USN :

CMR Institute of Technology, Bangalore
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
II - INTERNAL ASSESSMENT

Semester: 8-CBCS 2017
Subject: OPERATION AND MAINTENANCE OF SOLAR ELECTRIC SYSTEMS (17EE832)
Faculty: Ms Reshma P Eldho

Date: 20 Jun 2021
Time: 09:00 AM - 10:30 AM
Max Marks: 50

Instructions to Students :

Attend any 5 full questions

Answer any 5 question(s)

Q.No		Marks	CO	PO	BT/CL
1	Explain the function and working of 'Solar Pathfinder'. What are the local environmental parameters those are affecting on the energy efficiency and design of the PV System?	10	CO3	PO1,PO2,PO3	L2
2	Explain the need of the System Protection for the PV Solar System. With suitable example and elaborate the importance of (i) Lightning and surge protection, (ii) Over-current protection and (iii) .Fault-current protection in the PV Solar Systems.	10	CO3	PO1,PO2	L1
3	Explain (i)) Net metering and (ii)Gross metering in a PV Solar Power generation systems.	10	CO4	PO3	L1
4	Calculate the energy yield for a system consisting of 18 modules in a string. The array is installed flat on a roof with an orientation and tilt of 20° from true north and 40° respectively. Due to the roof inclination an efficiency of 93% is obtained for a system installed at a location with PSH of 4.5 and an average ambient temperature 22°C. The Sharp modules with maximum power rating of 185W each is used for the system. Temperature coefficient of power -0.42 % /°C. Consider the inverter efficiency as 95% Assume the factors which are not given.	10	CO3	PO2	L3
5	Explain the following terminology with a suitable diagram about (i) DC wiring and (ii) Cabling routes and required lengths (iii) System grounding/earthing, and (iv) Inverter installation for the PV System.	10	CO2	PO3	L2
6	For a PV System to be installed in Sydney(Ambient temp of 0 deg C to 50 deg. C), Calculate minimum number of number of modules in a string with the given data: Voc= 30.2 V , Temp. Coefficient of VOC = - 0.104V/ 0C VPM =24V , Temp. Coefficient of Vpmax = - 0. 854%/ 0C Expected voltage drop across DC Cables =1% MPP Voltage range = 268 -400 V Safety margin for minimum inverter input voltage = 10%	10	CO3	PO1	L3

Figure 7.6 Solar Pathfinder in use

Source: Global Sustainable Energy Solutions

Solar Pathfinder

A Solar Pathfinder is used to determine the extent of shading at the intended PV installation site. It is used to identify objects which will cause shading and the times of year when shading will occur.

A Solar Pathfinder requires a sunpath diagram for the latitude of the location. This diagram is then placed inside the Pathfinder, the diagram is rotated so that the white dot on the rim lines up with the magnetic declination given for that location and then the entire Pathfinder must be rotated so that the needle at the base points to magnetic north. The transparent dome is then placed over the top of the Pathfinder.

When the Pathfinder is placed at a given location, the objects surrounding it will cast a shadow on the dome (and the diagram inside) and the outline of these shadows is then traced onto the sunpath diagram in wax pencil to determine when the array in that location will be shaded. If no shadow is cast on the Solar Pathfinder the site will be shade-free all year.

The horizontal arcs represent the sun's path across the sky for each month of the year. In Figure 7.8 the large tree to the north of the site will shade the array at some point of the day in every month except for November, December and January. Vertical lines represent the hours of the day: throughout the year this array would be shaded before 8.00am. Demonstration videos showing how to set up and use a Solar Pathfinder are available on www.solarpathfinder.com/video.

Though the Solar Pathfinder is an excellent tool, it cannot always be used effectively. If the building on which the solar array will be located has not yet

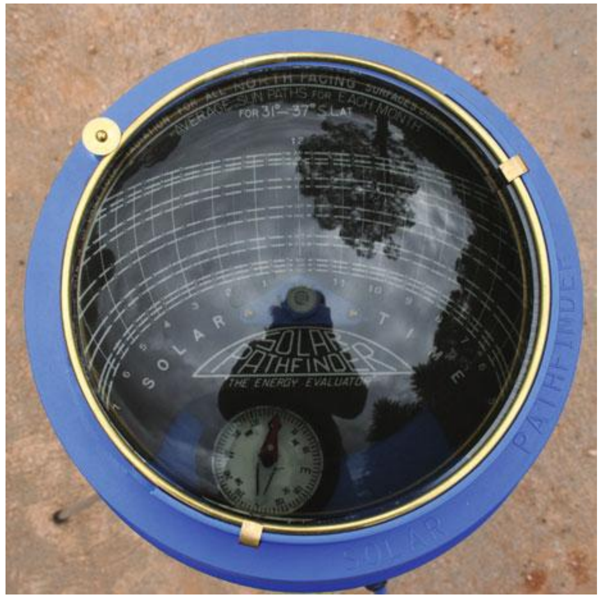


Figure 7.7 Solar Pathfinder, showing trees to the north and to the right shading the site

