knees to squat down to your load. Keep the load close to your body, and straighten your legs to lift.
- Never lift a heavy object above shoulder level.
- Avoid turning or twisting your body while lifting or holding a heavy object.

Keep a wide base of support. Make sure that your feet are spread apart for good balance.

When picking up an object, squat down, bending at the hips and knees only.

Maintain good posture. Keep your back straight, chest out and shoulders back.

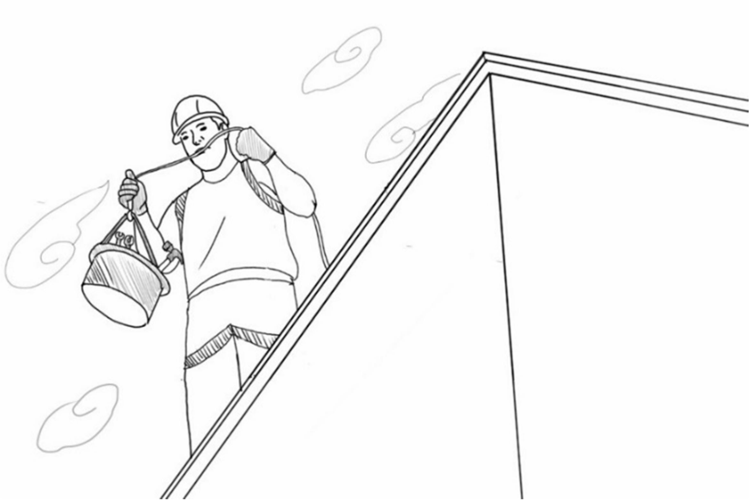
Slowly lift by moving your hips and knees as you stand.

Hold the load close to your body while lifting.

When changing direction, use your feet.

As you change direction lead with your hips.

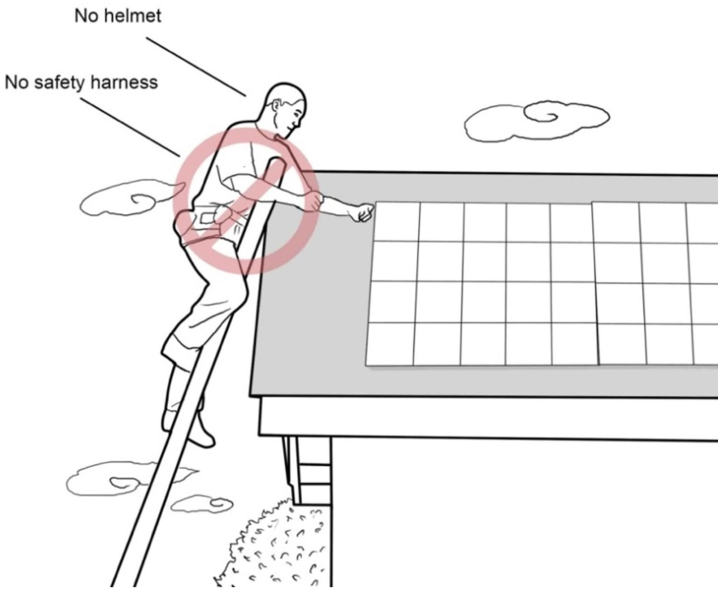
When setting down the load, squat with your hips and knees. Do not drop!



When working on a roof-top or at heights, never carry equipment while ascending or descending a ladder. Always use a line.

2.7. Injuries

Factors that cause injuries on an installation site



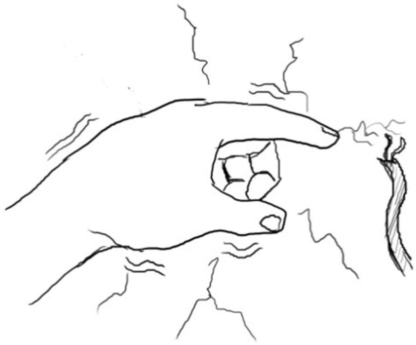
Safety when working on electrical installations is very important. Failure to adhere to best practices could lead to serious injuries or even death!

Electrical accidents are usually caused by the following factors:

1. Unsafe equipment and installations, e.g. improper grounding.
2. Unsafe working environment, e.g. work conducted in an improperly marked area.

Unsafe procedures, e.g. working at heights without appropriate fall protection.

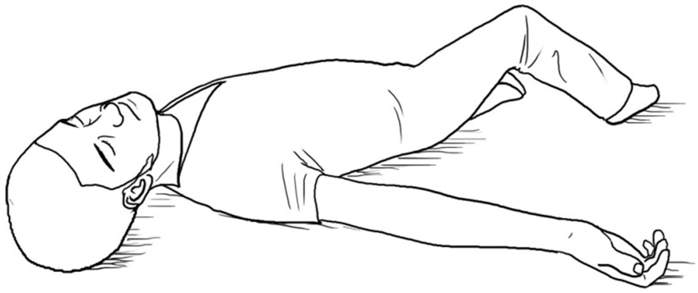
Common injuries



Common injuries experienced by electrical installation workers include:

1. Electrocution can already occur when an electrical worker is exposed currents of less than 75mA.
2. Death by electrocution could occur when an electrical worker is exposed to currents above 75mA for an extended period. **Call an emergency healthcare hotline if this occurs!**

3. Burns can be sustained as a result of direct contact with current or arc flashes.



4. Injury sustained from a fall. These kinds of injuries vary greatly, e.g. from mild concussions to broken bones to death.

When working on solar systems, the most common injuries are electrocution shocks and injuries sustained after a fall.

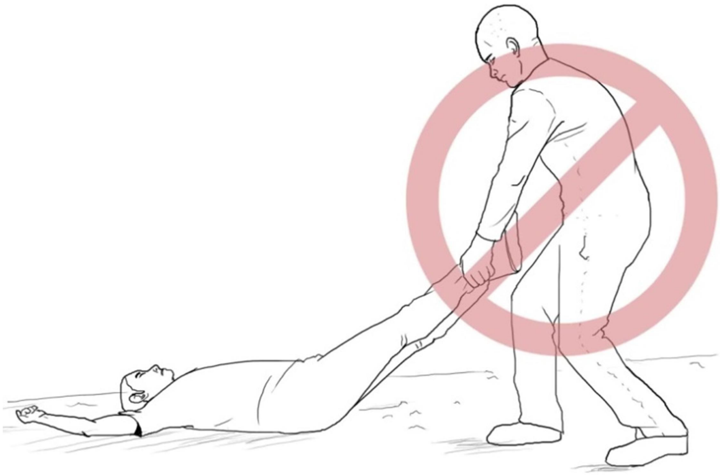
2.8. First aid

Call emergency healthcare personnel

In the event that a co-worker is injured on site, you must act quickly and decisively.

Steps to follow:

1. Call for emergency help if not serious.
2. Minimise the injury. Only move the victim if necessary.
3. Control severe bleeding.
4. Ensure that the victim's air passage for breathing is not constricted. If necessary, give CPR if trained to do so.
5. Treat the victim for shock.



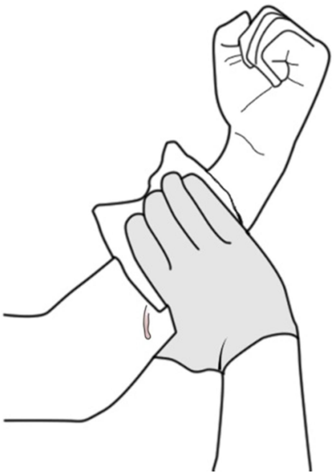
Only move the victim if necessary

Control severe bleeding

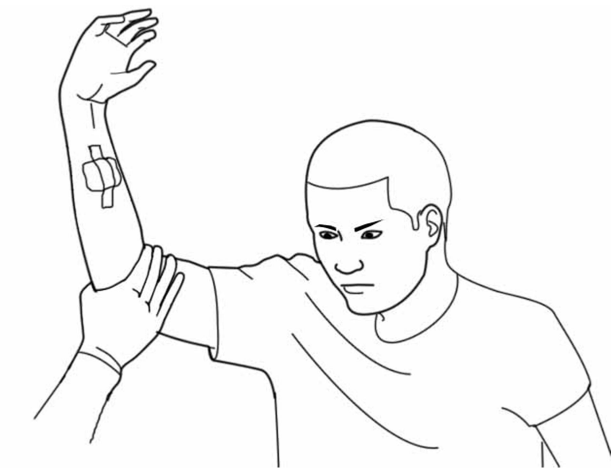
Ensure that the victim's air passage is not constricted

Administer CPR

Bleeding



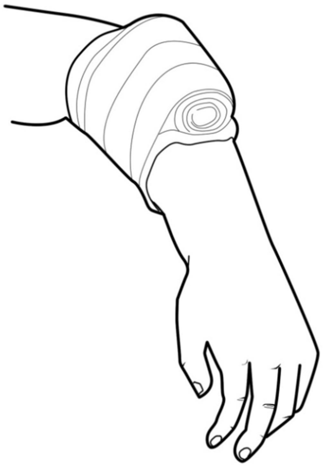
Apply direct pressure to the wound



Dress wound; raise injured area above heart level

First aid actions

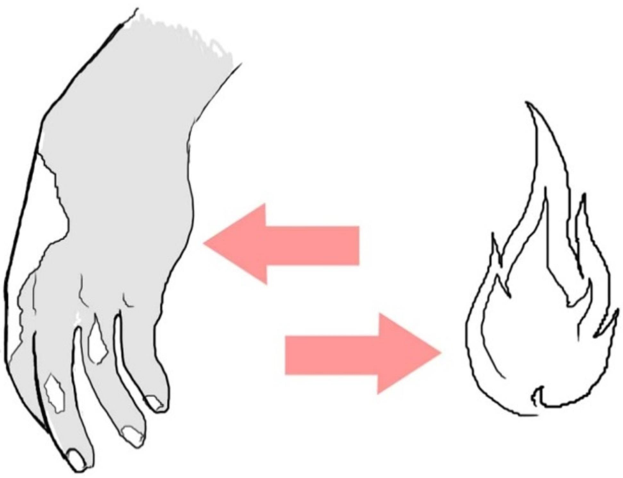
1. Apply direct pressure to the wound.
2. Apply dressing to the wound.
3. Raise the injured area to a level above the heart.
4. Apply pressure bandage and wrap tightly over the wound.
5. Call and wait for emergency healthcare personnel.



Apply pressure bandage

Call and wait for emergency personnel

Burns

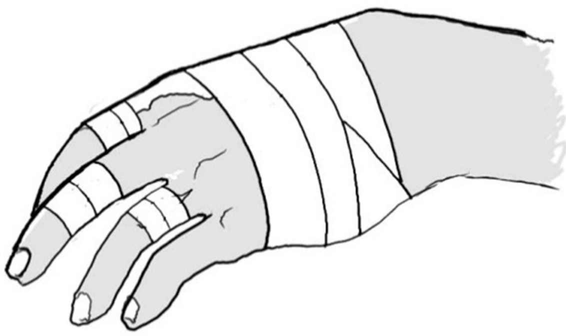


Remove victim from source of burn

First aid actions

1. Remove the victim from the source of the burn or stop the flames (in case of electrical burns, isolate the victim from the source or isolate the source).
2. Cool the burn by immersing in cool water or placing burnt area under a running tap.

Cool the burned parts with clean cold water

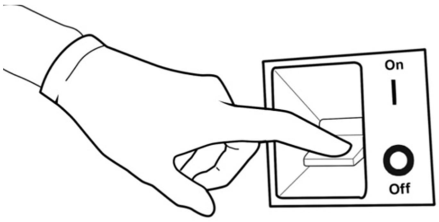


Using a clean bandage, cover the burned parts of the skin

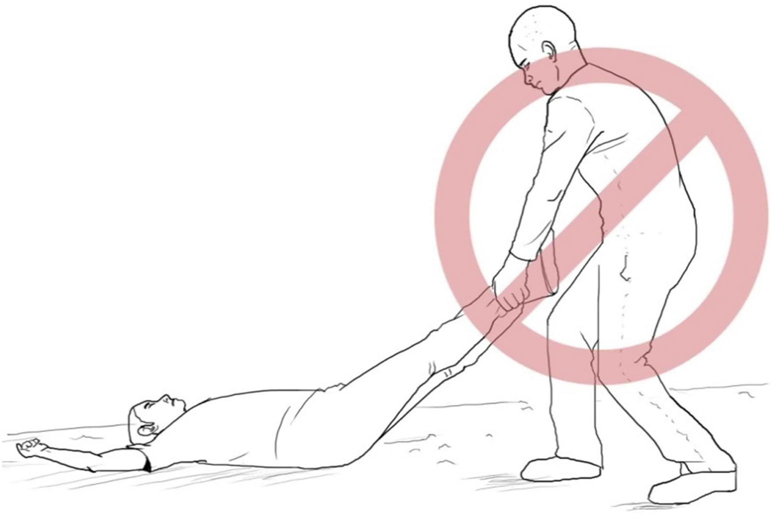
Call and wait for an ambulance

3. Using a clean bandage, cover the burn.
4. Call and wait for emergency healthcare personnel.

Electrocution



Turn off the power source

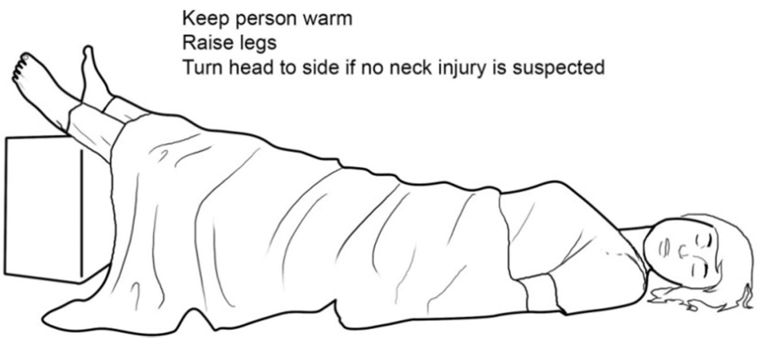


Do not move a victim unless he/she is in immediate danger

Administer CPR if necessary

First aid actions

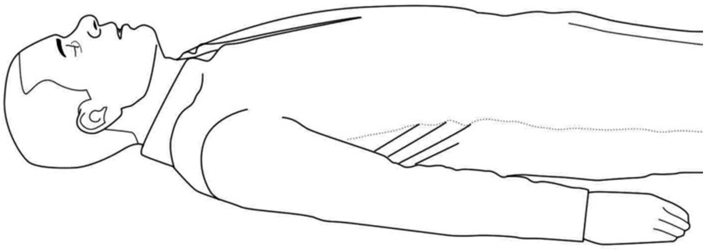
1. Turn off the power source. Do not come in contact with the victim until power has been disconnected.
2. Do not move a victim unless they are in immediate danger.
3. Administer CPR if necessary.
4. Treat for shock.
5. Call and wait for emergency healthcare personnel.



Treat for shock

Call and wait for an ambulance

Shock



Ensure the victim lies down on their back

Ensure that the victim's breathing passage is free

First aid actions

1. Ensure the victim lies down on their back.
2. Ensure that the victim's breathing passage is free.
3. Ensure that the victim's body temperature is maintained at 37°C
4. Call and wait for emergency healthcare personnel.

Ensure that the victim's body temperature is maintained at 37°C

Call and wait for emergency personnel

3. COMPONENTS OF SOLAR PHOTOVOLTAIC SYSTEMS

About this module

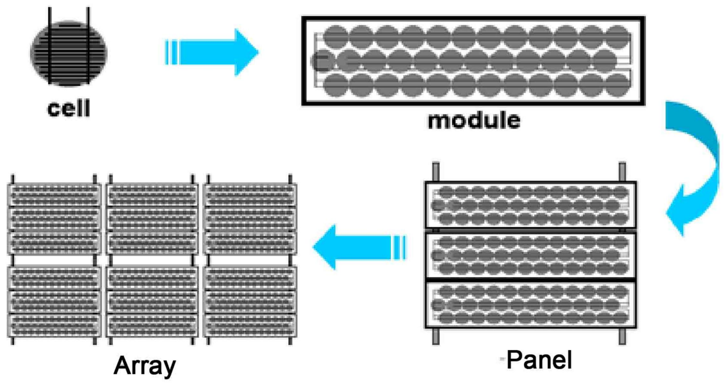
A solar system consists of various components, each with a specific function. For technicians to successfully install home back-up systems that run on solar energy, they need to understand the importance of these components, their functions within the system, and how they are interconnected. This module describes the individual components and their functions.

Learning outcomes

At the end of this module, the participant is able to

- Describe the basic functions of the components of a solar system
- Identify the different configurations for solar panel and battery interconnections
- Distinguish between DC and AC loads

3.1. Solar panels

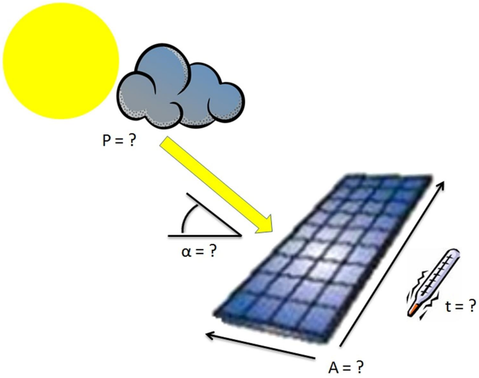


FROM CELL TO ARRAY

A solar system consists of the following components, which perform various functions in the system. These components are electrical loads, solar panels, inverters, charge controllers, batteries, cables and protective devices.

SOLAR PANEL

- Many solar cells connected together form a solar panel. Depending on its size and the required energy, several solar panels can be combined to meet any energy demand.
- Solar panels are the basis of every solar power system.
- Silicon is used to make the solar cells that go into solar panels.



A solar PV system
that will not generate much energy

SOLAR PANEL ARRAY

- Multiple solar panels are connected to form an array.
- Larger systems need an array to supply the required electrical power.

In some instances, more than one array is required.

WHAT AFFECTS THE ENERGY OUTPUT?

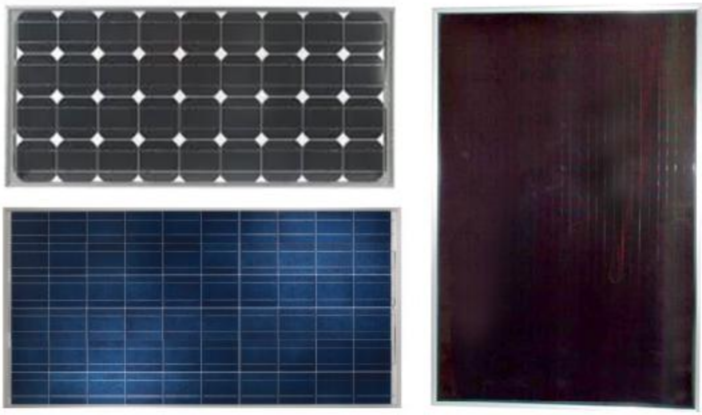
There are a few factors that affect the energy output that can be obtained from a solar panel.

1. Panel area. The larger the solar panel, the more electricity is produced. If you double the surface area of your panels, you also double the electricity output.
2. Panel direction. To get the most electricity from a solar panel, it must be facing the sun.
3. Heat - solar panels also work best when kept cool. The hotter the panel, the less power it provides.
4. Brightness - the more sunlight that falls on the panel, the more electricity is produced. If there is shade on a panel, the electricity output falls greatly.

NOTE

1. Electricity generated from solar panels does suffer from a major issue: sunlight is not available for 24 hours a day.
2. The amount of solar energy that can be converted into electricity varies greatly depending on
   - Time of day
   - Time of year
   - Location
   - Prevalent weather conditions.

Types and technologies



Monocrystalline (top left), polycrystalline (bottom left), amorphous (right) solar panel types

Characteristics of different solar panel types

	Monocrystalline	*Polycrystalline*	*Amorphous*
Cell efficiency	15-25%	13-16%	6-8%
Required area for 1 kW_P	10 m^2	11 m^2	15 m^2

TYPES OF SOLAR PANELS

There are three common silicon solar panel technologies available for commercial use.

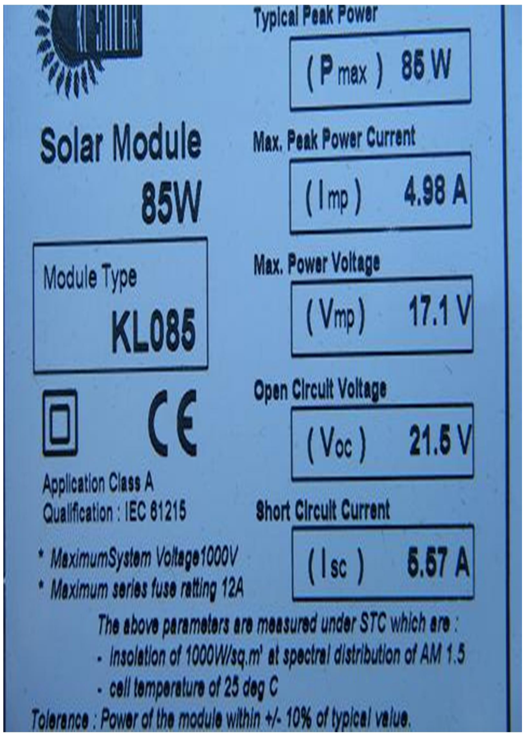
1. Monocrystalline
2. Polycrystalline
3. Amorphous silicon

It is easy to see the difference between these different types of solar panels.

- Monocrystalline panels are black with a square wafer look. Polycrystalline are bluish and have an iridescent crystal look. Amorphous panels have a uniform black look, sometimes with faintly visible lines.
- Solar panels come in various sizes which are rated based on their output power in watts.
- A label on the back of a solar panel indicates the output power.
- The output power (W) of a solar panel can only be achieved under ideal conditions, that is, when the sun has a radiation power of 1 kW/m^2 (at noon, no clouds) and at a panel temperature of 25°C.

- A good quality crystalline solar panel can last more than 20 years.

Ratings of solar panels

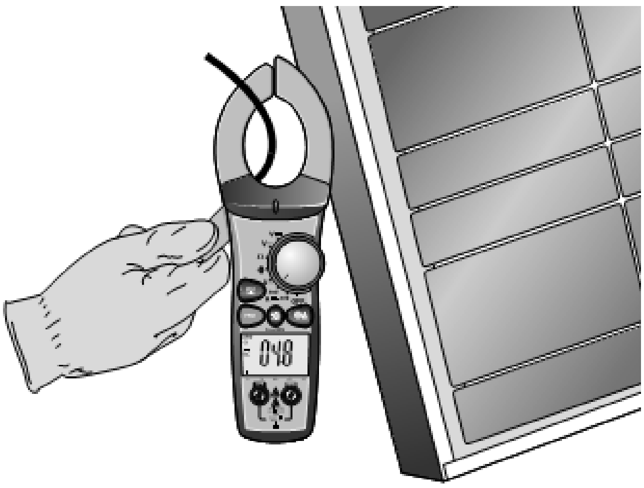


Label of 85 W_P solar panel

Label on solar panel, indicating:

- Power P_{MAX} 85 W
- Operating current I_{MP} 4.98 A
- Operating voltage V_{MP} 17.1 V
- Voltage without load V_{OC} 21.5 V
- Short-circuit current I_{SC} 5.57 A

The electric power, voltage and current which are labelled on a solar panel are only achieved at 1 kW/m² irradiance and at a solar cell temperature of 25°C! Therefore, the rated power is often given as "Watt peak" (W_P). A module which is rated 85 W_P reaches its peak power output of 85 W only under these specific conditions. If the irradiance is less than 1 kW/m² or the temperature is above 25°C, then the module generates less power.

