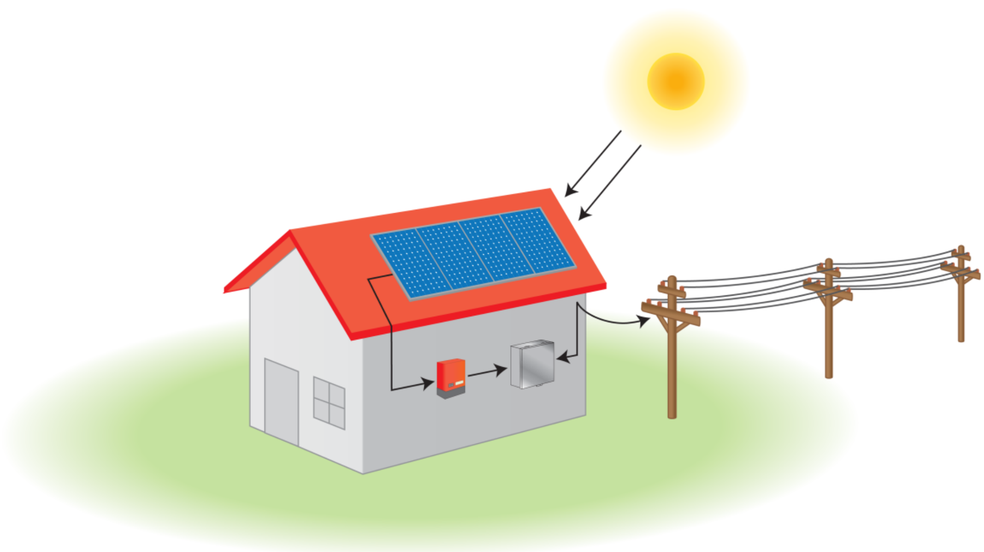
Introduction

In this topic you will learn about the arrangement and operational features of grid connected PV power systems, including functions such as synchronisation, safety and control features. You will also learn about how to determine the solar resource available at a given location, and the factors to consider when planning out a PV system.



Photovoltaic (PV) Power Systems

A basic grid-connected PV power system consists of the following components:

PV Power System Components		
Component	**Illustration**	**Function**

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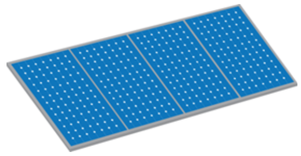
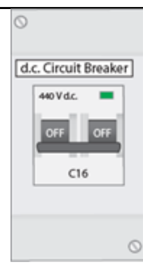
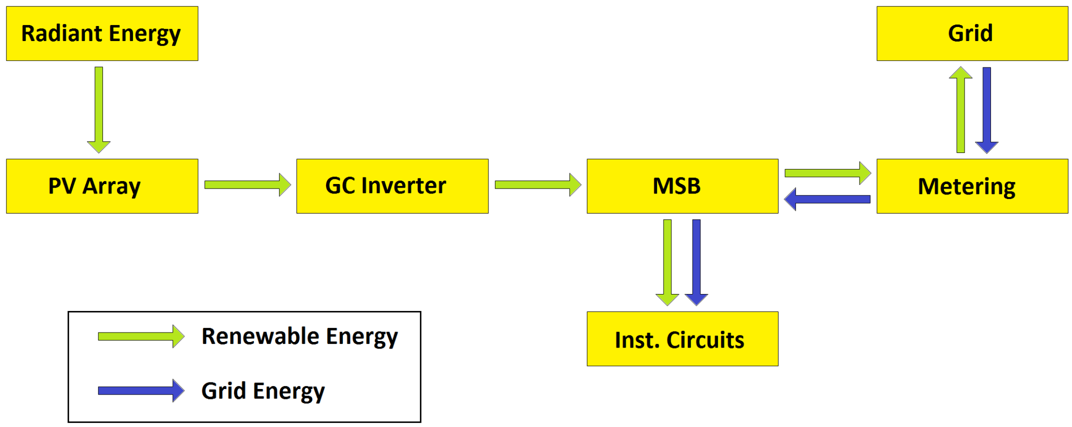
PV array		Converts radiant energy into electrical energy.
Inverter		Converts direct current into alternating current.
Metering		Measures the imported and exported electrical energy
d.c. Controls and Protection		Protects d.c. equipment against overcurrent and provides a point of isolation.
a.c. Controls and Protection		Protects a.c. equipment against overcurrent and provides a point of isolation.

In addition, PV power systems may include:

- Batteries – to store excess electrical energy.
- Charge controller – to control the battery charging parameters.
- Voltage regulator – to maintain the d.c. voltage within a set tolerance.
- System monitoring – to monitor and log system operating parameters for analysis.

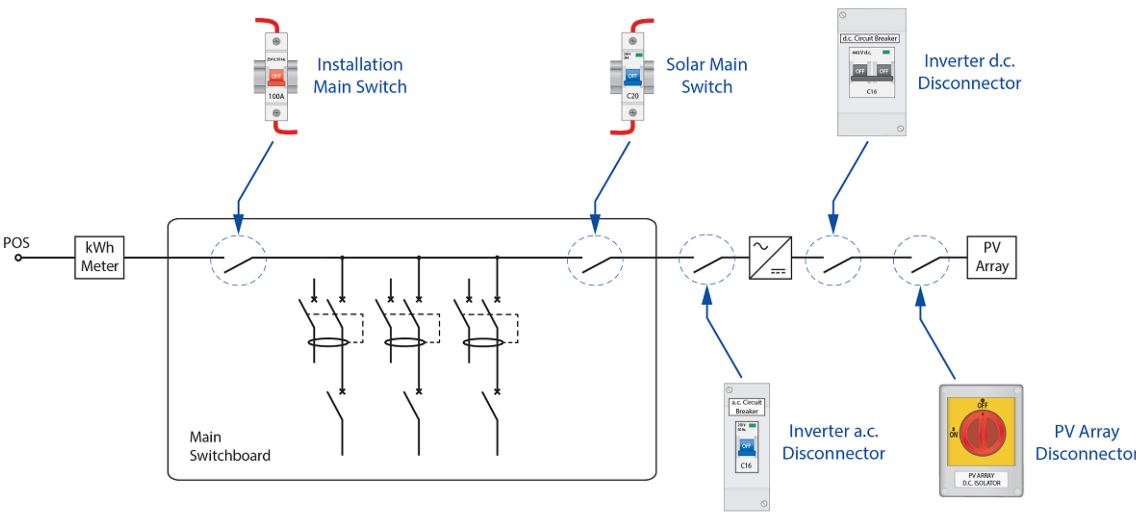
PV System Relationships

The following block diagram shows the basic relationships and power flow between the major components in a grid-connected PV system.



PV System Configuration

The following diagram shows a typical arrangement of control and protection in a basic grid-connected PV power system.



This next diagram shows typical connections for a basic grid-connected PV power system.

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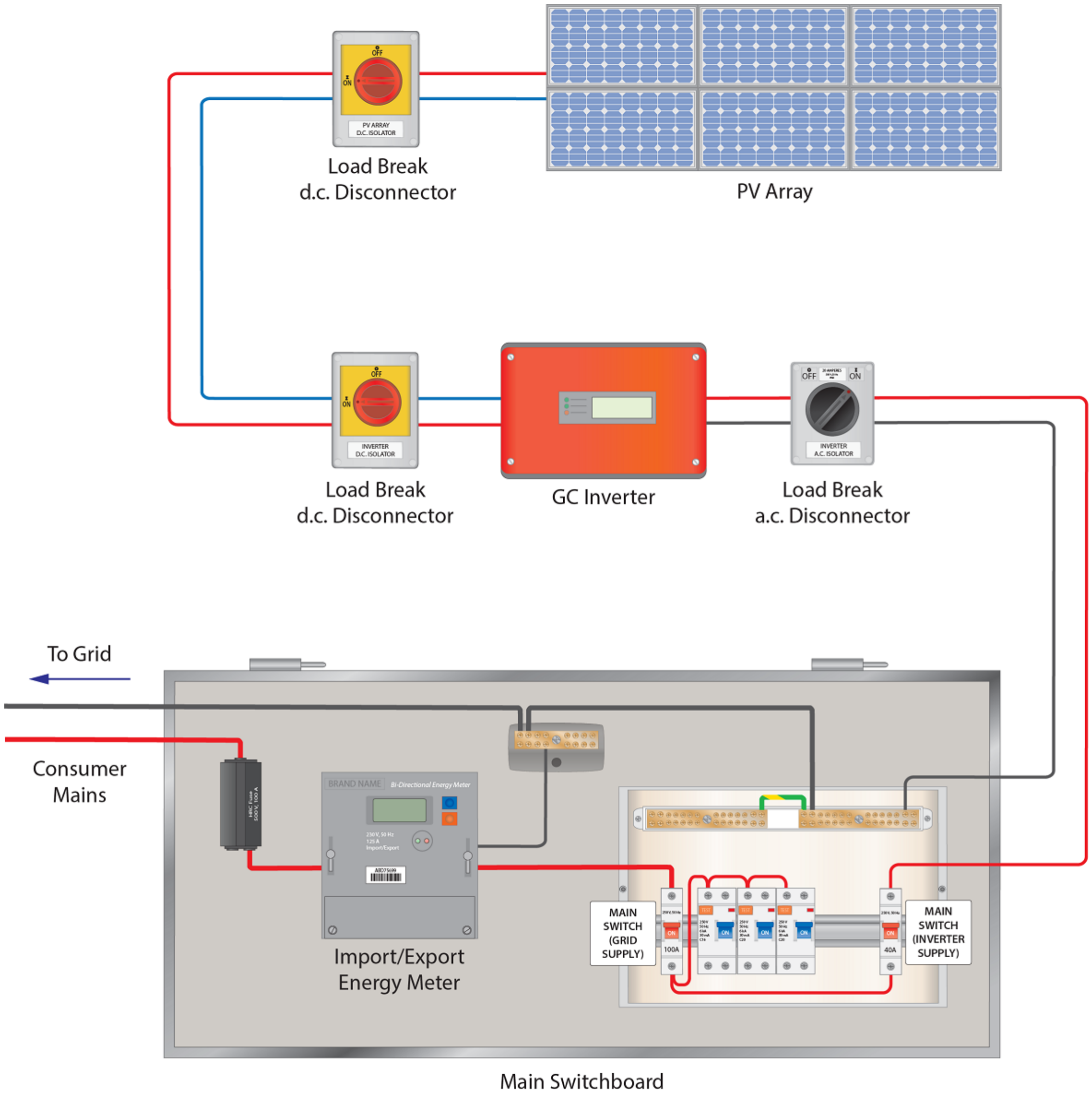

Since the implementation of AS/NZS 5033:2021, most installations will no longer require a roof-top load-break isolator. Use of a 'disconnection point' (DP) is now an acceptable arrangement, and in practice, this will simply be the plug and socket connection of the PV module.

It's important to note that these plug and socket connections are not suitable to be disconnected under load conditions, and so there are some particular requirements that apply to installations using DP arrangements, including labelling and identification (e.g. see AS/NZS 5033:2021 Clause 4.3.5.2.1).

PV System Features

The following table highlights the various features of grid-connected PV power systems.

PV Power System Features	
Synchronisation	A grid-connected PV power system provides a high quality, synchronised PWM true sine wave output to the grid and to the installation.

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Maximum Power Point (MPP) Tracking	MPP tracking adjusts the load resistance placed on the PV system to maintain maximum efficiency for the given irradiation and operating temperature at the time.
Passive Anti-islanding Protection	Passive protection disconnects the PV system when abnormal grid voltage or frequency is sensed. The voltage and frequency limits are specified in AS/NZS 4777.2:2020 Table 4.1 and Table 4.2. One of the primary reasons for anti-islanding protection is to prevent the grid from being supplied by PV systems in the event that it has been shut down (e.g. for maintenance).
Active Anti-islanding Protection	Active protection produces a voltage or frequency shift in the event that the grid goes off-line (e.g. due to maintenance or power outage), causing passive protection to disconnect the PV power system.
Metered Energy	Energy metering is used to determine how much energy is exported/imported to and from the grid. This can be achieved by the use of separate import and export meters, or by a single meter that indicates resultant import/export.

RCD Protection

It should be noted that prior to the 2016 edition of AS/NZS 4777.1, it was not permitted to install an RCD between the consumer mains and a grid connected inverter, however this requirement was changed in AS/NZS 4777.1:2016.

It is now permissible to use an RCD to meet the mechanical cable protection requirements and isolation requirements of AS/NZS 3000:2018 for the cable between the grid-connected inverter and the connecting switchboard, provided the inverter is not a multimode inverter.

If an RCD is used, the RCD must:

- Operate in all active and neutral conductors.
- Be compatible with the inverter as per the manufacturer's instructions.

It remains prohibited to connect an RCD between a multimode grid-connected inverter and the connecting switchboard.

This learning activity consists of 6 parts designed to develop your understanding of grid-connected PV system features.