Source: Global Sustainable Energy Solutions

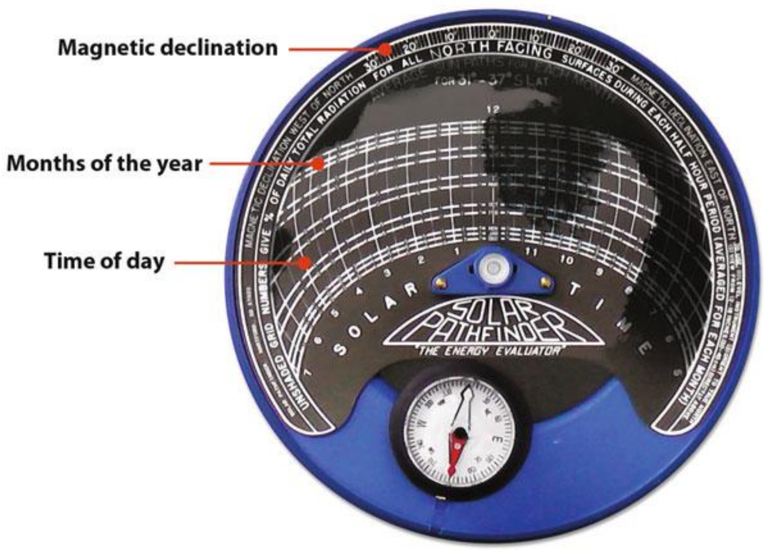


Figure 7.8 Example of a sunpath diagram with the shading traced on it; it is important to use the correct sunpath diagram for the latitude of the site

Source: Global Sustainable Energy Solutions

been constructed, then the Solar Pathfinder cannot physically be located at the same height as the proposed array. A full assessment of the effects of shadows on the proposed array cannot be undertaken until after the construction. Solar Pathfinder software is also available: rather than tracing the shadows onto the sunpath diagram, a photo can be taken of the shaded dome and uploaded to the computer. This software is also able to adjust the shading analysis at ground level for a given height – allowing the Solar Pathfinder to be used in circumstances where it cannot be physically located at the same height as the proposed array.

from the National Renewable Energy Laboratory (NREL), and the PVGIS online tool can be used to calculate the effect of tilt and orientation on power output for any location in Europe and Africa (see Chapter 15).

Is the site shade-free?

As explained in Chapter 3 shading on a PV array can significantly decrease its output. Some sources of shading such as dust, dirt and bird droppings are unavoidable and must be cleaned off regularly. Any permanent source of shading needs to be identified during the site survey. Potential sources of shading may include:

- Trees and vegetation: it is important to bear in mind that trees that do not shade the PV array at the time of the site assessment will grow and may shade the PV array in a few years, so this should be discussed with the owner before installation. The owner may agree to prune the tree regularly and ensure it does not shade the array. If this is not possible, for example, if the tree is on a neighbouring property, another location should be considered, or the neighbour may be consulted.
- Other buildings, including neighbouring properties or buildings on site. Be aware that new buildings may be constructed, shading areas currently suitable for arrays.
- Components of the building on which the array is to be installed; chimneys, TV aerials, satellite dishes and other sections of roof could all shade the

Figure 7.4 Poorly chosen site where trees are shading the PV array

Source: Global Sustainable Energy Solutions

Figure 7.5 In this installation the chimney is shading the array

Source: SMA Solar Technology AG (not an SMA installation)

array if it is not located properly. The user should be made aware that future rooftop installations should not shade the array at any time.
- The natural landscape: mountains or hills may shade a solar array, particularly when the sun is low in the sky.

The PV array should be installed where it will not be shaded during the day. Shading will decrease power output and may damage the modules over their lifetime. Some shading may be acceptable very early or late in the day; however, this decision should be left to a qualified PV system designer.

It is also important to consider local regulations regarding shading or 'solar access'. Many US states have enacted laws to prevent people from growing trees or extending their houses in ways that would shade an existing PV system on a neighbouring property. Many locations have no such law, but good communication between neighbours can help to ensure that they do not make changes to their property that will adversely affect the PV system.

Aside from observing the physical objects on site it is also important to conduct a thorough shading analysis. The sun does not stay at the same point in the sky throughout the year so even though an object may not be shading the proposed location on the day of the site assessment does not mean it won't be shading the location at some other time.

There are a number of tools available to estimate shading on a site throughout the year. The following examples only require one visit to estimate the solar resource for the entire year:

array. The following points are key reasons why the short-circuit current of the array is used:

- A PV module is a current-limited device, i.e. the highest current it can produce is its I_{sc}.
- The short-circuit current is the maximum current a PV module can produce at a given temperature and irradiance.
- The maximum current that an array can produce is the sum of the short-circuit currents of each string in the array.

Since the short-circuit current can vary depending on the temperature of the solar modules and the irradiance, these two important factors should be taken into account when designing photovoltaic systems.

Fault-current protection

It is important to note that there is a limit to the amount of current that can pass in either direction through a PV module without damaging it. This is known as the 'maximum series fuse rating', 'reverse current rating' or 'over-current protection rating' and is stated on the module data sheet. If a fault occurs within one string it is possible that the current from the other strings will feed into the faulty string. If this current exceeds the maximum series fuse rating the module is likely to suffer damage. This is normally only a problem for arrays with multiple strings, i.e. the sum of the currents of all the non-faulty strings exceeds the maximum series fuse rating. To prevent this occurring, string fuses or miniature circuit breakers (MCBs) are often used, and these must be rated for use in a DC PV system.

To determine whether fault-current protection is necessary, designers need to know the short-circuit current of the array and the modules' maximum series fuse rating. National codes normally specify what is required and should always be consulted. For example, in the UK string fuses are required whenever the reverse current rating of the modules (I_r) is less than the combined short-circuit current of all the strings minus one multiplied by 1.25, shown as follows: $I_r < \{I_{sc} \times (\text{number of strings} - 1) \times 1.25\}$. As a rule of thumb, string fuses are required in all arrays of four or more strings, and the fuses used must meet the following requirements:

- Fuses must be fitted to both the positive and negative string cable.
- Fuses must be rated for DC (see Chapter 5 regarding the difference between AC and DC fuses).
- Fuses must be rated: ($V_{oc} \times$ number of modules in the string $\times$ 1.15).
- Fuses must have a tripping current (I_{trip}) of less than $2 \times I_{sc}$ or less than $2 \times$ current-carrying capacity of the string cable (whichever value is lowest should be used).
- If the system does not have string fuses, then the string cable should have a minimum current rating of $I_{sc} \times (\text{number of strings} - 1) \times 1.25$.