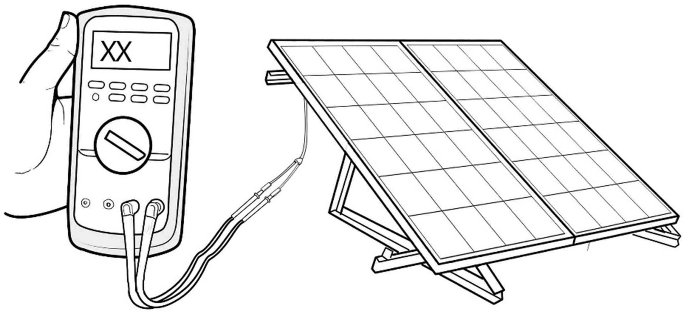


Solar panel measurement: short-circuit current

HOW TO MEASURE SOLAR PANEL PARAMETERS

When a solar panel is manufactured, it is tested to ensure it meets the required standards. There are two important parameters to be considered during testing;

1. The **short-circuit current (I_{SC})** is the current measured when the solar panel terminals (positive and negative) are connected together and there is no load.



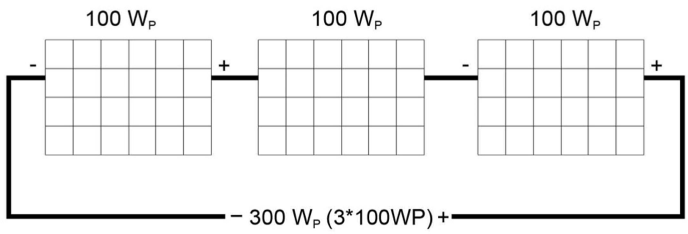
Solar-panel measurement: open-circuit voltage

2. The **open-circuit voltage (V_{OC})** is the voltage across the negative and positive terminals of the solar panel when it is not connected to any load.

Solar panel array connection

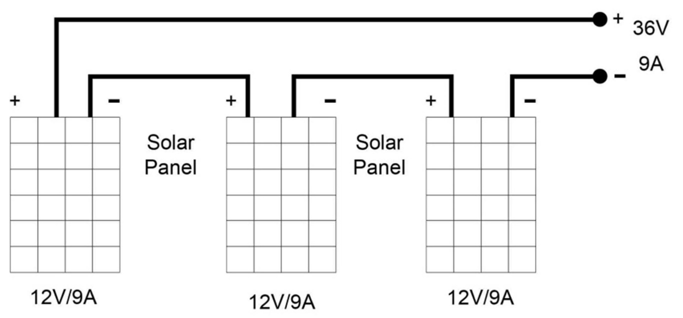
CONNECTING IDENTICAL SOLAR PANELS IN AN ARRAY

For example, if you have three solar panels that are rated at 100 W_P and they are to be connected either in series or parallel combinations, the total output power from the array will be 300 W_P.



PV ARRAY CONNECTION

- Solar panels are connected to form arrays. When solar panels are connected to form an array, the total power from that array is the sum of the power rating of each individual solar panel.
- Interconnecting solar panels to form an array can be done in three different ways.
  1. Series connections to increase the output voltage of the solar panel array.
  2. Parallel connections to increase the output current of the solar panel array.
  3. Series-parallel connections to increase both the output voltage and the current of a solar panel array.



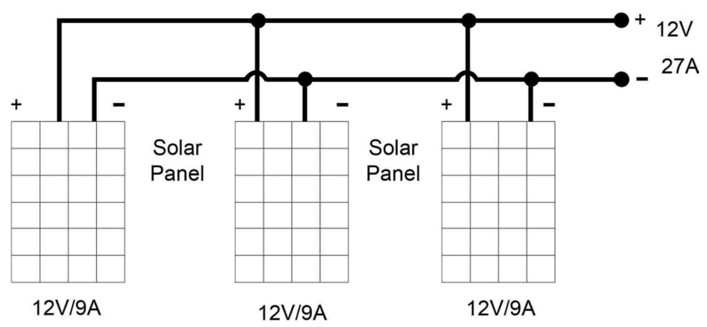
Identical solar panels connected in series

For example, you have three solar panels, each with 12 V and 9 A, connected in series. The output current and voltage of the array are then 36 V/9 A, respectively.

SOLAR PANELS IN SERIES

- When identical solar panels (solar panels having the same parameters) are connected in series, they produce a higher output voltage.
- This increased output voltage is the sum of voltages on the individual solar panels.

To connect solar panels in series, the positive (+) terminal of a solar panel is connected to the negative (−) terminal of the next solar panel in the array.



Identical solar panels connected in parallel

In this connection, three solar panels with 12 V and 9 A are connected in parallel. The output current and voltage are then 12 V/27 A, respectively.

SOLAR PANELS IN PARALLEL

- When identical solar panels are connected in parallel, they achieve a higher output current.
- This increased output current is the sum of current on the individual solar panels.

To connect solar panels in parallel, the positive (+) terminal of a solar panel is connected to the positive (+) terminal of the next solar panel in the array.

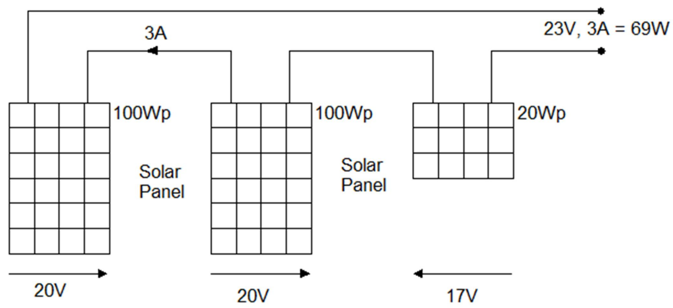
Array power output and mismatching

If you connect solar panels that have different power ratings, the output power from the array will be much less than the sum of the power output of each module. How much power is lost depends on the type of connection, the difference between the modules and the operation mode.

Connecting modules with different electrical specifications is called mismatching.

Mismatching connections **must be avoided** as mostly a lot of the power output of the individual modules is lost.

When modules with different currents are connected in series to a load (charge controller + battery) then the module with the weaker current acts as a resistor or load in the circuit. The stronger module(s) generate current which flows through the circuit. This current is reduced due to the resistance of the weaker module and it creates a voltage drop over the weaker module. This voltage drop has a polarity in the opposite direction, therefore reducing the total voltage of the series connection of all modules. It also consumes power of the other modules.



Solar panels of different sizes connected in series

In this example the voltage drop over the weaker module is 17 V. Therefore the total voltage of the circuit is 2x20 V – 17 V = 23 V. The total output power is even less than the power of a single one of the stronger modules.

When mismatched PV modules with **same** voltages are connected in parallel, then the total power is the sum of the individual powers of the modules.

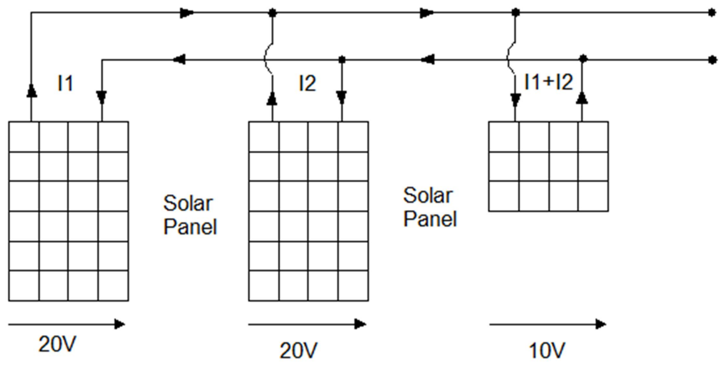
But when mismatched PV modules with **different** voltages are connected in parallel then the module with the lower voltage can act as a load in the circuit. If no load is connected to the circuit then the current of the modules with the higher voltage flows into the module with the lower voltage. If the current is high this can lead to damage of the module with the lower voltage

MISMATCHED SOLAR PANELS IN SERIES

- When solar panels with different output current are connected in series the module with the lower current acts as a resistor in the circuit, reduces current and power of the circuit and even consumes power generated by the other modules.

MISMATCHED SOLAR PANELS IN PARALLEL

- When mismatched solar panels with the same voltage are connected in parallel there will be no loss of power
- When mismatched solar panels with different voltages are connected in parallel then the solar panels with the higher voltages supply their current into the solar panels with the lower voltage.

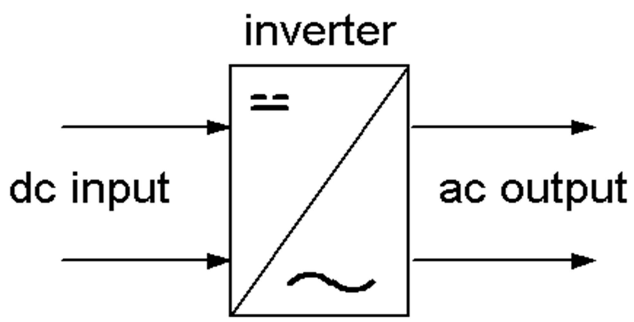


Mismatched solar panels connected in parallel

3.2. Inverters

Function of inverters

An inverter is an electrical device that converts direct current (DC) into alternating current (AC).We need AC to supply power to most electric appliances found in homes or offices.



Inverters have an input side and an output side

DEFINITION

The system voltage is the input voltage on the DC side of the inverter. The system voltage is usually graduated in steps of 12 volts. (12 V, 24 V, 48 V, 60 V, etc.)

On the input side the inverter is connected to the DC input power source, e.g. directly to the battery bank or solar array.

The output side supplies AC power to the consumer (usually 220 to 240 V).

Classification of inverters

Inverters are broadly classified based on two criteria:

1. Input voltage
2. Output waveform

GRID-TIE INVERTER

- Grid-tie inverters convert DC electricity from the solar panel(s) to AC electricity which can then be used by conventional home appliances.
- Grid-tie inverters come in various sizes rated in kW to match the power output from the solar array.

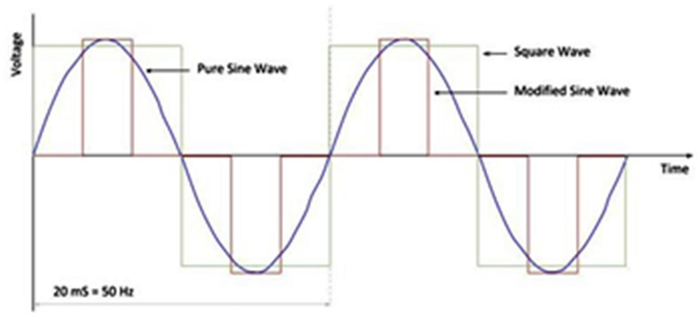
Typical 3.5 kVA battery inverter used in Nigeria

- Grid-tie inverters supply electricity directly to the end user and are unable to charge batteries.
- Grid-tie inverters cannot function as standalone equipment without a connection to the grid, a battery inverter or a generator.

BATTERY INVERTER

- Battery inverters convert DC electricity from the battery to AC electricity which can then be used by conventional home appliances.
- Battery inverters come in various sizes rated in kVA. Their input voltages (system voltage) differ according to these sizes.
- Inverters with a lower power output (i.e. below 1 kVA) usually use a lower battery voltage (24 V or below), while high-power inverters usually need a higher battery voltage.

Inverter rating	*System voltage*
0.8 kVA	12 V
1.5 kVA	24 V
2.0 kVA	24 V
3.0 kVA	48 V
3.5 kVA	48 V
5.0 kVA	60-96 V



Types of output waveform

OUTPUT WAVEFORM

There are three types of output waveforms found in most inverters.

1. **Square wave** is the simplest and most basic. It is useful in only a handful of applications such as lighting. This is the cheapest inverter type.

2. **Pure sine wave** inverters give an output that is very similar to the output waveform from the electrical grid. You must use this type of inverter if you have sensitive equipment such as many electronic devices connected to your system. This is the most expensive inverter type.
3. **Modified sine wave** inverters are the midpoint between the square wave and pure sine wave inverters. Most household and small office equipment will run on this inverter type with no problems.

3.3. Batteries

A solar panel produces electricity during the daytime when the sun is shining. The panel cannot store energy. When electricity will be needed during the night, it must be stored, for example in batteries.

Powerwall, a modern lithium-ion battery by Tesla Inc. recently introduced internationally
– Courtesy: Infinigeek

COMMON TYPES

There are two main types of batteries that are suitable for use with solar photovoltaic systems.

1. **Lithium-ion (li-ion) batteries** are the most recent technology on the market. They are commonly found in high-end electronic equipment such as mobile phones and laptops.
   - Li-ion batteries are not commonly used in home solar PV applications due to their high cost.
   - Relative to their size and weight, Li-ion batteries have a long lifespan and a high energy storage capacity.

- On average a Li-ion battery can last up to 5 years from date of manufacture depending on how it is used.

2. **Lead-acid batteries** are the most common battery used in solar systems. They are very robust and with proper operation it can reach a lifespan of 2 to 10 years. There is a large variety of manufacturers for this type of battery technology.
   - Lead-acid batteries can be found in different voltage ranges, i.e. 2 V, 6 V, and 12 V.
   - In Nigeria, these are the most cost-effective batteries in the market.

Typical 6 V and 12 V wet cell batteries

LEAD-ACID BATTERIES

Care must be taken to ensure that batteries are installed in locations with adequate ventilation.

Lead acid batteries are classified based on two criteria.

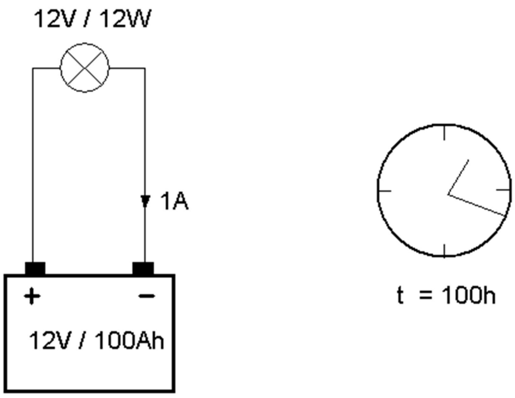
1. Usage/application (starter vs. deep cycle)
   - The starter battery is commonly used to start car engines. It is not suitable for solar applications.
   - The deep cycle battery is specifically made for applications such as solar systems.
2. Cell type (wet vs. dry)
   - The wet cell (flooded) battery is a commonly available battery type. The battery acid in this type of battery is liquid. Wet cell batteries require regular

Typical 12 V sealed battery
– Courtesy: www.chargeinverters.com

maintenance and are now more commonly replaced by the dry cell battery.

- The dry (sealed) battery is easy to install and use. In the sealed battery, the battery acid is not liquid but takes the form of gel or is absorbed by a sponge (AGM). Sealed batteries are maintenance-free.

Understanding the specifications of a battery



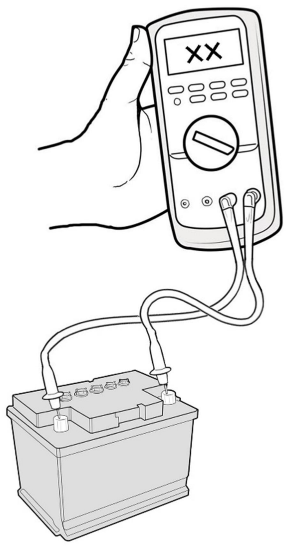
100 Ah battery for a 12 W load

BATTERY SPECIFICATIONS

- Batteries are storage devices for electric energy. Electric energy is measured in Wh or kWh.
- Most batteries used in solar systems are 12 V batteries.
- Large batteries can store more energy than small batteries.
- The size of a battery is expressed in its capacity (C). The unit is amp hour (Ah).
- A 12 V battery with C = 100 Ah can store the electric energy of 1,200 Wh (12 V × 100 Ah = 1,200 Wh).

If a 12 W DC light bulb is connected to that battery, it will draw a current of 1 ampere. The battery can supply that current for 100 hours when fully charged.

Knowing the charge level



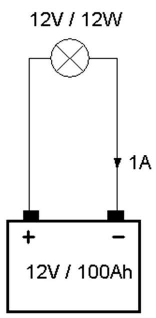
BATTERY STATE OF CHARGE (SoC)

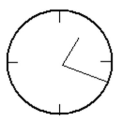
- The state of charge describes the battery's charge level, i.e. fully charged or empty. The unit of measurement is %.
- A fully charged battery has a 100% SoC.
- A half full battery has a 50% SoC.
- An empty battery has a 0% SoC.
- SoC can be determined by a voltage measurement, but is not always reliable.

On a 12 V lead-acid battery, when you measure (at rest):

Voltage reading	*SoC*
12.9 V	100%
12.7 V	75%
12.5 V	50%
12.3 V	25%
12.1 V	0%

Discharge level





% DoD

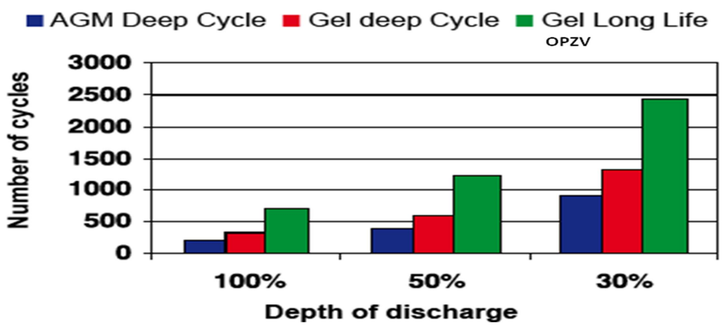
DEPTH OF DISCHARGE - DoD

- Describes how much of the battery capacity is discharged by using it. The unit is %.
- For example, if a 12 W DC light bulb is connected to the battery type in the figure, the battery will draw a current of 1 ampere. If the bulb operates for 10 hours, it will discharge 10 Ah from the battery. Given a 100 Ah battery, this discharge is 10% of the battery capacity. The DoD will be 10%.
- If the same bulb is operated for 50 hours, the DoD will be 50%.

Battery life

Battery life is expressed in cycles, meaning a battery can be used for a certain number of cycles only. After that, it gets weak and loses its capacity (ability to store energy). For example, a 12 V/100 Ah battery which has been used for very many cycles might only have a remaining capacity of 50 Ah. This means it has become a "smaller" battery.

The deeper you discharge the battery, the fewer cycles you will have over time.



BATTERY LIFE

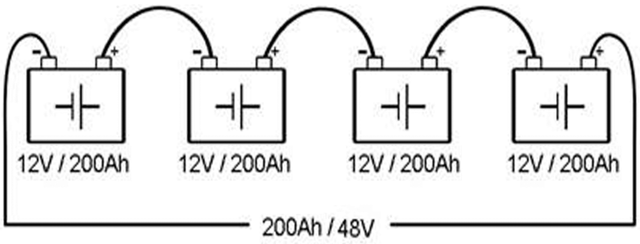
- Depends on how often you discharge a battery.
- Depends on the depth of discharge (DoD).
- Depends on the storage temperature.
- Every time you discharge a battery, you shave off a bit of the battery's lifetime.
- The process of discharging and recharging is called a cycle.
- In solar systems, a cycle is usually one day, as the battery gets discharged at night and recharged during the day.
- Discharging only 10% of the capacity (DoD = 10%) is a shallow cycle. Discharging 100% of the capacity (DoD = 100%) is a deep cycle.
- Deep cycles are more harmful and shorten the battery life more than shallow cycles.

Even when a battery is not used and just stored the lifetime is "consumed". This is called the float or shelf life. The float life depends very much on the temperature at which it is stored and on its state of charge. A good quality gel battery can be stored up to 10 years at 20°C but only 6 years at 30°C. The SoC must always be maintained at 100% when storing which requires recharging every 3 to 4 months.

Battery bank connection

CONNECTING BATTERIES IN SERIES

For example, if you have four batteries that are rated at 200 Ah/12 V and they are connected in series combinations, the total output power from the battery bank will be 48 V, 200 Ah.

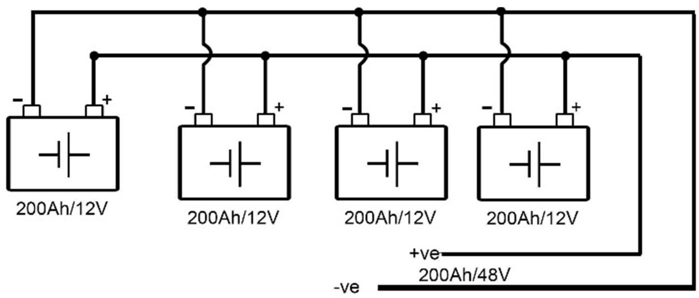


Series connected batteries

For batteries to be connected in series, the negative terminal of a battery must be connected to the positive terminal of the next battery.

CONNECTING BATTERIES IN PARALLEL

For example, if you have four batteries that are rated at 200 Ah/12 V and they are connected in parallel combinations, the total output power from the battery bank will be 12 V, 800 Ah.



To connect batteries in parallel, the negative terminal of a battery must be connected to the negative terminal of the next battery and the positive terminal to the next positive terminal.

MISMATCHING BATTERIES IN A BATTERY BANK

When batteries of different types are connected in series, the following happens:

- Smaller (or older) batteries discharge faster and deeper; they will fail faster.

BATTERY BANK CONNECTION

When batteries are interconnected to form a bank, the total voltage and capacity of the battery bank is dependent on whether batteries are connected in series or in parallel connections or both. There are three connection types.

1. **Series connections** to increase the output voltage of the battery bank.
2. **Parallel connections** to increase the output capacity of the battery bank.
3. **Series-parallel connections** to increase the output voltage and capacity of the battery bank.

Never connect dissimilar batteries!!!

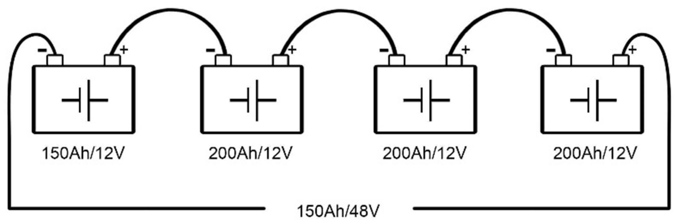
Batteries in a battery bank must be of the same age, type, classification and capacity.

- Smaller (or older) batteries charge faster and overcharge; they will fail faster.
- Bigger (or newer) batteries will never get fully charged, as the high voltage of the smaller battery is the signal for the charge controller to stop the charging process. Their lifetime will be shortened too.

When batteries of different types are connected in parallel, the following happens:

- Smaller (or older) batteries discharge faster and deeper; they will fail faster. Bigger batteries discharge into the smaller (or older) ones; energy is wasted.

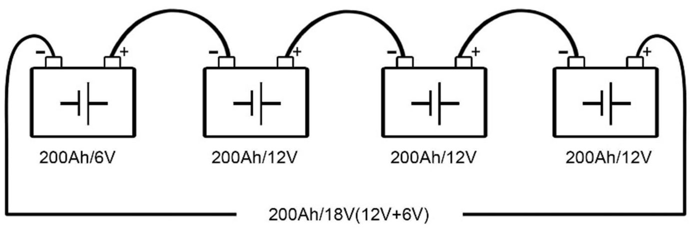
In series connections – batteries with same voltage but different capacities



An old battery has lost some of its capacity. It has become a "smaller" battery. An old 200 Ah battery connected in series with new 200 Ah batteries will affect the system as described above!