Topic 1.1 Learning Activity

In this skills practice, you are required to draw block and circuit diagrams of various grid-connected PV power system arrangements.

Topic 1.1 Skills Practice

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Solar Radiation Parameters

The quantity of electrical energy produced by a photovoltaic (PV) cell depends on:

- The quantity of solar energy arriving at the surface of the PV cell.
- The system losses.

In order to maximise the quantity of solar energy collected by a PV cell, the cell must be positioned so that it is facing the optimal direction, at the optimal angle. Shading and the build-up of dirt on the surface of a PV cell can reduce the quantity of solar energy collected.

Irradiance and Irradiation	
Irradiance (G)	The quantity of solar power available at a surface at any instant in time, measured in watts per square meter (W/m^2).
Irradiation (H)	The quantity of solar energy available at a surface over a given time period, measured in kilowatt hours per square meter (kWh/m^2).

Solar Radiation Terms

The following table defines some terminology that you will need to know to understand this topic.

Solar Radiation Terms	
Term	**Definition**
Sunshine hours	Sunshine hours are the average hours of sunlight received at a location (e.g. a city) over a given time period (e.g. a day, a month or a year).
Solar window	The solar window is the area of the sky through which the sun moves throughout each yearly cycle.
Latitude	Latitude is a coordinate indicating the north-south position of a point on the earth.
Longitude	Longitude is a coordinate indicating the east-west position of a point on the earth.
Zenith	The zenith is a point directly above a location.

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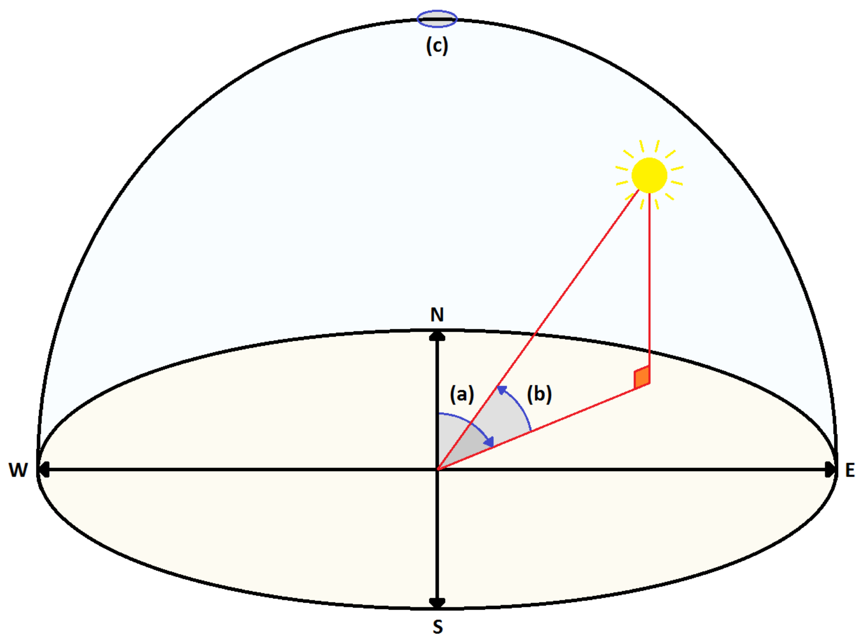
Azimuth angle	The azimuth angle is the angle between the sun and true north in a clockwise direction. Applied to a PV array: • An azimuth angle of 0 degrees indicates that the array faces due north. • An azimuth angle of 180 degrees indicates that the array faces due south.
Altitude angle	The altitude angle is the angle between the horizon and the sun.
Tilt angle	The tilt angle is the angle between the horizontal plane and the plane of a photovoltaic module.

The following diagram shows how the Zenith, azimuth and altitude angles relate to a given point.



(a) Azimuth Angle (b) Altitude Angle (c) Zenith

Solar Radiation Data

Solar data is available in a range of forms, for a number of purposes. The primary reasons for analysing solar radiation data in relation to a PV installation are to:

Determine optimal locations and positioning of PV arrays.

Estimate or analyse PV system power output.

Some common methods of presenting solar data are shown in the following table.

Solar Radiation Data		
Type	**Example**	**Description**

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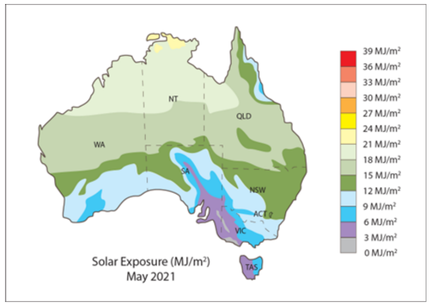
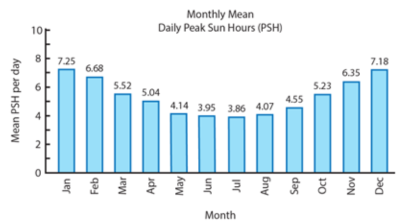
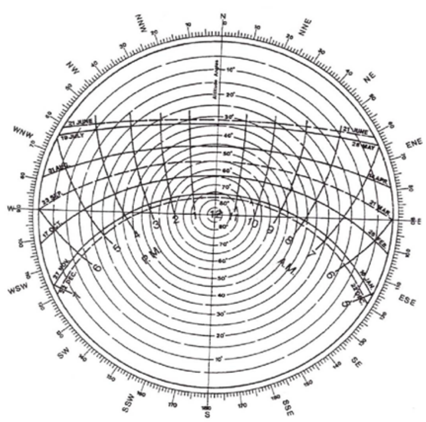
Solar Contour Maps		Solar contour maps can be sourced from the Bureau of Meteorology (BOM), to show data such as daily solar exposure and average daily irradiation.
Irradiation Charts		Solar analysis software/apps can be used to produce charts of average irradiation across a given span of time. The chart pictured shows the monthly mean irradiation at a given site over a 12 month period.
Sun Path Diagrams		A sun path diagram shows the path of the sun at a given latitude. Sun path diagrams are useful during the design of a PV installation as they can be used to determine the times and dates at which a PV array will become shaded by objects in the vicinity. Guidance on the use of sun path diagrams is provided below.

Sun Path Diagrams

To examine how to use a sun path diagram, consider the following scenario of a PV system installed at a latitude of 35^0 south.

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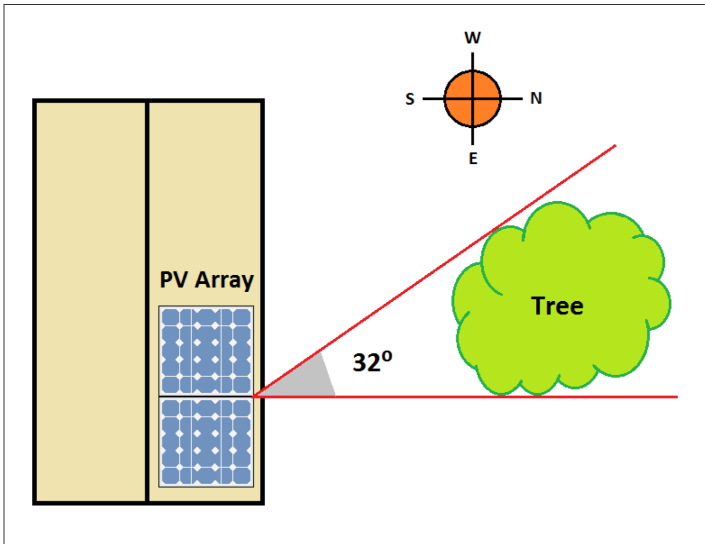
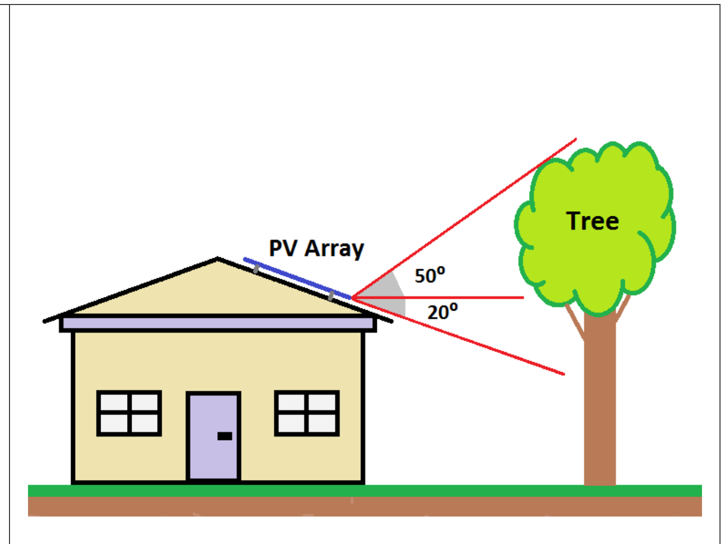


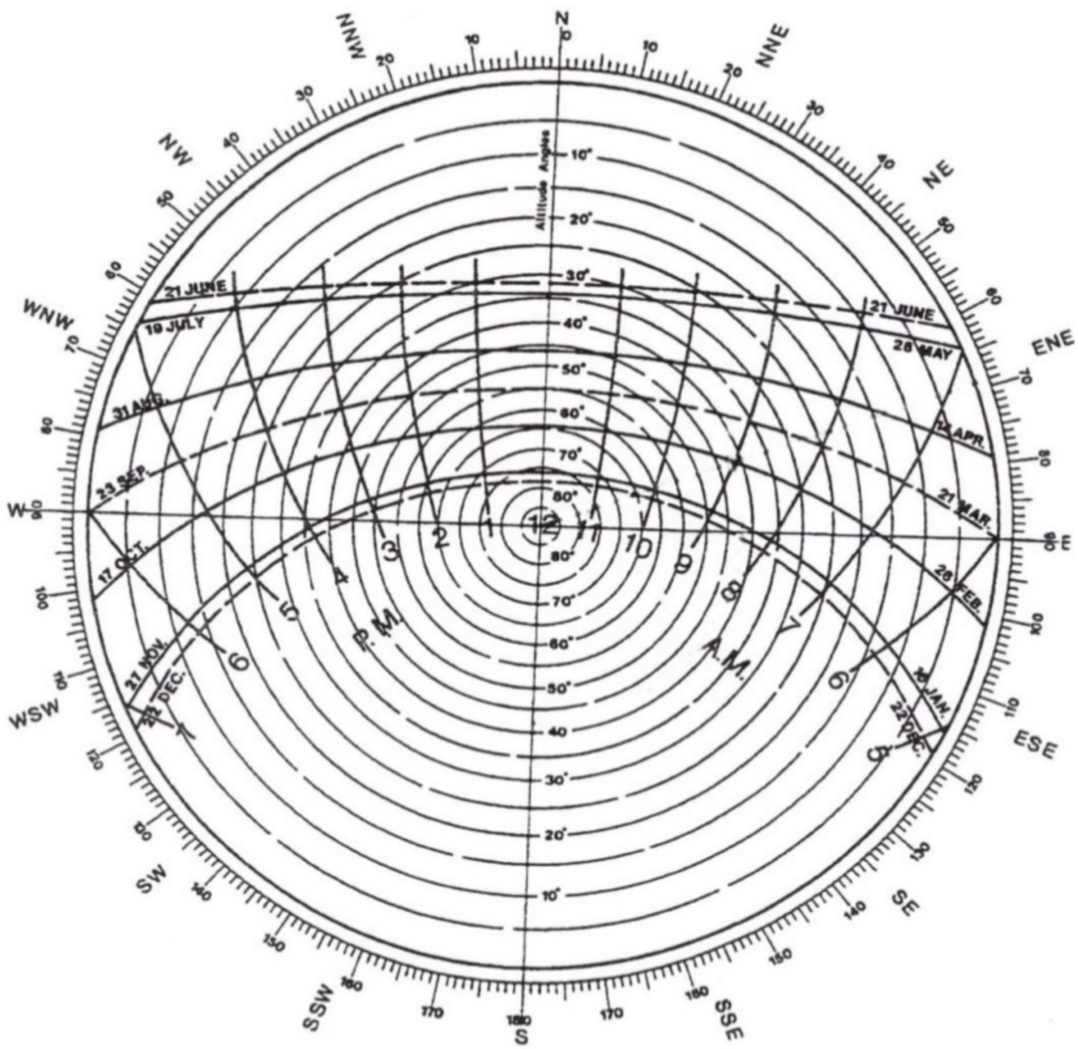
Site Plan



Elevation

A sun path diagram for the given latitude can be used to determine when the array will be shaded by the tree (for the purposes of this exercise, we will assume that the tree is regularly maintained so that its size remains the same throughout the year).

A sun path diagram at a latitude of 35^0 south is shown below. The curved lines across the circular dial represent the solar window, with specific curves representing the specific path of the sun across the sky for particular dates.