National codes and regulations must be consulted.

Box 8.1 Fault-current protection example

National Australian Standards are slightly different to those in the UK. In Australia fault-current protection is required when the combined short-circuit current of all strings in the array minus one is greater than the reverse current rating of the modules, i.e. $I_r < I_{sc} \times$ (number of strings −1).

Example: Is fault-current protection required for an array with 5 strings, each module has a short-circuit current of 5.69A and a maximum series fuse rating of 15A?

First calculate $I_{sc} \times$ (number of strings −1) = 5.69 × (5 − 1) = 22.76A

22.76A is larger than the maximum series fuse rating of 15A, so fault-current protection is required.

When the potential fault current of the array is less than the modules' reverse current rating, then over-current protection is not required, but the cables used throughout the array should be appropriately sized to handle the maximum possible fault current.

Lightning and surge protection

Lightning protection and surge protection requirements are usually included in national codes and regulations, and can even differ from region to region within a country. For example, in Australian/New Zealand Standard AS/NZS 1768: 2007, surge arresters are required when the array feeds supply to critical loads (e.g. telecommunication repeater stations) or if the PV array has a rated capacity greater than 500 watts. A surge arrester is commonly found in commercial PV inverters. In systems where this is not the case, protection is recommended through the use of metal oxide varistors (MOVs). According to AS1768, an MOV should be selected with a continuous operating voltage of greater than $1.3 \times V_{oc}$ of the array and a maximum discharge current greater than 5kA. If a lightning protection system is in place the PV system may need to be integrated into it – how this is done should be confirmed as consistent with prevailing national codes and regulations.

Grounding/earthing

Grounding/earthing systems are specified by local codes and standards. The array mounting structure and the array itself are considered separately. Grounding/earthing the mounting structure is generally done for lightning protection and to provide a path for fault currents to flow. Whether an array conductor is required to be grounded/earthed and in what manner is a more complex matter. Following the recommendations of local standards and codes is necessary.

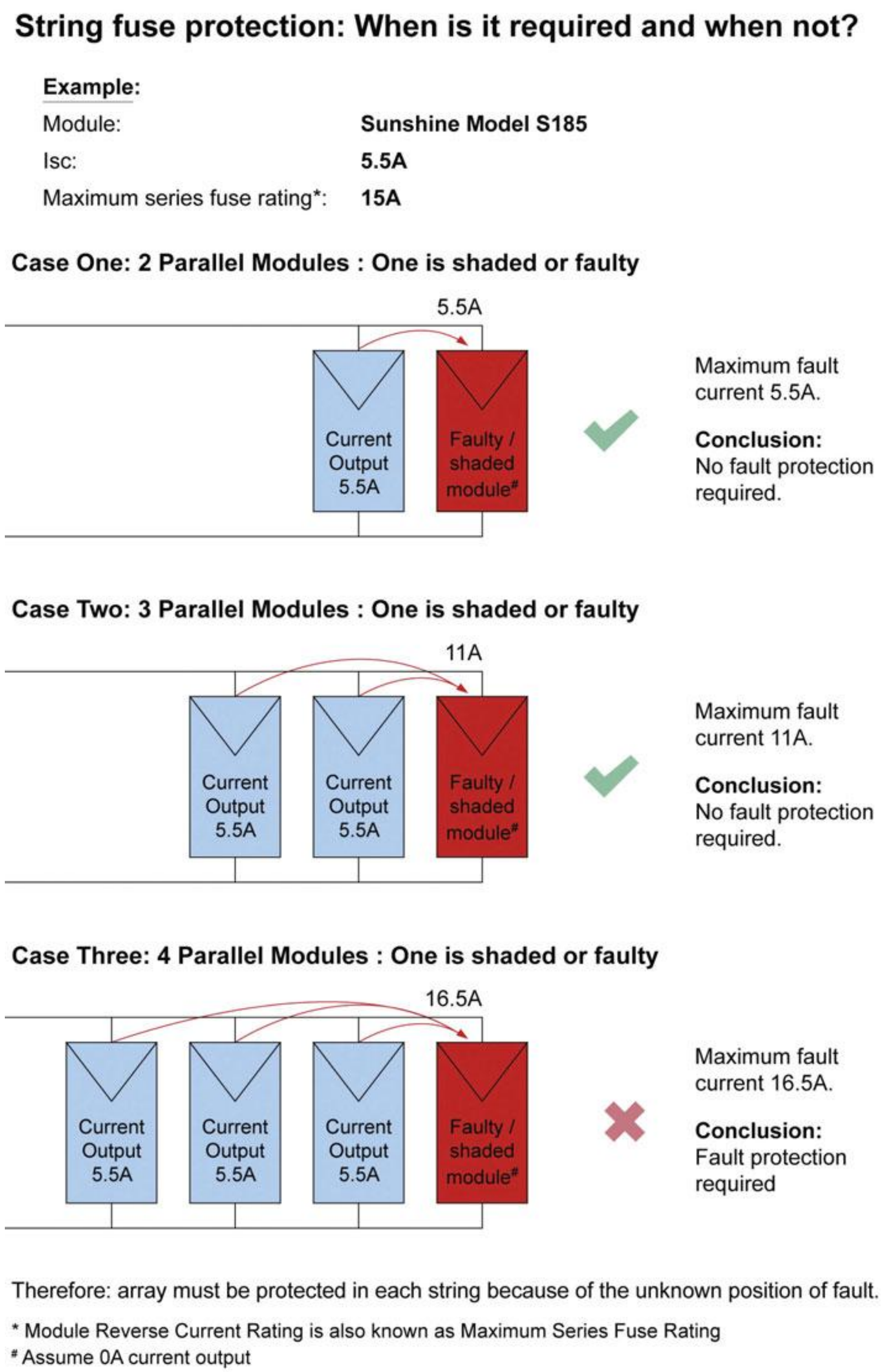


Figure 8.3 Example of when string protection is/isn't required by Australian Codes