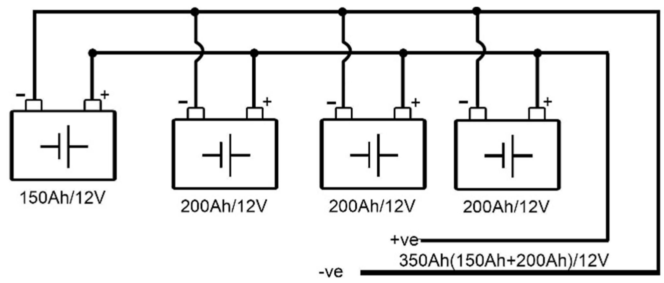
For example, you might encounter a battery bank of four batteries (shown at left) where one is rated 150 Ah/12 V and the other three are rated at 200 Ah/12 V, all connected in series. The output voltage from the battery bank is 48 V but the output capacity is controlled by the battery with the lowest capacity rating. In this case, the 12 V/150 Ah battery.

In series connections – batteries with same capacities but different voltages



The charge controller does not know that one of the batteries is only 6 V. It charges the battery bank as a 48 V battery bank whereby each battery receives 12 V. This leads to total overcharging and destruction of the 6 V battery.

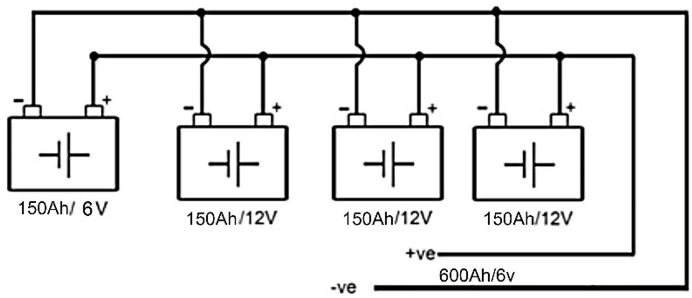
For example, you might find a battery bank with four batteries where one is rated 200 Ah/6 V and the other three are all rated at 200 Ah/12 V and connected in series. In this situation, the total voltage of the battery bank becomes 42 V ((3 × 12 V) + 6 V) while the capacity remains 200 Ah.



Different battery sizes connected in parallel

For example, a battery bank has four batteries where one is rated 150 Ah/12 V and the other three are rated at 200 Ah/12 V, all connected in parallel. The output voltage from the battery bank is 12 V, while the output capacity is 750 Ah (150 Ah + 3 × 200 Ah).

In parallel connections – batteries with same capacities but different voltages



For example, a battery bank consists of four batteries where one is rated 150 Ah/6 V and the other three are rated at 150 Ah/12 V, all connected in parallel. The 12 V batteries will immediately discharge heavily into the 6 V battery, as the battery voltages of all batteries "meet" on the same level. This heavy discharge and under-voltage will lead to their destruction. The 6 V battery will immediately be lifted up to a much higher voltage, close to 12 V, and be heavily overcharged, which will also lead to its destruction.

3.4. Charge controllers

The charge controller has four main functions:

1. **To charge** the batteries safely, quickly and completely.
2. **To protect** the batteries from deep discharge, if the charge controller has a load controller function included.
3. **To protect** the battery from overcharge.
4. **To prevent** reverse current from the battery to the solar panels.

FUNCTION OF A CHARGE CONTROLLER

- The charge controller regulates the power output from the solar panel array, which is used to charge your battery. This is done by managing the voltage delivered by the solar panel array to the battery.

There are two main technologies for charge controllers:

1. Pulse width modulation (PWM).

2. Maximum power point tracking (MPP or MPPT)
   - Most charge controllers can also act as load controllers for your DC loads, providing a low-voltage disconnect (LVD) to keep your batteries from becoming too deeply discharged.
   - Some also have features allowing a timed disconnect and an ON/OFF function based on light levels. This can be used for automatic switching of security lights in the evening.
   - Advanced charge controllers automatically schedule battery equalisation, which is a maintenance measure to extend battery life.

Victron 12 V 10 A PWM charge controller

PULSE WIDTH MODULATION (PWM)

- It is the most common charge controller type.
- Charging voltage of the battery is regulated to the required level by high frequency ON/OFF switching.

This switching is done automatically by the charge controller.

Victron 12/24 V 20 A MPPT charge controller

MAXIMUM POWER POINT TRACKING (MPPT)

- MPPT controllers allow the solar array to operate in the voltage range with an optimised power output, independent from the battery voltage.
- MPPT devices can provide up to 30% more useable power.

They are more expensive and mostly for larger solar arrays.

3.5. Electrical protective devices

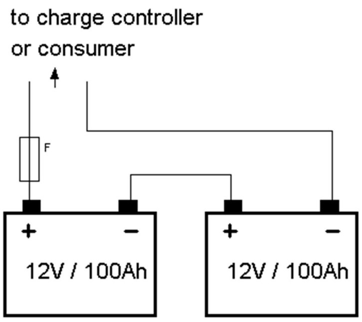
Typical disconnect switch used to isolate the solar panel array from the charge controller
– Courtesy: www.soneparcanada.com

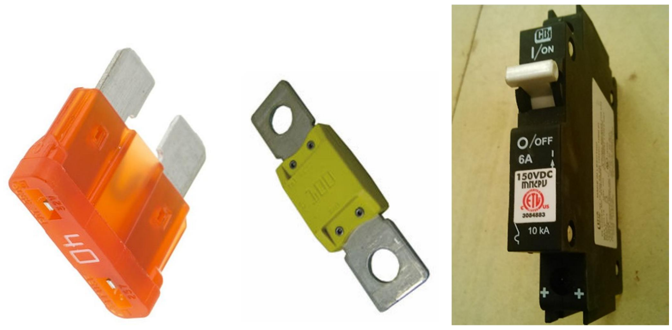
DISCONNECT

- For personnel and system safety and maintenance, you may consider installing disconnect switches which can isolate various system components.
- Disconnect switches installed between the solar array and the charge controller are advisable at DC voltages from 60 V and above to ensure safe installation and maintenance work. Disconnect switches must be made for DC switching and have an ampere rating in line with the maximum solar array current.

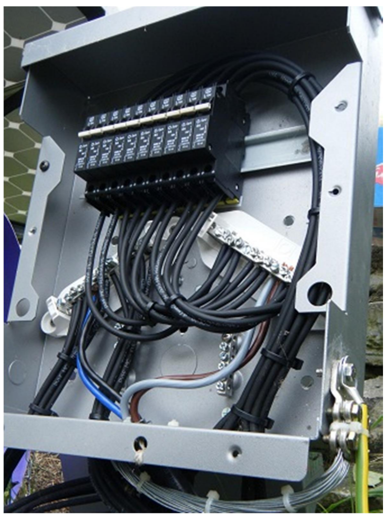
Conventional AC switches cannot be used. Every power disconnect of a system under load causes a spark. DC sparks are much more destructive than AC sparks and can destroy a disconnect device not designed to handle DC sparks.

Fuses and circuit breakers





Left to right: Automotive fuse, DC fuse, DC circuit breaker



Combiner box of a 4 kW solar array, combining 10 solar panel circuits to feed in one cable to the charge controller

A short circuit between the two battery poles releases a very high current; the larger the capacity the higher the current. On a large battery, this can easily melt the wires and start a fire. Therefore, the battery or battery bank should be protected with a suitable DC fuse. DC circuit breakers can only be used if they can manage the high short-circuit current which occurs in a battery short circuit.

AC fuses cannot be used on the DC side.

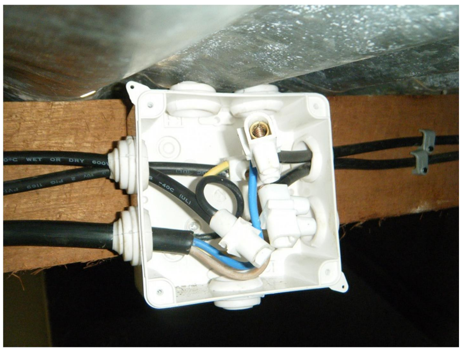
For smaller batteries and smaller DC load currents, automotive fuses can be used; **larger currents and battery banks require DC fuses** with higher ampere and voltage ratings**.**

- In the wiring between the battery and the charge controller: DC circuit breaker or DC fuse.
- In the wiring between the inverter AC output and the electrical consumers: AC circuit breaker.

COMBINER BOX

- The combiner box is an enclosure in which the solar panel circuits are interconnected to form a solar array.
- The output of the combiner box is usually a two-wire cable which connects to the charge controller.

The combiner box contains the disconnect switch or a DC circuit breaker for each solar array circuit.



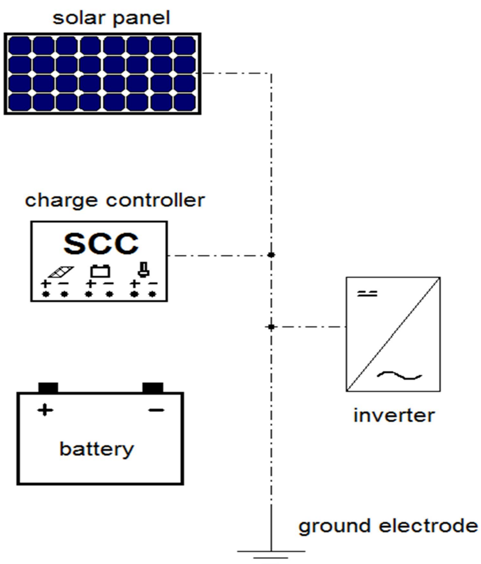
JUNCTION BOX

A junction box is a general name for an enclosure in which wires and cables of different circuits are interconnected.

3.6. Grounding

Why do we ground our solar system?

Equipment grounding can be used for protection from dangerous voltages due to faulty equipment. It also helps to protect equipment from dangerous voltages in case of lightning strikes.



REASON AND TYPES OF GROUNDING

Equipment grounding means connecting all metal bodies of the equipment together and to the ground electrode. These bodies include solar panel frames, inverter and charge controller housings, metal junction boxes, as well as potential electrode (PE) conductors on the AC side of the installation.

Grounding ensures that the metal parts of all system components are on the same voltage and zero potential to earth.

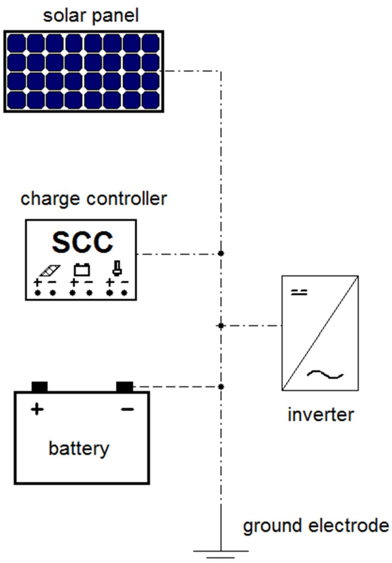
Hence, in the event of a lightning strike, current flow through the equipment, which could cause damage or injuries, is not possible.

System grounding, by contrast means connecting either the positive or the negative wire of the battery to ground. System grounding is necessary when manufacturers demand it for the proper function of their equipment. Certain types of solar panels must be negatively grounded; otherwise they lose power output due to the accumulation of electrostatic charge. Also, some personal protective devices

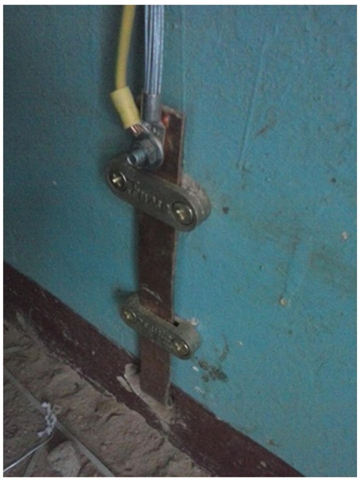
Equipment grounding connection on solar panel frames

such as DC RCDs will not function without system grounding. Grounding only one of the DC poles increases the risk of electric shock during installation and maintenance work on the solar system.

System grounding – for the proper function of certain types of equipment such as some types of inverters, protection devices or solar panels.



System grounding schematic



Connecting a solar system to the ground electrode

Laying ground electrode through a solid copper band

4. SOLAR PHOTOVOLTAIC SYSTEM CONFIGURATION

About this module

Solar power systems can be installed in a variety of configurations which are dependent on the location and application. This module introduces students to the different configurations for solar power systems and the components required to achieve them.

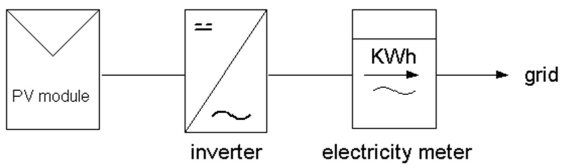
Learning outcomes

At the end of this module, the participant is able to

- Identify the various configurations of solar power systems
- Suggest an appropriate configuration for a solar power system based on application

4.1. Grid-connected systems

Components of a grid-connected system



Grid-connected system schematic

A grid-connected system consists of the following components:

- Solar module, array
- Inverter
- Load (e.g. lamp, fan, pump)
- Electrical accessories (e.g. switches, sockets, cables, etc.)
- Electric utility grid

4.2. Off-grid systems

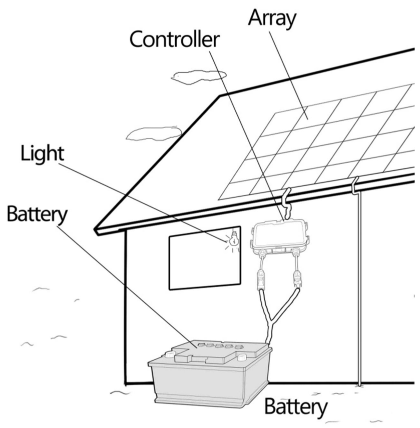
Components of an off-grid system

An off-grid solar PV system (also referred to as standalone PV systems) are designed to operate independently of the electrical grid and are generally designed and sized to supply power to either DC or AC electrical loads, or both simultaneously.

COMPONENTS

An off-grid solar electric system consists of the following components:

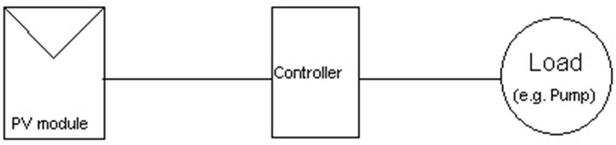
- Solar module, array
- Batteries
- Charge controller
- Inverter
- Load (e.g. lamp, fan, pump)
- Electrical accessories (e.g. switches, sockets, cables, etc.)



Components of an off-grid solar system

Off-grid solar system configurations

1. Off-grid system without battery storage and DC load only



One possible application in this case is pumping water. Water is pumped as long as the sun is shining. Excess water can be stored in a tank. A float switch in a tank can disconnect the pump when the tank is full.

Cattle drinking from a trough
– Courtesy: Prof. Dr.-Ing. Habil Ingo Stadler

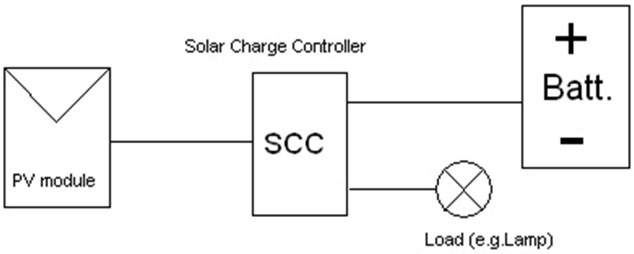
OFF-GRID SYSTEM WITHOUT BATTERY

This kind of system is commonly used for non-critical systems where electricity is not required at night.

In systems like these, the controller can have various functions such as:

- Stabilising the voltage to stay below a certain level
- Disconnecting the load when the voltage is too low (not enough sunshine)
- For example, converting DC to AC for an AC pump.
- Disconnecting the pump when the tank is full using a float switch.

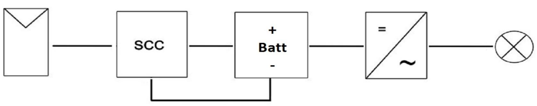
2. Off-grid system with battery storage and DC loads only



Example application: Supplying electricity for lighting

Power supply for lighting in Australia -
Courtesy: Prof. Dr.-Ing. Habil Ingo Stadler

3. Off-grid system with AC loads



Example: Solar panels to provide electricity for telecommunications masts

Solar PV system used to power AC loads (only) of a telecommunications tower

OFF-GRID SYSTEM WITH BATTERY

This kind of system is commonly used for non-critical systems where electricity is required at night.

Simple and efficient, no AC conversion needed.

Availability of DC loads is limited, mostly 12 V light bulbs, DC fridges and phone charging. Very few 24 V devices on the market.

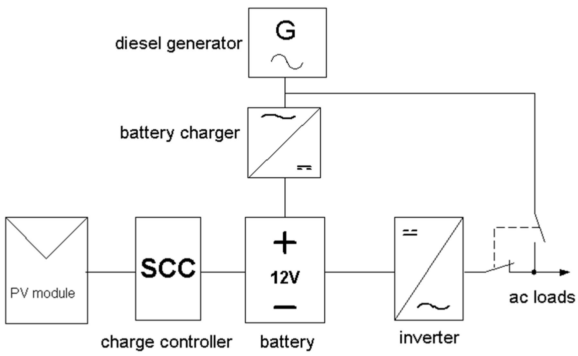
OFF-GRID SYSTEM WITH AC LOADS

This kind of system is commonly used in situations where grid-quality electricity is required both during the day and at night.

A combination which also uses DC loads powered directly from the battery or the charge controller is possible.

4.3. Hybrid systems

A hybrid system is a power supply system, which has more than one power generator. The generators can work alternatively or simultaneously. There are various power sources and various ways in which a hybrid system could be connected.



As with both system configuration types mentioned above, a hybrid system consists of the same components as an off-grid system; however, it also includes an alternate source of electricity such as a diesel/petrol generator or a small wind turbine.

5. BASIC SYSTEM SIZING

About this module

In order for an installer to successfully install a 1 kW_P solar system, they need to understand how to select the appropriate components for the system.

Learning outcomes

At the end of this module, the participant is able to

- Analyse the requirements of a solar PV system no larger than 1 kW_P
- Select appropriate system components to achieve expected outputs

5.1. Electrical loads

AC loads

These consist of the common household equipment, which we use every day. They include equipment such as televisions, water heaters, air conditioners, light bulbs, refrigerators, etc.

AC loads designed for the Nigerian market operate on a 220 V to 240 V range.

AC-powered television

CFL bulb

DC loads

Typical DC solar freezer

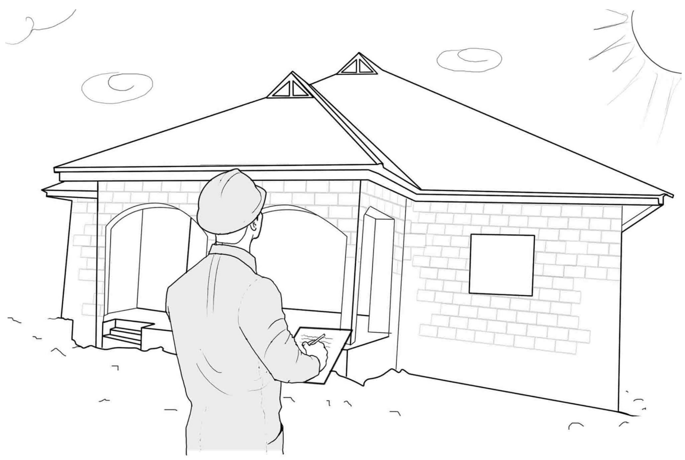
LED lamp

These loads consist of equipment that runs on DC. This equipment cannot be connected directly to the electrical grid. DC loads include televisions, refrigerators, light bulbs, pumps, fans, etc.

Most DC loads operate on 12 V; but a few, mostly light bulbs and fridges, are available for 24 V.

5.2. Step-by-step calculations

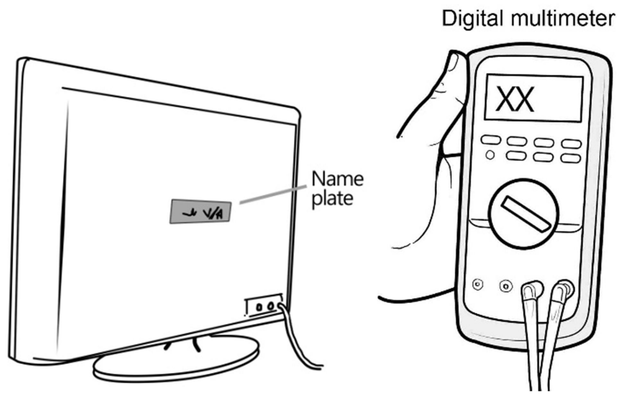
Task 1 – Evaluating the energy requirement

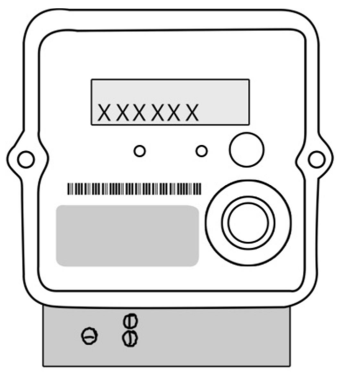


To install an off-grid or hybrid system, you need to perform eight steps:

1. Evaluate the energy demand (load assessment)
2. Size the battery bank
3. Estimate available solar re- source
4. Size the solar panel array
5. Size the charge controller
6. Size the inverter

To adequately evaluate the energy requirement, all loads within the system (essential, critical and non-critical) must be taken into consideration.





Energy meter

7. Optimise the system
8. Size the cables

Three methods to obtain the power rating of an appliance:

1. Direct reading on the name plate (can often be very inaccurate).
2. Direct measurement of voltage and current using a multimeter to determine power.
3. Direct measurement of energy consumed using an energy meter.

The energy requirement of an electrical system depends on the loads within the system. A load is any piece of electrical equipment or appliance that is used in the home or office.

When sizing a battery-based solar system, it is important to know which electrical loads need to be powered and for how long.

Electrical loads vary in their type and how much power they draw. Some equipment such as water pumps and air conditioners draw a large starting current, which could be up to five times the operating current. However, these high starting currents only last for 0.5 seconds. Other loads such as water heaters, electric irons and kettles usually have a constant but large power draw once they are turned on.

Some loads (energy-efficient or energy-saving) are best suited to solar systems. For example, LED and CFL bulbs (energy-saving bulbs) are better than the regular incandescent bulbs (they consume only between 10% and 40% of the

To calculate the energy requirement of a two-bedroom home, for example, you may use a table similar to the one below.

Load analysis						
	Loads	Power need (Watt)	Qty	Total power (Watt)	Daily usage (hours)	Daily energy (Watt-hours)
1	Air conditioner	1,200	3	3,600	6	21,600
2	CFL light bulb	20	10	200	8	1,600
3	Refrigerator	120	1	120	8	960
4	Microwave	1,000	1	1,000	0.1	100
5	Kettle	2,000	1	2,000	0.1	200
6	Electric iron	1,500	1	1,500	0.5	750
7	Television (on)	68	1	68	3	204
	(off – standby)	5.1	1	5.1	21	107
8	Satellite receiver (on)	17	1	17	3	51
	(off – standby)	16	1	16	21	336
9	DVD player	15	1	15	2	30
10	Home theatre	150	1	150	4	600
11	Electric hair dryer	250	1	250	0.2	50
12	Fan	70	2	140	4	640
13	Fluorescent tube	30	6	180	5	900
14	Computer	20	1	20	5	100
15	Water heater	1,200	2	2,400	0.25	600
	Total					**28,953**

For example, to calculate the daily energy requirement for the television, follow these steps:

1. Determine the power consumed by the television (this can usually be found on the name plate at the back of the TV). In our example, it is 68 W.
2. Ask the system owner how many hours per day he/she uses the television. In our example, this is 3 hours
3. The daily energy requirement (E_{daily}), for the TV is 68 W x 3 h = 204 Wh
4. Repeat for each appliance.

energy required by incandescent bulbs).