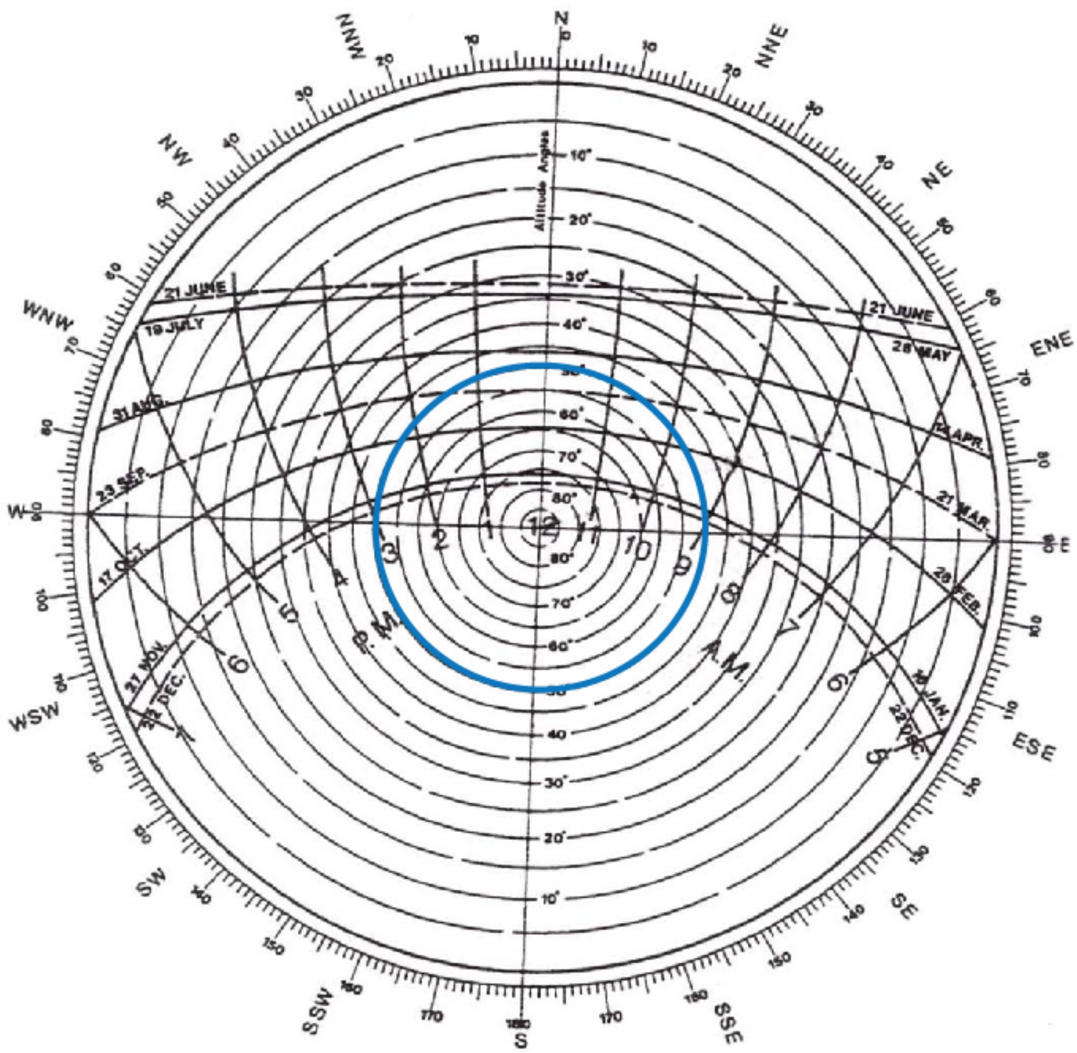
Latitude 35^{0} south

To determine shading, we must take the altitude angle and the azimuth angle into account. In this scenario, the array will become shaded at any time when both of the following occur:

The altitude angle of the sun is less than 50^{0}, i.e. when the sun drops below the angle of elevation between the array and the tree.

The azimuth angle of the sun is between 0^{0} (N) and 32^{0} (NNW), i.e. when the sun is at a point that puts the tree between the sun and the array laterally.

The altitude angle of the sun is indicated by the concentric rings of the diagram, so we can indicate the angle of tree elevation on the diagram by drawing a circle at the 50^{0}, shown below:



Next, we can indicate the lateral angle by drawing lines from the centre of the diagram out to the edges in the appropriate cardinal directions (i.e. North, South, East, West etc.). Noting the orientation of the site plan, it can be seen that the lateral angle in this scenario stretches from dead North (0^0) to 32^0 West of North. This is indicated as follows:

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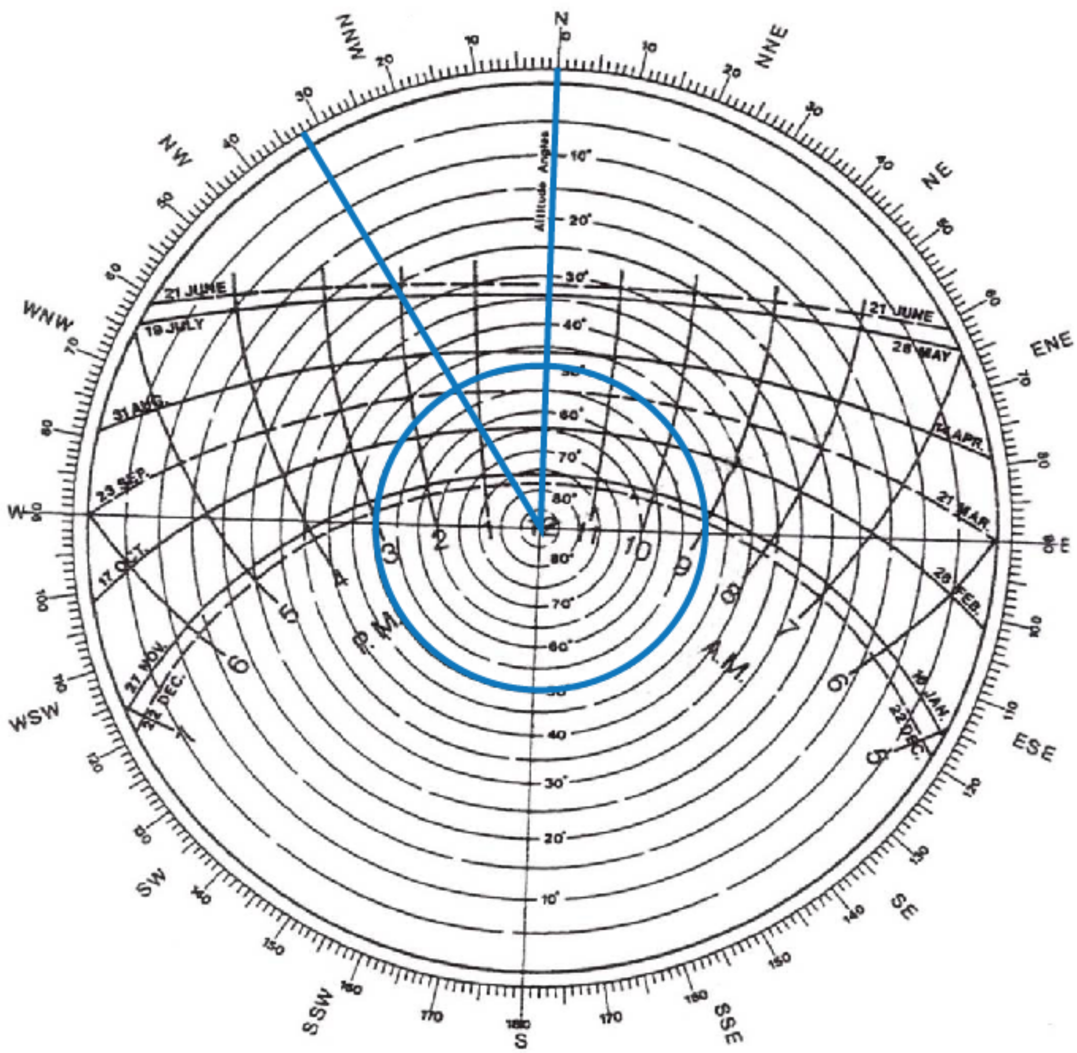

From this, we can highlight the portion of the solar window during which the array will become shaded – that is when the altitude angle of the sun is less than 50^0 **and** the azimuth angle of the sun is between 0^0 (N) and 32^0 (NNW) – indicated in red below:

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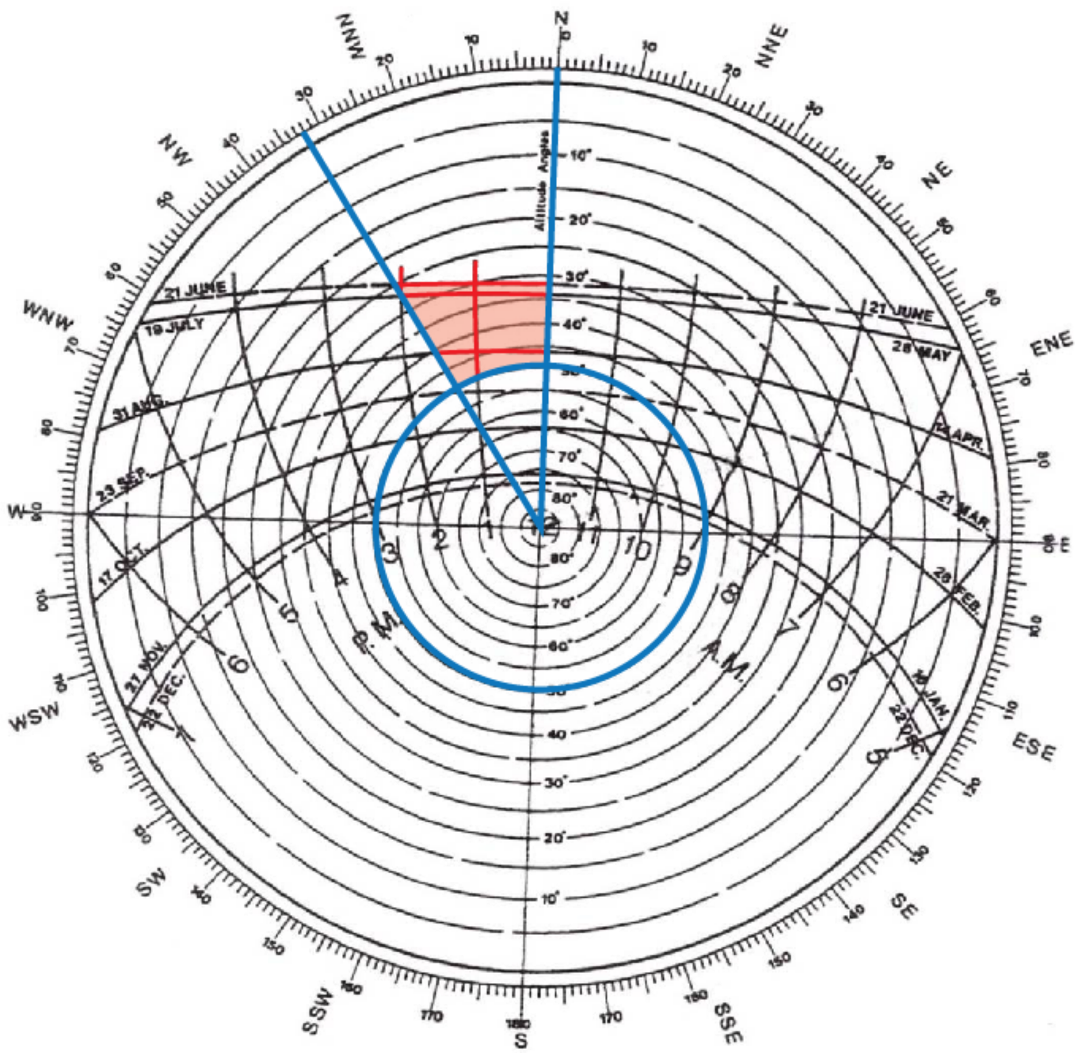

From here we can determine the actual times and dates during which the array will be shaded (assuming the tree is maintained at its current size throughout the year). The following table summarises the results.

Months	**Shading**
1st Jan – 21st Mar	The array is not shaded by the tree.
21st Mar – 14th Apr	The array starts to become shaded for a short period each day, increasing to a period of approximately 1.5 hrs on 14th April – between 12 pm and 1:30 pm.
14th Apr – 28th May	Shading starts at 12 pm each day, and increases from 1.5 hrs per day to 2 hrs per day on 28th May.
28th May – 19th Jul	The array is shaded for approximately 2 hrs per day – between 12 pm and 2 pm.
19th Jul – 31st Aug	Shading starts at 12 pm each day, reducing from 2 hrs per day to 1.5 hrs per day on 31st August.

31st Aug – 23rd Sep	Shading reduces from 1.5 hrs per day to nothing on 23rd of September.
23rd Sep – 31st Dec	The array is not shaded by the tree.

This learning activity consists of 6 parts designed to develop your understanding of solar terminology and methods used to determine the availability of solar energy.