Source: Global Sustainable Energy Solutions

Table 10.2 Example of an installation checklist (Cont'd)

Item no	Type of item	Quantity required	Details	OK
11	Main DC array disconnect switch between solar array and inverter			
12	Cable from disconnect to inverter			
13	Conduit if required			
14	Fastening hardware for this cable/ conduit			
15	Inverter model			
16	Fastening hardware for inverter			
17	Cable between inverter and switchboard			
18	Conduit if required			
19	Fastening hardware for this cable/ conduit			
20	PV AC main switch			
21	Required signage			
22	Installation Tools (recommend technician prepares a list)			

Interconnection with the utility grid

The system in which small-scale power generators (such as rooftop PV systems or small wind turbines) are connected to the grid is referred to as interactive distributed generation.

The consumer uses electricity from both sources (PV system and utility grid) as required (as opposed to a stand-alone system where they can only use electricity produced by the PV array). This varies slightly depending on the metering arrangement (see Chapter 5 for details): when net metering is used, electricity produced by the PV system is used at that point of attachment, any excess is exported back to the grid and additional electricity is purchased from the grid when the PV system is not producing enough. If gross metering is used, all electricity is exported to the grid and the electricity required by the load is imported from the grid so that no electricity flows directly from the PV system to the load.

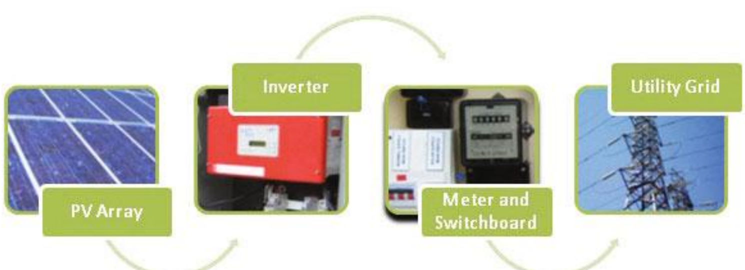


Figure 10.8 In grid-interactive systems, the PV array is connected to the inverter, which is then connected to the switchboard and then the grid; national codes and regulations cover the specifics and should always be followed

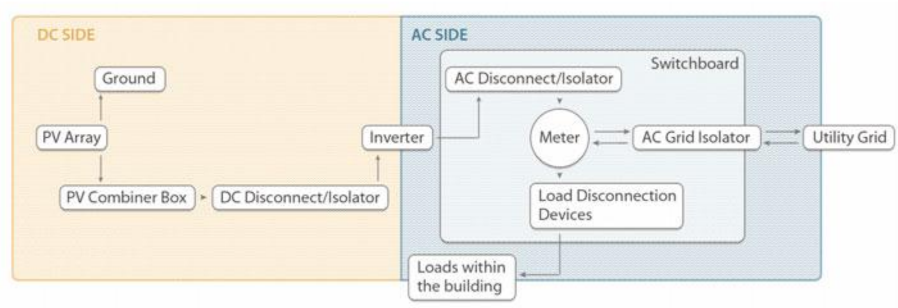


Figure 10.9 Summary of the connection of components of a grid-connected PV system using net metering

Source: Global Sustainable Energy Solutions

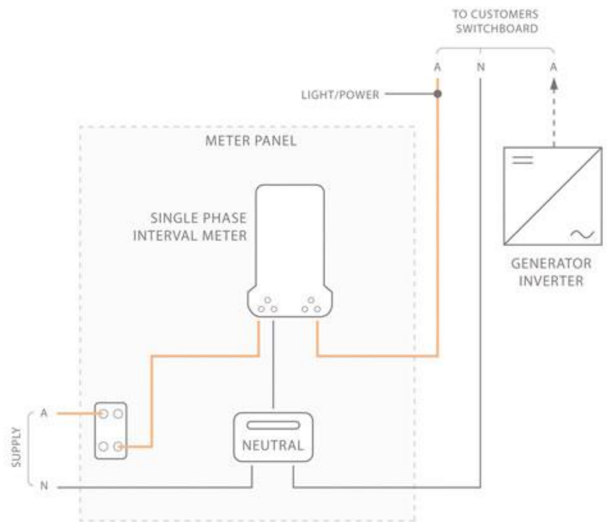


Figure 10.10 Wiring diagram showing a net-metering arrangement; only the power not used on the property is exported

Source: Global Sustainable Energy Solutions

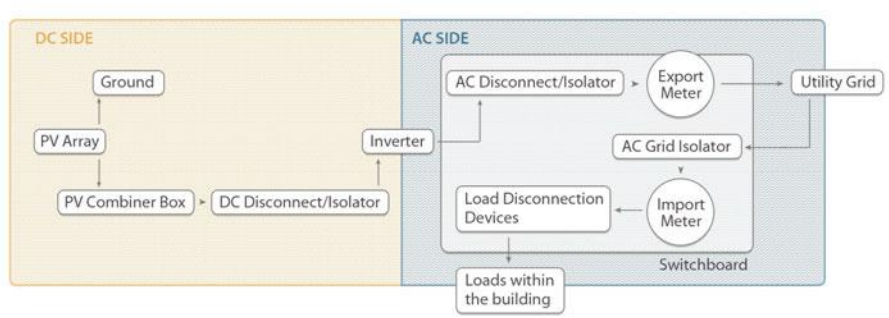


Figure 10.11 Summary of the connection of components of a grid-connect PV system using gross metering