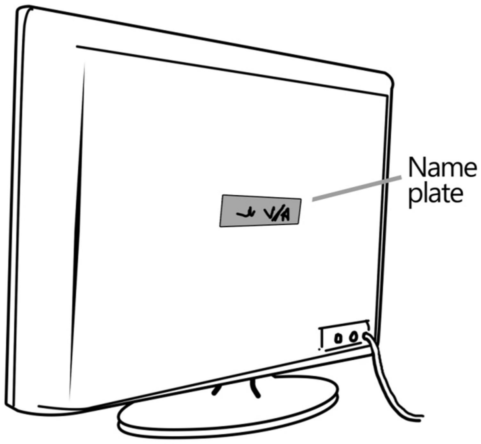
Some AC loads as CFL lamps and motors (e.g. in fridges) have a very poor power factor, which means that they draw a lot of extra (so called reactive power) from the power source (generator, inverter) to supply the rated electric power. For example, a typical energy-saving lamp has a power factor of 0.6. From the point of view of the power source, a 10 W energy-saving lamp consumes 10 W/0.6 = 16.7 W. The 120 W motor in the fridge with the same poor power factor consumes 120 W/0.6 = 200 W.

Other uncommon but equally important loads are vampire or phantom loads. These loads occur when equipment is on standby. For example, your decoder consumes electricity while on standby.

POWER FACTOR

The power factor refers to the real electricity that can be used from a power generator such as an inverter.

It also refers to the amount of power that is required to operate a load such as a CFL lamp.



NOTE

Do not forget to calculate the energy consumed by vampire loads (standby consumption) in a system.

The standby consumption for our TV is 5.1 W. As it is used for 3 hours per day, it is on standby for 21 hours per day.

$$5.1\text{ W } \times 21\text{ hours} = 107.1\text{ Wh}$$

The total daily energy consumption of the TV is 204 Wh + 107.1 Wh = 311.1 Wh

EXERCISE

Calculate the energy requirement of your home.

Task 2 – Battery bank sizing

All energy requirements calculated above must be stored in the battery. The battery will supply the energy when needed.

Follow these steps to determine the battery bank capacity:

1. Determine the daily energy requirement of loads in your system:

Taking our example for the two-bedroom home, we exclude heavy loads such as the air conditioner, microwave, electric kettle, iron and water heater.

The remaining daily energy consumption is 7,498 Wh.

2. Divide this value by the efficiency of the inverter. The efficiency of a good quality inverter is approximately 90%.

To adequately size the battery bank, you must consider the following criteria:

- Efficiency of the inverter (ηinv). Generally assume your inverter has an efficiency of 90%.
- Battery depth of discharge (DoD). For a good battery life: do not discharge more than 30% daily. In other words, always leave the battery at least 70% charge.
- System voltage. This must be selected in accordance with the

$$= \frac{E_{daily}}{0.9}$$

7,498 Wh ÷ 0.9 = 8,331 Wh

This is the energy demand, which has to be supplied by the battery.

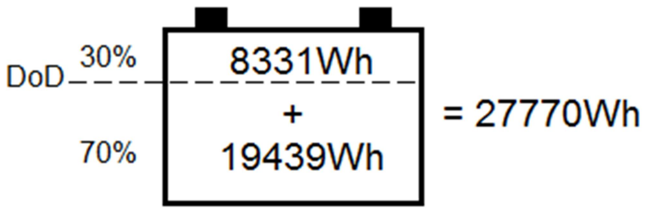
3. Divide this value by the depth of discharge (DoD) of the battery to determine the required battery energy capacity.

As seen in the previous chapter, the lifetime of a battery is short when discharged 100% every day. In order to reach an acceptable battery lifespan, we choose a DoD of no more than 30% every day. A good quality deep cycle gel battery can last 1,300 cycles in this mode of operation.

A DoD of 30% means 8,331 Wh can only make up 30% of the battery's energy capacity, since this is our daily energy demand.

$$Required\ battery\ energy\ capacity = \frac{E_{demand}}{0.3}$$

8,331 Wh ÷ 0.3 = 27,770 Wh. This is the required energy storage capacity of the battery. If we discharge our daily energy demand of 8,331 Wh from this battery, then the DoD is not more than 30% and we can reach a long lifespan of 2 to 5 years depending on the battery's quality.



4. Divide the required battery energy capacity by the system voltage to determine the battery capacity in ampere-hours (Ah)

$$Battery\ capacity = \frac{Energy\ storage\ capacity}{Selected\ system\ voltage}$$

$$C = \frac{27{,}770\ Wh}{48\ V} = \mathbf{579\ Ah}$$

The battery bank configuration could look like this:

inverter input voltage (DC side). For our purpose, we assume a system voltage of 48 V. This means you will need a minimum of 4 units of 12 V batteries.

DECIDING ON THE SYSTEM VOLTAGE

If you have a high energy demand that calls for a powerful solar array, the currents running through the charge controller can be very high. Then it is better to step up the system voltage and reduce the charging currents and cost for the charge controller.

Use the table below to decide on the appropriate voltage for your system.

Mean daily energy consumption (kWh/d)	*Peak power for minutes (kW)*	*Min. system voltage (V)*
0-4	0-1	12
2-6	1-2	24
4-12	2-4	48
8+	4-8	60+

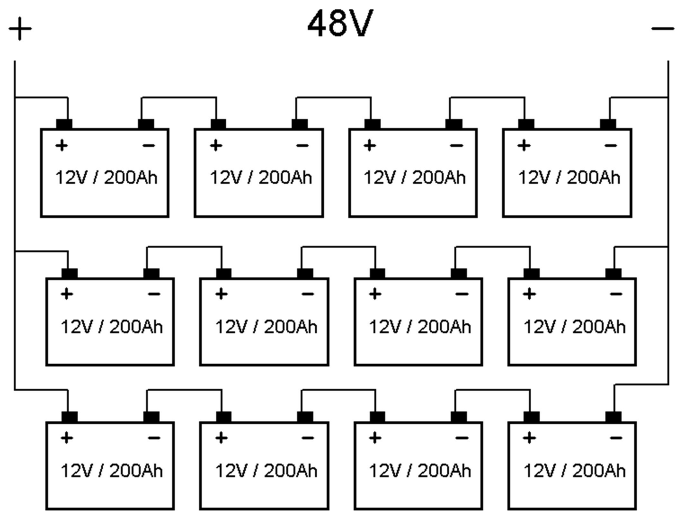
NOTE

In sizing a battery, it is important to install one large enough to operate the appliances for at least 24 hours without recharging. In climates that have long periods of cloudy weather, a larger battery may be needed.

REMEMBER

When buying a battery, the voltage and the ampere-hour rating must be known.

For a solar PV system in a home, the voltage will usually be 12 V, 24 V or 48 V.



The capacity of the battery will depend on the energy requirements of the appliances.

Manufacturers rate their batteries in ampere-hours, not watt-hours.

To convert the calculated watt-hours to ampere-hours, divide the watt-hours by the battery (system) voltage.

The battery bank has a system voltage of 48 V and a required capacity of 579 Ah.

We know that the batteries available to us in the Nigerian market are rated as 12 V, 200 Ah.

Hence, we require four batteries connected in series (12 V × 4 = 48 V) and three strings connected in parallel (200 Ah × 3= 600 Ah).

EXERCISE

What would be the required battery bank capacity if the air conditioner, electric kettle, microwave, electric iron and water heater are connected to the system?

What battery bank size would be required to provide your home with electricity for 24 hours?

If the air conditioner, iron, electric kettle and microwave are not included on the system, what will be the appropriate battery bank capacity?

Task 3 – Estimating available solar energy

To calculate the solar energy available in any location, we refer to the term peak sun hours (PSH).

Overview of PSH in Nigeria:

Climate	*PSH*	*Locations*
Mangrove swamp	4	Yenegoa, Lagos
High rainforest	4.5	Ibadan, Awka, Enugu
Guinea savannah	5	Abuja, Kaduna
Sudan savannah	5.5	Kainji, Kano
Sahel savannah	6	Sokoto

PEAK SUN HOURS (PSH)

This factor identifies the total amount of sunshine available in a particular location for an average day.

E.g. 5 PSH means the solar energy at a site is 5 $kWh/m^2/d$.

Task 4 – Sizing the solar array

When sizing the solar panel array, it is important to note that it must provide the daily energy required by your system. The solar panel array must be able to recharge the battery to a 100% SoC during all or most of the days.

In order to determine the required size of the PV array, follow these steps:

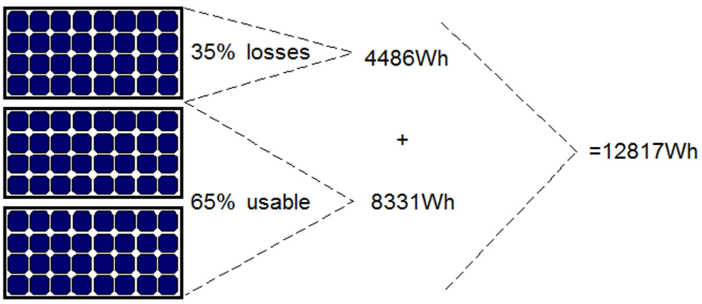
1. Divide the daily energy requirement by the performance ratio of the solar system.

The energy demand is the demand of all electrical consumers including the efficiency of the inverter.

In our two-bedroom home example, this was 8,331 Wh/d.

$$8{,}331\ Wh \div 0.65 = 12{,}817\ Wh$$

12, 817 Wh is the solar energy demand. This is the energy which the solar array has to generate under ideal conditions.



2. Divide this value by the appropriate PSH for your location.

Using the two-bedroom home example, and assuming that the location for installation is in Oshogbo, Osun State.

$$Required\ size\ of\ solar\ panel\ array = \frac{12{,}817\ Wh}{4.5\ h}$$
$$= \mathbf{2{,}848\ W_P\ or\ 2.85\ kW_P}$$

SELECTING THE SOLAR PANELS

Once you know the required size of the solar panel array, you need to determine the number and type of solar panels needed. In our example, if we have a 48 V

When sizing the solar panel array, it is important to take into consideration the following:

- Total available solar resource. This depends on where you are located in Nigeria. For ease of calculation, you should use the PSH values discussed in module 1 of this handbook.
- Performance ratio: In real life, solar panels do not live up to the manufacturers' ratings. The power output is reduced, mainly due to hot temperatures and dust on the panels and also due to wiring resistance. Under actual conditions, solar panels generate only about 65% of the rated output power.

NOTE

Solar panels with 36 cells have a maximum power voltage of approximately 17 V. These solar panels can be used to charge a 12 V battery. The nominal voltage of this panel type is 12 V.

Solar panels with 72 cells have a maximum power voltage of approximately 34 V. These solar panels can be used to charge a 24 V battery bank. The nominal voltage of this panel type is 24 V.

Nominal voltage refers to the respective voltage of a battery that a solar panel can be used to charge. Today, most solar panels are manufactured in nominal voltages of either 12 V or 24 V.

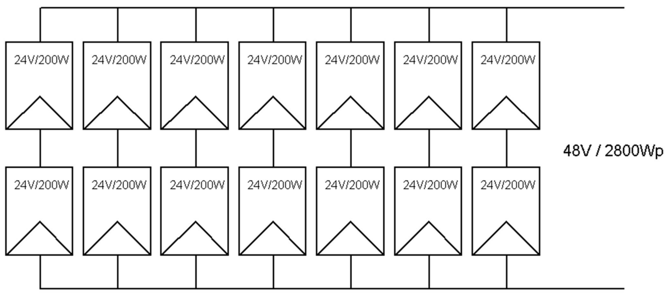
battery bank, we need two solar panels with a nominal voltage of 24 V in series.

Assume that you have access to 200 W_P solar panels each with a nominal voltage of 24 V.

Hence, you will require:

$$\text{Number of solar panels} = \frac{2{,}848 \text{ Wh}}{200} = 14.24 \text{ solar panels}$$

Rounding up to the nearest whole number, you will require 14 units of 200 W_P solar panels for this system. What the solar array will look like:



The easiest way to determine the nominal voltage of a solar panel is to look at the label on the back. If the open-circuit voltage (V_{OC}) is greater than 12 V and less than 24 V, its nominal voltage is 12 V. Similarly, if the circuit voltage (V_{OC}) is greater than 24 V, and less than 48 V, the nominal voltage is 24 V.

EXERCISE

Assuming there are only 180 W_P solar panels available in Nigeria, how many solar panels would you need to charge a battery bank if all equipment at your home is connected?

How many 180 W_P solar panels would be needed to supply the air conditioner, iron, electric kettle and microwave?

Task 5 – Charge controller sizing

The charge controller is in between the solar panel and the loads. It must manage the maximum current from the solar array because strong sunshine for short periods can cause solar panels to produce 20% more output than their maximum power rating. To determine the required size of the charge controller for your system, you could either check the maximum current rating on the data sheet of your solar panels or use the following calculation:

$$\textit{Required size of charge controller} = \frac{\textit{Size of solar panel array } (Wp)}{\textit{Maximum power voltage of array}} \times 1.2$$

The maximum power voltage of a 24 V solar panel is approximately 35 V. This data is included on the label or written on the datasheet. The maximum power volt-

When sizing the charge controller, the most important factor to consider is the current rating. Charge controllers are rated according to the maximum input current that they allow. They usually come in sizes of 10 A, 20 A, 30 A, 40 A, etc.

A charge controller might be working at several voltages (12 V, 24 V), but the maximum current is fixed and independent of operating voltage.

age of the array is the sum of the maximum power voltages which are connected in series.

Going back to our system, we have two 24 V panels connected in series; hence the maximum power voltage = 2 × 35 V = 70 V.

$$\text{Size of solar panel array (Wp)} = 14 \times 200\ \text{Wp} = 2800\ \text{Wp}$$

Hence,

$$\text{Required size of charge controller} = \frac{2800\ \text{Wp}}{70\ \text{V}} \times 1.2 = 48\ \text{A}$$

You must at this point select a charge controller that is rated 48 A. The closest available size in the Nigerian market is the 50 A charge controller. This is the charge controller you should select.

Task 6 – Inverter selection

Returning to our two-bedroom home:

The total power draw of all equipment – excluding the air conditioner, microwave, water heater, electric kettle and electric iron – is 1,181 W.

Inverters should not run continuously at their limit.

Hence, you should select an inverter that can support a continuous power rating of 20% more power than you need. In our example, that would be 1,181 W x 1.2 = 1,417 W.

Oversizing the inverter too much is also not advisable, since an inverter running well below its maximum power output is also operating with a very low efficiency. Unnecessary costs should also be considered.

When making your selection, remember that inverters are rated in volt-amperes (VA) and you should convert this rating to watts (W). This can be done by dividing the continuous power rating by 80%.

Hence,

$$\text{Required inverter size} = \frac{1,417\ \text{W}}{0.8} = 1,772\ \text{VA}$$

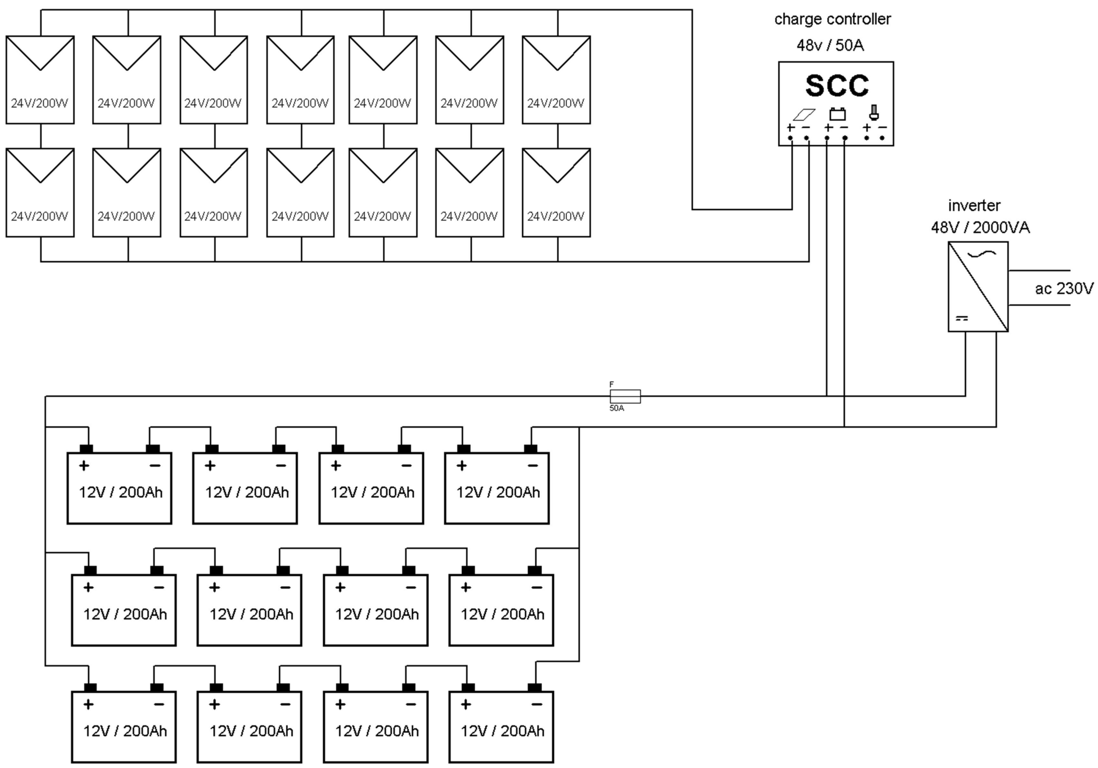
Now, select the inverter that has the closest rating. In Nigeria, this would be the 2 kW inverter.

When sizing the inverter, always consider the following:

- Output voltage. Ensure that the selected inverter's output voltage is suited to operate by Nigerian standards of 220 V to 240 V.
- Continuous power draw. From your calculated energy requirement, consider which loads will be running at the same time. You will have to discuss your client's needs and ensure that the selected inverter can meet those needs.
- Surge handling capability. Loads such as refrigerators create brief power surges during operation. You must take this into consideration when selecting the inverter. However, most inverters can handle short power surges of 2 to 3 times the rated output power if they do not last more than 0.5 to 2 seconds.

- Future loads. When selecting the inverter, always consider that new loads will probably be added to the system. Assume a 20% increase in power draw and provide for it.

The complete system could look like this:



6. INSTALLING A 1 KW$_P$ SOLAR SYSTEM

About this module

The installation of solar systems, though a relatively straightforward process, must be executed in a precise manner. This module describes the steps required to install a battery-based solar system that consists of a solar panel array no greater than 1 kW$_P$ and a battery bank of 9,600 Wh.

Learning outcomes

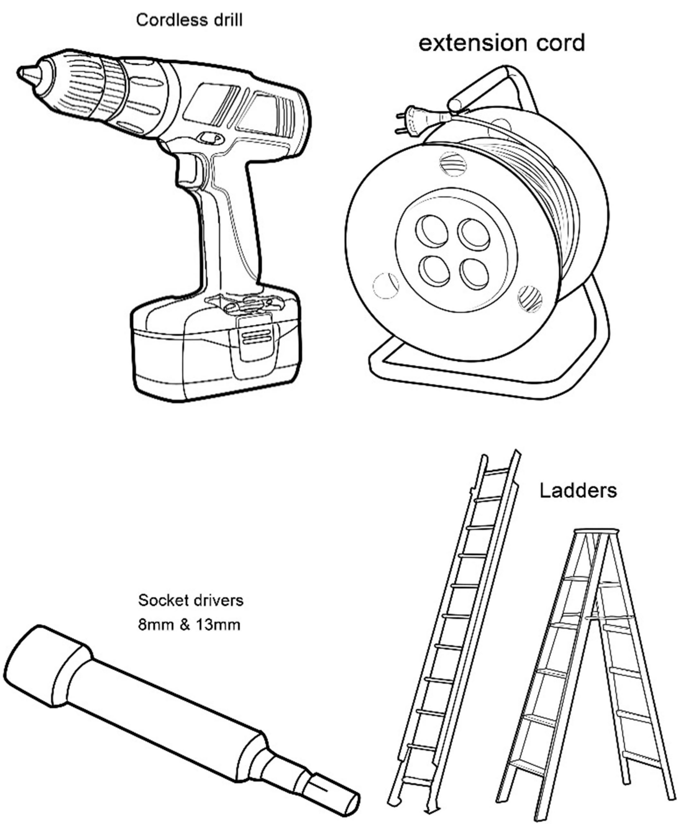
At the end of this module, the participant is able to

- Install solar power systems for domestic and smaller commercial applications

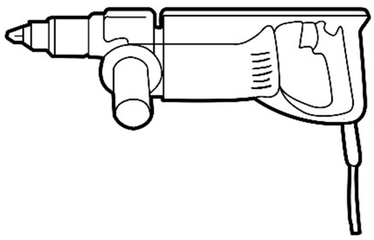
» *Always read the manuals*

Most damage to equipment during installation or operation happens because the technician or operator did not take the time to read the manuals properly. Every charge controller and inverter has different functions, switches, indicator lamps and connectors. Their functions must be studied before anything is connected. Many devices (especially charge controllers) require a specific setup procedure for optimised system performance.