Topic 1.2 Learning Activity

Last modified: Monday, 16 October 2023, 4:02 PM

Positioning PV Arrays

The solar radiation arriving at the surface of a particular fixed PV panel can vary throughout the year due to various factors. The following factors need to be taken into consideration:

PV Array Setups	
Seasonal change	Seasonal changes will result in variations in the angle of incident solar radiation on the panel.
Shading and soiling	Shading and soiling will act as a barrier to solar radiation arriving at the surface of the panel.
Cloud cover	Cloud cover will reduce the amount of direct solar radiation arriving at the panel.
Time of day	The quantity and angle of incidence of solar radiation will vary throughout each day as the sun moves through the solar window.

To obtain maximum irradiation on any given day in Australia, PV arrays should be mounted facing (true) north, at a tilt of approximately 20^{0} to 30^{0}. If north facing roof space is not available, the following factors should be considered when selecting the most appropriate location:

- Shading.
- Ventilation.
- Ease of maintenance.
- Method of mounting.
- Length of the cable run.
- Aesthetics.
- Council regulations.
- Heritage considerations.

Solar Tracking

Solar tracking systems are designed to automatically adjust the tilt and orientation of a PV array to follow the position of the sun throughout the day.

There are two main types of solar tracking systems:

- Single-axis – adjusts orientation from east to west to follow the sun's path across the sky.
- Dual-axis – adjusts both orientation and tilt to track the sun's movement throughout the day and throughout the year.

The following diagram shows an example of dual-axis tracking:

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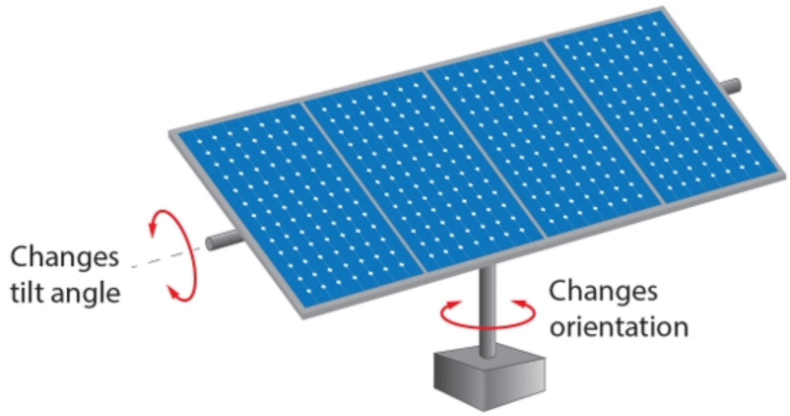

The effect of solar tracking is to optimise irradiation of the array throughout the day, thereby increasing total energy production. However, there are also some downsides to solar tracking, such as:

- Higher cost.
- More maintenance required.
- Consumes some energy.

Due to these downsides, solar tracking is typically only practical and cost effective for large-scale PV installations.

This learning activity consists of 6 parts designed to develop your understanding of the factors affecting the irradiation of PV arrays, and how irradiation can be maximised.

Topic 1.3 Learning Activity

In this skills practice, you are required to determine the solar access for a PV array installation site at your location, and to determine an appropriate position, orientation and tilt angle for a proposed PV array.

Topic 1.3 Skills Practice

Undertaking this topic quiz will help you to confirm your understanding of the PV system configurations, solar parameters and terminology, and the factors affecting the irradiation of PV arrays.

Topic 1 Content Quiz

Last modified: Monday, 16 October 2023, 3:11 PM

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Introduction

In this topic you will learn about the various terminology used in relation to the various types of photovoltaic modules and the operating principles of the photovoltaic modules.

Semiconductors

A semiconductor is a material that displays the properties of both a conductor and an insulator, depending on the circuit conditions. Examples of semiconductor devices include diodes, transistors and photovoltaic (PV) cells.

Silicon is the most widely used material in semiconductor devices. A pure silicon crystal has no free electrons, however:

- An n-type impurity, having an extra electron, can be added to silicon, resulting in an overall negative (n-type) charge.
- A p-type impurity, having one less electron, can be added to silicon, resulting in an overall positive (p-type) charge.

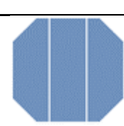
Adding impurities to silicon is known as 'doping'.

p-n Junction

When a p-type and n-type material are placed side by side, a 'p-n junction' is formed, which either conducts or insulates depending on some external factor. A PV cell is a photosensitive p-n junction, where photons striking the junction produce enough energy to free electrons. These free electrons can then flow through an externally connected circuit.

Photovoltaic Terms

The following table defines some terminology that you will need to know to understand this topic.

Photovoltaic Terms		
Term	**Definition**	
Band gap energy	The band gap energy of a semiconductor material is the minimum energy required to free an electron.	
Cell		A cell is a single PV unit, typically producing a nominal output voltage of 0.5 V.

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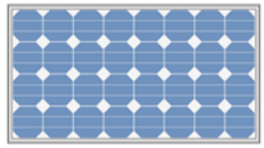
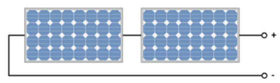
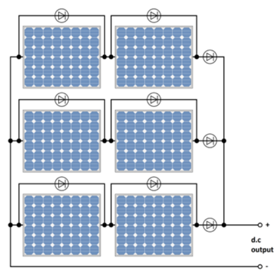
Module		A module is a number of PV cells (typically 30, 36, or 72) connected in a series ‘string’, and packed into a robust protective housing.
String		A string is two or more modules connected in series.
Array		An array is a number of interconnected modules. The nominal output voltage and current ratings of the array will depend on the series-parallel arrangement of the modules.

Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

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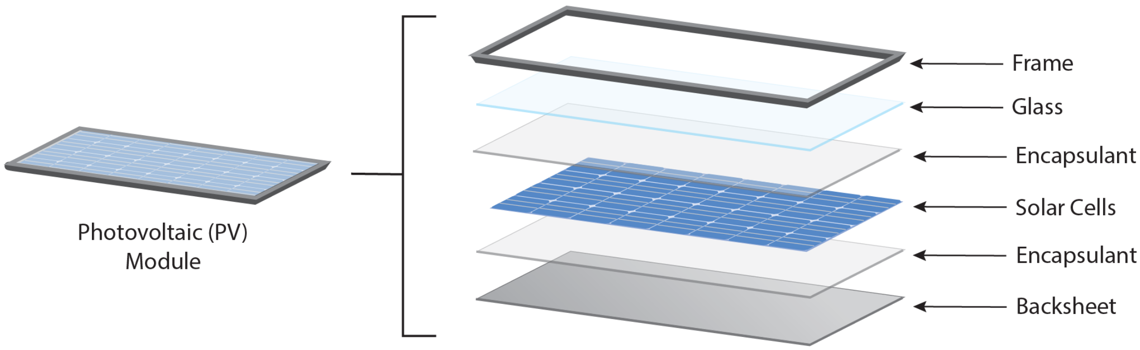
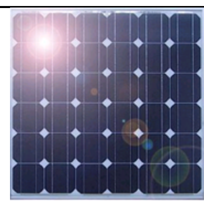
Types of PV Modules

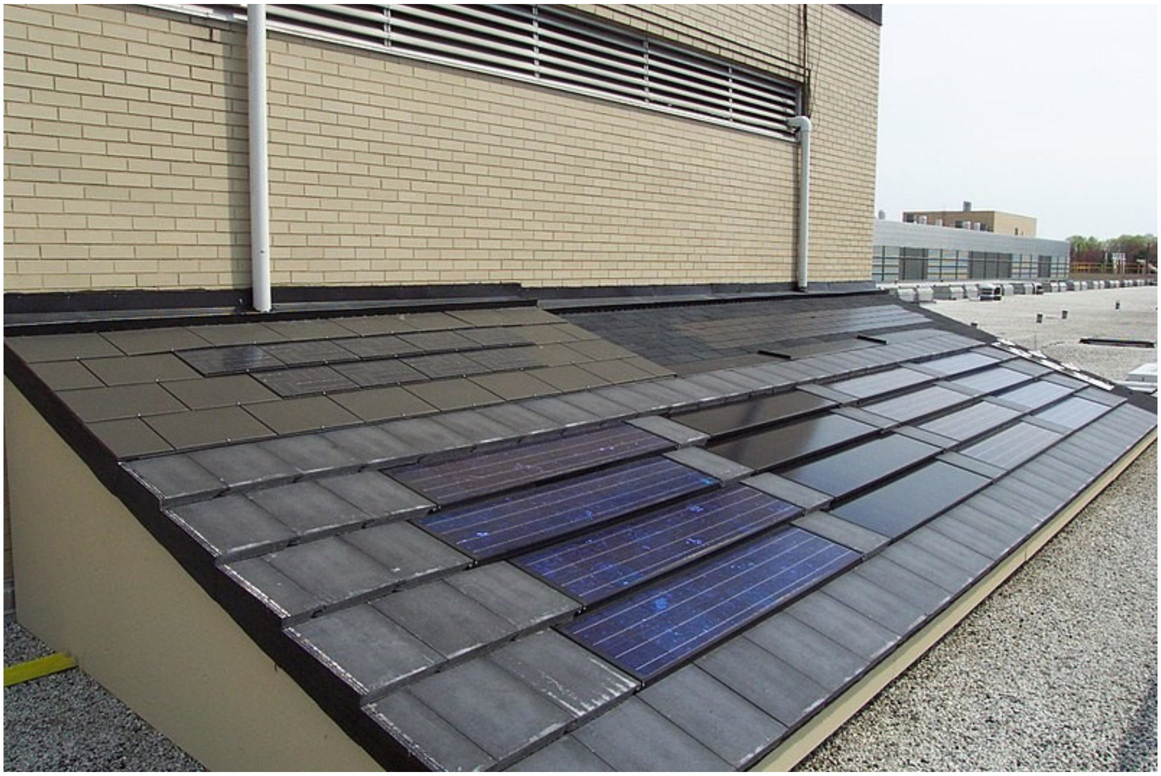
The following diagram shows the basic structure of a PV module:



There are three main types of PV cells and modules. Some basic features of the different types are compared in the following table.

PV Module Types		
Type	**Image**	**Characteristics**
Monocrystalline PV cells		• Typical efficiency of 15% to 22%. • Most sensitive to the red-end of the spectrum. • Made from a thin slice of a single large silicon crystal.
Polycrystalline PV cells		• Cheaper than monocrystalline cells. • Typical efficiency of 13% to 19%. • Most sensitive to the red-end of the spectrum. • Made from slices of cast silicon ingot that consists of many crystals, giving them their speckled appearance.
Amorphous PV cells		• Cheaper to produce than crystalline cells. • Typical efficiency of 7% to 10%. • Most sensitive to the blue-end of the spectrum. • Made by applying layers of doped non-crystalline silicon to a substrate. • Can be manufactured to be flexible. • Offer easy integration into building materials (e.g. windows).

The following photo shows an example of amorphous PV modules being used as roof tiles:



Emerging Technologies

PV technologies are currently being developed to include multiple p-n layers, each doped with slightly different materials to achieve a wider spectral response, thereby increasing cell efficiency.

Amorphous microcrystalline cells are also currently being developed, which incorporate both an amorphous and microcrystalline layer.

Operating Conditions

PV modules need to be capable of withstanding various conditions, including:

- Weather conditions such as:
  - High temperatures.
  - Rain and hail.
  - Strong winds.
- Accumulation of dirt and dust.
- Corrosion.
- Vandalism.

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Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

This learning activity consists of 5 parts designed to develop your understanding of photovoltaic (PV) terminology, module features and characteristics.

Topic 2.1 Learning Activity

Last modified: Wednesday, 20 September 2023, 8:42 AM

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Photovoltaic Cell Characteristics

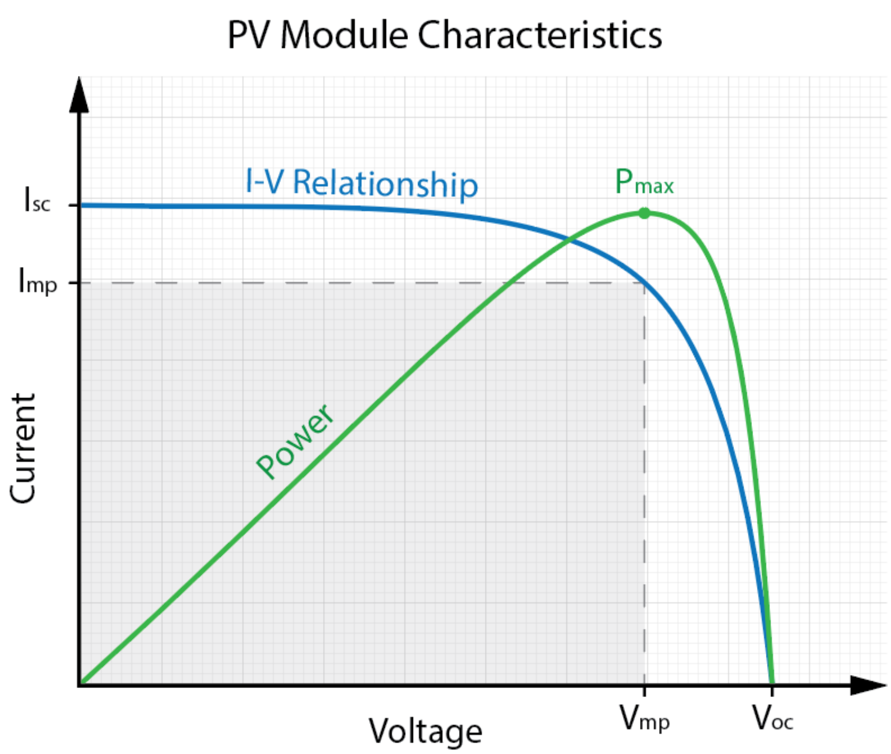
A photovoltaic (PV) cell is a constant current generator. This means that at a given irradiance the cell output current remains constant. The power output however depends on the load that is connected:

- As the load resistance decreases towards zero ohms (i.e. a short circuit), the cell output voltage also decreases towards zero. When the voltage reaches zero, the output power also becomes zero (remember that P = VI).
- On the other hand, as the load resistance increases towards infinite ohms (i.e. an open circuit), the cell output voltage will rise to a level at which current will conduct internally across cell. This causes the output current, and therefore also the output power, to drop to zero.