Source: Global Sustainable Energy Solutions

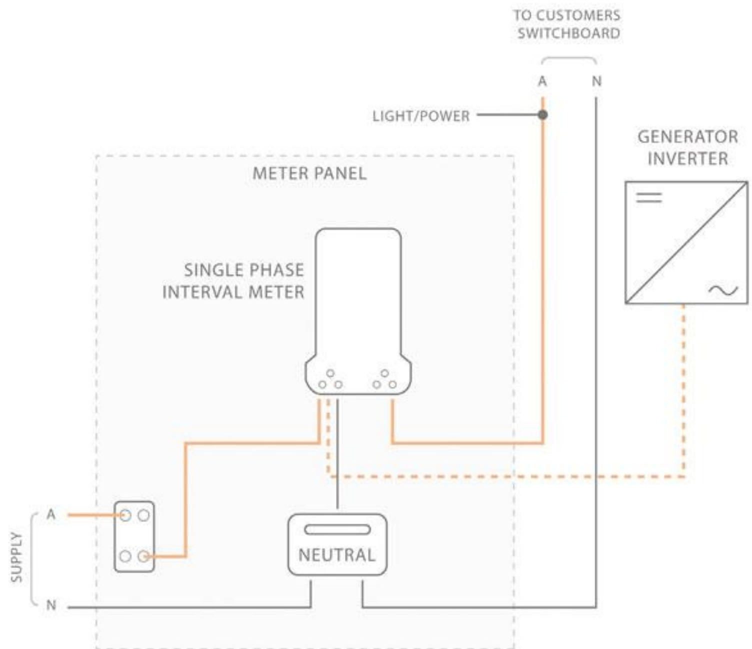


Figure 10.12 Wiring diagram showing a gross-metering arrangement where all power produced by the PV system is exported to the grid

Source: Global Sustainable Energy Solutions

In order to connect a PV system to the utility grid an interconnection agreement contract is typically required. Given that utility grid systems vary according to country of installation, so do interconnection agreements and policies. Often the agreement depends not only on local standards and regulations but also on the utility, which must agree to import the electricity produced by the PV system. Some local laws require utilities to buy the power produced by PV systems (as in the UK). However, elsewhere it is left to utilities to decide. Electricity providers worldwide have different regulations concerning safety issues that arise from connecting the grid to multiple power generators. Some of these safety issues are current overload and islanding (see Chapter 5), when electricity is fed to the grid during a power outage, which could represent a serious hazard for electricians working with power lines. Inverters are now built to prevent islanding and they should turn themselves off when the grid is down. It is not uncommon for the local utility to insist on its own inspection of the system before its initial activation.

Required information for installation

In order to install a PV system, drawings and diagrams are usually required by the local authority that authorizes the PV system installation. These drawings illustrate the on-site location of the equipment components, as well as the electrical configuration of the system. Some examples of the drawings that should be completed for each system follow:

- Electrical diagram: A simplified diagram showing the PV array configuration, wiring system, over-current protection, inverter, disconnects, required signs

10

Installing Grid-connected PV Systems

Guidelines for the installation of PV systems vary by country, as there are different standards and regulations to apply in various regions. The specific permits, requirements, metering policies, interconnection standards, installer authorizations and other country-specific codes and regulations will determine the procedures undertaken when installing a PV system. The manufacturer's instructions should also be carefully followed during the installation. The main issues discussed below include installation of system components and requirements for connecting a PV system to the utility grid.

PV array installation

It is highly advisable that PV installers take time to carefully plan the precise location of the array before deciding on the installation methodology. This is commonly done by measuring the available installation area and marking the boundaries of the array(s) as well as the location of the mounting system's attachment points on the installation area, i.e. the roof, using a string or chalk line. The next step is to install the attachment hardware (array mounting structure) to secure the mounting system to the roof. If mounting on a rooftop, care should be taken to ensure that attachment screws are securely embedded into the rafters or other structural supporting members to provide maximum attachment strength.

Once the attachment points are secured, the mounting system should be assembled. Several types of mounting systems for PV modules are available and the choice depends on the specific application. The main types of mounting systems and their installation are explained in Chapter 6. Once the mounting system is fully assembled, the process of installing PV modules can begin. Many proprietary mounting systems rely on a compression clamp to secure the module frame to the mounting rails. It is imperative that the module clamps are fully compatible with the mounting system being installed.

DC wiring

Typically, PV modules intended for use in grid-connected systems are supplied complete with the interconnection cables wired from a sealed junction box with plug and receptacle connectors at the end of each cable length. A string of modules is formed by connecting adjacent modules together in series (positive to negative or negative to positive). Once the desired number of modules is connected in series and that string is formed, the individual circuit needs to be brought to a central location, typically a PV combiner box, where it will be connected in parallel with any additional series strings. Any module string fusing will also be installed in the PV combiner box. DC wiring is a very important component of the PV system and there are several key factors that must be considered during design and installation.

Cabling routes and required lengths

Once the location of all equipment has been decided, the cable route must be determined. The main cabling routes are shown in the Figure 10.1. For any installation, installers should seek to minimize the length of these cable routes. As discussed later in this chapter, the cable length and cross-section determines the voltage and power losses sustained.

