**Solar Electric Technician Training**

**Module 5: Installation and assembly**

This handout provides the learners with comprehensive guidance and resources for successful installation and assembly of any types of solar PV systems.

## Final verification and preparation before installation

After completing the preparation steps outlined in Module 4, it’s essential to conduct a final verification and preparation phase. This stage ensures that all prerequisites are met before moving forward with the actual installation of the solar PV system. The final verification steps are vital as they help determine whether the solar PV project will be completed within the stipulated timeframe. While many of the tasks in this phase are carried out in coordination with the engineering team, it is also important for solar technicians to be aware of these details, as they are the ones performing the actual installation on site.

**Final verification steps**

### Location evaluation

* 1. **Solar exposure:** The site’s solar exposure will be confirmed to maximize energy generation. Additionally, the site’s latitude, longitude, and azimuth angle will be checked to ensure alignment with optimal solar.
  2. **Shading analysis:** A final shading analysis will be conducted using tools such as solar pathfinders or online calculators. Potential obstructions, such as trees or buildings, will be reevaluated to determine their impact on the system’s efficiency.

### Permits and regulations

1. **Permit verification:** All necessary permits will have been obtained from local authorities, ensuring that the installation complies with both national and regional electrical codes, building codes, and safety standards.
2. **Regulatory compliance:** Requirements from the National Electrical Code (NEC), International Building Code (IBC), and any local utility interconnection guidelines to verify full compliance will be reviewed.

### Structural inspection

1. **Mounting location assessment:** The structural soundness of the mounting locations (roof, ground, or pole) will be verified, including reassessment of factors such as roof type, slope, and load-bearing capacity.
2. **Structural engineer consultation:** If needed, a structural engineer will be consulted to confirm that the structure can support the solar PV system's weight and ensure safety and stability.

## Pre-installation confirmation

Before proceeding to the actual site, hold a final discussion with the installation manager and engineering team. Ensure that the following have been confirmed:

* All aspects of the site assessment checklist have been thoroughly addressed.
* There are no outstanding issues or concerns that could impact the installation process.

## Ready to proceed with installation

With the final verification completed and all prerequisites confirmed, no we are prepared to move forward with the installation of the solar PV system. The next section will guide us through the essential steps and best practices for a successful and efficient installation.

### Installation preparation

###### Final equipment check

* **Inventory verification:** Confirm that all components—solar panels, inverters, mounting hardware, wiring, and other necessary materials—are on-site and match the specifications outlined in your project plan as per approved BoQ (Balance of Quantity).
* **Equipment inspection:**Inspect all equipment for any signs of damage or defects. Ensure that all components meet manufacturer specifications and industry standards.
* **Tool and accessory list:** Drill, wrench set, screwdrivers, pliers, wire cutters, level, tape measure, torque wrench, crimping tool, multimeter, and other tools as per the requirements.

###### Safety measures

* **Safety gear:**Ensure that all installation personnel are equipped with appropriate safety gear, including helmets, gloves, safety glasses, and fall protection equipment.
* **Safety plan:**Review and adhere to a comprehensive safety plan that includes procedures for handling electrical components, working at heights, and emergency response.

###### Site preparation

* **Workspace organization:** Organize the installation site to facilitate smooth workflow. Ensure that tools, materials, and equipment are readily accessible and that the area is clear of obstacles.
* **Site clearance**
  + **Obstruction removal:** Clear the installation area of debris, vegetation, or other obstacles that may interfere with the installation process or system performance.
  + **Surface preparation:** Ensure the ground or roof surface is clean, level, and structurally sound. Remove any loose debris or materials that could damage the mounting structure or solar modules.
* **Marking and layout:** Accurately mark the locations for mounting hardware and solar panels according to the design specifications. Use measurement tools and alignment guides to ensure precise placement.
* **Preparation and assembly of mounting structure:** Mostly the common types of mounting structure are ground mount, pole mount and roof mount. They are to installed accordingly. The basic procedures for installing them in tabulated below:

| **Ground mount systems** | **Pole mount systems** | **Roof mount systems** |
| --- | --- | --- |
| **Site preparation:** Level the ground and mark locations for posts based on the system design and manufacturer's instructions. | **Pole installation:** Securely anchor the pole in a concrete base or ground mount, ensuring proper depth and orientation. | **Roof inspection:** Check the roof's integrity and load-bearing capacity, and identify potential obstructions or penetrations. |
| Dig holes, insert posts, and secure with concrete, ensuring proper depth and alignment. | **Bracket installation:** Attach mounting brackets to the pole, ensuring proper alignment and spacing. | **Mounting bracket installation:** Secure brackets to the roof using appropriate fasteners, such as lag bolts or concrete anchors. Ensure proper spacing and alignment based on the system design and manufacturer's instructions |
| **Frame assembly:** Attach rails to posts, ensuring alignment and levelling. Install cross-bracing as needed for stability. | **Rail installation:** Fix rails to the brackets, ensuring proper alignment and levelling | **Rail installation:** Attach rails to the brackets, ensuring proper alignment and levelling. Install cross-bracing as needed for stability. |
| **Module mounting**: Secure solar modules to the rails using clamps or other fasteners, following the manufacturer's torque specifications. | **Module mounting:** Secure solar modules to the rails using clamps or other fasteners, following the manufacturer's torque specifications. | **Module mounting:** Secure solar modules to the rails using clamps or other fasteners, following the manufacturer's torque specifications. |

## Cable routing, wiring, and conduiting

### Cable routing basics

* **Planning:** Determine the optimal route for cables to minimize distance and avoid interference with other system components or potential obstructions. Consider factors such as cable length, voltage drop, and accessibility for maintenance.
* **Protection:** Use conduits and cable protectors to shield cables from physical damage, UV exposure, and environmental factors. Ensure proper sizing of conduits based on the number and size of cables.

### Series and parallel wiring (Solar PV module example)

###### Interconnection of PV modules

Two or more interconnected PV modules form what is called an array. The power generated by the PV array is theoretically the sum of the power rating of each PV module. For instance, when you have three interconnected the resultant power output is 300 Wp.

A diagram of a diagram

Description automatically generated

*Figure: Interconnected PV modules PV modules of 100 WP each, the resultant power output is 300 WP.*

There are three different ways in which PV modules can be interconnected.

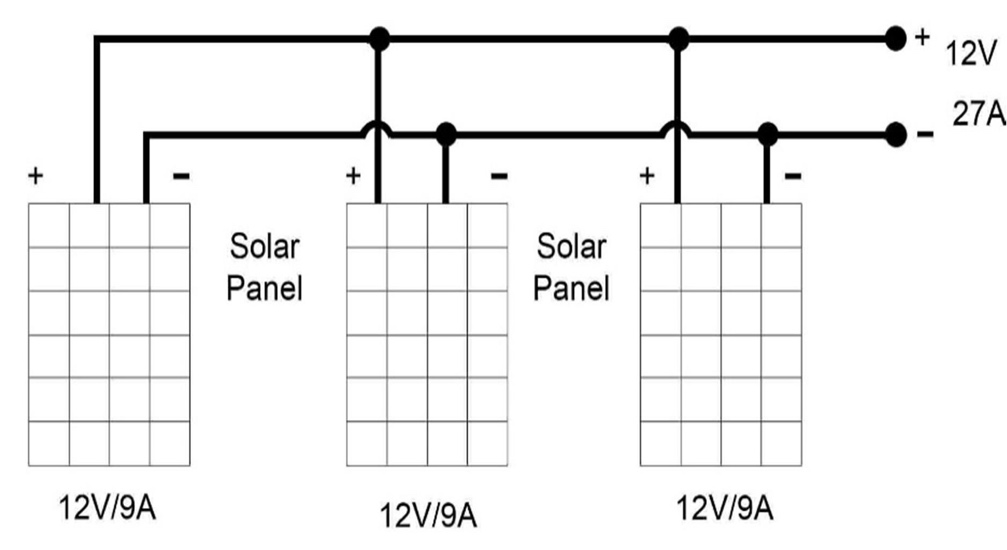
* **Series connections** increase the output voltage of the solar PV array. With this connection method, the negative terminal of a PV module is connected to the positive terminal of the next PV.

A diagram of a solar panel

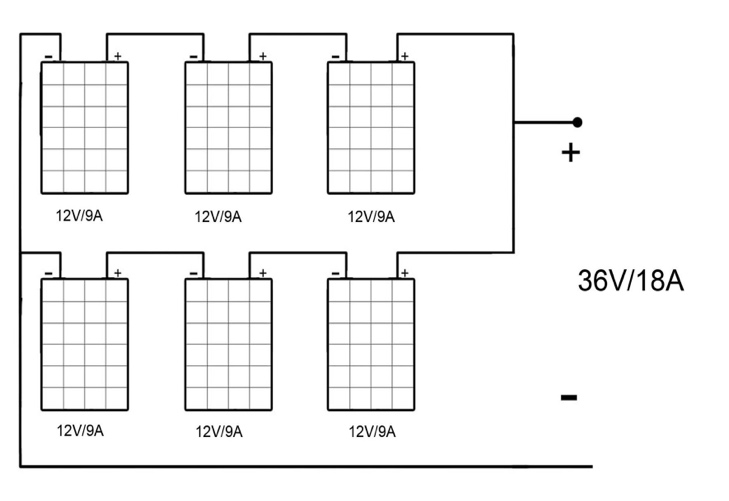
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*Figure: Series-connected PV modules*

* **Parallel connections** increase the output current of the solar PV array. With this connection method, negative terminals are connected to negative terminals in the PV module and positive terminals to positive terminals.