I-V Characteristic Curve

This relationship between cell output voltage and current can be represented by an "I-V curve". In order to understand the operation of a PV cell, we need to understand this I-V relationship.

Every PV module has a specific I-V characteristic curve that will be provided in the module specifications. The diagram below shows an example of an I-V curve and associated power curve plotted on a graph:



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The 'maximum power point (P_{max})' (sometimes indicated as 'MPP') is the point on the I-V curve at which maximum output power is achieved.

The ‘fill factor’ for a given PV module is the ratio of the P_{max} to the product of the short-circuit current and open-circuit voltage, as indicated by the following equation:

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

Where:

FF	=	Fill factor
P_{max}	=	Maximum power point in watts (W)
I_{sc}	=	Short-circuit current in amperes (A)
V_{oc}	=	Open-circuit voltage in volts (V)

Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

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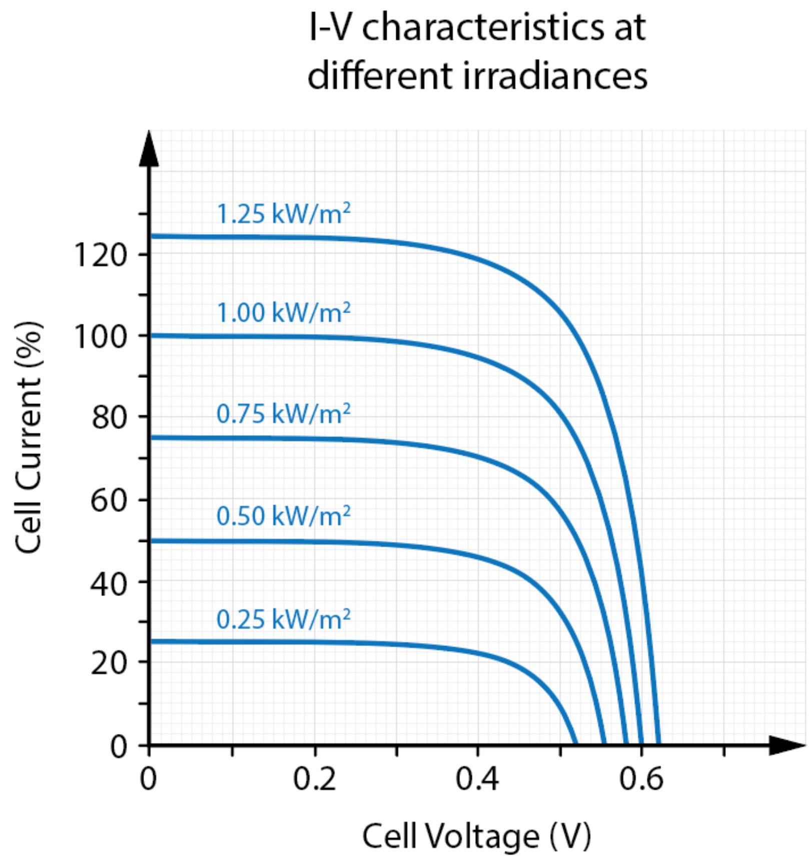
Effect of Irradiance

If the irradiance of a PV module decreases, then the output of the PV module also decreases, as shown by the following module I-V curves:



Effect of Temperature

As the temperature of a PV cell increases, the cell breakdown voltage decreases, resulting in reduced P_{max}.

During development, PV cells are tested to determine their performance under different operating conditions. The nominal operating cell temperature (NOCT) is the temperature reached by a PV cell under the following conditions:

- An irradiance of 800 W/m^2.
- An ambient temperature of 20^{0}C.
- A wind velocity of 1 m/s.
- Mounted such that air can circulate around the back side of the cell.

NOCT is used as a benchmark against which to compare the cells performance at other temperatures.

The following I-V curves show how temperature affects cell performance:

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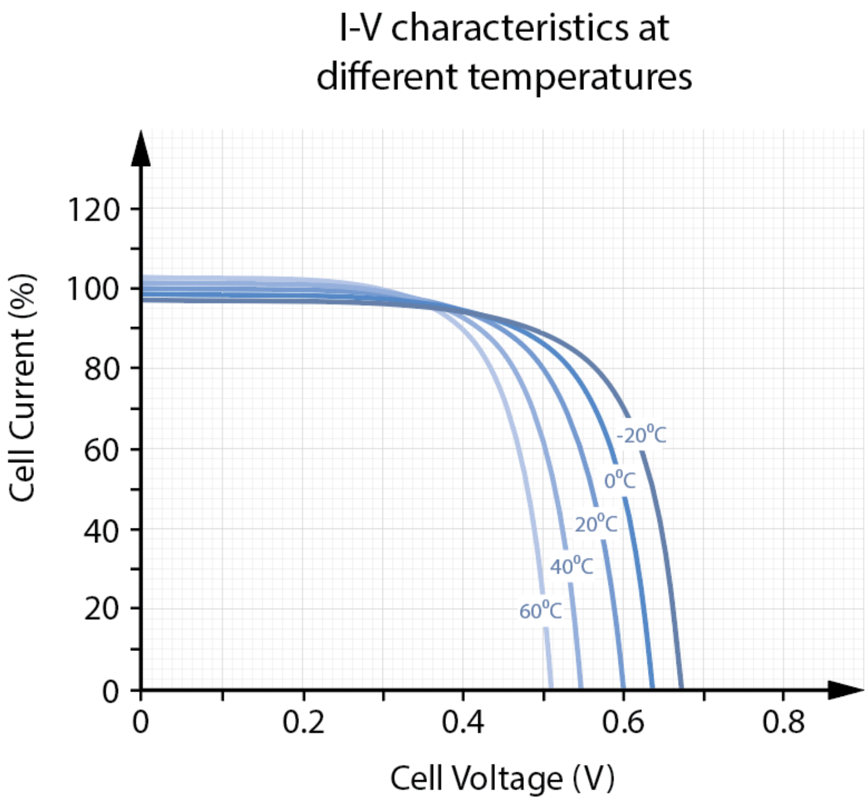

The NOCT can be used to determine the actual operating temperature of a PV module for given ambient temperature and irradiance conditions, as indicated by the equation:

$$T_{cell} = T_{amb} + \frac{G\,(NOCT - 20)}{800}$$

Where:

T_{cell}	=	Cell temperature in degrees Celsius (^{0}C)
T_{amb}	=	Ambient temperature in degrees Celsius (^{0}C)
G	=	Irradiance in watts per square metre (W/m^2)
NOCT	=	Nominal operating cell temperature in degrees Celsius (^{0}C)

?

Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

Temperature Coefficients

Temperature coefficients indicate how the various operating characteristics and parameters of a PV module will be affected by variations in cell temperature.

Temperature coefficients may be given for:

- Short-circuit current (I_{sc}).
- Maximum-power current (I_{mp}).
- Open-circuit voltage (V_{oc}).
- Maximum-power voltage (V_{mp}).
- Output power (P).
- Fill factor (FF).
- Efficiency (η).

PV Module Ratings

PV modules are rated to describe a range of operating parameters, which are provided by the manufacturer in the form of 'specifications' or 'data sheets'.

PV module ratings indicate the operating characteristics of the module under standard test conditions (STC) which are:

- An irradiance of 1 kW/m^2.
- An ambient temperature of 25^{0}C.
- An air mass of 1.5.

The following table describes some of the main ratings and details that will be of interest when comparing and selecting PV modules.

PV Module Ratings		
Rating	**Example**	**Description**
Rated Power (P_{max})	170 W	• Indicates the maximum power output of the module, i.e. optimal performance. • Helps you understand how much energy you can expect to generate.
Voltage at P_{max} (V_{mp})	34.8 V	• Indicates the module voltage at optimal performance. • Important for determining the system arrangement to achieve the desired operating voltage, and for selecting/ matching other parts of the system.
Current at P_{max} (I_{mp})	4.9 A	• Indicates the module current at optimal performance. • Important for determining the system arrangement to achieve the desired operating current, and for selecting/ matching other parts of the system.
Open Circuit Voltage (V_{oc})	43.5 V	• Indicates the module voltage under an open circuit condition (e.g. no load connected). • It's important that the other parts of the system are rated to withstand the total open circuit voltage of the array.
Short Circuit Current (I_{sc})	5.5 A	• Indicates the module current under a short circuit (i.e. zero ohms) condition. • It's important that the other parts of the system are rated to withstand the total short circuit current of the array.
Temperature Coefficient of P_{max}	-0.5%/^{0}C	• Indicates how the power output will be affected by changes in temperature. • The example indicates that for every degree Celsius increase above 25^{0}C (i.e. STC), the power output will be reduced by 0.5%.
Temperature Coefficient of V_{oc}	-165 mV/^{0}C	• Indicates how the module voltage will be affected by changes in temperature. • The example indicates that for every degree Celsius increase above 25^{0}C, the open circuit voltage will decrease by 165 mV.
Temperature Coefficient of I_{sc}	0.06%/^{0}C	• Indicates how the module current will be affected by changes in temperature. • The example indicates that for every degree Celsius increase above 25^{0}C, the short circuit current will increase by 0.06%.
Dimensions	1593 x 790 x 50 mm	• Indicates the physical size of the panel. • Important for determining the number of panels that will fit on a given roof space.

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Weight	15.4 kg	• Indicates the physical weight of the panel. • Important when planning how panels will be handled safely on the job.

Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

De-Rating Factors

PV modules should be de-rated to accommodate the following factors:

- Manufacturing tolerance.
- Soiling (dirt and dust).
- Operating temperature.

A manufacturing tolerance will be listed on the PV module data sheet, for example a tolerance of +/- 5% requires that a de-rating factor of 0.95 (5% reduction) is applied to the module.

To account for soiling of modules, the 'rule of thumb' is to apply a de-rating factor of 0.95, but further de-rating may be required for modules installed in dry, dusty locations, or in other areas that may be subject to heavy soiling.

The output power of a module should be de-rated based on its *operating temperature*, using the output power temperature coefficient of the module. Typical temperature coefficients are:

- Monocrystalline modules: - 0.45%/^{o}C
- Polycrystalline modules: - 0.5%/^{o}C
- Amorphous modules: - 0.2%/^{o}C

It should also be noted that PV modules deteriorate over time; the power output of bulk silicon cells is reduced by approximately 1% per year.

This learning activity consists of 8 parts designed to develop your understanding of PV module operating characteristics and ratings.

Topic 2.2 Learning Activity

In this skills practice, you are required to draw and label the equivalent circuit of a PV cell, and to draw and label the I-V curves for a PV module under various operating conditions.

Topic 2.2 Skills Practice

Undertaking this topic quiz will help you to confirm your understanding of PV technologies, including terminology, modules, operating characteristics and ratings.

Topic 2 Content Quiz

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Introduction

In this topic you will learn about the arrangement of PV arrays, including series and parallel module configurations, and the arrangement of blocking and bypass diodes. You will also learn about BIPV products, and the factors to consider when selecting PV modules for a given installation.

PV Array Configurations

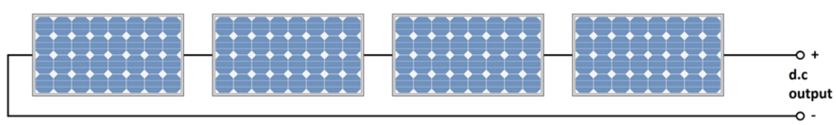
An array consists of a number of PV modules connected in series, parallel, or series-parallel.

- Connecting PV modules in series increases the output voltage, whilst the output current remains the same.
- Connecting PV modules in parallel increases the output current, whilst the output voltage remains the same.

Care should be taken to accurately match module types and ratings that are to be connected together into an array. The output current of a string is limited to the lowest output current of any individual cell within the string.

Worked Example 1 – Modules in Series

The following diagram shows four PV modules connected as a series string. Each module has a power rating of 120 W, a nominal voltage of 24 V, and a rated current of 5 A.