Additionally when planning cable routes, the PV array wiring should be installed in such a way to minimize any conductive loops. Reducing conductive

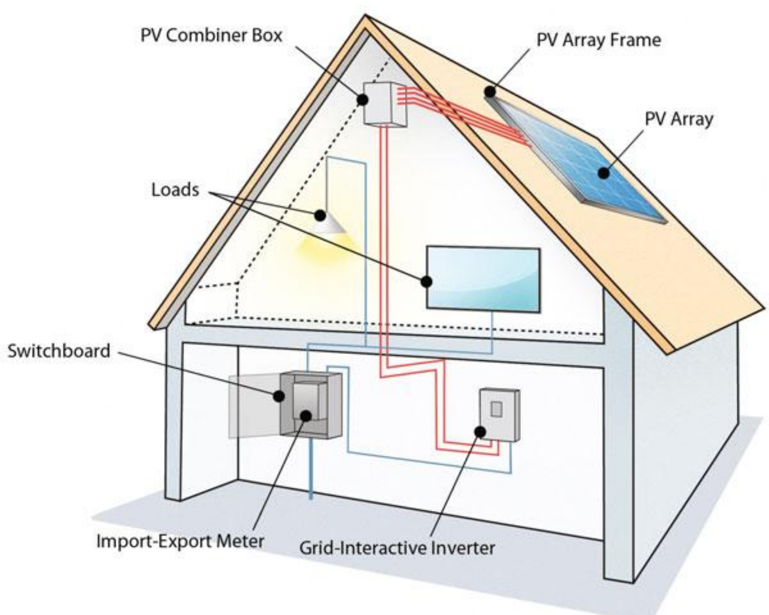


Figure 10.1 The main cabling routes are shown in red; if the installation does not include a PV combiner box then the cable will run directly from the PV array to the inverter. This diagram shows a net-metering arrangement; different metering arrangements are introduced in Chapter 5 and discussed later in this chapter

Source: Global Sustainable Energy Solutions

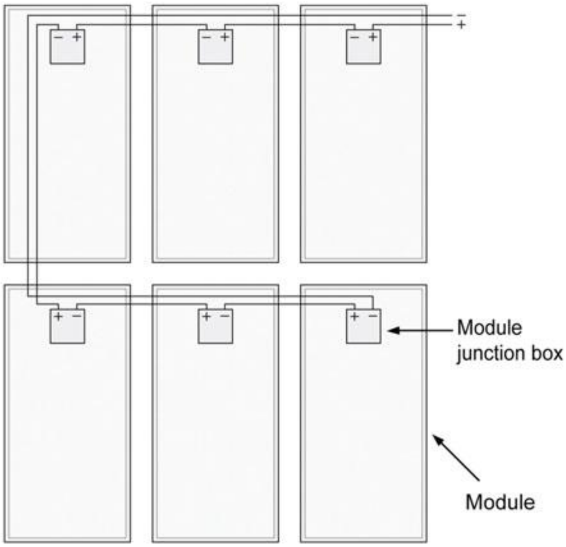


Figure 10.2 Example of correct PV wiring where conductive loops have been reduced

Source: Global Sustainable Energy Solutions

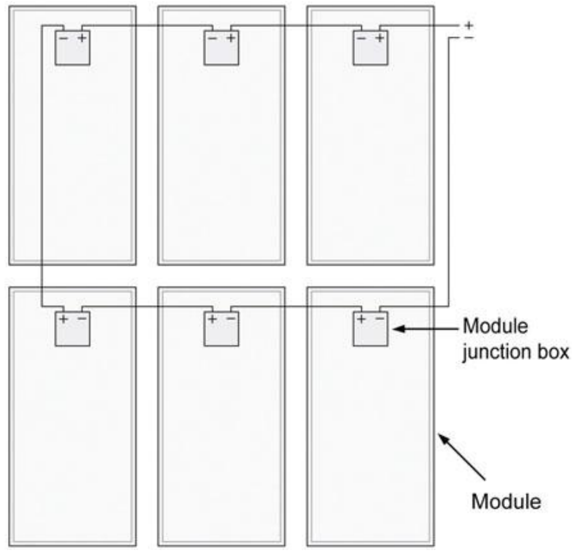


Figure 10.3 Example of incorrect PV wiring where the wiring is a conductive loop

Source: Global Sustainable Energy Solutions

Figure 10.4 Photograph of a conductive loop

Source: Global Sustainable Energy Solutions

loops will lower the risk of lightning induced over-voltages in the array wiring, as well as reducing interference to AM/FM radio signals.

The cable route from the PV array to the inverter (via the PV combiner box) is DC and a cable rated at the appropriate DC voltage and current should be used. Local regulations and country-specific standards will determine the required current-carrying capacity and voltage rating of cabling used. Copper conductors are generally preferred to aluminium and are available in single- or multi-strands. All cabling is insulated to protect the wire from the surrounding environment and to protect people and equipment. Cable insulation varies based on ratings for temperature, sunlight, oil or water resistance and location (dry, wet). The colour of the insulation indicates the polarity of the conductor and is generally governed by national electrical codes/standards. The standards for cable insulation colour differ greatly from one country to the next. In many parts of the world brown insulation indicates a positive conductor and blue or grey insulation indicates a negative conductor. However, red (positive) and black (negative) is also a very common colour combination. Green and yellow insulation typically indicates a grounded/earthed conductor, but this is not the case everywhere. It is imperative that the colouring given in local wiring codes is followed during installation.

Cable sizing

When selecting any cable for a system (i.e. sizing the cable) both current-carrying capacity (CCC) and the expected voltage drop must be considered, i.e. how much current the conductor is able to carry and the power losses sustained due to the conductor's internal resistance.