* **Series-parallel connections** increase both output voltage and current of a solar PV array.



###### PV module array connection and mismatching

Earlier in this module, it was mentioned that when you connect PV modules, either in series or parallel to form an array, the total output is the sum of the individual power ratings for each solar panel. However, this only applies when modules with identical electrical specifications are connected. If modules with different electrical specifications are interconnected this can result in a big waste of installed PV output power, depending on the degree of mismatch (the difference in electrical specifications) the type of connection and the operation mode (solar radiation, connected load). Interconnected PV modules of different electrical specifications are said to be “mismatched”.

###### Mismatched series-connected PV modules

A diagram of a solar panel

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When mismatched PV modules with different voltages but the same current are connected in series then the total power is the sum of the individual powers of the modules.

But when mismatched PV modules with different currents are connected in series then the module with the weaker current acts as a resistor in the circuit. The stronger module(s) generating 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. How big the voltage drop will be depending on how big the difference between the modules is and on the strengths of solar radiation. A higher mismatch and a strong current generate a higher voltage drop.

The resulting output voltage of the circuit is the voltage(s) of the stronger module(s) minus the voltage drop created by the weaker module. In our example it is: 2 x 20 V – 17 V = 23 V. As the voltage drop over the weaker module is 17 V opposed to the voltage of the other modules this module consumes 17 V x 3 A = 51 W power form the other modules.

The resulting power is the product of the output voltage and the current of the solar modules, which is much lower than the maximum current of the stronger modules.

In our example it is 34 V x 3 A = 69 W.

In case of a substantial mismatch of electrical specifications the resulting power can be even less than the individual power of the strongest module(s).

If modules are equipped with a so-called bypass diode, the effect of power loss across each module is less significant as the opposing voltage drop over the weaker module is limited to the diode voltage of approximately 0.6 V. Also, the current in the circuit will be higher as some current passes through the diode and the total resistance of the circuit will be lower.

## Wiring Standards:

* **Dc wiring**: Follow the positive and negative connections for solar modules to the charge controller or inverter. Ensure proper polarity and use color-coded cables for easy identification.
* **AC wiring:** Ensure correct phase connections for inverters and other AC components. Follow the appropriate wiring diagram based on the system configuration (single-phase or three-phase).
* **Single and three-phase systems:** Verify connections according to system specifications and local electrical codes. For three-phase systems, ensure balanced load distribution across the phases.
* **Cable management:** Secure cables with ties and clips to prevent movement and damage. Maintain proper bending radii for cables to avoid stress and potential failure.
* **Insulation:** Ensure proper insulation for all wiring, especially in exposed areas or where cables pass through walls or roofs. Use appropriate wire types and sizes based on the system voltage, current, and environmental conditions.

## Installation manuals, technical documentations and diagrams

### Understanding manuals

* **Inverter manual:** Read and follow installation steps, including electrical connections, mounting instructions, and configuration settings. Pay attention to voltage and current ratings, grounding requirements, and any special considerations for the inverter model.
* **Charge controller manual:** Review wiring diagrams, configuration settings, and installation requirements for the charge controller. Ensure compatibility with the solar modules, batteries, and other system components.
* **Water pumps and controller's manual**: Check installation instructions for pump placement, controller setup, and electrical connections. Verify compatibility with the solar PV system voltage and current ratings.
* **Battery manual:** Understand battery connection, mounting, and maintenance procedures. Follow safety guidelines for handling and installing batteries, and ensure proper ventilation if using lead-acid batteries.
* **Balance of System (BoS) manual**: Familiarize yourself with additional components such as fuses, disconnects, and protection devices. Ensure proper sizing, placement, and connection of these components based on the system design and local electrical codes.

## Site preparation

### Taking measurements

As with any installation job, you need to understand, which measurements are important. As the supervisor in charge of installation, you must be familiar with how to take measurements and interpret the results. For photovoltaic installations, the most important measurements are:

###### Solar irradiance

A diagram of a jet engine

Description automatically generatedThis is the quantity of solar resource available at the installation site. For large multi-megawatt systems, this measurement is taken using a pyrometer or a pyrheliometer.

Figure: Pyrometer (left), Pyrheliometer (right)

Prior to installation, solar irradiance is usually measured for multi-megawatt projects over longer periods of time (i.e. as longitudinal data over 6 to 12 months). For smaller domestic or commercial systems, solar irradiance is mostly measured for system evaluation purposes.

###### Lengths

Knowing how to measure linear distances and lengths is critical for planning the installation of a solar PV system. Some of the linear measurements that you shall be required to take include:

* Length of each cable type to be installed
* Position of the solar PV modules
* Length of shadow cast by modules, trees or other objects

Lengths are measured using a tape measure.

###### Angles

To properly install a solar PV system, you need to be conversant with angles and trigonometry. This is critical when determining parameters such as the angle of inclination and the minimum distance to mitigate shading. Angle measurements can be taken using instruments such as an inclinometer.

###### Current, voltage and power

The solar PV system is an electrical power supply system. Your ability to use a multimeter to measure electrical parameters such as current and voltage is critical for your success as a solar PV installation professional.

### Shade analysis and sun path chart

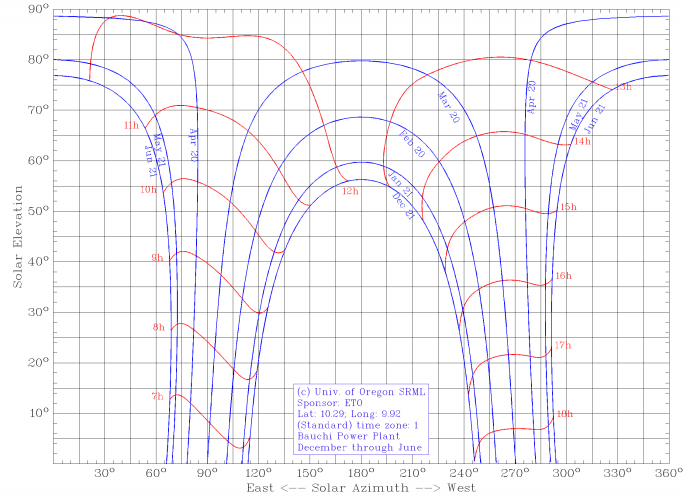


Figure: Sample Sun chart – Courtesy: University of Oregon, http://solardat.uoregon.edu

When you are deciding on the location of your solar PV array, you must always consider the possibility of shading caused by trees and nearby man-made objects such as buildings, poles and telecommunications towers.

The sun chart is a useful tool, which allows system designers and installers to understand the availability of sunshine over the year, as well as to understand the shadow that would be cast by the PV array. The sun chart has two axes; the solar elevation and the solar azimuth.

The sun path chart in figure above explains the sun’s location in the sky for six months (December to June).

The solar azimuth axis (horizontal axis) indicates the sun’s direction in the horizontal plane for a given location. The North is assigned an azimuth of 0° while the South is defined by an azimuth of 180°. The East and West, where the sun rises and sets, have an azimuth of 90° and 270°, respectively.

On the other hand, the solar elevation axis (vertical axis) indicates the sun’s height over the sky during the day. These two axes are connected via the blue lines, which indicate a particular day of the year in which the values were measured. In this case, the 20th or 21st of every month.

The sun path chart would be incomplete without information on the time of day at which the sun is at a particular location. At the intersection of the red lines, which show the time of day, and the blue lines, which show the day of the year, you can reasonably know the location of the sun all year round. For site planning, however, a sun path analysis instrument such as the solar pathfinder may be used to determine the shading effect of trees and other objects like houses and telecommunications equipment in the vicinity of the PV array.

From the above chart, we can deduce that that at 9 am on April 20, the sun is at an elevation of 40° to the horizontal and at an azimuth of 80° (i.e. located in the Northeast).

### Orientation and inclination of PV modules

To maximize the performance of a solar PV module, it must be installed at the optimum orientation (angle of inclination and azimuth).

* **Angle of inclination**: This is the angle that the solar PV array makes with the horizontal plane to the ground.
* **Azimuth:** The azimuth is an angular measurement in a spherical coordinate system. The vector from an observer (origin) to a point of interest is projected perpendicularly onto a reference plane; the angle between the projected vector and a reference vector on the reference plane is called the azimuth. The sun is the point of interest, the reference plane is the horizon or the surface of the sea, and the reference vector points north. The azimuth is the angle between the north vector and the perpendicular projection of the sun down onto the horizon. For Nepal, it is advisable to point the solar PV modules facing true south.

### https://encrypted-tbn1.gstatic.com/images?q=tbn:ANd9GcSWdncAUkOFXka-Rd3j_NSJtZFqcq6giM5WC02g9tLTpPkeFjKlFAInter-row shading

When you install a large solar PV array with numerous strings, you always have to consider the possibility of inter-row shading. Inter-row shading occurs when the solar PV module in front casts a shadow on the module behind it.