6.1. Required tools

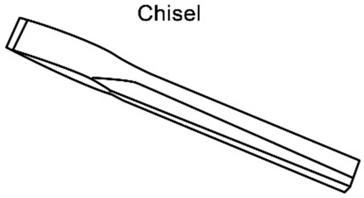


Drill

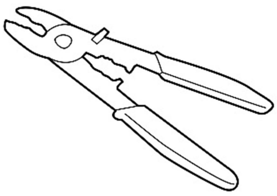


Phillips driver bits

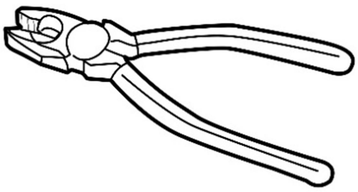
Chisel



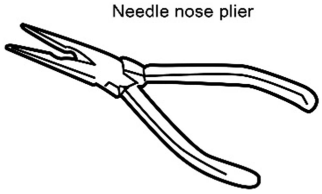
crimping tool



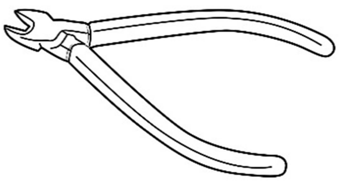
Line man's plier



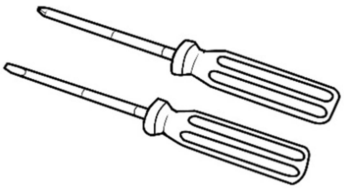
Needle nose plier



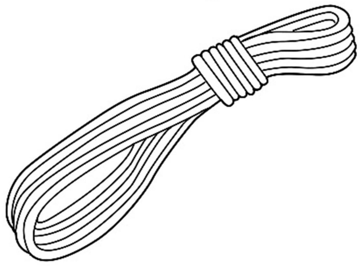
Wire cutter



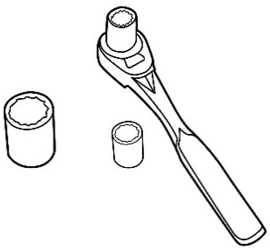
Screw driver set



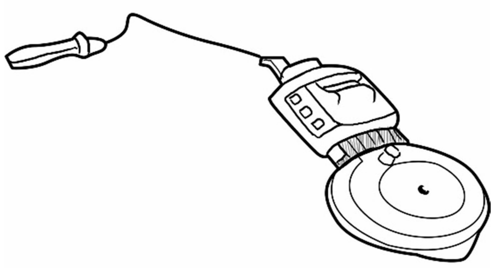
Rope



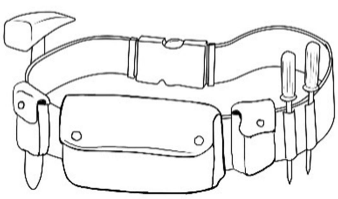
Ratchet wrench



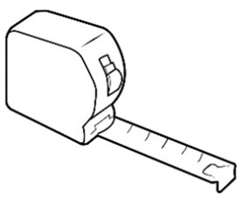
Electrician's chalk line



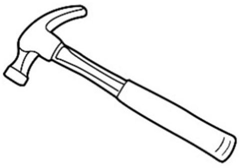
Tool belt



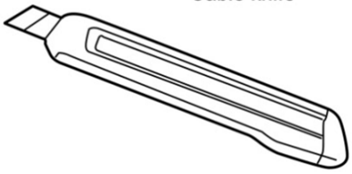
Tape measure



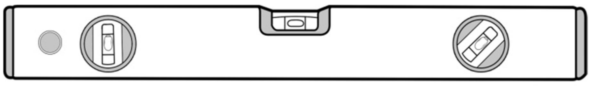
Hammer



Cable knife



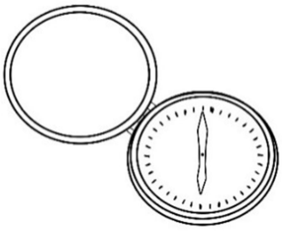
Clamp Meter



Spirit Level

Calculator

Compass



6.2. Suitable surfaces

Solar panels can be installed on various different surfaces. However, most systems are installed on poles, rooftops or on the ground.

On poles

Solar panels mounted on poles
- Courtesy: www.acutrack.com

Usually chosen for smaller systems such as street and traffic light systems.

Advantages	Disadvantages
Good theft protection	Difficult to clean

On rooftops

Solar panels mounted on a pitched roof

Rooftop installations are usually chosen when land is limited. This option provides good theft protection. However, cleaning is difficult.

Advantages	Disadvantages
Good theft protection	Depending on the roof design, difficult to install and clean
No extra space required	

On flat surface or ground

A ground-mounted solar array
– Courtesy: Melissa Van Hoorne, http://blog.solarmicronics.co

Ground mounting is usually used when installing very large solar panel arrays and when land is abundant.

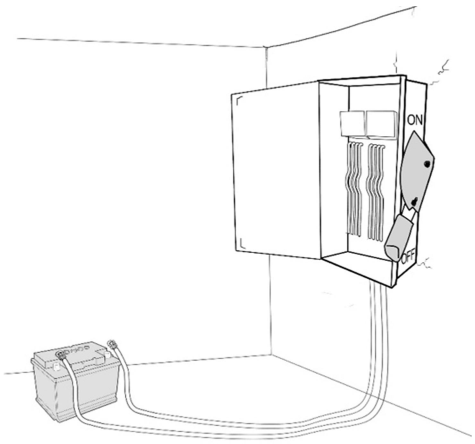
Ground mounting techniques could also be used when installing on flat, concrete roof surfaces.

Advantages	Disadvantages
Easy to install and clean	Requires abundant land Poor theft protection

6.3. Installing batteries

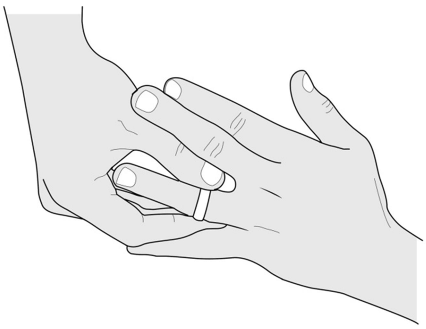
24 V battery bank

Working with battery systems can be the most dangerous part of solar electric installations and maintenance. Batteries can be dangerous!



Care should always be taken to prevent arcing at or near battery terminals. Always open the main DC disconnect switch between the batteries and the inverter prior to servicing or working on the battery bank.

You should also take note of ventilation for the battery bank, especially when using flooded/wet-cell batteries.



Remove all jewellery

Battery banks can store voltages with very high current potentials. These higher potentials can create electrical arc hazards. Metal tools and personal jewellery can create arcing on batteries that lead to severe burns or battery explosions. Remove jewellery and always use appropriate tools when working with batteries.

Protect your eyes by wearing safety goggles

Always wear eye protection when working on liquid lead-acid batteries.

Poor connection (left), good connection (right)

Poor battery connections cause voltage drop, heat and sparking. Sparking will quickly destroy the battery connector.

Currents on the battery cables can be very high during normal operation. Choose the correct cable size and the right connectors to connect batteries.

It is recommended that a cable size **not smaller than 16 mm²** is used to connect batteries

Batteries protected in vented battery box

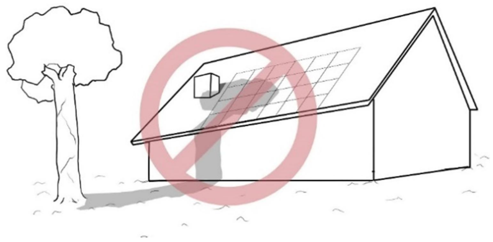
A short circuit on the battery terminals can result in an enormous release of energy with strong sparks. Batteries must be protected from accidentally falling items and other mechanical impacts. The installation must allow some airflow as batteries get slightly warm when used.

6.4. Installing solar panels

Shading

Make sure that no trees, poles, higher buildings, chimneys or other natural or man-made structures cast a shadow on the solar panels.

- Always install solar panels so that they receive the same amount of sunlight throughout the day.



Even a small shadow can result in a huge energy loss

- Before finalising the mounting orientation, confirm that there are no obstacles (natural or man-made) that will cast a shadow or cause shading on the solar panels.

Handling solar panels

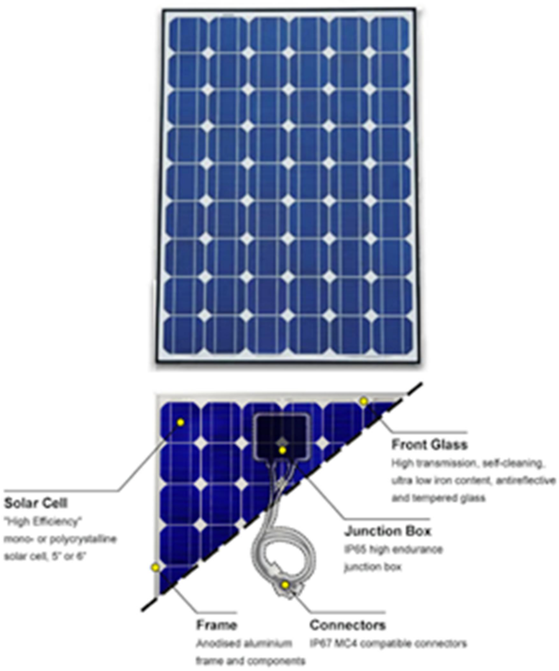
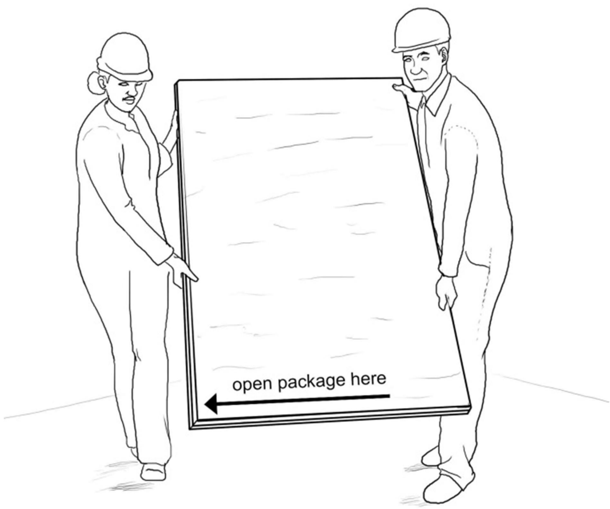


Illustration of solar panel with different parts

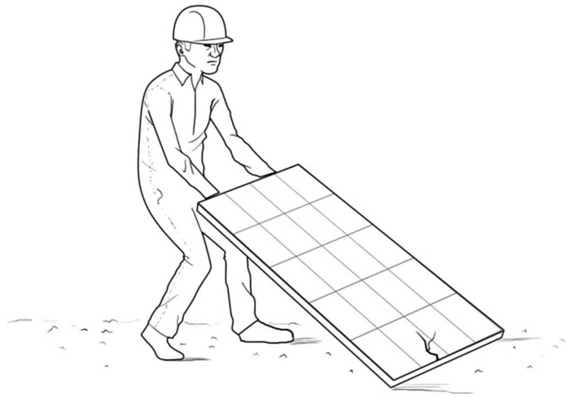


Always transport modules in their original packaging

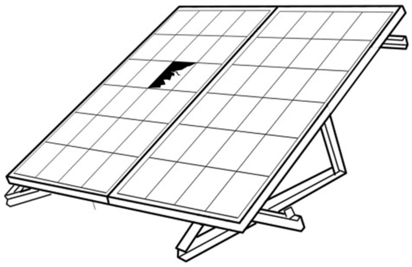
Solar panels usually have an aluminium frame and are covered with strong glass that can withstand the impact of hailstones. However, care must be taken when modules are transported or lifted.

Always remember:

1. To prevent damage to the module, transport the modules in their original packaging until installation.
2. Inappropriate transport and installation may break the module.
3. Hard objects can strike the back of a module causing permanent damage.
4. When one cell is broken, the whole solar panel is destroyed and unusable.
5. Store solar panels in a cool, dry place.
6. Protect solar panels against scratches and similar damage.
7. Do not rest a solar panel unprotected on its edges as this can damage its frame.
8. Ensure the solar panels do not bow under their own weight.

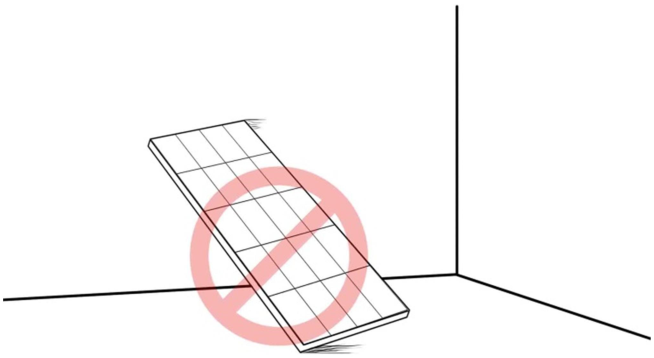


Inappropriate transport and installation may break the module



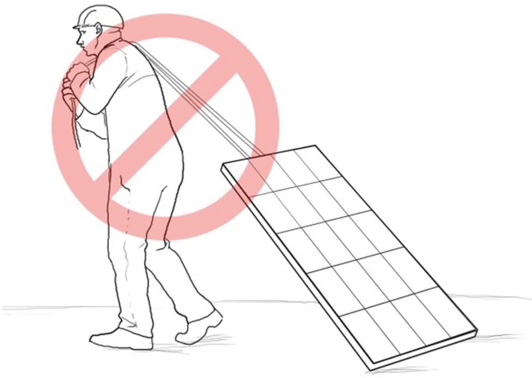
Broken solar panel cell

When one cell is broken, the whole solar panel is either unusable or permanently compromised and its use is limited to a low value and lower power application.

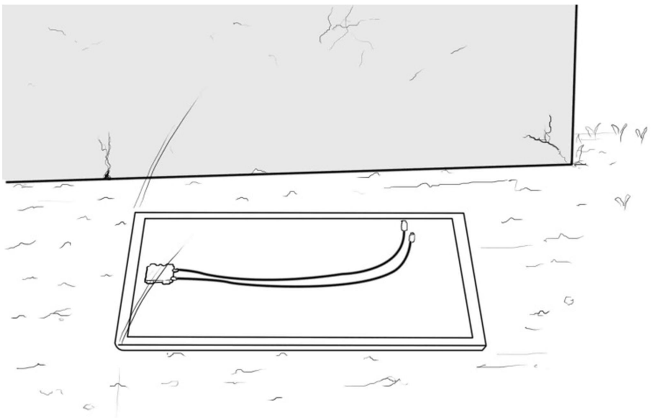


Do not rest a solar panel unprotected on its edge

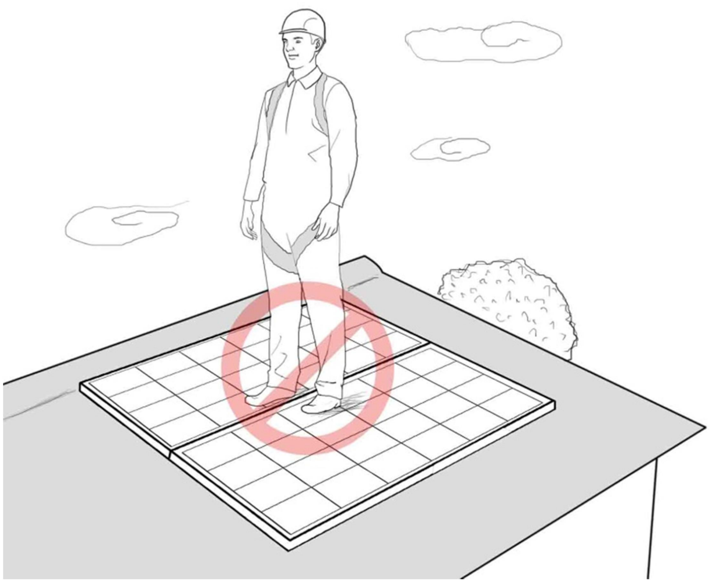
9. Never move or lift the solar panels using the cables or at the junction box.
10. Do not set the face of the solar panels down hard on any surface.
11. Do not subject the face of the solar panels to mechanical stress.
12. Do not stand on solar panels.
13. Do not drop or place objects on the solar panels.
14. Do not expose the solar panels to chemicals.
15. Do not immerse solar panels in liquids.
16. Do not install modules when it is raining.
17. Do not drill holes in the frame. Do not cut or modify parts or rails of the solar panel.
18. Completely cover solar panels with opaque materials when installing and wiring to halt the production of electricity.
19. Do not use chemicals on solar modules when cleaning.
20. Do not wear metallic jewellery which may cause electrical shock.
21. Do not touch cable electrical contacts.



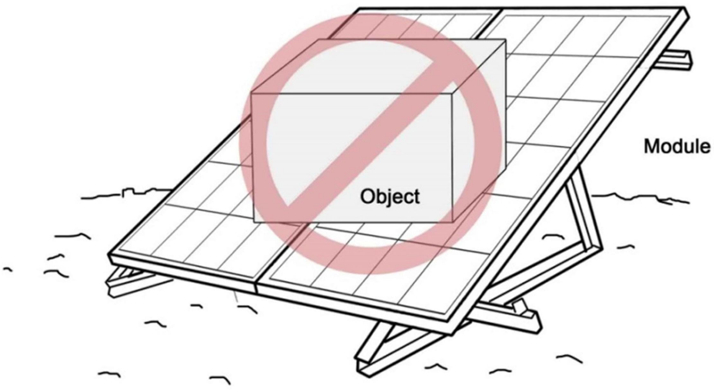
Never move or lift the solar panels using the cables or at the junction box



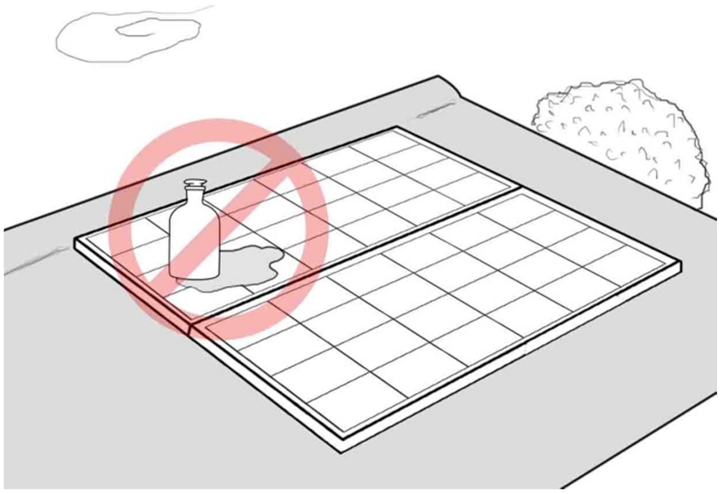
Do not forcibly set down the face of the solar panels on any surface



Do not stand on the solar panel

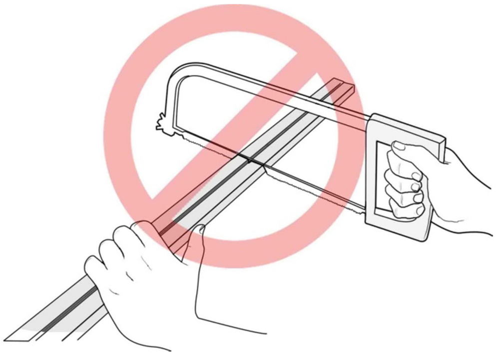


Never place any object on the solar panel

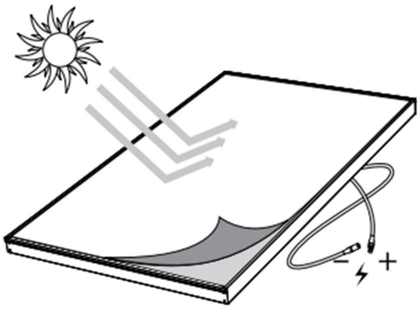


Do not expose the solar panels to chemicals

Do not install modules when it is raining

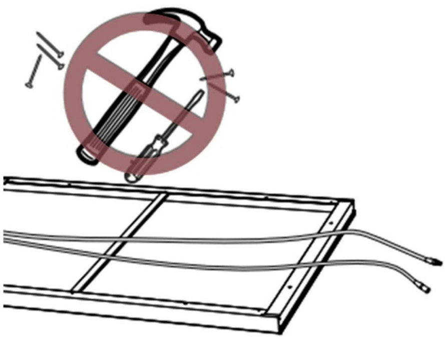


Do not cut or modify the parts or rails of solar panels



Cover solar modules during installation (daytime) to reduce the risk of shock

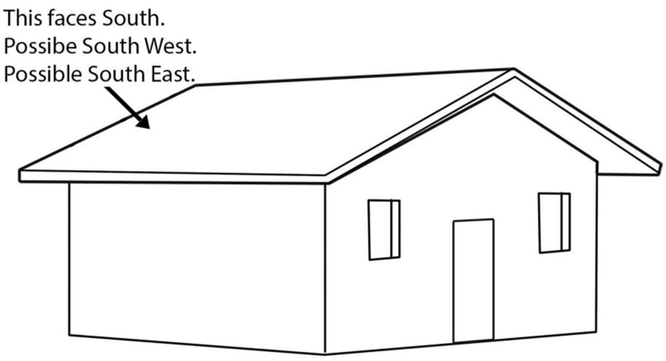
Do not drill holes in the frame unless absolutely necessary

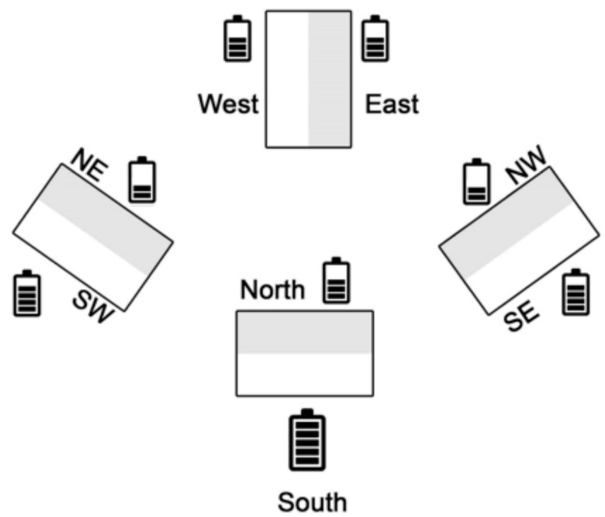


Keep foreign objects away from the back surface of the solar panel

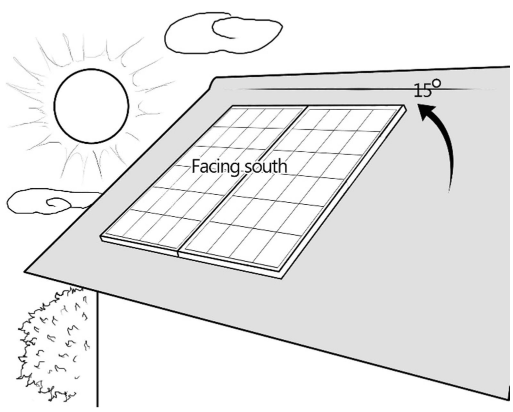
Mounting of solar modules

BEFORE YOU BEGIN





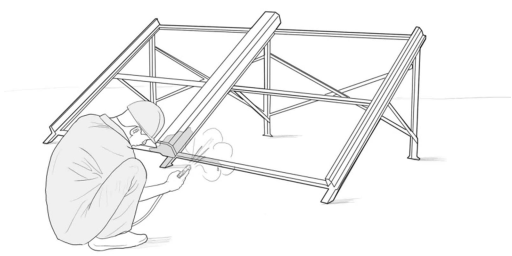
The orientation of a solar panel determines how much energy can be generated



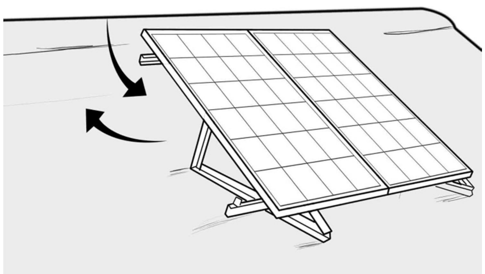
Ensure that the solar panels always face south and are at 15°

- The power output from the solar panel is highest when the sun faces the panel directly.
- To generate maximum electricity from solar panels in Nigeria, always position the panels so that they face south.
- In Nigeria, the optimum slope for the solar panels is 15°.
- A non-ideal orientation (north, east west) could reduce the performance of the solar panels by up to 35%.

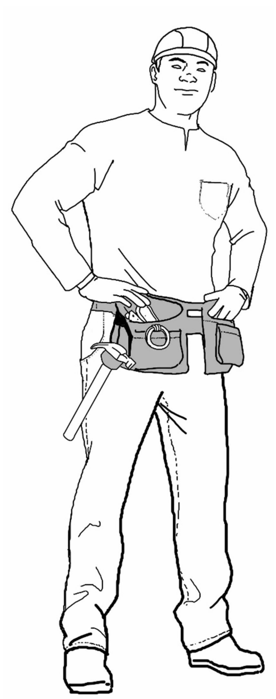
Installing the solar panel



Mounting materials should be made of aluminium (preferably), or be adequately coated with anti-rust paint.