Cables are classified by their rated CCC at certain operating temperatures. The CCC indicates the amount of current that can pass through the wire or cable before it sustains damage. CCC is determined by: wire type (copper or aluminium), wire size/gauge, insulation rating (wet rating for outdoors), highest insulation temperature and location (free air, conduit or buried). CCC decreases with increasing temperature.

Voltage drop is a crucial issue in PV systems. Voltage drop increases with increasing current and decreasing conductor size (i.e. the smaller the cross-sectional area of the cable or wire, the higher the internal resistance of the conductor, hence the larger the voltage drop). The sizes and resistances of terminations, fuses and disconnect/isolator devices may also contribute to voltage drop. For grid-connected PV systems, it is common practice for cables to be sized so that there is no more than a 1 per cent voltage drop through either DC or AC conductors. Most national codes specify a maximum allowable voltage drop and should be consulted; in Germany, for instance, codes specify a maximum voltage drop of 1 per cent, but in Australia a 5 per cent voltage drop is currently permissible. As voltage drop represents a reduction in system power output, reducing voltage drop in cabling as much as possible is recommended. It is often cheaper to purchase larger cable than to purchase additional modules to compensate for the loss of output. If voltage drop is not properly accounted for, it may affect the operation of the inverter sensing circuits.

Box 10.1 Voltage drop calculation

The length of cabling route is 15m from the PV array to inverter; copper cabling (resistivity of copper is 0.0183Ω/m/mm²) is used with a cross-sectional area of 2.5mm² and it must carry a current of 5A. According to Ohm's law, voltage drop is calculated as:

Voltage drop = 2 × length × current × resistance (2 accounts for 2 cables, 1 +ve and 1 –ve)

Here resistance = resistivity/area, so

Voltage drop = (2 × length [in metres] × current [in amps] × resistivity [in Ω/m/mm²])/area [in mm²]

Voltage drop = (2 × 15m × 5A × 0.0183Ω/m/mm²)/2.5mm²

Voltage drop = 1.098V

If the voltage at the maximum power is known, then the voltage drop as a percentage can be calculated; if the voltage at maximum power is known to be 155V then the voltage drop is calculated as follows:

Voltage drop (%) = Voltage drop/voltage at maximum power × 100%

Voltage drop (%) = 1.098V/155V × 100%

Voltage drop (%) = 0.71%

Therefore if this voltage drop is sustained in a $10kW_p$ installation, the power loss sustained will be 71Wp, meaning the installation has effectively been reduced to 9.929kWp PV installed before any other system de-ratings are applied (see Chapter 9 for system de-ratings).

US installers often deal with American wire gauge (AWG) cable sizes. It is necessary to convert these gauges into the equivalent mm² value for use in the above formula. Conversions are given in Table 10.1

Table 10.1 US wire gauge conversion table

AWG	Size in mm²
14	2.00
12	3.31
10	6.68
8	8.37
6	13.30
4	21.15
2	33.62
1	42.41
0	53.50

PV array cables should also be rated for use in wet conditions, be UV stabilized, have suitable insulation for protection from the elements, and be rated for the maximum system output voltage and current in accordance with local electrical standards. Many companies are now manufacturing cable labelled 'solar cable' specifically for use in PV systems. Solar cable is designed to ensure safety in the outdoor environment, providing high resistance to UV and double insulation (also known as double sheathing). Solar cable is designed to carry DC current and voltage and many local standards require it to be marked so that it can easily be distinguished from other power cables. It is available in many sizes allowing system designers flexibility in ensuring that voltage drop is minimized. Solar cable is often flexible, so it is easier to install. It is good practice whenever possible for cables to be installed out of direct sunlight and secured so that they are not fixed directly on the roof and cannot move around in the wind. Mechanical protection greatly reduces the risk of cabling being damaged and possibly causing a ground/earth fault or even a fire. Cables should always be secured and conduit may be used to protect them. As well as deteriorating under adverse weather conditions, cables are also at risk of attack by animals such as possums or rodents; laying cable in conduit can provide protection from all these problems.

PV combiner box

PV combiner boxes (discussed in Chapter 5) are used to combine multiple PV strings into fewer parallel circuits in order to reduce the amount of wiring required. The PV combiner box enclosure must be the correct size, so it adequately houses the correct amount of cables without any risk of crushing them. The cables inside the combiner box should be appropriately coloured and labelled and the box must be rated suitable for use in the environment in which it is installed.

Figure 10.5 Example of an array cable left loose and unsupported

Source: Global Sustainable Energy Solutions

Figure 10.6 An electrician installs a small white PV combiner box next to the array

Source: Global Sustainable Energy Solutions

System grounding/earthing

Grounding, also referred to as earthing, is used to ensure that the exposed conductive parts (i.e. the array frame) of a system are equipotential, which means there is no voltage difference between the components and the ground. The metal frames and metal mounting structure of PV panels can be grounded so that the voltage in these surfaces does not reach dangerous levels. This ensures that a person touching a conductive component will not receive an electric shock. It is important to remember that people coming in contact with the PV array, i.e. the system owner cleaning the modules, may have very little experience with electrical systems and ensuring their safety is paramount. The grounding/earthing rules and standards vary widely between countries, and the system and individual components should be earthed as per the standard in that country. Certain module types will require earthing to ensure maximum performance of the modules (e.g. SunPower module range) and this is a requirement of the module manufacturer. The installer should ensure that the inverter and module manufacturers' instructions are followed as well as national codes. See Figure 10.7.