When considering the effect of inter-row shading, always include the following criteria:

* **Effective period of operation**: PV modules work in the presence of sunlight. You have to determine the time span during which some shading would be acceptable. It is recommended that if there is shading, it should not occur between 8 am and 4 pm (8 hours).

Figure: Shadow caused by solar PV modules

* **Latitude at which you are installing the PV array**: The latitude (φ) is a geographic coordinate that specifies the north-south position of a point on the earth’s surface. Latitude is an angle, which ranges from 0° at the equator to 90° (north or south) at the poles. Lines of constant latitude, or parallels, run parallel to the equator as circles. The latitude affects the location of the sun in the sky at different times, which in turn affects the length of the shadow that could be cast.
* **Size of the solar panels:** The dimensions of the solar PV modules have a direct correlation with the length of the shadow cast.
* **Orientation of the PV array**: The angle of inclination and azimuth of the array play a major role in the occurrence of inter-row shading. At a larger angle of inclination, there is bound to be a longer shadow cast by the preceding photovoltaic module.

### Required area for inter-row spacing

Inter-row shading could drastically reduce the amount of energy that can be obtained from a PV array. To mitigate this effect, you have to interpret the sun path diagram or use industry-accepted rules of thumb - but first you need to identify the following parameters:

* Module length and width
* Required array length, width and area
* Module orientation
* Tilt angle
* Sun path chart

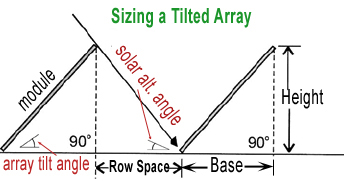


Figure: Calculating for inter-row shading

Courtesy: www.thesolarplanner.com/steps\_page5b.html

Once you have the above-listed parameters, it becomes a simple case of multiplication to calculate the required distance (based on a rule of thumb) between rows.

In situations where the solar photovoltaic array does not face true south, a more complicated method must be used to determine the required row spacing. Here, you would need to read values off the sun path chart and interpret them using trigonometric laws and principles.

To do this, you must apply the following formulae:

The module height is the vertical distance from the horizontal plane on which all the stands are to the top of the module. It may be calculated using Pythagoras’ theorem as follows:

Combining the two formulae above, the space between rows can be calculated as:

## Installation surfaces

Solar PV modules are commonly mounted in four different ways:

### Roof mounting

Most residential solar PV systems are roof-mounted, especially in urban areas. The roof offers a suitable location for the PV modules when no space is available on the ground.

Roof mounting can be divided into two groups:

* Flush mounting: For this type of mounting, the PV modules are installed very close (flush) to the roof. Here, the photovoltaic modules take the orientation (azimuth and inclination) of the roof. Flush-mounted solar photovoltaic modules generally provide the advantage of better aesthetics. A flush-mounted system consists of footings to fasten the system to the roof (to which rails are then fastened), tails to which the photovoltaic modules are fastened and clamps which hold the modules to the rails.
* Tilt-up mounting: This type of mounting is used when you have a flat roof. The PV modules are inclined at the ideal orientation to achieve a maximum energy output from the array.

Solar panels on a roof

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Figure: Flush-mounted PV modules on a pitched roof

### Ground mounting

This is the easiest type of mounting setup. It can be realized if you have a client with sufficient land who can also afford the cost of laying cables over a few extra meters.

This is similar to the tilt-up system mentioned above; however, the mounting structures are secured via concrete bases or foundations.



Figure: Ground-mounted solar PV array

Courtesy: Melissa Van Hoorne, http://blog.solarmicronics.co

### Top-of-pole mounting

This mounting type is more common with street lighting, traffic lighting or other off-grid applications as can be seen across Nepal. In this system, a hole is dug in the ground and the pole is set in the hole while concrete is poured to surround the pole. This mounting system is generally limited by the maximum amount of PV modules that can be installed.



Figure: Pole-mounted PV array – Courtesy: Accutrack Solar System, www.accutrack.com

### Building Integrated Photovoltaics (BIPV)

Commonly called BIPV (building-integrated photovoltaics), this mounting type refers to systems in which PV cells and modules are directly incorporated in building materials such as window glass or roofing tiles.



Figure: PV modules integrated in the windows of SMA GmbH headquarters in Kassel, Germany – *Courtesy: SMA Solar Technology*

| **Mounting method** | **Advantages** | **Disadvantages** |
| --- | --- | --- |
| Roof mounting | * Usually provides the best access to sunlight * Utilises “unused” roof space, thereby saving space on the ground * Reduces costs due to proximity to the electrical load centre * Minimises effects of on-site installation | * Orientation (azimuth and inclination) of the solar PV array is determined by the existing roof. * Less ventilation under the PV modules means operation at higher temperatures. * Roof size determines the maximum number of PV modules that can be installed. * Maintenance work on the roof could affect the PV modules, e.g. need for removal * Installation could cause leaks in the roof because of holes for proper mounting. |
| Ground mounting | * Suitable for all types of solar PV systems. * Flexible orientation of PV array. * Roof penetration issues are not a problem. * Allows for easy maintenance. * Easier to install. * Panels operate at cooler temperatures than roof-mounted systems due to greater ventilation underneath the solar panel array. | * Concrete base needs to support the weight of the array. * Need for preparation of ground at the installation site (clearing of vegetation, digging of cable trenches, protection from unauthorised personnel, etc.). |
| Top-of-pole mounting | * Operates at cooler temperatures, like ground-mounted systems * Flexible orientation of PV array. * Enables flexible seasonal adjustments of the array (automatically or manually), enabling you to increase your energy yield over the year. | * Fair amount of ground work required prior to this method. Analysis to determine the soil type, wind loading, etc. must be carried out. May add extra costs if the information is not readily available. * Need for preparation of ground at the installation site (clearing of vegetation, digging of cable trenches, protection from unauthorised personnel, etc.). * Maximum number of PV modules that can be installed on a pole-mounted structure to minimise risk of storm damage. |
| Building-integrated photovoltaics (BIPV) | * Solar PV array can be installed in any part of the building. * Offers better aesthetics. PV modules can be installed unobtrusively on the building. | * Expensive when compared to the other mounting techniques. * Installed along with the building, so the PV array does not usually have an optimum orientation, potentially leading to energy losses. |

Table: Comparisons of the different mounting techniques

|  |
| --- |
| ***Note:*** If you intend to make use of pre-fabricated mounting systems, be sure to read, understand and follow the manufacturer’s manual prior to installation. If you fabricate the mounting structure yourself, ensure that it is sturdy enough to withstand the weight of the solar panels and the effect of wind gusts and that it does not pose a threat to life or property in its immediate vicinity.  Always be mindful of shading when choosing a mounting system. Plants grow over time and the location in which you place your solar photovoltaic array could be susceptible to shading from subsequent plant growth. |

### Ideal surfaces for batteries, inverters and charge controllers

The central requirement for installing batteries, inverters and charge controllers are:

* Clean and dry space/ surface
* Adequate ventilation
* Easily accessible for maintenance

## Planning work schedules

Before beginning installation activities, during the site assessment phase it is important to have a clear idea of how many tradesmen are needed to complete the installation within the agreed time frame. Activities to consider include:

* **Equipment delivery to site**

Before beginning to install system components, ensure that the PV modules, batteries, inverter, charge controller, etc. are available on site or are made available.

* **Identification of installation tasks**

For you to be able to adequately plan a work schedule and know the type of professionals required, you should identify all necessary tasks to complete the installation of the photovoltaic system.

* **Complexity of each installation task**

Once you have identified each task, the next step is for you to determine the complexity of each task. This gives you the necessary information to determine the number of personnel that you require to complete the installation job.

* **Required tools and materials**

Before you begin installation, ensure that all necessary tools and equipment to complete the installation are available on site. For example, you do not want to be in the middle of installation process only to discover that you forgot to order a ladder and are therefore unable to install the PV modules on the roof because it is inaccessible.

## Installing a solar PV system

The proper connection of system components is integral to reliable system performance. This module walks the students through the steps and procedures that are required to successfully install a photovoltaic system.

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

* Install photovoltaic system components and systems
* Explain how to wire PV system components, terminate cables and commission systems

### Understanding electrical drawings

Electrical work drawings are important to the installer because they help communicate the engineer’s design. As a supervisor of electrical installations, you will be responsible for the interpretation of a wide range of electrical drawings and diagrams. Therefore, you must be able to understand different circuit symbols and identify the electrical components that they represent.

###### Types of electrical drawings

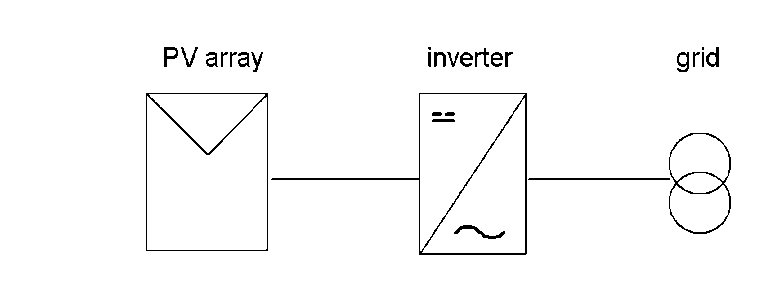
* **Block diagrams** are used to show how principal system components are interconnected. These components are represented by blocks connected by lines to show their relationships.