Sufficient back ventilation of the panel. During operation, solar panels get very hot, so it is important that you provide space for air to circulate below the panels.



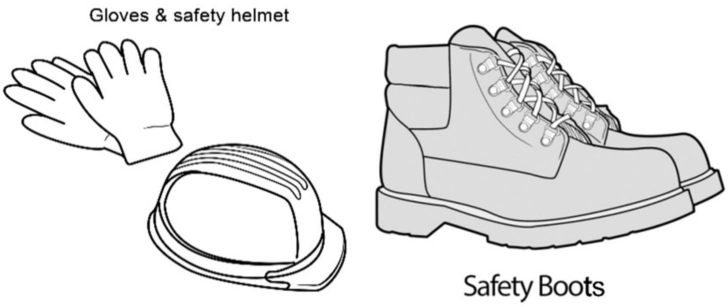
Appropriate protective clothing

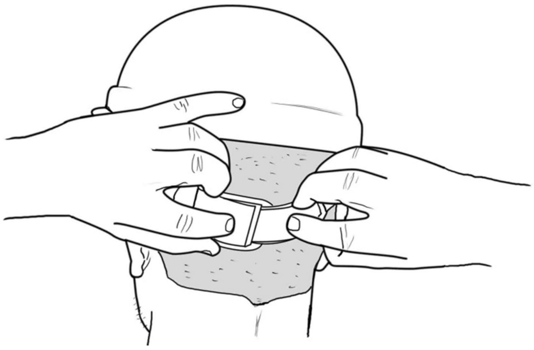
When using mounting materials for solar panels, follow these rules:

- Choose durable, corrosion-proof and UV-resistant material.
- Make sure that mounting materials are adequately coated with anti-rust paint or thoroughly galvanised to prevent rusting
- When installing the panel, make sure to provide for sufficient back ventilation.
- Choose mounting materials that allow for strain-free expansion and contraction due to natural ambient temperature variations.
- Ensure the long-term stability of the installation material and location.

When installing solar panels, follow these safety instructions:

1. Always wear appropriate work clothes and protective equipment:
    - Work clothes for both the upper and lower body should fit well and allow you to move freely.
2. Always wear protective equipment such as:
    - A hard hat when working in areas with falling objects.
    - Insulated gloves for working with electrical components.



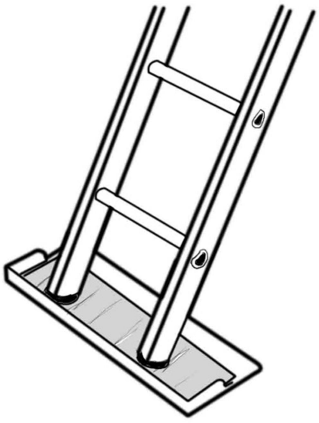


Always inspect ladders

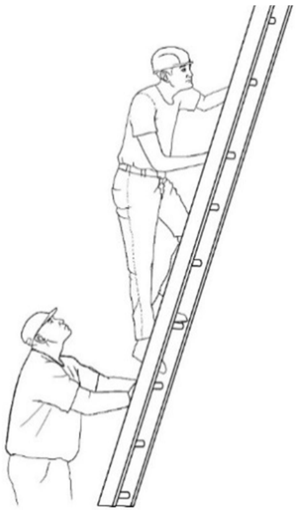
Use ladders with steps that are broad enough to permit safe work

- Insulated boots to insulate you from electric shocks.
- Solar modules generate electricity when exposed to light. You will need to wear insulating gloves when working on electrical connections.

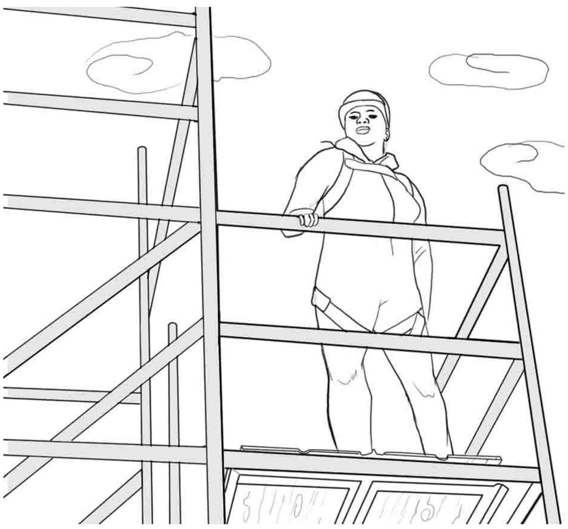
3. Observe safety practices for climbing up and down ladders and stepladders:
   - Before use, always inspect ladders to make sure they are in good condition.
   - Use ladders with steps that are broad enough to permit safe work.
   - Choose a safe spot to anchor ladders and stepladders.
   - Always work with a partner. One person should hold the ladder steady.
   - When you use a two-stage ladder, secure it with ropes to prevent it from sliding sideways, and have your partner steady the ladder.
4. When working in high places, wear harnesses and use scaffolding:
   - When working at heights of two metres (2 m) or more, use scaffolds or other equipment to ensure a stable work platform.



Anchor ladders by securing them to avoid slip. This can be easily done using a wooden board



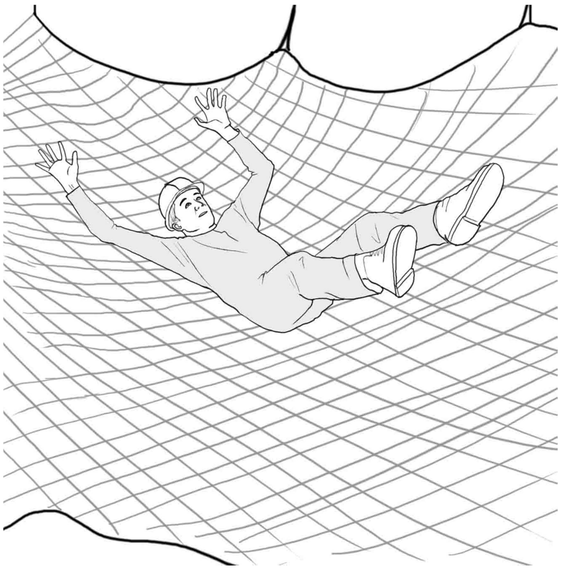
Always work with a partner



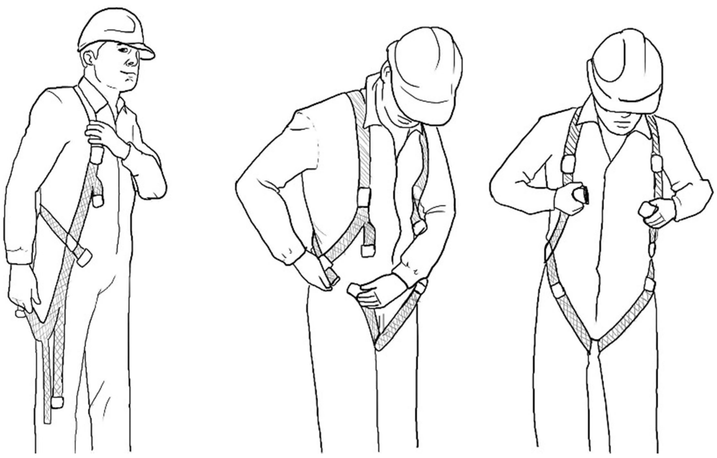
Scaffolding and guardrail

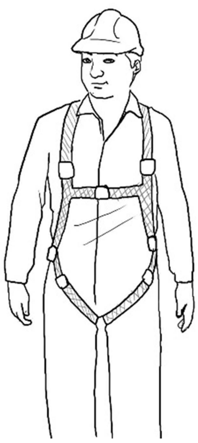
- Scaffolds should be designed and erected by a qualified person.
- When it is difficult to erect a stable work platform, install safety nets or wear harnesses, and take other precautions to prevent falls.
- Fasten harnesses securely, and check that the length of lifelines is 2 m or less.
- Securely attach the primary support line to a metal fixture installed for that purpose on a ridge or beam.

5. Install enclosures and covers:
   - At openings, and at other dangerous locations, install enclosures, guardrails, or covers at the end of work decks that are three metres (3 m) or more above ground.
   - When it is extremely difficult to install enclosures, guardrails, or covers, or when they must be removed to work in that location, install a safety net, wear a harness, and take other measures to prevent falls.
6. Protect against falling objects:
   - When objects are tossed down from a height of 1.8 m or more, appoint a person to act as a monitor on the ground. This person should make sure no one is in harm's way and



Safety net





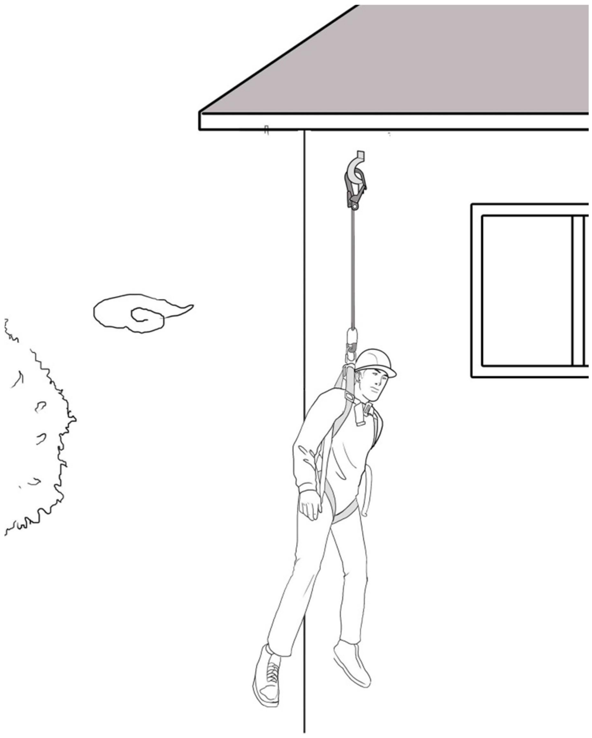
Wearing a body harness

warn others about falling objects.

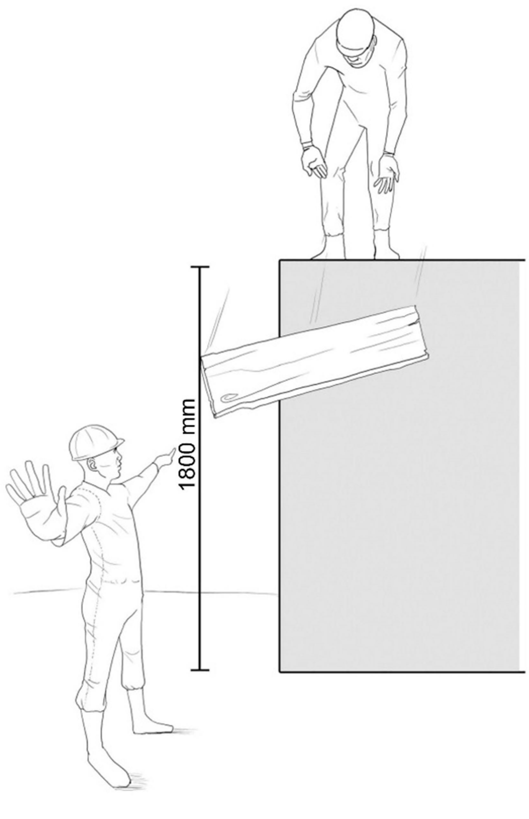
- Prevent people not working on site from entering and exposing themselves to unnecessary risks.
- Arrange tools and materials neatly and secure them with ropes, or use bags or other measures to prevent objects from falling.

A body harness is used for protection against falls whilst working at heights. When using a body harness, the following must be taken into consideration:

1. The harness must be fastened to a hook which is anchored on a fixed, solid surface such as a concrete wall or ceiling.
2. Ensure that all hooks are working perfectly and that there is no rusting on any metal parts.
3. The lifeline connected to the body harness must ensure that in the unfortunate event of a fall, the wearer of the body harness is sufficiently protected from slamming into the ground.
4. If the body harness has been subjected to the stress of fall protection, it should be replaced with a new one.

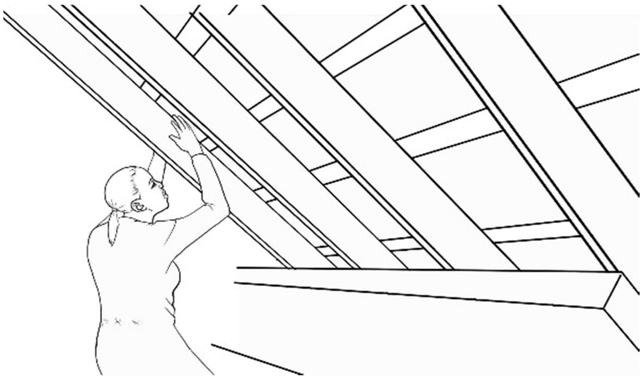


Safety harness, length of lifeline is 2 m or less

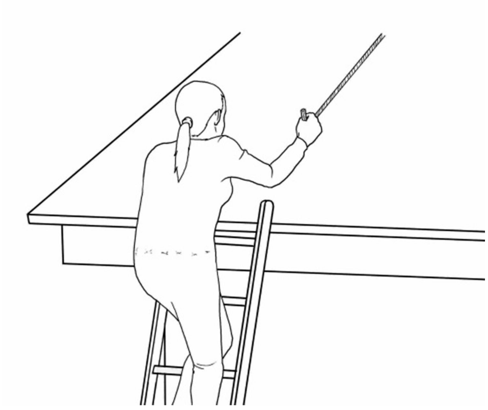


6.5. Installing solar panels on a roof

Preparing a shingle roof for installation

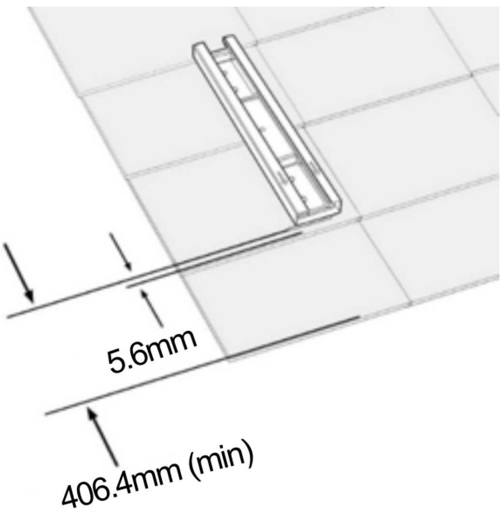


1. Locate rafters or trusses on the inside of the roof.

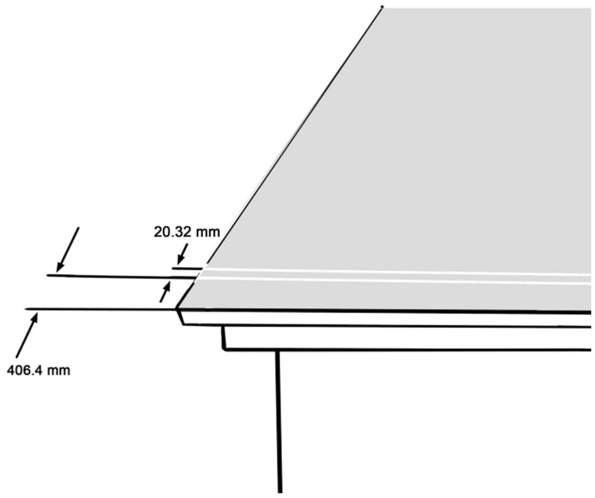


2. Locate and measure the locations of the rafters in the attic or at the outside eave and transfer measurements to the roof.

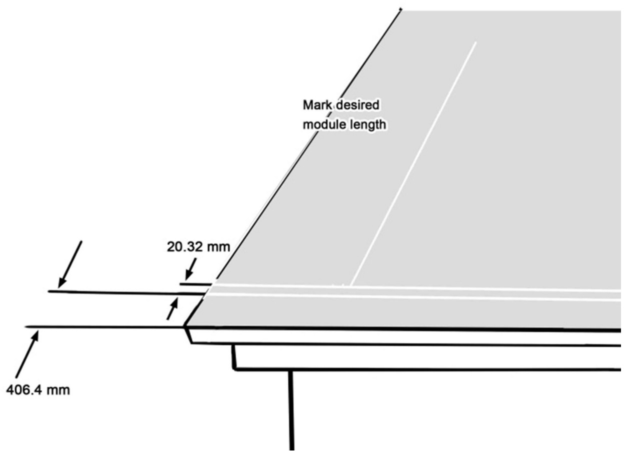
3. Scan the roof with a high sensitivity stud finder.



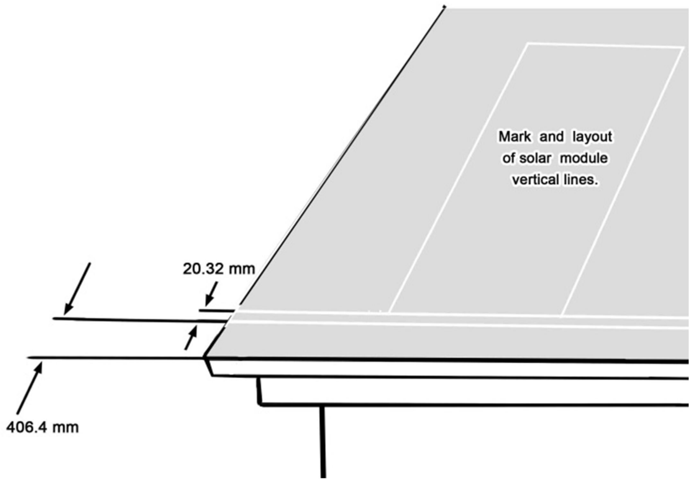
4. Measure up at least 400 mm from the eave. Snap a chalk line. This marks the location of the bottom edge of the slider bottom. This line needs to be at least 5.5 mm away from the nearest front edge of the shingles.



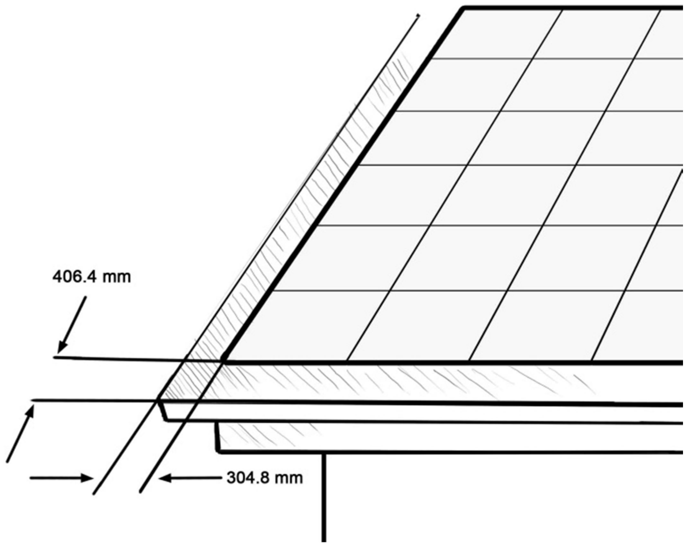
5. Measure up 20 mm from chalk line and snap a new chalk line. This marks the location of the bottom edges of the modules.



6. Measure up from the solar panel chalk line to the desired module length to form the array. Snap horizontal lines at the measured locations.

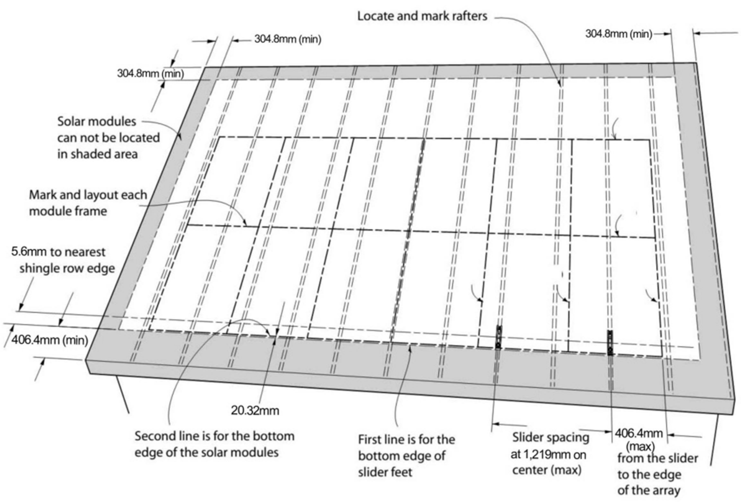


7. Mark and layout of solar module vertical lines.

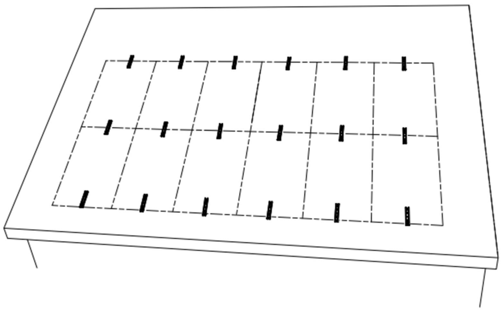


8. The array must be installed at least 400 mm from the eave of the roof and 300 mm from the sides of the roof. This distance should ensure sturdiness.

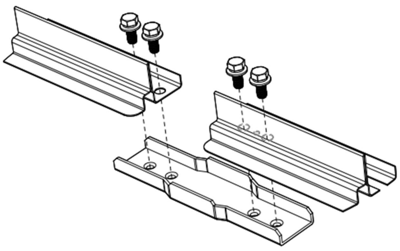
Installing solar panel mounts and supports on a pitched roof



1. Before installing sliders, check the layout of rails and splices.

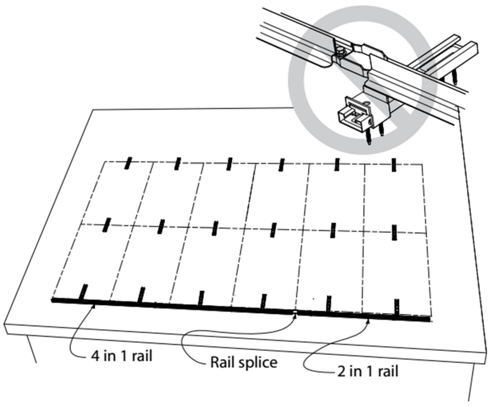


2. Place all sliders in desired locations.



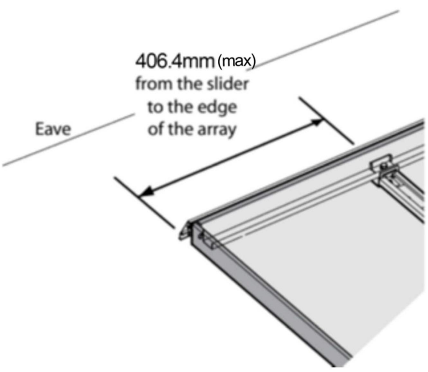
Pre-assemble rails and splices

3. Move the rails with splices into position. Ensure that there is no overlapping between slider locations and splices.



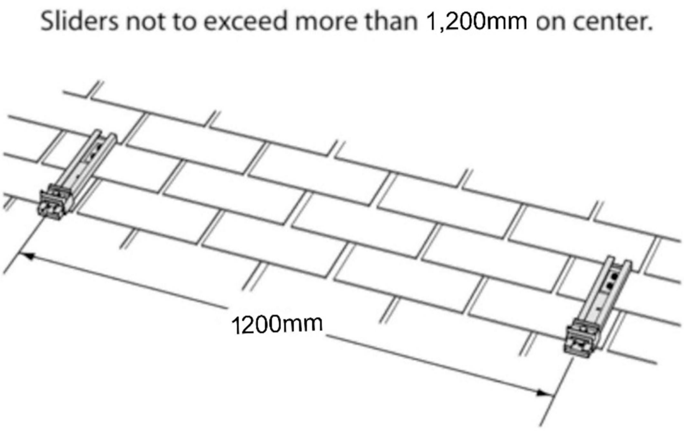
Do not permit overlapping

4. If these overlap or seem too close:
   - Shift rails horizontally
   - Move sliders to next rafter or remove splices to switch the long and short rails to opposite sides
   - Reattach splices after rails are switched and recheck for overlap.