Inverter installation

The inverter should be installed as close as possible to the modules in order to minimize DC cable lengths (longer cables lead to larger power losses). Inverters should be located in a shady, sheltered and well-ventilated area. They should not be exposed to temperatures outside the range specified on their data sheet (normally −25°C to 60°C). Additionally, the wall on which the inverter is installed must be able to support its load. Over-current protection and

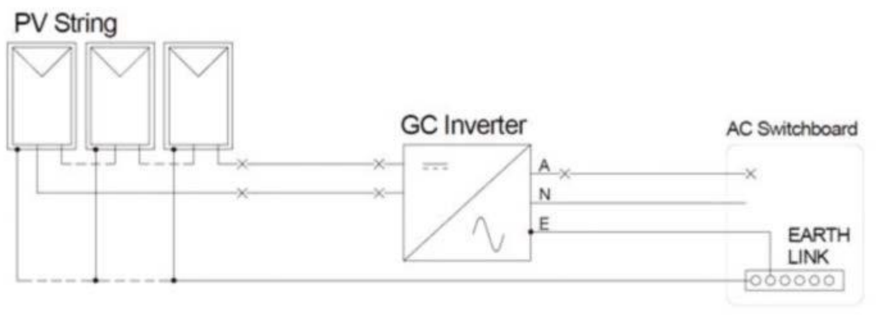


Figure 10.7 It is common practice to ground each component of the PV system separately so that if one is removed the others will remain grounded, i.e. the earth of the array is not connected to the earthing wire from the inverter. The technique shown in this diagram is compliant with Australian National Standards. Techniques vary so local standards should always be consulted

Source: Clean Energy Council (Australia)

disconnection switches should be installed in close proximity to the inverter. The inverter can be installed at any point in the system installation process; it may be installed at the same time as the mounting system if desired.

Installation checklist

Installers should ensure that all tools and relevant equipment are ready and available for the installation. Below is an example of a checklist for PV installations.

Table 10.2 Example of an installation checklist

Item no	Type of item	Quantity required	Details	OK
1	PV module model XYZ-90			
2	PV mounting structure			
3	Hardware for connecting module to mounting structure			
4	Hardware for connecting mounting structure to roof			
5	Hardware for ensuring roof is watertight			
6	Cable between module & PV combiner box (if one exists)			
7	Conduit if required			
8	Fastening hardware for this cable/ conduit			
9	PV combiner box (if one exists)			
10	Hardware for fastening PV combiner box to wall			

(4) ~~Anual~~ Annual Energy yield
= Annual irradiation rate × Total power produced by entire array × Total derating factor

Annual irradiation rate = 4.5 × 365 days
= 1642.5 —— (1)

Total power produced by entire array = 185 × 18
= 3330 Wp —— (2)

~~Total~~ derating Factor

Source of Loss.	Derating Factor
a) Temperature	0.8992 (Calculated)
b) Dirt / Soiling	0.90 (Assume)
c) Manufacturer's tolerance	1 (Assume)
d) Shading	1 (Assume)
e) Orientation & tilt angle	0.93. (Given)
f) Voltage drop	0.90 (Assume)
g) Inverter Efficiency	0.95 (Given.

Derating factor due to temperature

$$f_{temp} \text{ Derating factor} = 1 - \frac{\gamma_{mp}\% \times V_{mp}}{100}$$

V_{mp} = Voltage at maximum power
γ_{mp} = Temperature coefficient of power

$$f_{temp} = 1 - \frac{0.42 \times 24}{100} = 0.8992$$

(4) Continuation ...

Net derating factor = Product of derating factor of all sources of losses

$= 0.8992 \times 0.9 \times 1 \times 1 \times 0.93 \times 0.90 \times 0.95$

$= \underline{0.6435}$ —— (3)

Annual energy yield $= 1642.5 \times 3330 \times 0.6435$

$= \underline{3519.639}$ kWh/year

(5) Step 1 : Calculate cell Temp

Ambient Cell Temperature ⟶ 0 - 75 °C

Min voltage occurs at maximum temperature

Step 2 : Finding voltage at maximum temperature

$V_{mp} = 24\,V$ at $25°C$ (STC)

Temperature coefficient of $V_{mp} = 0.854\,\%/°C$

$= \frac{0.854}{100} \times 24\ V/°C$

$= 0.20496\ V/°C$

Voltage at 75°C = $\text{Voltage}_{STC} - \gamma_v \left(T_{x°C} - T_{STC} \right)$

$= 24 - 0.20496\,(75 - 25)$

$= 24 - 10.248$

Voltage at 75°C = 13.752 V

Step 3:

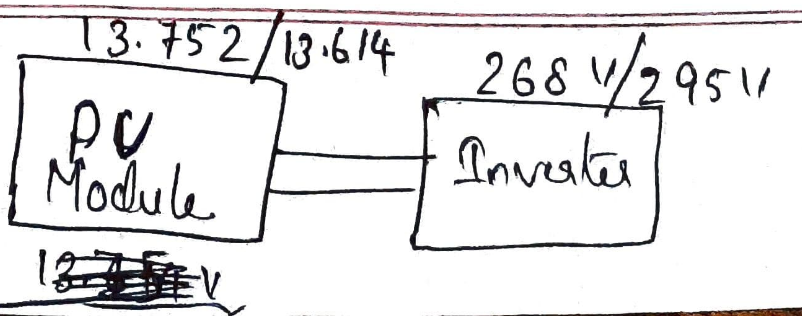
Find Minimum no of modules in string

{ Consider 1% voltage drop across dc cables
{ 10% safety margin of inverter

1% DC cable voltage drop ⟹ η reduced by 1%

⟹ 99% efficient system

$= \frac{99}{100} \times 13.752 = 13.614\ V$



Minimum inverter rating by considering 10% safety margin → 110% rating

$$= \frac{110}{100} \times 268 = 295\,V$$

Minimum No of modules in string $= \frac{295}{13.752} = 21.6$ modules

= 22 modules.