Figure: Block diagram of a grid-connected PV system

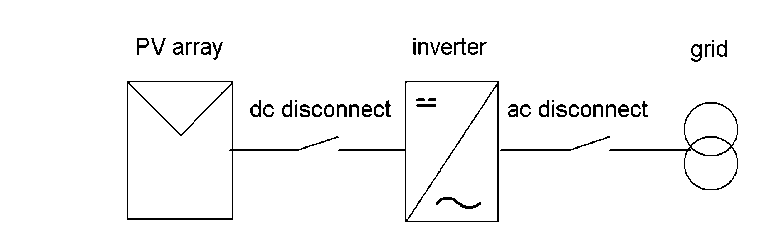
* **Circuit drawings** provide a graphical representation of an electric circuit. They are mostly represented on the layout/floor plans of a building or an installation site.
* **Single-line diagrams** (SLD) (or one-line diagram) are a type of block diagram containing more detailed technical information. On the single-line diagram, unlike the block diagram, all system components are represented. These components appear in the form of internationally standardised schematic symbols.

Figure: SLD of a grid-connected PV system

* **Schematic diagrams** are simplified representations of the system’s electrical circuit using standardised symbols. They indicate all system components and their connections, and also provide information such as polarities and electrical specifications.

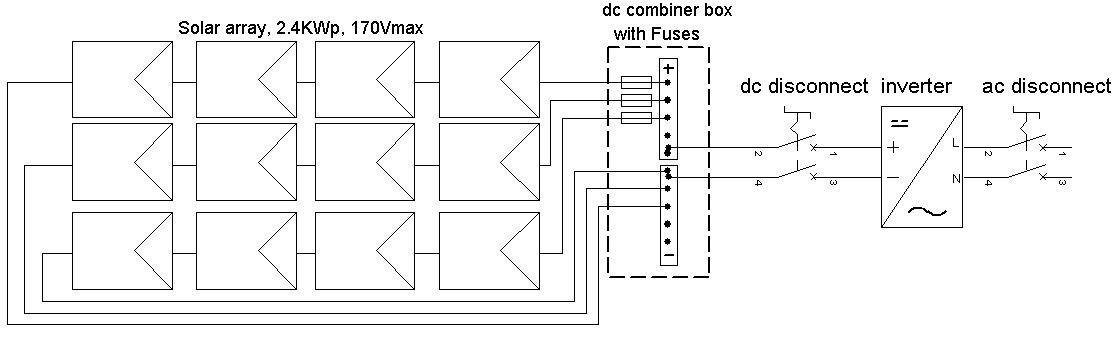


Figure: Schematic diagram of a grid-connected PV system

* **Wiring diagrams** are a simplified representation of the system’s electrical circuit using standardised shapes. The wiring diagram shows how to make connections between different components and provides additional information such as polarities and the relative arrangement of devices and terminals.

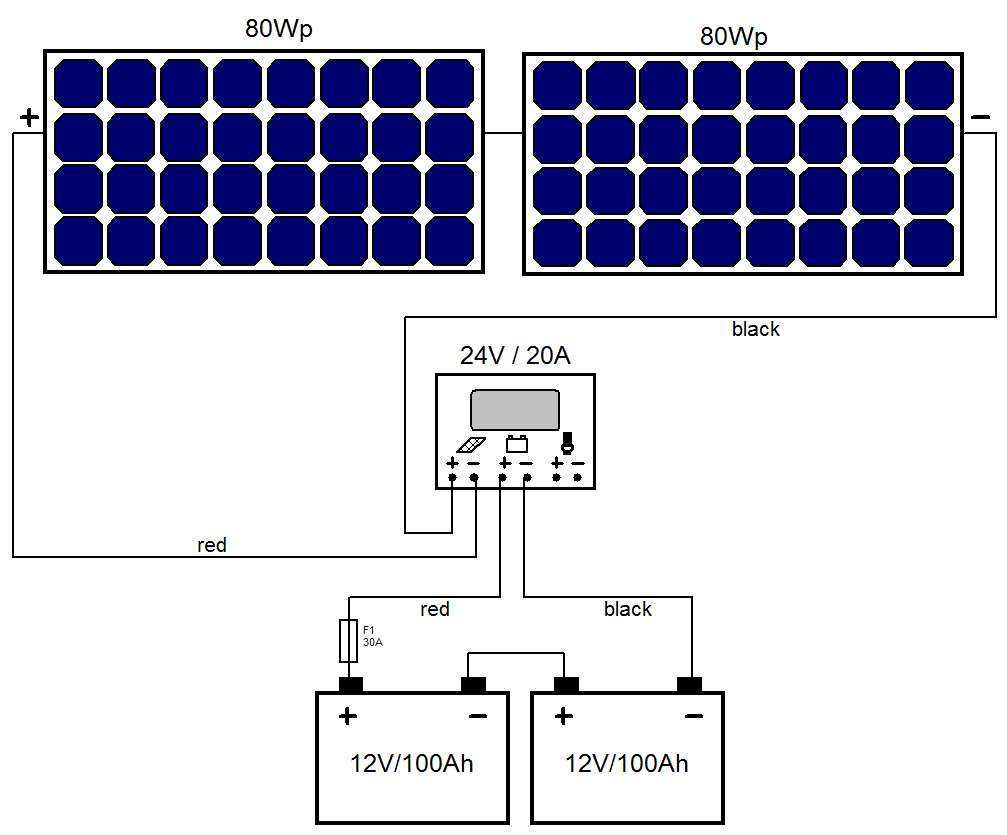


Figure: Wiring diagram of an off-grid PV system

###### Commonly *used symbols in electrical drawings*

| **Symbol** | **Description** | **Symbol** | **Description** |
| --- | --- | --- | --- |
| C:\Users\Uche\Desktop\lamp.JPG | Lamp (Standard) | C:\Users\Uche\Desktop\Capture.JPG | Lighting outlet position – general symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Fluorescent luminaire | C:\Users\Uche\Desktop\Capture.JPG | Wall mounted luminaire |
| C:\Users\Uche\Desktop\Capture.JPG | Self-contained emergency lighting luminaire | C:\Users\Uche\Desktop\Capture.JPG | Emergency lighting luminaire (or special circuit) |
| C:\Users\Uche\Desktop\Capture.JPG | Machine, general symbol  \*function, etc. | C:\Users\Uche\Desktop\Capture.JPG | Load, general symbols \*details |
| C:\Users\Uche\Desktop\Capture.JPG | Motor starter, general symbol \*indicates type |  | Socket-outlet, general  symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Twin socket-outlet, general symbol | C:\Users\Uche\Desktop\Capture.JPG | Switched socket-outlet |
| C:\Users\Uche\Desktop\Capture.JPG | Twin switched socket-outlet | C:\Users\Uche\Desktop\Capture.JPG | Switch, general symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Two-way switch, single pole | C:\Users\Uche\Desktop\Capture.JPG | Intermediate switch |
| C:\Users\Uche\Desktop\Capture.JPG | Pull switch, single-pole | C:\Users\Uche\Desktop\Capture.JPG | microphone |
| C:\Users\Uche\Desktop\Capture.JPG | loudspeaker | C:\Users\Uche\Desktop\Capture.JPG | Antenna, general symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Machine, general symbol \*function M=Motor G=Generator | C:\Users\Uche\Desktop\Capture.JPG | Generator, general symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Indicating instrument, general symbol \*function V = Voltmeter A = Ammeter etc. | C:\Users\Uche\Desktop\Capture.JPG | Integrating instrument or energy meter \*function Wh = Watt hour VArh = Volt ampere reactive hour |
| C:\Users\Uche\Desktop\Capture.JPG | Plug male | C:\Users\Uche\Desktop\Capture.JPG | Coax plug male |
| C:\Users\Uche\Desktop\Capture.JPG | Wire connection  (Two wires) | C:\Users\Uche\Desktop\Capture.JPG | Wires crossing  (Not connected) |
| C:\Users\Uche\Desktop\Capture.JPG | Terminal block | C:\Users\Uche\Desktop\Capture.JPG | Noiseless earth |
| C:\Users\Uche\Desktop\Capture.JPG | Chassis earth | C:\Users\Uche\Desktop\Capture.JPG | Socket (plug female) |
| C:\Users\Uche\Desktop\Capture.JPG | Slow operating relay \*Delay on | C:\Users\Uche\Desktop\Capture.JPG | Wire connections (crossed) |
| C:\Users\Uche\Desktop\Capture.JPG | Terminal connector | C:\Users\Uche\Desktop\Capture.JPG | Earth connection |
| C:\Users\Uche\Desktop\Capture.JPG | Protective earth | C:\Users\Uche\Desktop\Capture.JPG | Equipotentiality |