When connected in series:

- The nominal voltage of the string is equal to the sum of the voltages of each module, i.e. 24 + 24 + 24 + 24 = 96 V d.c.
- The rated current of the string is equal to the current of each module, i.e. 5 A d.c.
- The rated power of the configuration is determined either by adding the module power ratings or by multiplying the total voltage by the total current, i.e.
  - 120 + 120 + 120 + 120 = 480 W
  - 96 x 5 = 480 W
- So we end up with a 480 W, 96 V, 5 A array.

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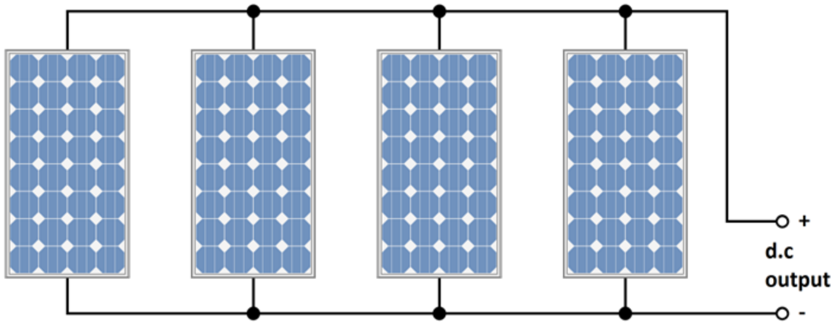
Worked Example 2 – Modules in Parallel

The following diagram shows four PV modules connected in parallel. Each module has a power rating of 120 W, a nominal voltage of 24 V, and a rated current of 5 A.



When connected in parallel:

- The nominal voltage of the configuration is equal to the voltage of each module, i.e. 24 V d.c.
- The rated current of the configuration is equal to the sum of the currents of each module, i.e. 5 + 5 + 5 + 5 = 20 A d.c.
- The rated power of the configuration is determined either by adding the module power ratings or by multiplying the total voltage by the total current, i.e.
  - 120 + 120 + 120 + 120 = 480 W
  - 24 x 20 = 480 W
- So we end up with a 480 W 24 V, 20 A array.

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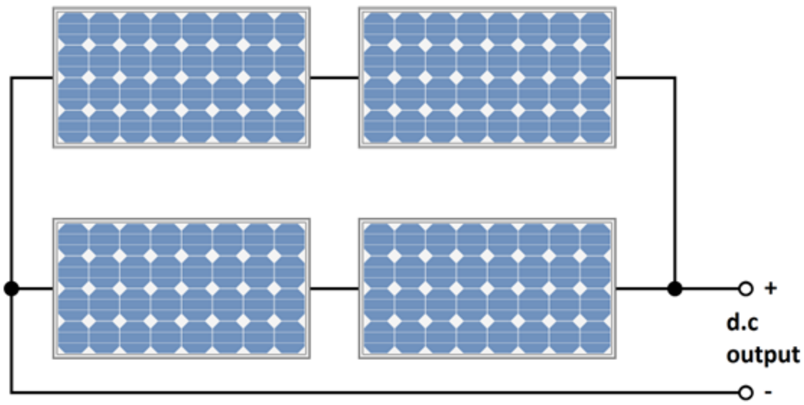
Worked Example 3 – Modules in Series-Parallel

The following diagram shows four PV modules connected in series-parallel – two parallel strings, each consisting of two series connected modules. Again, each module has a power rating of 120 W, a nominal voltage of 24 V, and a rated current of 5 A.



When connected using this series-parallel configuration:

- The nominal voltage of the configuration is equal to the voltage of each string, i.e. 24 + 24 = 48 V d.c.
- The rated current of the configuration is equal to the sum of the currents of each string, i.e. 5 + 5 = 10 A d.c.
- The rated power of the configuration is determined either by adding the module power ratings or by multiplying the total voltage by the total current, i.e.
  - 120 + 120 + 120 + 120 = 480 W
  - 48 x 10 = 480 W
- So we end up with a 480 W, 48 V, 10 A array.

Shading

Shading of modules can occur due to a variety of factors, such as:

- Soiling.
- Trees.
- Buildings and other structures.

Shading or failure of a single PV cell can reduce the output current of a string to zero, and can even result in the string becoming a load on other parallel connected strings.

Bypass Diodes

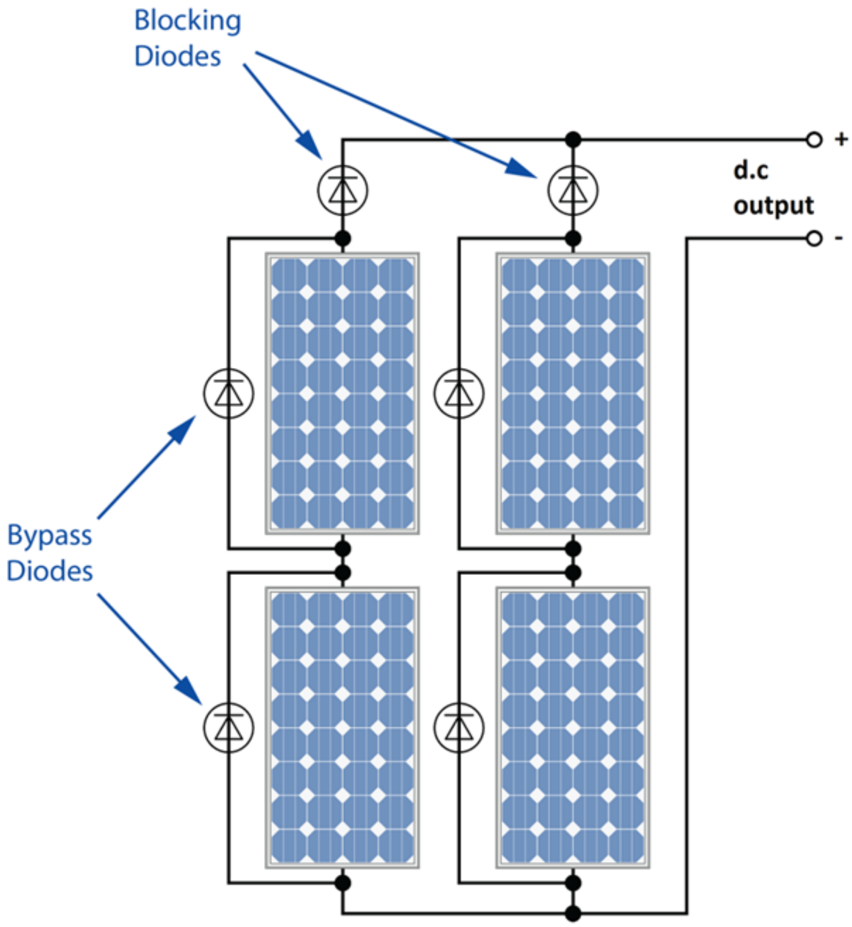
Bypass diodes are connected in parallel with each module, so that modules containing one or more shaded or failed cells are bridged out of the circuit. This allows the string to continue generating current (although at a reduced voltage). Bypass diodes are typically embedded into modules, but may also be located in the module connection box.

Blocking Diodes

If part of a string becomes shaded, the bypass diode effectively removes the shaded module from the circuit, meaning that the string keeps operating, but at a reduced voltage. If a second string, connected in parallel, is operating at full voltage, then the difference in output voltage between the two strings would cause current to 'back-feed' into the shaded string from the unshaded string.

To prevent this, blocking diodes are connected in series with each string. The blocking diode allows current to leave the shaded string, but pre ? current from back-feeding into it.

The following diagram shows the arrangement of a PV array with blocking and bypass diodes.



This next diagram shows the operation of an array that consists of two 72 V d.c. strings (each consisting of three 24 V d.c. modules):

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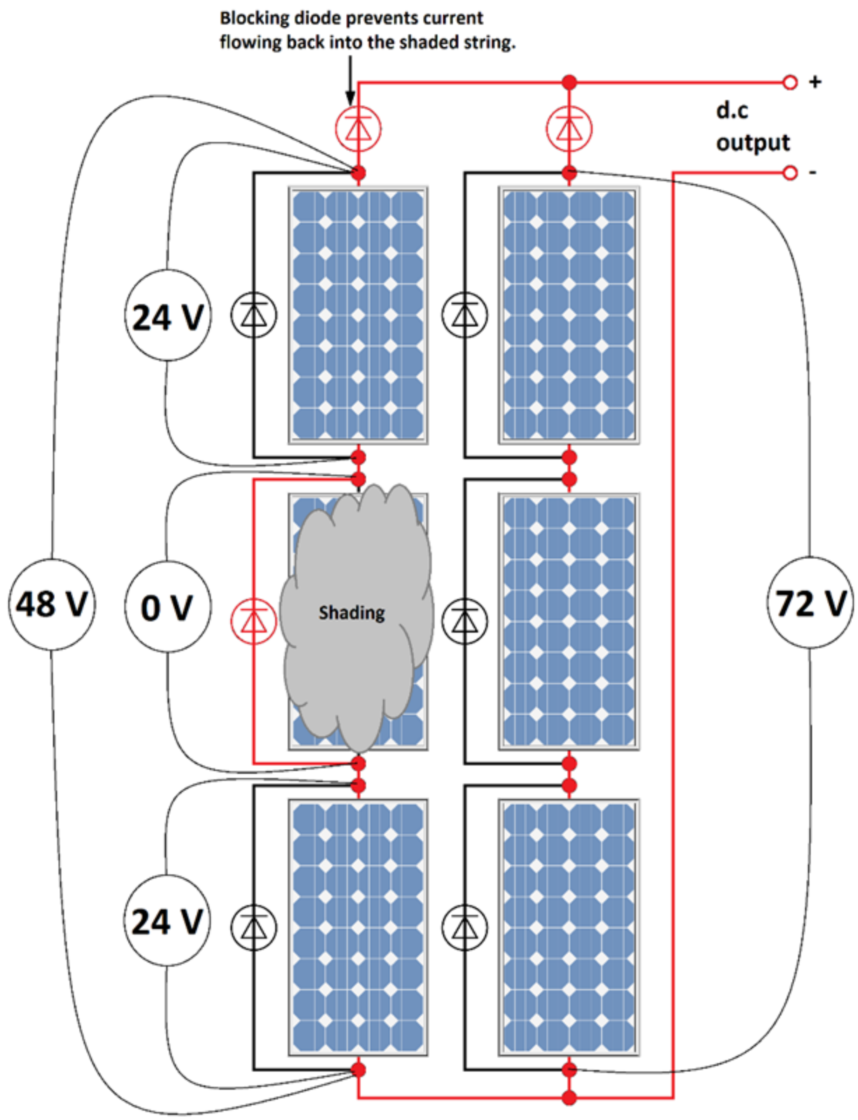

Notice how the bypass diode has effectively removed one of the modules from the circuit, thereby reducing the string voltage to 48 V, whilst the voltage of the other string remains at 72 V. The blocking diode in the shaded string prevents current flowing back into the shaded string.

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Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

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Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

AS/NZS 5033:2021 states the requirements for selecting, arranging and installing blocking and bypass diodes in PV arrays.

Australian Standards

Australian Standards containing requirements related to the installation of PV arrays include:

- AS/NZS 5033:2021 Installation and safety requirements for photovoltaic (PV) arrays.
- AS/NZS 4777.1:2016 Grid connection of energy systems via inverters – Installation requirements.
- AS/NZS 4777.2:2020 Grid connection of energy systems via inverters – Inverter requirements.
- AS/NZS 4509.1:2009 (R2017) Stand-alone power systems – Safety and installation.
- AS/NZS 4509.2:2010 (R2017) Stand-alone power systems – System design.
- AS/NZS 3000:2018 Wiring Rules.

This learning activity consists of 6 parts designed to develop your understanding of PV array arrangements and connection configurations.

Topic 3.1 Learning Activity

In this skills practice, you are required to draw a PV array wiring diagram, indicating the connections between modules, bypass diodes and b’ ? ng diodes, and the polarity of the array output.

Topic 3.1 Skills Practice

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There are a number of factors that need to be considered in the design of a PV array. Some of the main factors are described in the following table.

PV Array Selection	
Factor	**Impact**
Energy yield	The desired energy yield from an array will be central to the total size of the array, as well as the type of modules used. It could also determine the need for axis tracking and/or monitoring systems.
Type of installation	Arrays in domestic installations must not have an open circuit voltage exceeding 1000 V, which can affect the arrangement of modules for these arrays (note that the 2016 edition of AS/NZS 4777.1 still limits the maximum d.c. voltage to 600 V for domestic installations). The location/environment for installation can also have an effect on the type of modules to be selected. For example building integrated PV products may be better suited to certain situations.
Available space	The space available for the installation of the array will be a limiting factor as to the size.
Cost	The initial cost, available rebates and expected 'payback' period typically plays a significant role in determining the size of an array desired by a customer. This consideration must also extend to ensuring compatibility with the other system equipment, such as inverters, in a way that provides the most cost effective system as a whole.