Caution: The maximum distance from the slider to the edge of the array is 400 mm.

Installing the standard slider assembly



Each adjustable slider is equipped with pre-installed butyl sealant pads. The protective cover must be removed prior to installation on the roof. A hole is located at the centre point of the slider. It can be used as the site window for placing it on the previously snapped chalk line.

There are two arrows at one end of the slider. The arrows must be pointing towards the eave of the roof. The arrows indicate the location of indents on the slider that prevent the standard slider bottom bracket from falling out.

Place the slider assembly in the measured location and install the self-drilling screws at the upper and lower locations.

The arrow on the standard slider assembly points to eave.

6.6. Connecting system components

Connecting solar panels

Feeding of module wires through roof sheets

When connecting solar panels, observe following rules:

- Be aware that a solar array already generates its full voltage with only a little sun.
- Choose a main feeder cable from the array to the charge controller which keeps the voltage drop below 3%.
- For our 1 kWP 48 V system, a cable size of 25 m^2 is required for a cable run of up to 30 m between the solar panel array

Junction box protected from rain

Grounding the metal frame of a solar array

and the charge controller.

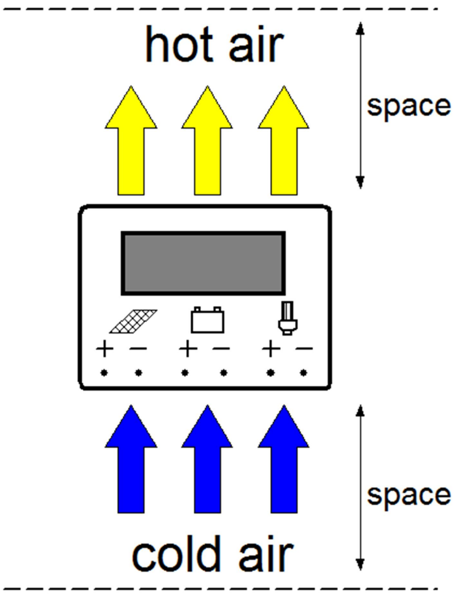
- Avoid unnecessary cable length.
- Use screw connectors for all connections; splicing is very unreliable.
- Connect solar module cables to a charge controller feeder cable inside a junction box or DC combiner box.
- Observe the colour code, positive = red, negative = black.
- Junction boxes must be protected from the rain, preferably inside the roof.
- Secure cable, protect from mechanical stress and impact from stones.

In locations where the PV array is exposed and could be susceptible to lightning strikes the array should be grounded by connecting the negative terminal to ground, even for smaller systems such as our example. A bare copper cable of minimum size 10 mm^2 should be used to connect the metal frame of the PV array to a grounding electrode.

If the solar panel array is installed on a roof of a building with an existing lightning arrester, it is **usually** not required to ground the metal frame of the solar panel array.

Otherwise, grounding the metal frame of the solar panel array is not necessary.

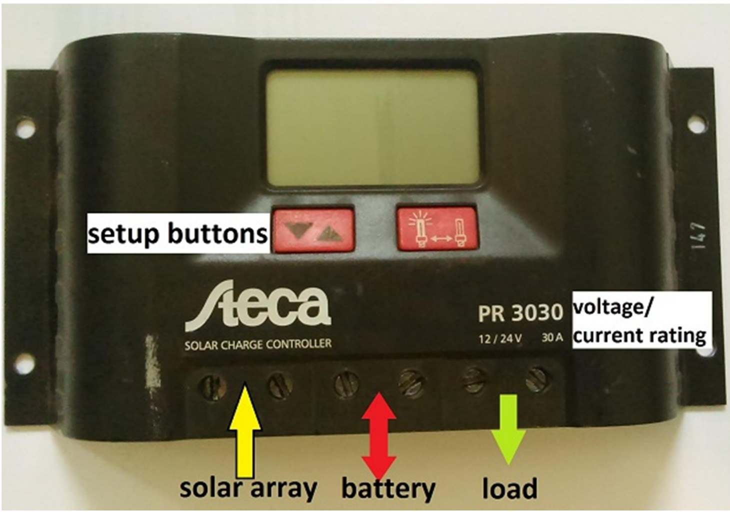
Installing the charge controller



Cooling of a charge controller

Charge controllers get hot during operation; space for enough airstream must be observed when choosing the installation site.

If the solar array is connected before the battery, the charge controller might get damaged due to overvoltage!



Typical PWM charge controller

When installing the charge controller, observe the following rules:

- Read the manual.
- Check to ensure that the voltage and current ratings match the solar array.
- Mind the ventilation space around the charge controller as specified in the manual.
- Mind possible setup options for different battery types.
- First, connect the battery.
- Second, connect the solar array.
- Make sure all connections are tight.

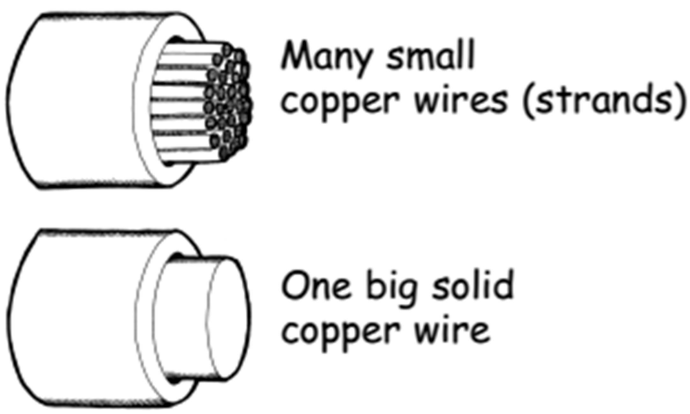
Many charge controllers can operate at different system voltages, e.g. 12 and 24 V. The voltage is usually detected automatically as soon as the battery is connected.

Solar system circuits

Solar power systems can typically be divided into the following circuits:

- Solar source circuit: Interconnection between solar panels terminating at the PV combiner box.
- Solar output circuit: Circuit between the combiner box and the DC disconnect which is used to isolate the solar panel array from the rest of the system.
- Charge controller input circuit: Interconnection between the DC disconnect and the charge controller (solar panel array and battery bank).
- Charge controller output circuit: Interconnection between the charge controller and DC loads.
- Inverter output circuit: Interconnection between the inverter and the main distribution board.

Types of wires and cables

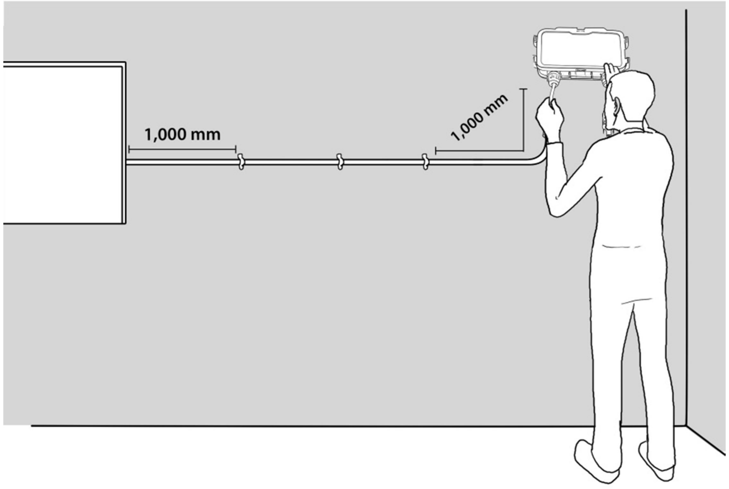


For solar power installations, you should use well insulated copper cables. These cables can either be stranded (with many small wires) or solid (one solid core). These cables can be used when installing solar systems; however, note their individual advantages and disadvantages.

Rules for wiring

Two important rules for connecting wires in a solar system:

1) Always use a screw-type connector.
2) Always tighten the screws firmly.



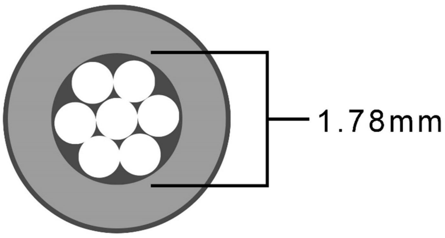
- **Wiring rule 1:**

  Never use longer wires than you really need. Wires should be kept as short as possible.

  Ideally, leave an extra metre (1 m) at each end of the cable when laying to allow for easy termination.

- **Wiring rule 2:**

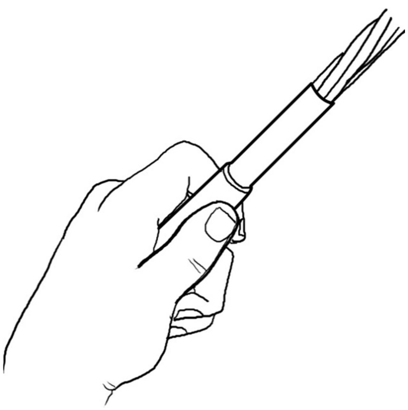
  Always use the right cable for the job.



Cross-sectional area: $2.5mm^2$

- **Wiring Rule 3:**

  Never use cables less than 2.5 mm^2 when wiring solar systems.



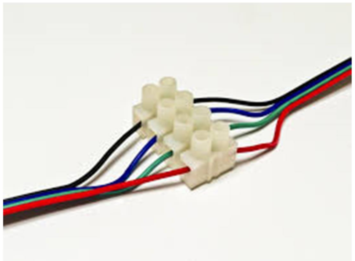
Poor termination and insulation could lead to fires
– Courtesy: www.completeepc.co.uk

- **Wiring rule 4:**

  Ensure that cables are properly terminated and well insulated.

- **Wiring rule 5:**

  Never twist wires together. Always use connectors.



- **Wiring rule 6:**

  Always use proper wire connectors.

  Do not use wire nuts. Instead use screw-type connectors.

Cable colour	Usage
Red	Neutral
Blue	Live wire
Black	Live wire
Green/Yellow/Bare	Grounding

- **Wiring rule 7:**

  Ensure that all cables used follow the correct wire coding for AC and DC systems in Nigeria.

The cable size to be selected in a solar system is dependent on three criteria

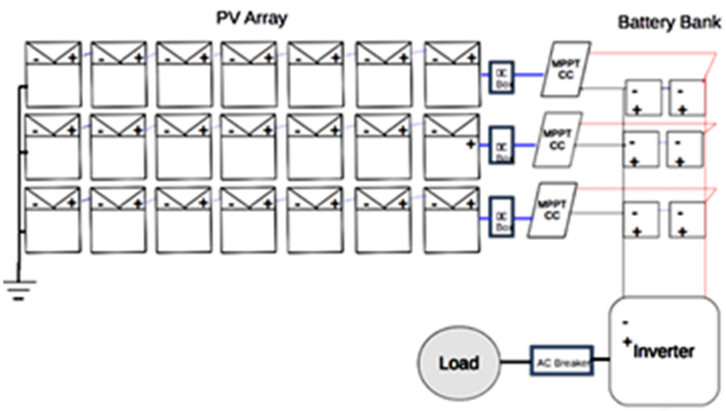
- Allowed maximum power loss
- Length of cable run
- Maximum rated current

Always check cable manufacturer **ampacity charts** before connecting cables in a solar system.

6.7. Step-by step installation

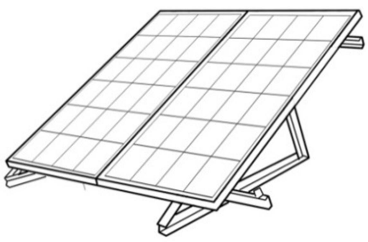
Before you begin with the installation of a solar system, you must prepare the site. Site preparation involves the following:

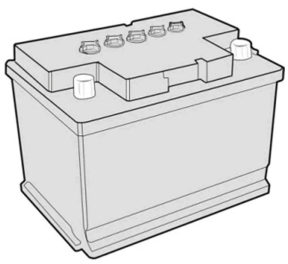
- Confirm the location where the solar panels will be installed.
- Confirm that there is no shade or shade causing feature on site which could interfere with the irradiance received by the solar panel array. This could be trees, buildings or other man-made structures in the area such as electricity poles.
- Other relevant issues such as clearance from the ground (if the solar panels will be ground mounted) and slope (gradient) of the ground also need to be carefully considered.

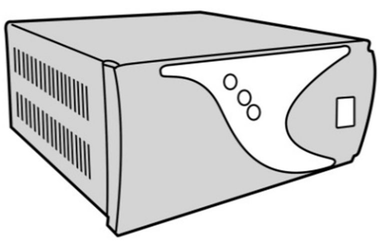


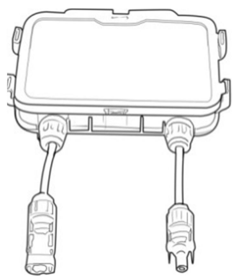
Prepare the installation diagram. This could be a single-line diagram showing the interconnection between system components.

Equipment and materials for installation





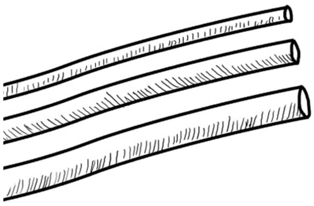


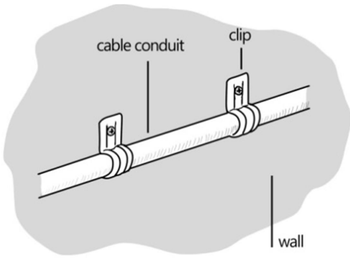


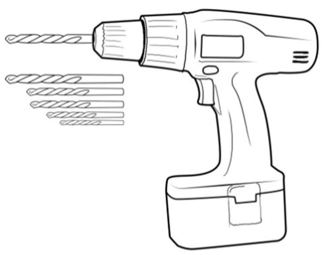
Prepare all the necessary equipment and materials required to complete installation. These include:

1. Solar panels
2. Batteries
3. Inverter
4. Charge controller(s)
5. Cables of different sizes
6. Cable conduits/trunking and associated clips
7. Power drill with appropriate drill bits
8. Cable fishing tape
9. Screws and pegs
10. Screwdrivers
11. Cable labels

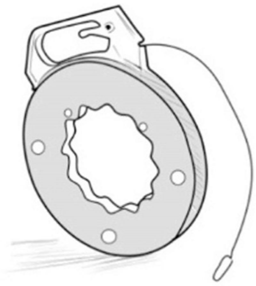
12. Electrical tape
13. Chalk line
14. Pliers
15. Wire cutter
16. Spirit level







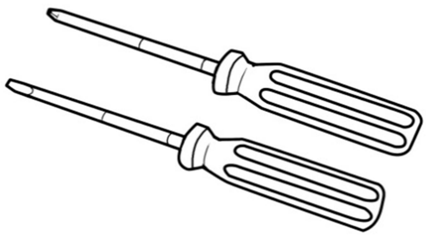
Power drill with appropriate drill bits

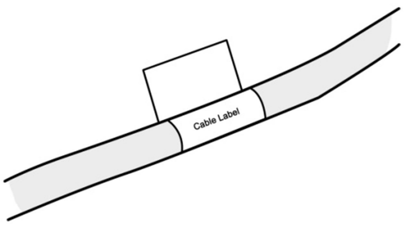


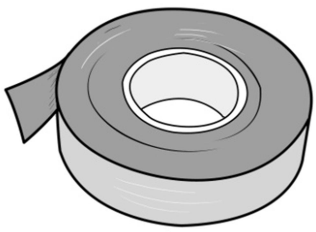
Cable fishing tape

Screws and pegs

Screw driver set

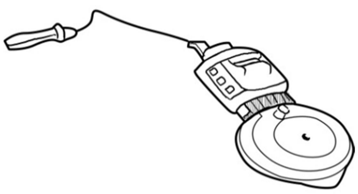




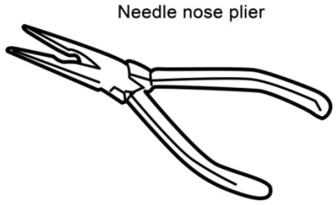


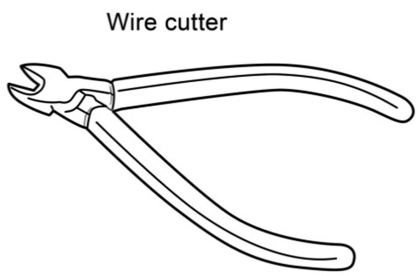
Electricians tape

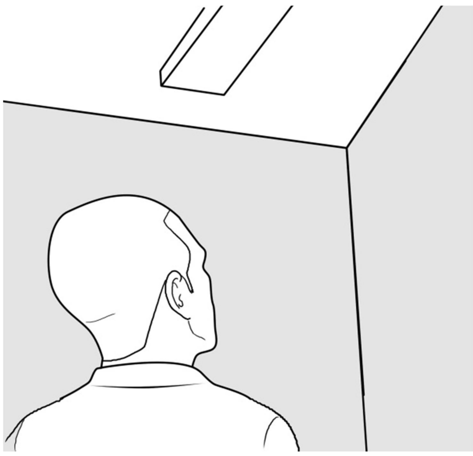
Electricians chalk line



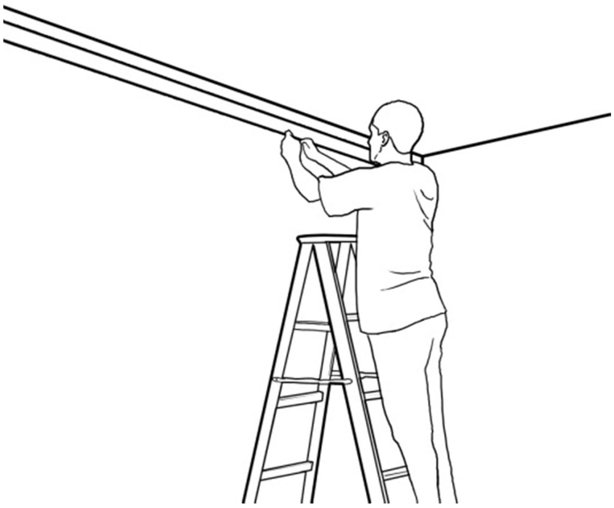
Needle nose plier



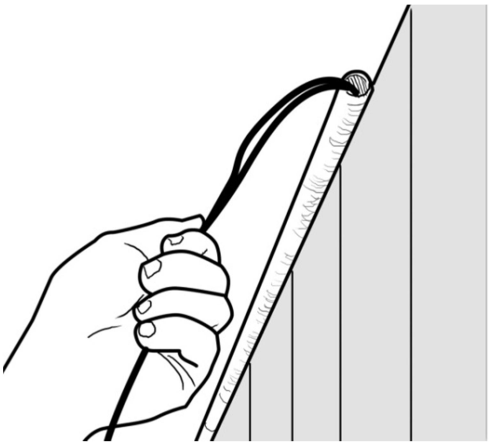




1. Determine and decide on the installation location of the system components and cable route.

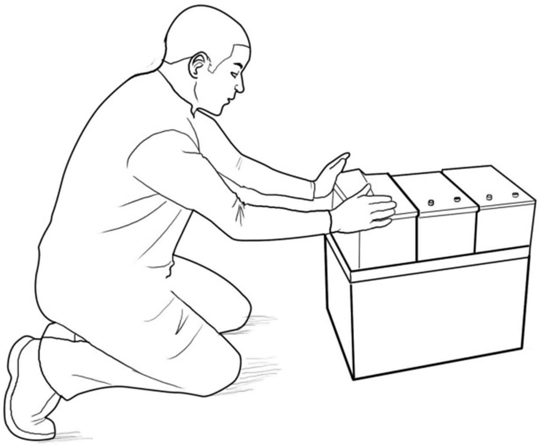


2. Install conduits (pipes and trunkings) along the planned cable route.

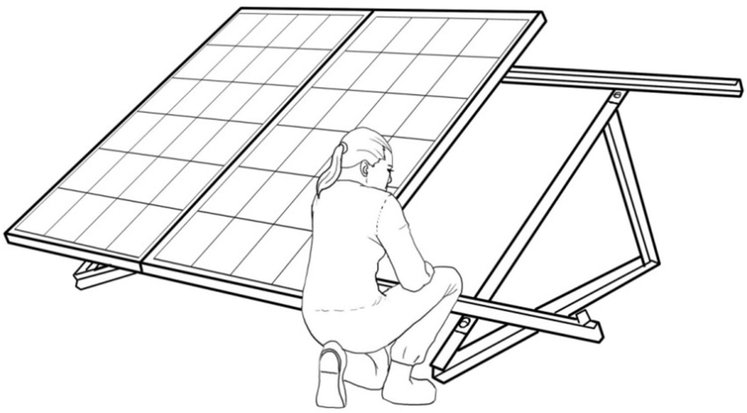


3. Install cables in conduit.

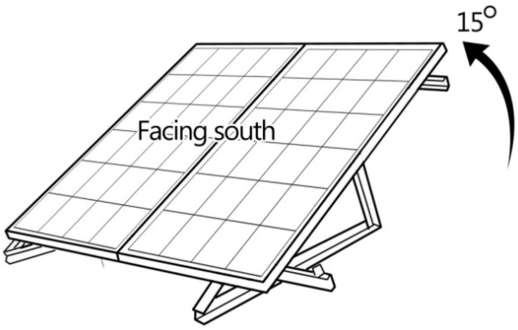
4. Determine and decide on the installation location of the system components and cable route.
5. Always leave one metre at the end of every cable for termination.



6. Install components at the determined location.

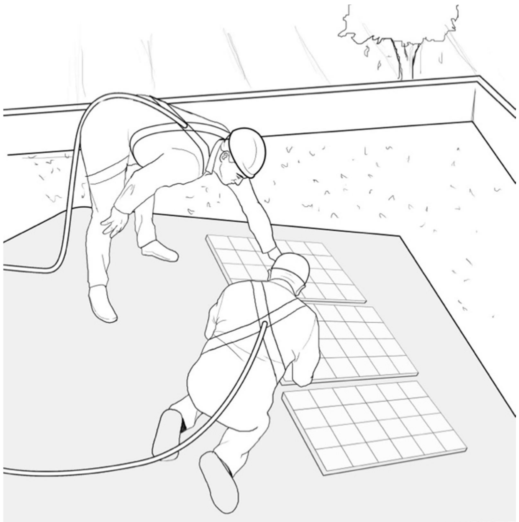


7. Install solar panel mounting systems.

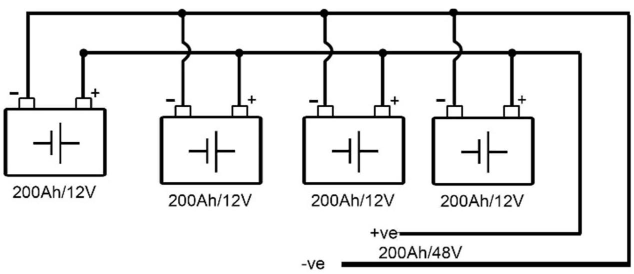


The default installation angle for solar panels in Nigeria is at an angle of 15^0 from the horizontal and facing southwards. In cases where the critical months occur in the summertime during the rainy season, there may be justification for a shallow south angle (5^0) or even a northward tilt of (5^0). Panels should never be mounted completely flat (0^0).