Table: Symbols used in schematic and wiring diagrams

| **Symbol** | **Description** | **Symbol** | **Description** |
| --- | --- | --- | --- |
| C:\Users\Uche\Desktop\Capture.JPG | Capacitor, general symbol | C:\Users\Uche\Desktop\Capture.JPG | Inductor, core, winding or choke |
| C:\Users\Uche\Desktop\Capture.JPG | Inductor, core, winding or choke with magnetic core | C:\Users\Uche\Desktop\Capture.JPG | Semi-conductor diode, general symbol |
| C:\Users\Uche\Desktop\Capture.JPG | Contractor coil | C:\Users\Uche\Desktop\Capture.JPG | Relay to AC supply |
| C:\Users\Uche\Desktop\Capture.JPG | Slow-release relay. Delay off | C:\Users\Uche\Desktop\Capture.JPG | General relay (DC supply) |
| C:\Users\Uche\Desktop\Capture.JPG | Slow operating relay. Delay on | C:\Users\Uche\Desktop\Capture.JPG | Mechanically latched relay |
| C:\Users\Uche\Desktop\Capture.JPG | Normally open PB (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Normally closed PB (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | Emergency stop PB (N/O) indication contact |  | Emergency stop PB (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | Pull switch (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Pull switch (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | Turn/rotary switch (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Turn/rotary switch (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | Normally open contact (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Change over or two contact Made position |
| C:\Users\Uche\Desktop\Capture.JPG | Limit switch (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Flow switch (N/O) |
|  | Time delay (N/O) Delay on closing |  | Thermal switch – overload (N/O) |
| C:\Users\Uche\Desktop\Capture.JPG | Temperature switch (N/O) | C:\Users\Uche\Desktop\Capture.JPG | Pressure switch (N/O) |
| C:\Users\Uche\Desktop\Capture.JPG | Normally closed contact (N/C) |  | Fused switch open contact (N/O) |
| C:\Users\Uche\Desktop\Capture.JPG | Limit switch (N/C) | C:\Users\Uche\Desktop\Capture.JPG | Flow switch (N/C) |
|  | Time delay (N/O) Delay on re-opening |  | Thermal switch-overload (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | Temperature switch (N/C) |  | Pressure switch (N/C) |
| C:\Users\Uche\Desktop\Capture.JPG | 3-phase winding-star | C:\Users\Uche\Desktop\Capture.JPG | Rectifier |
| C:\Users\Uche\Desktop\Capture.JPG | Inverter | C:\Users\Uche\Desktop\Capture.JPG | Primary cell – long line  positive, short line negative |
| C:\Users\Uche\Desktop\Capture.JPG | Battery |  | Fuse link, rated current in amperes |
|  | Notes:  (1). If the direction of change is not obvious, it may be indicated by an overhead on the outline of the symbol.  (2). A symbol or legend indicating the input or output quantity, wave front, etc. may be in each half of the general symbol to show the nature of change |  |  |

Figure: Symbol used in domestic circuit diagram

###### Required tools and equipment

There are a variety of tools and equipment used in the installation of photovoltaic power systems. A selection is included below.

| **Tool** | **Function** |
| --- | --- |
|  | Drilling holes in surfaces |
|  | Connecting electrical installation equipment to a power supply |
| Macintosh HD:Users:ddb:Desktop:2016 mrch:fishing tape.jpg | For running cables in conduits |
|  | For work requiring access to high places |
|  | Determining the azimuth of the solar photovoltaic array |
| A calculator with a screen  Description automatically generated | For basic arithmetic calculations |
| A black and white drawing of a cable  Description automatically generated | Cutting cable insulations to terminate them |
| A drawing of a hammer  Description automatically generated | Hammering nails |
|  | Carrying basic installation tools. To be worn around the waist |
| A drawing of a tape measure  Description automatically generated | Measuring distances |
|  | Protecting workers; functions as a line when working on elevated surfaces (above 2 m) |
|  | Screwing in nuts and bolts |
|  | Making straight-line markings on installation surfaces |
|  | Fastening screws |
| A drawing of a chisel  Description automatically generated | Punching holes in the installation surface, used together with a hammer |
|  | Terminating cable lugs |
| NO NAME:2016 mrch:fluke clamp meter.jpg | Measuring electrical parameters |
| A black and white drawing of a cable  Description automatically generated | Identifying cables and their respective circuits after installation |
|  | Insulating cables with broken insulation |
| A black and white drawing of a needle nose pliers  Description automatically generatedA line drawing of a pliers  Description automatically generated | Holding cables |
|  | Determining whether a surface is straight or slanted |
| A wire cutter with a hole in the end  Description automatically generated | Cutting long wires |
|  | Fastening conduits and equipment to mounting surfaces |

### Installing the photovoltaic array

You cannot have a functional system without solar PV modules. Knowing where and how to install the PV array can make the difference between proper system performance and system failure.

###### Handling PV modules

Solar photovoltaic modules are manufactured to withstand difficult weather conditions. Their aluminum frames and tempered glass covering further provide strength. However, they could be damaged if they are not handled properly during transportation and installation.

It is important to note the following when handling and transporting solar PV modules:

* Until installation, always **transport the modules in their original packaging** to prevent damage.



* Inappropriate handling may break the module.



* Hard objects can strike the back of a module and cause permanent damage.
* When one cell is broken, the whole solar PV module is unusable or permanently compromised and its use is limited to a low value and lower power application.
* Store PV modules in a cool dry place.
* Protect the PV modules against scratches and similar damage.
* Do not rest a PV module unprotected on its edges, as this can damage its frame.

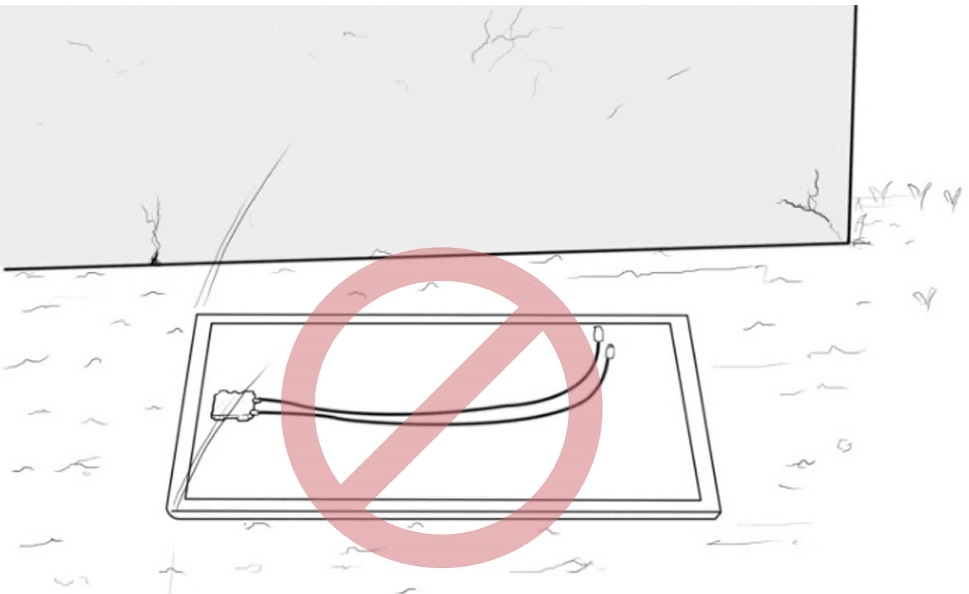
A drawing of a broken tile

Description automatically generated

* Ensure the solar PV modules do not bow under their own weight.
* Never move or lift the PV modules using the cables or at the junction box.



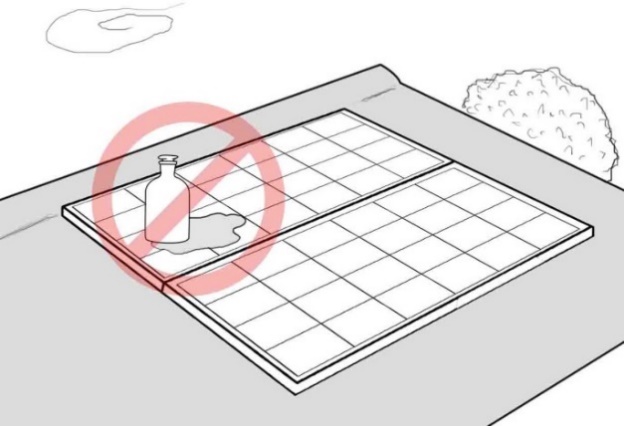
* Do not lay the solar PV module face down on any surface.



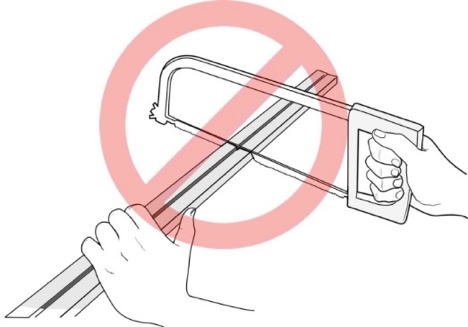
* Do not subject the face of the PV module to mechanical stress.
* Do not stand on the PV modules.



* Do not drop or place objects on the PV module.
* Do not expose the solar photovoltaic module to chemicals.



* Do not immerse the solar photovoltaic module in liquids
* Do not install modules when it is raining
* Do not cut or modify parts or rails of the solar photovoltaic module. If you must drill holes in the frame, drill from the base or from the side and avoid damaging the solar cells.