Building Integrated Photovoltaics (BIPV)

A building integrated photovoltaic (BIPV) material is a material used to perform a building function (e.g. a window, skylight or roofing tile), that also incorporates PV, typically thin-film, technology.

Types of BIPV products currently on the market include:

- Roof tiles and shingles.
- Awnings.
- Windows and skylights.
- Spandrel glass.

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- Facades.
- Curtain walls.
- Flooring tiles.

Health and Safety Considerations

Once the proposed site has been surveyed and the relevant data collected, the task of selecting and arranging equipment for PV systems is primarily a desktop/computer-based job.

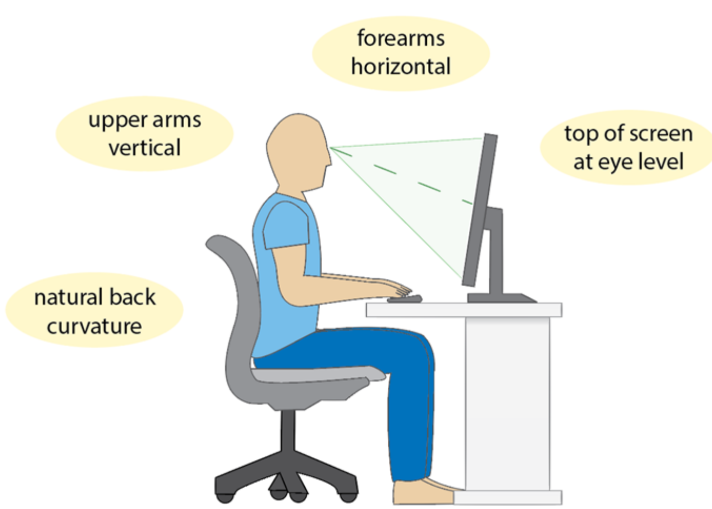
Although it may not appear hazardous, there are several health and safety risks associated with using a computer, particularly when used for extended periods. Some of the main hazards, risks and control measures associated with computer use are detailed in the following table.

Hazards and Safety – Computer Use		
Hazard	**Risk**	**Control Measures**
Poor lighting (too much or too little).	• Eye strain. • Headaches.	• Adequate workplace lighting. • Position computer display to minimise glare and reflection. • Set suitable screen brightness and contrast.
Incorrect posture.	• Muscle strains.	• Maintain correct posture.
Repetitive movements (mouse use, typing).	• Occupational overuse syndrome (OOS).	• Take regular breaks and conduct stretches of hands, arms, shoulders, neck and back.

When using a computer, your chair, desk and computer should be arranged so that:

- Your elbows are bent at roughly 90^0.
- Your forearms are parallel with the floor.
- Your wrists are straight.
- Your shoulders are relaxed.
- You don't need to twist your body or over-reach to use the computer equipment.

The following diagram highlights the correct posture for computer use to reduce the risks of muscle strains, ligament damage and occupational overuse syndrome (OOS).



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This learning activity consists of 5 parts designed to develop your understanding of PV array selection and associated health and safety considerations.

Topic 3.2 Learning Activity

Undertaking this topic quiz will help you to confirm your understanding of the arrangement of PV arrays, including series and parallel module configurations and the arrangement of blocking and bypass diodes.

Topic 3 Content Quiz

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Introduction

In this topic you will learn about the types of inverters used in present day grid connected systems, and the differences between them. You will also learn how to connect a grid-connect inverter to measure the input and output parameters at various loads.

Inverters

An inverter is an electronic device that converts a d.c. input into an a.c. output. There are two main categories of inverters:

- Standalone (SPS) inverters.
- Grid-connect (GC) inverters.

An SPS inverter will typically be used to convert the d.c. supply from a battery bank to an a.c. supply of a standalone power system.

SPS inverters must not be connected to the electricity grid.

In order to connect a PV power system to the electricity grid, a suitably rated GC inverter must be used. The Australian Standard symbol for a low voltage inverter is shown below:

Grid-Connect (GC) Inverters

The following block diagram shows the relationships between components within a GC inverter:

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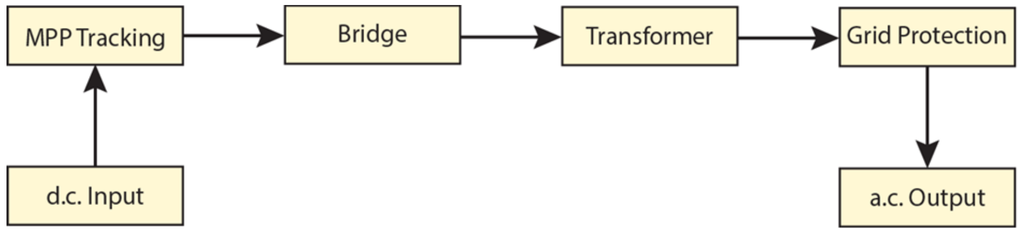

The basic purpose of each component is summarised below:

GC Inverter Components	
MPP Tracking	Maintains maximum module/string efficiency for the given operating conditions.
Inverter Bridge	Converts the d.c. waveform into an a.c. waveform using Pulse Width Modulation (PWM).
Transformer	Changes the voltage to 230 V and helps to smooth out the waveform.
Grid Protection	Matches the frequency of the inverter output with the grid, and disconnects the inverter from the grid in the event of abnormal grid parameters.

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Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

Types of GC Inverters

There are three main types of GC inverter, as summarised in the following table.

Types of GC Inverters	
Central/String Inverter	A central inverter (or 'string inverter') is connected to the entire PV array, and is typically mounted near the installation metering/main switchboard.
Multimode Inverters	A multimode inverter is capable of operating in several operating 'modes'. Multimode inverters with 'standalone mode' are becoming more widespread as they can be arranged with a battery bank to provide greater independence from the grid – the batteries are charged by the PV array during the day, and the stored energy is utilised at night.

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Micro-inverters	A micro-inverter system consists of several small inverters, each connected to individual modules within the array. Micro-inverters are typically mounted directly onto the array assembly, which means that the wiring running from the array to the switchboard will be a.c. PV modules are also now commonly available with in-built micro-inverters, thereby reducing installation time.

Advantages and Disadvantages

Some advantages of micro-inverters compared to central inverters, include:

- Reduced d.c. cabling.
- Increased efficiency.
- Increased reliability.
- Reduced output due to partial shading or soiling is limited to the affected module.
- Module level MPPT and monitoring.

The main disadvantages of micro-inverters are:

- Higher initial cost.
- Increased maintenance due to multiple units.
- Difficulty of maintenance due to roof mounting.

This learning activity consists of 4 parts designed to develop your understanding of the basic types and function of an inverter.

Topic 4.1 Learning Activity

In this skills practice, you are required to draw diagrams of low voltage inverters typically used in grid-connected PV power systems.

Topic 4.1 Skills Practice

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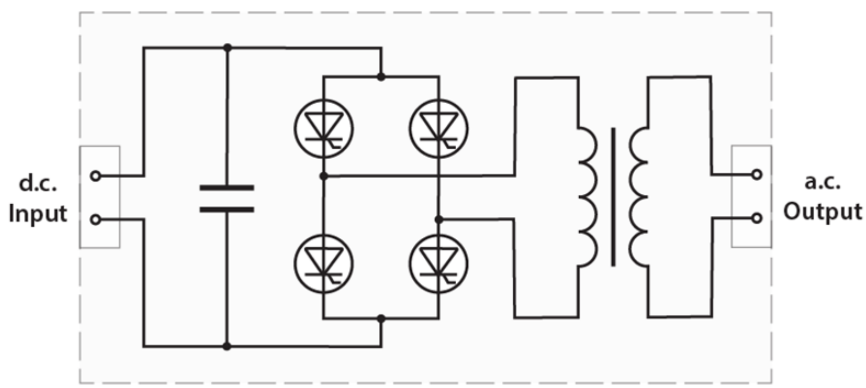
Principle of Inverter Operation

The principle of inverter operation is to rapidly switch a d.c. input, such that the direction of current flow is repeatedly reversed. Applying the switched supply to the primary winding of a transformer will result in an alternating magnetic flux, and a modified sine wave output on the secondary winding.

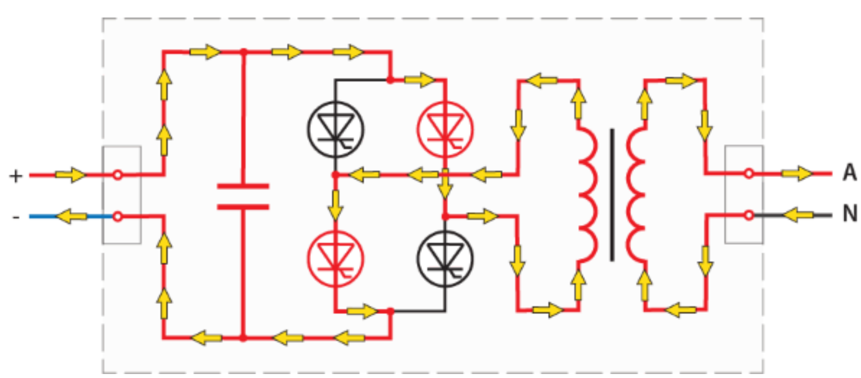
Inverter Bridge

An inverter bridge circuit consists of two pairs of silicon-controlled rectifiers (SCRs) that are switched alternately, producing a square wave.



Inverter Bridge Operation

The following diagram shows the basic operation of an inverter bridge – note how the switching of the two pairs of SCRs produces an alternating current output.

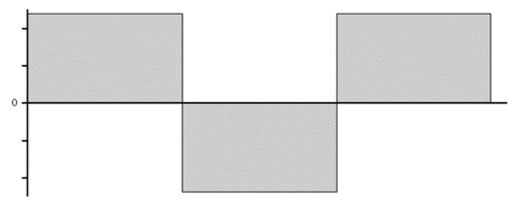
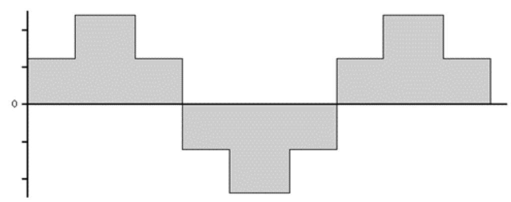
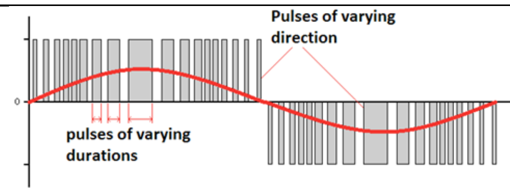


FET Inverter

A FET inverter operates the same way, but uses voltage controlled (field effect) transistors to switch the d.c. input.

Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a technique of rapidly switching the current in a series of pulses that each has the same magnitude but varies in duration (i.e. width). An accurate sine wave can be synthesised using this method. The following table shows the difference between square waves, modified sine/square waves and PWM synthesised waveforms. Note the current waveform resulting from the PWM technique, shown in red.

Type	Waveform
Square Wave	
Modified Sine/ Square Wave	
Synthesised Sine Wave (PWM)	

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Check your understanding of the content by clicking the link below then undertaking the activity.

Load the Activity

This learning activity consists of 3 parts designed to develop your understanding of inverter switching principles.

Topic 4.2 Learning Activity

In this skills practice, you are required to connect a grid-connect inverter into a circuit and observe the operating characteristics. You will need access to your RTO's practice facilities to complete this skills practice so ask your teacher/trainer about how to proceed.

Topic 4.2 Skills Practice

Undertaking this topic quiz will help you to confirm your understanding of the different types, operation and features of inverters used in grid-connect systems.

Topic 4 Content Quiz

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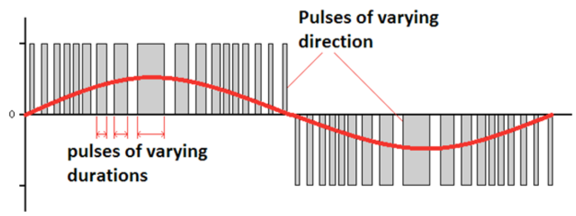
Introduction

In this topic you will learn about the types of inverters that are suitable for grid connected applications, and the factors to consider when selecting grid connect inverters.

Only specific types of inverters are suitable to be connected to the electricity supply grid. The features of GC inverters that make them suitable for this purpose are highlighted in the following table.

Grid-Connect (GC) Inverters	
Feature	**Operation**
True Sine Wave PWM Output	True (synthesised) sine wave PWM output is required to ensure the quality of the grid is not compromised. 
Frequency Synchronisation	Frequency matching synchronises the inverter output with the frequency of the grid.
Passive Protection	Passive protection disconnects the inverter from the grid when abnormal grid voltage or frequency is sensed.
Active Protection	Active protection produces a frequency shift in the event that the grid goes off-line (e.g. due to maintenance or power outage), causing the inverter passive protection to trip.
Maximum Power Point Tracking (MPPT)	An MPPT device adjusts the load resistance placed on a PV array, to maintain maximum efficiency for a given irradiation and operating temperature.