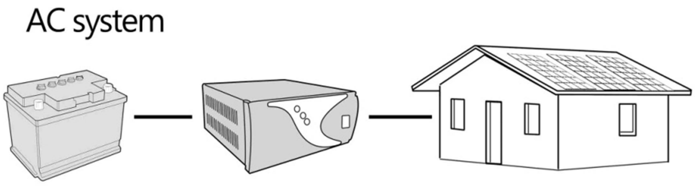
8. Mount solar panels on structures at an appropriate angle (15°) and orientation (facing south).



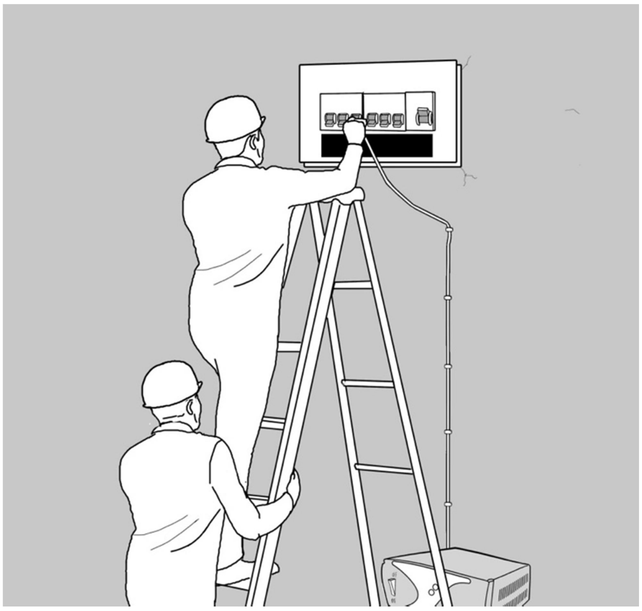
9. Connect solar panels according to desired series/parallel connection.



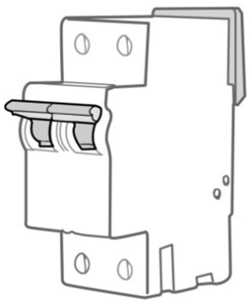
10. Connect batteries according to desired series/parallel connection.



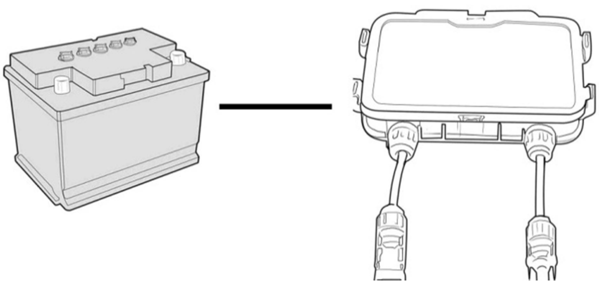
11. If it is an AC system, connect batteries to the inverter. Ensure that the inverter output switch is in the “OFF” position.



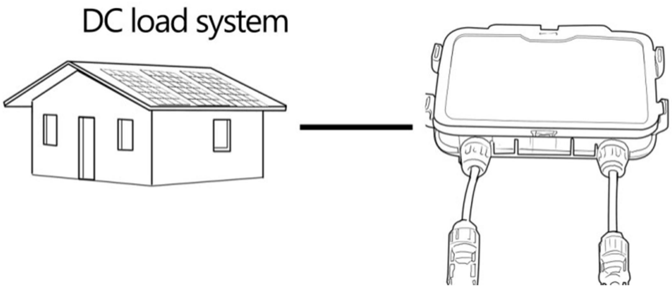
12. If it is an AC system, connect the inverter output to the home distribution board. Take care to ensure that only relevant circuits are connected.



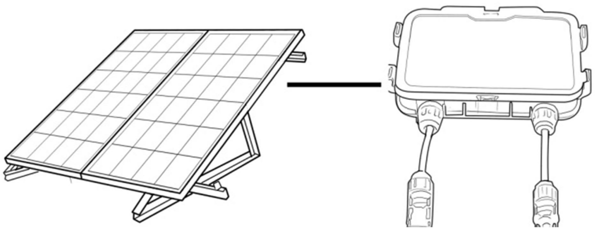
13. Ensure that the breaker is in the “OFF” position.



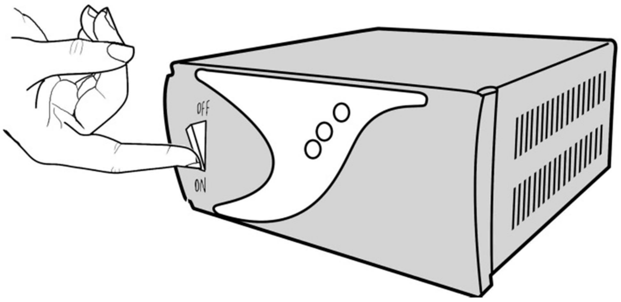
14. Connect batteries to the charge controller.



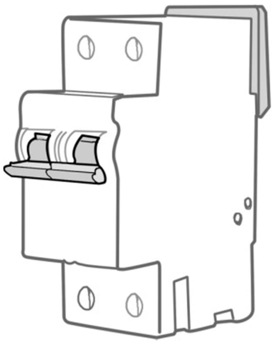
15. If the system consists of DC loads, connect such loads to the charge controller.



16. Connect the solar panel array to the charge controller.



17. Power "ON" the inverter.



18. Switch "ON" the distribution board breaker.

7. MAINTENANCE AND TROUBLESHOOTING

About this module

Once you have completed the installation of a solar system, it is important to ensure that the system is adequately and periodically maintained to minimise the possibility of failure. In the event of a failure, it is the responsibility of the installer to provide and implement solutions to restore proper functioning.

This module describes the maintenance activities required for a solar system. It also provides solutions to common faults that the student may encounter while at work.

Learning outcomes

At the end of this module, the participant is able to

- Explain the steps involved in carrying out maintenance work on each solar system component
- Outline the procedure for maintaining the different PV system components
- Outline the procedure for testing different PV system components
- Identify the different types of tools/equipment used for maintenance and repair.

7.1. Battery maintenance

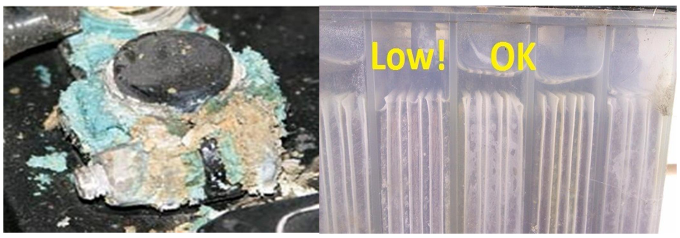
Battery maintenance activities

To extend the useful life of your system, you MUST carry out proper maintenance! Fortunately, when compared to the petrol/diesel generator, solar systems require very little maintenance.

REGULARLY INSPECT AND CLEAN THE BATTERIES

A visual inspection should be carried out once a month to assess the general condition of the battery bank. Be on the lookout for:

- Corrosion at the battery terminals
- Signs of melting on the battery casing
- Signs of electrolyte leaks
- Electrolyte level (on flooded batteries)



Corroded battery terminal (left); electrolyte level (right)

Battery maintenance is the most important of all maintenance activities. Poor battery maintenance could lead to system failure or, even worse, bodily harm or in some cases death.

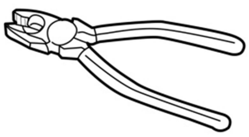
Battery maintenance should be done monthly.

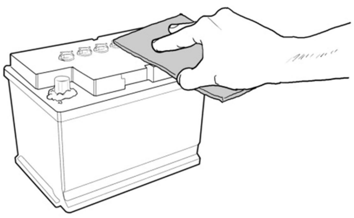
1. Always wear safety goggles.
2. Wear gloves for insulation and to prevent contact with battery acid.
3. Always use tools with insulated handles.

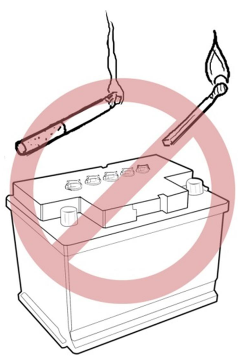
On flooded batteries, the electrolyte level can be checked by opening the caps or by looking in from the side if the housing is transparent. The level must completely cover the separators but remain below the edge of the caps (read battery manual). The separators should never be exposed to air or remain dry.

If a refill is required, use distilled water only – no tap water or battery acid!

4. Use a metal file/sand paper to remove corrosion from the battery terminals.
5. Check connections for tightness.
6. Clean all battery surfaces by removing all dirt and humidity.
7. Check the electrolyte level on flooded batteries.
8. Equalise batteries on a monthly basis. Most charge controllers do that automatically. Mind equalisation voltage and type of battery.
9. Bring old batteries to recycling; never dispose of them with normal waste or by leaving them outside (in nature).





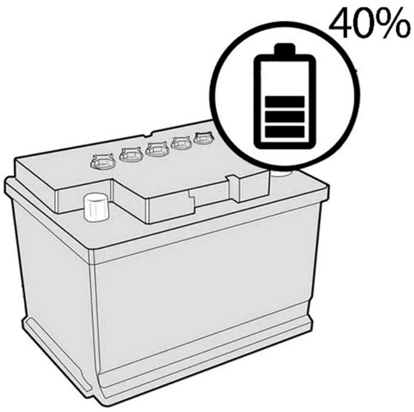


Never smoke or light a naked flame near a battery

CHECK BATTERY VOLTAGE

In most cases, you will encounter only the dry (maintenance-free) batteries. The most convenient way to determine the state of charge (SoC) and health of the battery is by measuring the voltage across a battery.

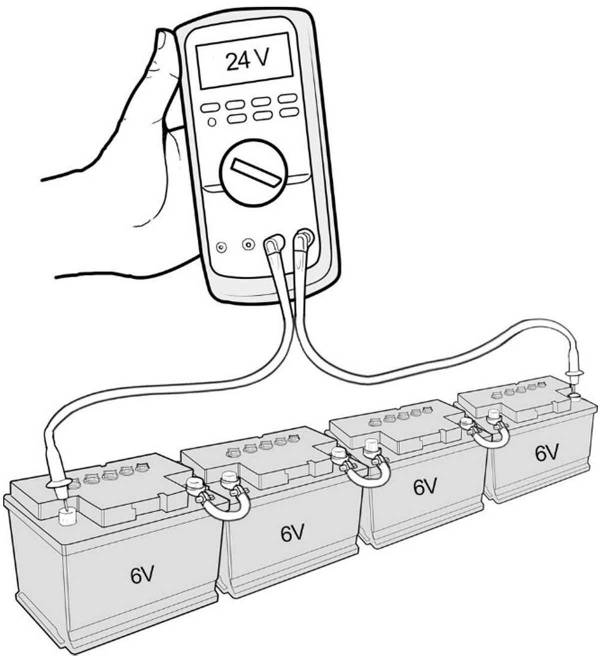
Voltage is measured using a voltmeter. The voltmeter should be connected across the negative and positive terminals of the battery.



60% DoD = 40% SoC

The most common battery types found in the Nigerian market are 12 V and 6 V lead-acid batteries. The table below shows expected readings at different charge levels.

State of charge	***12 V battery***	***6 V battery***
100%	12.9	6.45
75%	12.7	6.35
50%	12.5	6.25
25%	12.3	6.15
0%	12.0	6.0



24 V battery bank (four 6 V batteries) at 40% SoC

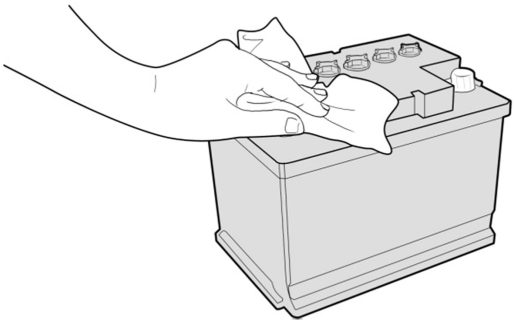
STATE OF CHARGE (SOC)

This refers to the percentage of battery capacity that is still unused.

For a 12 V battery used in a 48 V battery bank, at a 100% SoC you can expect a voltage reading of
51.6 V.

SoC can be detected with reasonable accuracy only when using a good quality multimeter that can accurately detect minute voltage differences.

Battery pre-maintenance activities



Clean the battery surface before you begin work

First aid box for treating injuries

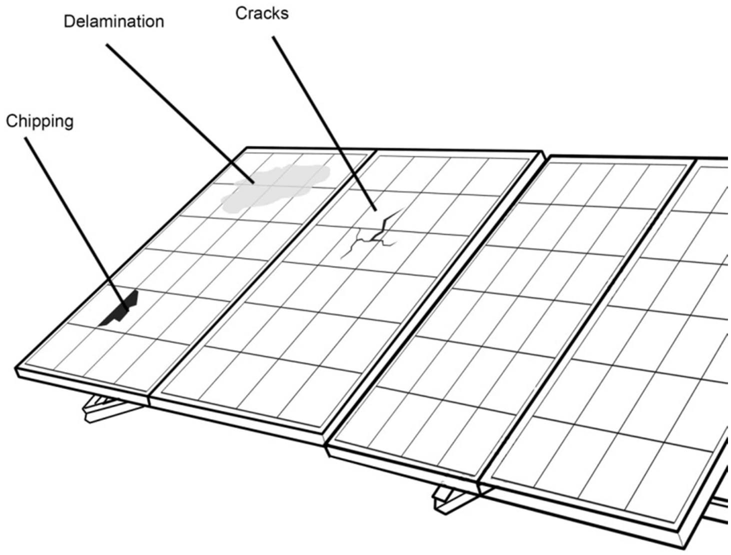
- Isolate the battery bank by disconnecting the input (supply) from the solar panel and the output (demand) of the load.
- If working with dry-cell batteries, you only have to clean the terminals and check for corrosion.
- If you are working on wet-cell batteries, ensure that the caps are tightly sealed to prevent dirt from entering the cells.
- Always have a first aid kit available.
- Always have a mixture of baking soda and water at your side in case of acid spills.

7.2. Solar panel maintenance

Solar panel array maintenance activities

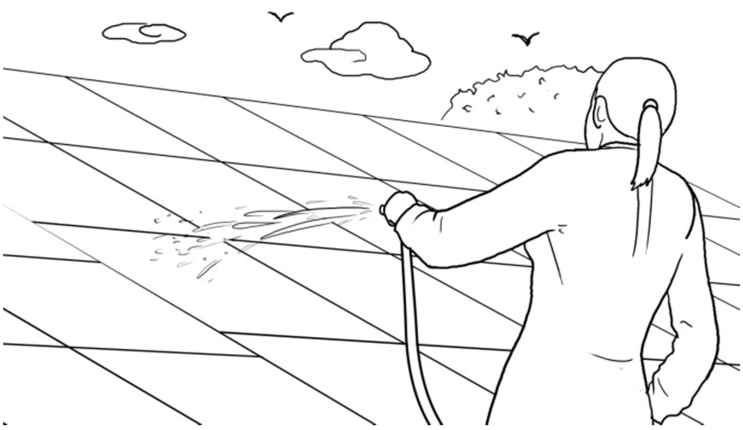
There is a common misconception that solar panels do not require maintenance. This is false! Some minimal maintenance is required to ensure that the solar panels perform optimally.

1. Inspect the condition of the array mounting structures annually. Bolts and frames used to fasten the solar panels should be visually inspected for rusting. Also make sure they are firmly secured. Check for attempts of theft.



2. Inspect the solar panels visually for signs of mechanical damage. Be on the lookout for:
   - Cracks
   - Delamination
   - Chipping
   - Corrosion
   - Discoloration and
   - Any other mechanical defects

   These effects should be noted and the solar panel array output monitored. If there is a notable reduction in the output of the solar panel array, the affected solar panels should be replaced with similarly rated solar panels.



3. Clean the collector surface of the solar panel.

   Solar panels should be cleaned according to the weather conditions. In seasons with lots of dust, you may need to clean every two to three days. In seasons with daily rain, cleaning may not be necessary for several weeks.

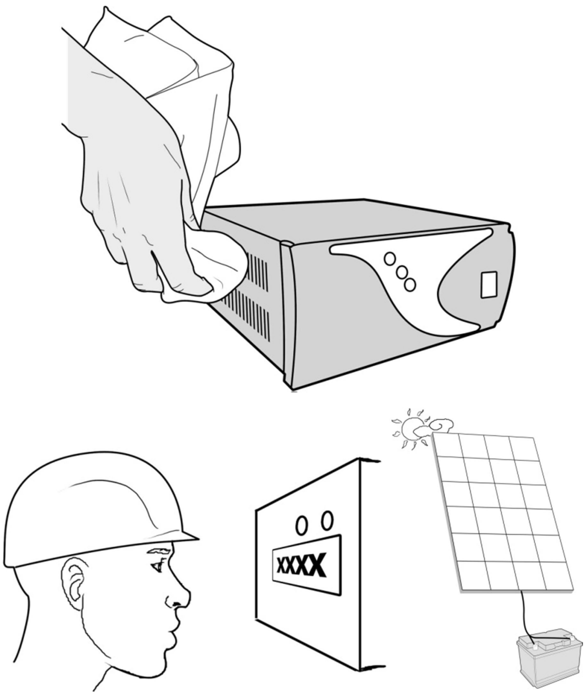
   To clean the panels, simply wash them with a water jet. If the panels have caked dirt, dust or bird droppings, use a soft sponge to wipe the panel surface.

4. Make sure no overgrown trees or shrubs are shading the module surface as this might reduce performance.

Never use a hard brush or scrubbing device to clean the surface of the solar panels, never use soap or detergents to clean the solar panels.

7.3. Inverter and charge controller maintenance

Because these components consist of almost no moving parts and are not exposed to chemicals or the environment, they are relatively easy to maintain.



Maintenance of the inverter and charge controller should be carried out whenever the battery bank is inspected – once a month.

Required maintenance activities:

1. Check connections for tightness. Use a dry cloth to wipe accumulated dirt and dust from all vents and surfaces.
2. Visually examine all indicators and displays to ensure that the solar panel array is charging the battery bank.

7.4. Maintenance of cables and connections

Rodent bites on cable

To maintain cables and wires used to interconnect system component:

1. Inspect all panels and boxes for signs of rodents or insect infestation; check connections for tightness, and check for waterproofness.
2. Inspect all switches and breakers for efficacy, especially when they are switched on and off. There should be no spark during switching.
3. Check for signs of corrosion or burning on the cables and their connection points.

4. Check cables for rodent bites.
5. Where possible, visually inspect all conduit pipes and trunkings for wear and tear.
6. Ensure that all grounding connections are intact.

7.5. Maintenance schedule

Fortunately, some maintenance tasks can be carried out by the system owner. The table below shows the frequency of maintenance activities for a solar system.

Maintenance task	*Daily*	*Weekly*	*Monthly*	*3 months*	*6 months*
Batteries			X		
Solar panel array		According to weather, i.e. daily, weekly or monthly			
Inverter			X		
Charge controller			X		
Cables and wiring (visual check)			X		

7.6. Troubleshooting

Fault finding

Before getting into detailed troubleshooting, start by asking the system owner/operator these questions, which might help to identify the problem easily:

- Has the weather been cloudy recently? Less sunlight means the system will generate less energy than the load consumes.
- Is the system a new installation? Failure(s) in a new system can be caused by faulty components or improper installation.
- Have there been any recent modifications to the system wiring?

Various faults can occur in solar systems at the different components. Common faults include:

- Low battery state of charge
- No charging from solar modules
- Inverter not functioning
- Tripping fuses or circuit breakers

- Have you added any new loads which were not part of the original system design?
- How old are the batteries? What is their condition? Are they still able to hold the required charge?
- Are the fuses and circuit breakers working properly? When fuses are blown, check for the reason (e.g. short circuit) before replacing the fuse.
- Are all wires connected securely? Is there any visible corrosion or are there any blank wires?

  Are modules dusty or shady?

PROBLEM: LOW BATTERY STATE OF CHARGE

Symptoms:

- Low voltage on battery
- "Battery low" indicator of the charge controller is "ON"
- Inverter not functioning (automatic low voltage disconnect)

Possible cause	*Solution*
Faulty connection between solar modules and charge controller	Check and fix connection to solar modules. Check breakers and disconnect switches.
Faulty connection between charge controller and battery	Check for broken wires or loose connections
Disconnection between modules in array. Disconnection in junction/combiner box.	Check module-to-module wires. Check breakers and disconnect switches.
Insufficient power coming from PV modules	Make sure modules are clean. Check for shading. Check all module-to-module wires.
Battery electrolyte is low	Add distilled water to cell.
Defective battery or cell	Check state of charge of each cell; if there is a significant difference (>0.5 V) between cells the battery needs to be replaced (only possible with single-cell batteries).
Loose or corroded battery terminal	Clean and tighten battery terminals.
Blown battery fuse	Check correct rating. Check for short circuit. Replace the fuse.

Overuse of the system	Leave appliances and lamps off to allow battery recharging or recharge the battery by other means. Check and inquire about connected loads and runtime.
Battery will not accept charge	Consider the battery age and history. Replace battery if old or damaged.
Voltage drop between module and battery too high	Calculate voltage drop. Replace cable with higher diameter if necessary.
Incorrect setup of charge controller	Consult the manual. Change setup accordingly.
Defective charge controller	Check operation of charge controller. Measure voltages and currents. Disconnect and reconnect. Replace the charge controller.

PROBLEM: NO SOLAR CHARGE

Symptoms:

- Low voltage
- Charging indicator of charge controller remains OFF while the sun is shining
- No current in cable from solar modules to charge controller

Possible cause	*Solution*
Faulty connection between solar modules and charge controller	Check and fix connection to solar modules. Check breakers and disconnect switches.
Faulty connection between charge controller and battery	Check for broken wires or loose connections.
Disconnection between modules in array, disconnection in junction/combiner box	Check module to module wires. Check breakers and disconnect switches.
Thick coating of soot or duct on the module	Clean module with water and soft cloth.
Broken module	Check for broken cells, broken glass or poor connection inside module.Replace solar cell module.

PROBLEM: NO AC POWER ON INVERTER OUTPUT

Symptoms:

- Appliances are not running
- Power indicator of inverter remains OFF
- Fault indicator on inverter is ON

Possible cause	*Solution*
Inverter switched off	Locate ON/OFF switch; switch ON
Short circuit in AC circuit or AC load	Disconnect all circuits and loads from inverter output. Disconnect DC input from inverter. Reconnect DC input. Check output. Check loads and load circuits. Reconnect AC loads one by one.
Inverter overloaded	Disconnect all circuits and loads from inverter output. Disconnect DC input from inverter. Reconnect DC input. Check output. Check power ratings of all AC loads. Reconnect AC loads one by one.
Inverter overheated	Disconnect all loads from inverter output. Let cool down. Check ventilation. Check power ratings of AC loads. Reconnect AC loads one by one.
Low battery voltage	Check battery voltage Follow steps in troubleshooting section "low battery state of charge"