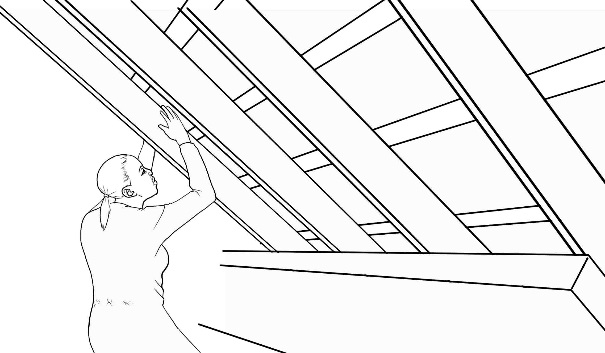


* Completely cover solar photovoltaic module with opaque materials when installing and wiring to halt production of electricity.
* Do not use chemicals on solar photovoltaic module when cleaning.
* Do not wear metallic jewellery, which may cause electrical shock.
* Do not touch cable electrical contacts.

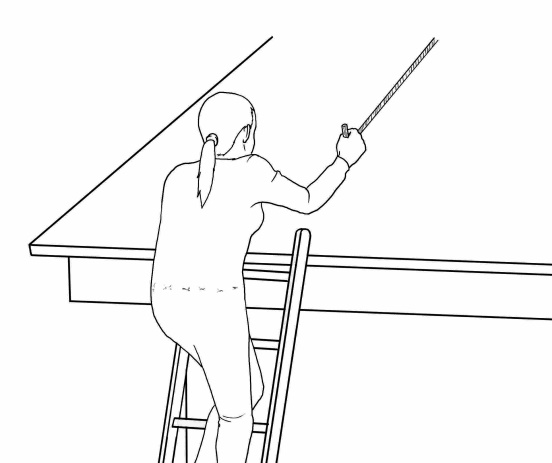
###### Preparing a shingle roof for installation

In earlier sections, we already identified the ideal orientation for installation of PV modules. Which is South facing with an inclination of 15°. You must ensure that the area you plan to install the modules are also free from obstructions such as trees and skylight, etc.

* Locate rafters or trusses on the inside of the roof



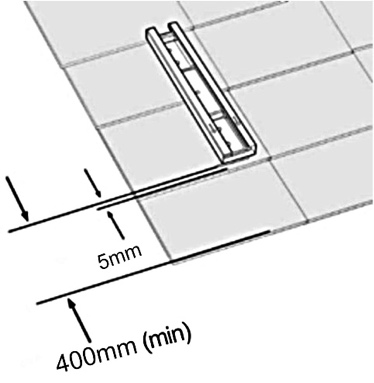
* Locate and measure the locations of the rafters in the attic or at the outside eave, and transfer measurements to the roof.



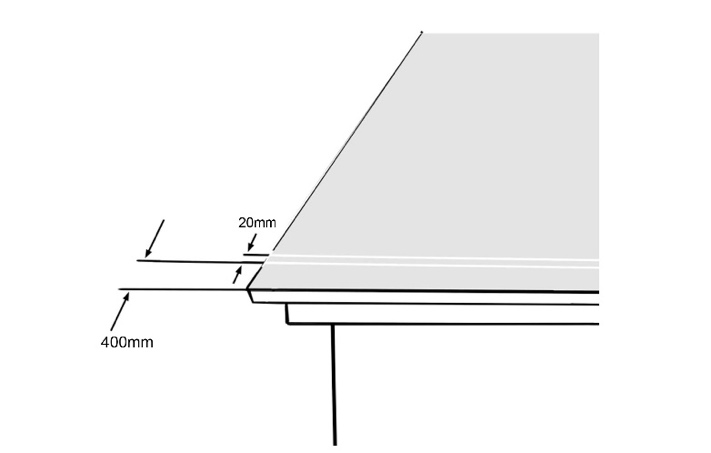
* If you are unable to locate the rafters, alternatively you may scan the roof with a high-sensitivity stud finder.



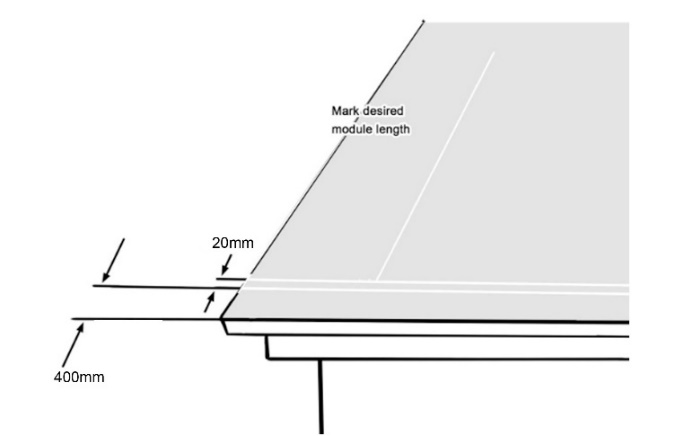
* Measure up at least 400 mm from the eave. Snap a chalk line. This marks the location of the bottom edge of the slider. This line needs to be at least 5.5 mm away from the nearest front edge of shingles.



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

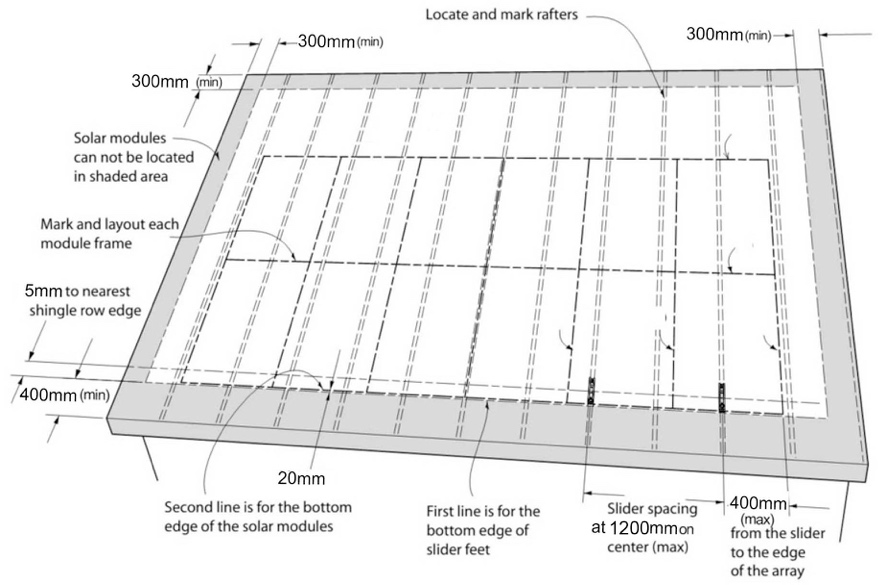


* Measure up from the solar panel chalk line to the desired module length to form the array.

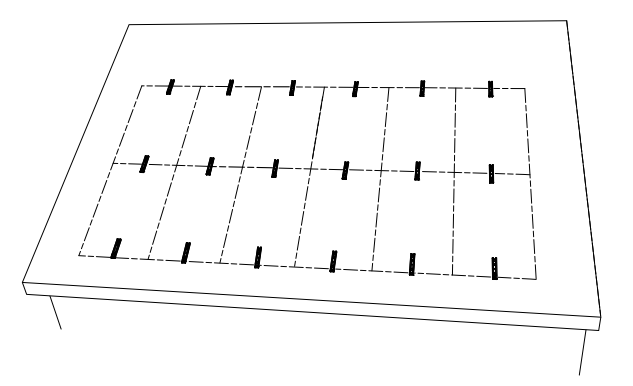


###### Using pre-fabricated mounts to install solar PV modules

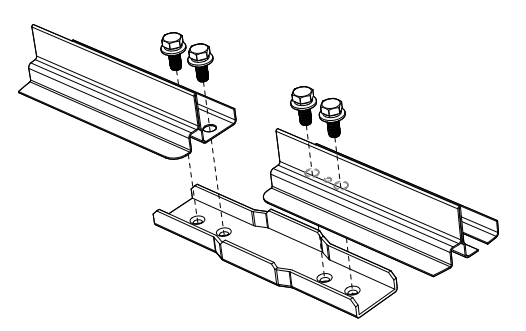
* Before installing the sliders, check the layout of the rails and splices.



* Place all sliders in the desired locations



* Place rails with splices into position. Ensure slider locations do not overlap with splices.

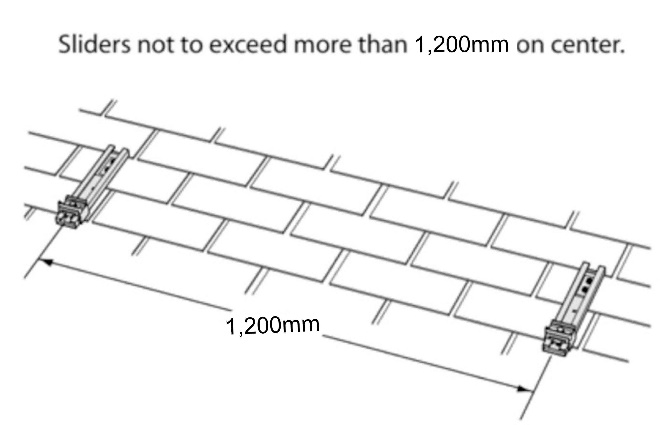
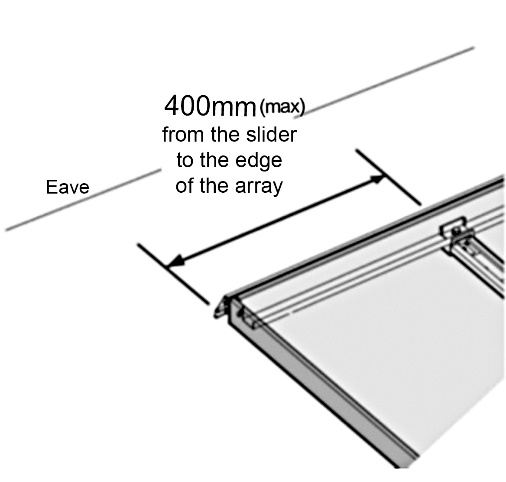


* If these overlap or seem too close:
  + - Shift rails horizontally or
    - Move sliders to the next rafter or remove splices to switch the long and short rails to opposite sides.
    - Reattach splices after switching the rails and recheck for overlap.

A drawing of a rail splice

Description automatically generated

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

******

* Installing a standard slider assembly.

Each adjustable slider is equipped with pre-installed butyl sealant pads. A 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 sight window for locating the slider on the previously snapped chalk line.

There are two arrows located at one end of the slider. The arrows should 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.

**Arrows on the standard slider assembly should point to the eave.**

###### 300px-MC4_connectorConnecting PV modules

Cables on the DC side of a solar system, whether grid-connected or off-grid, require particular attention, since voltages on the DC side are usually low and the current high. For example, if a 4 kW off-grid solar array feeds via a 10 m long cable of 2 × 6 mm² into a battery at 48 V system voltage, the voltage drop is 7% which means a 7% power loss.

Figure: MC4 connector, female (left) and male (right)

Ideally, the voltage drop on the DC side should not exceed 3%. Cables can account for a big part of the investment, especially if the solar array is far away from the battery or inverter. Stepping up to a higher system voltage can reduce required cabling and, therefore, costs.

Solar panels often come with a length of wire with a so-called MC4 (multi-contact 4 mm²) connector. These connectors are weatherproof and easy to plug together. There is a male and a female connector (for positive and negative connections), which makes it very easy to connect solar modules in series.

Figure: Wiring of solar modules with MC4 connectors

* However, the pre-mounted MC4 connectors can only be used to connect solar panels in series.
* When a parallel connection is required, you will need to cut off the MC4 connector (male or female) and use a common cable connector (screw connector).

When connecting solar PV modules, always observe the following rules:

* Be aware that a solar array generates close to its full voltage even with minimal sunlight.
* Choose a main feeder cable from the array to the charge controller to keep the voltage drop below 3%.
* Avoid unnecessary cable lengths.
* Use screw connectors for all connections. Splicing is very unreliable, since tight connections are difficult to assure and twisting weakens the wires. Splicing also complicates the disconnection of wires, which can be necessary for maintenance and troubleshooting.
* Connect solar module cables to the 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 rain, preferably inside the roof.
* Secure the cable and protect it from mechanical stress and impact from objects such as debris, hail, etc.



Figure: Connection of module wires in the junction box

Figure: Feeding of module wires through a conduit into the roof

### Installing the battery bank

Batteries are the most volatile component in a photovoltaic system. Work done on batteries always poses a risk and maximum care must be taken to avoid all forms of injury.

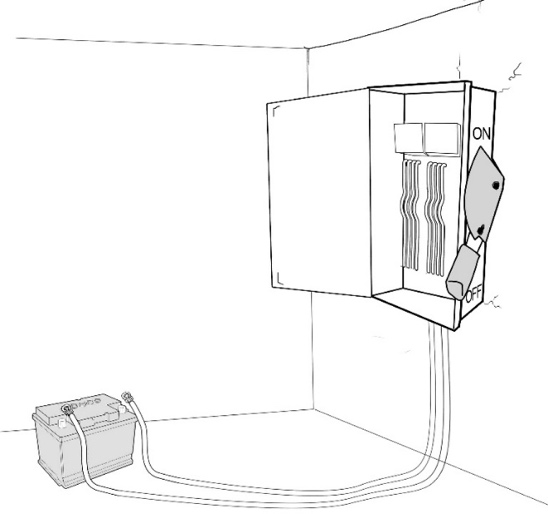


Figure: 48 V battery bank in a solar hybrid system

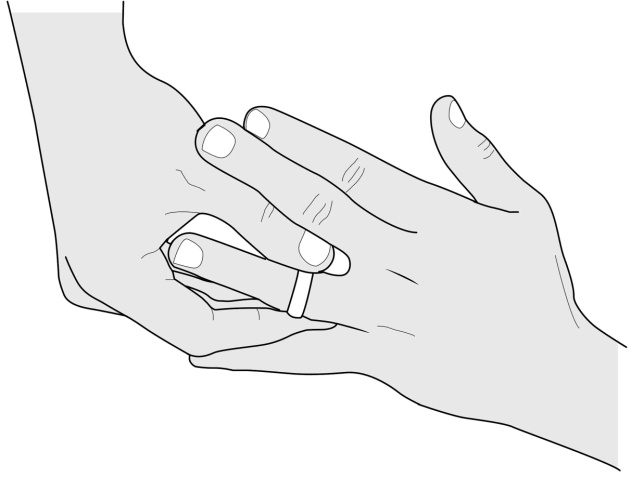
Courtesy: www.solarconnections.com.au

###### Precautions when working with batteries

* 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.



* Battery banks can store voltages with very high current potential. 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 personal jewellery and only use appropriate tools when working on batteries.



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



* Currents on the battery cables can be very high in normal operation. Choose the correct cable size and the right connectors to connect batteries.A close up of a battery

  Description automatically generated

Figure: Poor connection (left) and good connection (right)

* A short circuit on the battery terminals can result in an enormous release of energy with strong sparks. Batteries must be protected from mechanical impact (falling objects, etc.). The installation must also allow some airflow, as batteries generate warmth during use.

### C:\Users\me\Desktop\NAPTIN 2015\drawings,tables\space scc.BMPInstalling the inverter and charge controller

Most inverters do have a fan for cooling. Nevertheless, because inverters and charge controllers can get very hot during operation, you should always provide enough space for a cooling airstream when choosing the installation site. Never cover ventilation slots.

The inverter can draw high currents from the battery during operation. For example, a 24 V/2,000 VA inverter might draw 2,000 VA/24 V = 83 A under full load. The connector wires from the inverter to the battery must be strong enough to handle the maximum current.

Figure: Cooling in a charge controller

| **Inverter  wattage** | **Battery voltage** | | | |
| --- | --- | --- | --- | --- |
| **12 V** | **24 V** | | **48 V** |
| **Wire cross-section** | | | |
| 150 | 10 mm2 | 6 mm2 | - | |
| 250 | 16 mm2 | 6 mm2 | - | |
| 500 | 35 mm2 | 10 mm2 | - | |
| 1,000 | 50 mm2 | 25 mm2 | - | |
| 1,500 | 50 mm2 | 35 mm2 | - | |
| 2,000 | 70 mm2 | 50 mm2 | - | |
| 2,500 | 95 mm2 | 70 mm2 | 50 mm2 | |
| 3,000 | - | 95 mm2 | 50 mm2 | |
| 3,500 | - | 95 mm2 | 70 mm2 | |
| 4,500 | - | - | 70 mm2 | |

Table: Required cable sizes for DC side cabling of inverter

Many inverters are immediately destroyed when connected with the wrong polarity. If the label does not say ‘polarity protected’, you should assume it’s not. Always observe the following rules when installing an inverter:

* Read the manual.
* Mind the specified ventilation space around the charge controller according to the manual.
* Use the battery connection cables which are usually supplied with the inverter. Otherwise, use 16 mm2 cables.
* Check if the voltage rating matches the battery.
* Mind the polarity.
* Make sure all connections are tight.

Always observe the following rules when installing a charge controller:

* Read the manual.
* Check if the voltage and current ratings match the solar array.
* Mind the specified ventilation space around the charge controller according to 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.

|  |
| --- |
| ***Note:*** If the solar array is connected before the battery, the charge controller might sustain damage due to overvoltage. |

### Connecting the system components

###### DC connections

When connecting components on the DC side of a PV system, you must connect the negative (-) terminal before the positive (+) terminal.

###### AC connections

When connecting components on the AC side of a PV system, you may connect them as you usually connect equipment when wiring a house.

###### Circuits in a solar photovoltaic system

Diagram of solar panels

Description automatically generatedA solar photovoltaic system consists of a number of circuits, which are identifiable by the system components that they interconnect.

* **Solar source circuit:** This refers to the interconnection between PV modules. It terminates 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.

Figure: Circuits in a grid-connected solar system with no battery bank – Courtesy: Ryan Mayfield, Photovoltaic design and installation for dummies, Wiley, 2010

* **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.

### Step-by-step installation

It is important to prepare the site before starting to install components. Site preparation includes the following steps:

* Confirm the location where the PV modules will be installed.
* Confirm that there is no shade or shade-causing feature, which could interfere with the irradiance that the solar panel array receives. This might include trees, buildings or other man-made structures such as electricity poles.
* Develop a safety plan to be implemented once installation work begins.
* Determine the installation location of system components and cable routes.
* Prepare equipment and tools to be used during installation and ensure that they are available before installation work begins.
* Prepare the installation diagrams, i.e. a single-line diagram or wiring diagram, which shows the interconnection between system components.
* Install conduits (pipes and trunkings) along the planned cable route.
* Install cables in conduits.
* Label all cables according to circuits.
* Install solar panel mounting systems.
* Install system components in the pre-determined locations.
* Mount PV modules on structures at an appropriate angle (25⁰- 30⁰) and orientation (facing south).
* Connect PV modules according to desired series/parallel connection.
* Connect batteries according to desired series/parallel connection.
* For an AC system, connect batteries to the inverter (input side). Ensure that the inverter output switch is in the OFF position.
* Ensure that the main distribution board (MDB) breaker is in the OFF position.
* For an AC system, connect the inverter output to the home distribution board. Take care to ensure that only relevant circuits are connected.
* Connect the battery bank to the charge controller.
* If the system consists of DC loads, connect the loads to the charge controller.
* Connect the solar photovoltaic array to the charge controller
* Switch on the inverter
* Turn on all switched off breakers on both the AC and DC sides.

## Commissioning

Once installation is completed, before your client takes ownership of the system, it is important that you commission the system. Commissioning is the process of assuring that all the components of the photovoltaic system have been installed and tested and are fully operational according to the requirements of the owner.

### Commissioning requirements and activities

Commissioning of a solar photovoltaic system comprises the following activities:

###### Visual inspection

Visual inspection activities must be completed before and after the system is energised. This visual check ensures that:

* Number of PV modules connected in series and in parallel is correct
* All modules are properly wired
* PV array mount is properly fastened
* All cable conduits are properly installed
* All cables are properly terminated and appropriately labelled.

###### Electrical inspection

###### DC side

On the DC side of the installation, you must verify the following:

* Polarity of all cables (positive and negative)
* Open-circuit voltage of each array string
* Short-circuit current on each array string
* Voltage and readings at the critical connection points (junction boxes, disconnects and at the inverter) in the system
* Correct operating voltages and system current as specified for system design
* Wire insulation and resistance
* Effectiveness of grounding connections

**AC side**

Once you have verified that the DC side meets all requirements, you need to inspect the AC side. This is done by measuring AC voltages along the circuit. Start at the inverter as this is the origin of the AC circuit in your PV system (ensure that the AC disconnect and MDB breaker are in the “OFF” position). If this voltage measurement is as expected, then:

* Switch “ON” the AC disconnect and measure the output voltage and current from there.
* Switch “ON” the main breaker on the MDB and measure the output voltage and current from there.

At this point, if all is as expected, then you may declare the system technically sound. However, commissioning is not complete. You must now proceed with documentation.

###### Documentation

You must document the procedure for installation, commissioning and maintenance for the system owner. This can easily be done by creating a manual with all relevant information. Make sure that all documentation is simple, clearly presented and easy to understand.

The manual must include the following information:

* Date of commissioning
* Contact numbers in the event of system failure
* Emergency contact numbers
* Basic maintenance schedule for the system owner

###### Filling in a job card

The job card is to be filled in by you the installer and handed over to the customer with the photovoltaic system. In the job card, important information pertaining to installation and maintenance activities should be included. The job card should also include:

* **Site details**: Clearly state the installation location as well as the name and contact details of the owner.
* **Equipment details**: Indicate all installed equipment as well as quantities and locations. Maintenance requirements may be included if necessary.
* **Installer details:** Name and contact details (telephone numbers, email address and physical address) of the installer should be clearly and visibly stated on the job card.

## Three phase wiring

### Basic information on 3-phase wiring systems

A 3-phase wiring system is an electrical power distribution method commonly used in industrial and commercial settings. It provides three alternating currents (AC) with different phases, typically spaced 120 degrees apart.

It consists of:

* Three active/live conductors (phases): L1, L2, and L3.
* A neutral conductor (optional, used in some configurations).
* Earthing/ground conductor for safety.

**Common configurations:**

* Star (Wye) Configuration: Includes a neutral wire, with voltage between phases and neutral lower than phase-to-phase voltage (e.g., 400V phase-to-phase, 230V phase-to-neutral).
* Delta Configuration: No neutral wire, used for high-power loads (e.g., industrial motors). Phase-to-phase voltage is usually 400V.

### Basic science behind 3-phase systems

AC Voltage in each phase oscillates in a sinusoidal wave, peaking at different times. When one phase is at its peak, the other two are not, ensuring continuous and smooth power supply.

Phase shift: The phases are separated by 120° electrical degrees, ensuring balanced load distribution and minimizing voltage dips.

**Why use 3-phase power?**

* **More efficient power delivery:** 3-phase systems can deliver more power with smaller, less expensive wiring and components.
* **Stable power:** There is always power being delivered to the load, providing a smoother operation for motors and other equipment.
* **Balanced load distribution:** By distributing electrical loads equally across three phases, the system avoids overloads on individual phases, improving reliability.

**Voltage levels:**

* Phase-to-phase: In a 400V system, the voltage between two phases is 400V.
* Phase-to-neutral: Voltage between any phase and neutral in a star configuration is 230V.

### Advantages of 3-phase wiring systems

* Power efficiency: 3-phase power is more efficient than single-phase systems for transmitting large amounts of electrical power.
* Continuous power delivery: No drop in power delivery due to the 120° phase difference, making it ideal for heavy machinery.
* Cost-effective: Smaller cables are needed for the same power load, reducing material and installation costs.
* Higher power density: More power can be delivered through a single 3-phase line compared to a single-phase system.
* Balanced loads: Provides the ability to balance loads across the phases, improving stability and reducing the chance of system overload.
* Lower voltage drops: Especially over long distances, voltage drops in 3-phase systems are significantly less.

### Installation of 3-phase wiring systems

**Basic components**

* Three-phase supply cables (L1, L2, L3).
* Neutral wire (optional in some configurations).
* Earthing/grounding wire.
* Distribution board with 3-phase circuit breakers and safety devices.
* Main switchgear to isolate the 3-phase system.

### Step-by-step installation process

* **Check incoming supply:** Verify the 3-phase power supply voltage (400V phase-to-phase, or 230V phase-to-neutral).
* **Lay conduits:** Install electrical conduits or cable trays for safe routing of wires from the main supply to the distribution board and other load points.
* **Mount distribution board**: Secure the 3-phase distribution board, ensuring enough space for future upgrades.
* **Connect phase conductors**: Connect the three live conductors (L1, L2, and L3) to the incoming terminals of the main switch and breakers.
* **Neutral and ground**: Connect the neutral and ground wires to their designated terminals.
* **Distribute loads**: Assign circuits to each phase to balance the load, ensuring not all high-power loads are connected to a single phase.
* **install protection devices**: Install MCBs (Miniature Circuit Breakers), RCDs (Residual Current Devices), and fuses for protection.
* **Final inspection and testing**: Check all connections for tightness, measure continuity, insulation resistance, and perform a live voltage test to ensure the system is functional and balanced.

### Tools required

* Multimeter (for voltage and continuity tests).
* Insulation resistance tester.
* Wire stripper and crimper.
* Torque wrench (for tightening connections).
* Cable ties, labels, and identification markers.

### Distribution and load management

###### Balancing loads

* Distribute electrical loads evenly across the three phases to avoid overloading a single phase.
* Example: If you have three high-power devices, connect one device to each phase (L1, L2, and L3) rather than connecting them all to a single phase.

###### Using neutral

In the star configuration, neutral helps balance unbalanced loads. For instance, in 230V single-phase loads, the neutral wire carries the return current.

###### Circuit protection

* Install MCBs or MCCBs on each phase for individual protection. Use a three-pole breaker for 3-phase devices like motors or heavy machinery.
* Ensure RCDs are installed to detect ground faults, particularly in areas where moisture or wet conditions are a concern.

###### Monitoring and maintenance

* Regularly monitor the phase currents using a clamp meter to ensure loads are balanced.
* Test the insulation resistance of cables periodically.
* Check the earthing system for continuity and proper functioning.

### Troubleshooting common issues

###### Voltage imbalance

* **Symptom**: Different voltages measured between phases.
* **Solution**: Recheck connections, balance the load more evenly, or consult the utility provider if the issue persists.

###### Overloaded phase

* Symptom: MCB for one phase keeps tripping.
* Solution: Check if the loads are disproportionately connected to one phase. Redistribute loads across all three phases.

###### Tripping of residual circuit device (RCD)

* Symptom: RCD keeps tripping.
* Solution: Inspect for any faulty equipment, damaged cables, or moisture that could be causing ground faults.

### 7. Safety practices for 3-phase systems

* **Lockout/Tagout (LOTO)**: Always de-energize and lock out circuits before working on them to avoid electrical shocks.
* **Use of PPE**: Wear appropriate Personal Protective Equipment, such as insulated gloves, safety boots, and goggles.
* **Earthing**: Ensure a solid earthing system is in place and properly connected to reduce the risk of electrocution and equipment damage.
* **Voltage testing**: Always test for live circuits before working with any equipment.
* **Clear labelling**: Label phases, neutral, and ground wires clearly, as well as each circuit breaker, for easier maintenance and troubleshooting.