Inverter Regions

There are three 'regions' in Australia that will affect some of the particular operating parameters required for a grid-connected inverter. Each region is based on the type of grid to which the inverter will be connected. The reason for this is that a given inverter system has the potential to have a [illegible] significant effect on a smaller grid, than a larger grid.

Region	Grid Connection
Australia A	Connected to large interconnected power grid
Australia B	Connected to small interconnected power grid
Australia C	Connected to isolated/remote power grid

Most installations will fall into the 'Australia A' category. Several requirements in AS/NZS 4777.2:2020 require slightly different operating parameters depending on the particular region.

Grid Protection

Grid-connected inverter systems are required to incorporate a grid protection device that disconnects the inverter system from the grid in the event that the supply is disrupted, or operates outside of pre-determined voltage or frequency limits. Grid protection is typically incorporated within the grid-connected inverter, and consists of:

- Passive anti-islanding protection.
- Active anti-islanding protection.

Passive Anti-islanding Protection

Passive protection disconnects the inverter from the grid when an abnormal grid voltage or frequency is sensed. The voltage limits for passive protection are the same for all regions:

- A voltage of ≤70 V must be disconnected within 2 seconds.
- A voltage of ≤180 V must be disconnected within 11 seconds.
- A voltage of ≥265 V must be disconnected within 2 seconds.
- A voltage of ≥275 V must be disconnected within 0.2 seconds.

The passive protection frequency limits vary slightly by region, as described in the following table.

Region	Passive Protection Frequency Limits
Australia A and Australia B	• A frequency of ≤47 Hz must be disconnected within 2 seconds. • A frequency of ≥52 Hz must be disconnected within 0.2 seconds.
Australia C	• A frequency of ≤45 Hz must be disconnected within 6 seconds. • A frequency of ≥55 Hz must be disconnected within 0.2 seconds.

This learning activity consists of 4 parts designed to develop your understanding of inverter waveforms, ratings and specifications.

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Topic 5.1 Learning Activity

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GC Inverter Ratings

Any inverter used for grid-connected applications in Australia must comply with AS/NZS 4777.2:2020. When selecting an inverter, the inverter ratings must be carefully matched to the installation requirements. The following table shows some of the primary ratings to be considered.

GC Inverter Ratings	
Continuous rating	The maximum power at which the inverter can operate continuously without overheating.
Half hour rating	The maximum power at which the inverter can operate over a half hour period without overheating.
Surge rating	The maximum inrush current the inverter can withstand without damage.
d.c. voltage range (operating window)	The upper and lower d.c. input voltage limits.
a.c. voltage range	The upper and lower a.c. output voltage limits.
Peak efficiency	The maximum efficiency the inverter can achieve.
IP rating	The ability of the inverter to withstand the ingress of water and dust.

Inverter Operating Window

GC inverters will only operate within a specific range of d.c. input voltage – this is referred to as the "operating window" of the inverter. If the input voltage goes outside this range, then the inverter will cease to operate. This is of particular importance when selecting locations and cable routes between arrays and inverters, as excessive voltage drop in the connecting cable would result in the inverter output dropping to zero. The battery bank input port of a multimode inverter will also have a specified operating window.

Temperature Coefficient of Voltage

PV module temperature coefficient of voltage indicates the change in voltage that will occur for changes in ambient temperature. It is important to coordinate this rating with the inverter operating window, to ensure that the system will operate within the expected range of ambient temperatures.

Temperature coefficients are typically given in %/^{0}C, indicating the percentage change in voltage for a given change in temperature.

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Worked Example – Temperature Coefficient of Voltage

Consider a PV array that consists of 6 modules connected as a single string. Each module has the following STC voltage characteristics:

- Nominal Voltage (V_{MPP}): 36 V
- Open Circuit Voltage (V_{oc}): 45 V
- Voltage Temperature Coefficient: -0.35%/^{o}C

Determine the minimum and maximum nominal array voltages for an ambient temperature range of 0^{o}C to 50^{o}C.

(a) Array voltage at STC (25^{o}C)

36 x 6 = 216 V

(b) Array voltage @ 0^{o}C

-0.35 x (0 – 25) = 8.75%

216 x 1.0875 = 234.9 V

(c) Array voltage @ 50^{o}C

-0.35 x (50 – 25) = -8.75%

216 x 0.9125 = 197.1 V

If the expected temperature range for the installation was 0^{o}C to 50^{o}C, then the operating window of the inverter would need to be (at least) 197 V to 235 V.

Manufacturer's Data

A basic example of a manufacturer's datasheet for a GC inverter is pictured below:

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Input Parameters	
Max. d.c. power	3760 W
Max. d.c. voltage	500 V
d.c. voltage range	210 V – 410 V
Max. input current	22 A
MPP trackers	1
Max. number of strings	3
Output Parameters	
Nominal a.c. power	3250 W
Max. a.c. power	3640 W
Nominal a.c. voltage range	220 V – 240 V
Max. a.c. current	17 A
a.c. frequency / tol.	50 Hz / ±4 Hz
Power factor	1
Connection	Single phase
Efficiency	
Max Efficiency	95.7 %
Consumption: No Load / Standby	12 W / < 3.5 W
General	
International protection	IP66
Operating temperature range	-25 ⁰C ... +60 ⁰C
Dimensions (W x H x D)	400 x 600 x 240 mm
Weight	39 kg

Factors Affecting Inverter Selection

The selection of the inverter(s) for a given installation will depend on a number of factors, as summarised in the following table.

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GC Inverter Selection	
Factor	**Impact**
Power output of the array	The total power output of the array will determine the required power rating of the inverter(s).
Number of strings, and any variations in module orientation and/or tilt angles	Different types of inverters can support different numbers of strings. The selected inverter must have a capacity to suit the array configuration. For larger systems, several inverters may be required. This can provide several advantages, such as: • Failure of one inverter does not affect the entire PV power system. • If different parts of an array have different orientations or tilt angles, then connecting them to separate inverters allows for more effective MPP tracking. • Standard numbers and configurations of modules connected to a certain type of inverter gives the installation a modular characteristic. • Inverter outputs can be balanced across phases in three phase installations.
Maximum array parameters	The selected inverter(s) must be rated to withstand the maximum voltage, current and power that may be supplied by the array without sustaining damage. The Clean Energy Council (CEC) guidelines state that to ensure an efficient design, the inverter a.c. output power must not be less than 75 % of the array maximum power.
Batteries	A multimode inverter will be required for systems incorporating a battery bank.
Installation layout and environment	The layout and available locations for inverter installation could make micro-inverters the preferred choice over string inverters or vice-versa. The selected model of inverter must have a suitable design for any potentially detrimental influences that may exist in the installation location. For example, the IP rating must be appropriate.

This learning activity consists of 5 parts designed to develop your understanding of grid-connect inverter selection, including ratings, specifications and other factors.

Topic 5.2 Learning Activity

In this skills practice, you are required to select and size PV arrays and inverters to suit given grid connected PV power system scenarios.

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Topic 5.2 Skills Practice

Undertaking this topic quiz will help you to confirm your understanding of the features, rating and factors to consider when selecting grid-connect inverters.

Topic 5 Content Quiz

Last modified: Thursday, 7 September 2023, 10:31 AM

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Introduction

In this topic you will learn about the factors to consider when selecting Balance of System (BoS) equipment for PV power systems, including wiring, switchgear and controlgear. You will practice selecting equipment for given scenarios, and also learn how to estimate the energy yield, specific energy yield and performance ratio of a given system.

PV Switchgear Selection

The following table summarises the main factors to be considered when selecting a.c. and d.c. switchgear for PV power systems.

PV Switchgear Selection	
Factor	**Impact**
System Operating Parameters	Control and protection devices must be suitable for the operating parameters of the system. Important parameters to consider include: • **a.c. or d.c.** – a.c. switchgear is not suitable for use with d.c., and d.c. switchgear must **not** be polarised. • Devices must be capable of withstanding the maximum voltages and currents that may arise (i.e. $I_{S/C}$ and $V_{O/C}$). • Disconnectors need to be capable of breaking the PV array full-load and prospective fault currents.
Coordination with Connected Cables	Protection devices must be selected and arranged to ensure that the full load current is permitted to flow, but any overcurrent arising in the connected cables is disconnected before damage can occur.
Installation Environment	The installation location/environment may impact the features and IP rating required for switchgear.

AS/NZS 5033:2021 Appendix H provides guidance on selecting switch disconnectors for PV installations.

PV Wiring System Selection

The cables and associated cable support/protection for PV power systems should be selected in accordance with AS/NZS 3000:2018, AS/NZS 3008.1.1:2017 and AS/NZS 5033:2021. The following table summarises the main factors to be considered when selecting a.c. and d.c. wiring for PV power systems.

PV Wiring Selection	
Factor	**Impact**
System Operating Parameters	System wiring must be suitable for the operating parameters of the system. This should be done in accordance with AS/NZS 3008.1.1:2017, including the following considerations: • Required current carrying capacity will be determined by factors such as operating current and voltage drop. • Required insulation type will be determined by factors such as the operating voltage and temperature. Note that AS/NZS 5033:2021 requires that: • LV d.c. wiring is double insulated. • Cables directly terminated to plugs, sockets or connectors must be flexible (class 5).
Method of installation	The installation method and location (i.e. cable route) will have an effect on both the current carrying capacity of the cables and the need for mechanical protection. Note that AS/NZS 5033:2021 requires that d.c. cables installed within building cavities must be enclosed.

Other Design Considerations

There are a number of other, non-technical factors that can influence the design of a PV power system, including:

- Economic and financial factors.
- Legislative and regulatory factors.
- Contractual and institutional factors.

These factors are often interrelated, for example the cost of PV technology and the presence (or lack) of government incentives and rebates will often play a significant role in the size of PV systems. Feed-in tariffs, set by Electricity Network Providers, will also affect the 'pay-back' period of a grid-connected system.

Economic and Financial Factors

The cost of new and emerging technology always tends to drop over time due to 'economies of scale'. This is where increased demand for a product allows for increased scale of manufacture, which ends up being cheaper per component. The competitive nature of the market causes these reduced costs to be passed onto the customer. In addition, competition encourages innovation, and so the overall effect is that, over time, technology becomes both cheaper and more advanced. This has most definitely been the case in the renewable energy sector. Improvements in battery technology, increases in the scale of manufacturing, and the associated reduction in prices, have started to play an important role in this area.

Legislative and Regulatory Factors

In the case of PV power systems, the cost of the system is balanced against the cost of obtaining electricity from the grid. The continuing trenc ? been for PV power to become cheaper, and grid power to become more expensive. There have been a range of government policies, such as rebates, taxes and subsidies that have been implemented to either slow or quicken this process.

Local council rules can also affect the permissible designs and locations of PV systems within that local area.

Contractual and Institutional Factors

Finally, institutional policies and attitudes will invariably play a role in the design of a given PV power system. The approach and awareness of a customer will directly influence the degree to which they will adopt any given renewable technology.

This learning activity consists of 5 parts designed to develop your understanding of PV system wiring and switchgear selection.

Topic 6.1 Learning Activity

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Estimating Energy Yield

In Australia, the size of a given PV system will typically be based on the out-of-pocket cost and/or how many modules will actually fit on the available roof space. Once the size of the PV system is determined, the expected energy yield (average yearly energy output) can be calculated using the following equation:

$$E_{sys} = P_{array\_STC} \times f_{man} \times f_{dirt} \times f_{temp} \times H_{tilt} \times n_{pv\_inv} \times n_{inv} \times n_{inv\_sb}$$

Where:

E_{sys}	=	average yearly energy output of the array in watt hours (Wh)
P_{array_STC}	=	rated output power of the array under STC in watts (W)
f_{man}	=	manufacturing tolerance derating factor
f_{dirt}	=	dirt build up derating factor
f_{temp}	=	temperature derating factor
H_{tilt}	=	yearly (monthly) irradiation value for the selected site in kWh/m^2
n_{pv_inv}	=	efficiency of the cables between the PV array and the inverter
n_{inv}	=	inverter efficiency
n_{inv_sb}	=	efficiency of the cables between the inverter and the switchboard

Derating Factors

The derating factors to be used in the equation above will either be presented in manufacturer's data sheets or must be estimated based on the site conditions. The following table shows typical values.

PV System Derating		
Derating Factor	**Determined From**	**Typical Value**

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Manufacturing tolerance	Manufacturer's data sheets	0.97
Dirt build up	Estimated based on site conditions	0.95
Operating temperature	Manufacturer's data sheets and site conditions	0.84
Efficiency of system cables	Estimated based on route length, resistivity etc.	0.97
Efficiency of the inverter	Manufacturer's data sheets	0.92

AS/NZS 4509.2:2010 provides some guidance on derating of PV power systems.

Worked Example – Energy Yield

Estimate the energy yield of a 4.2 kW PV system with the following characteristics:

- Yearly irradiation of 1,570 kWh/m^2
- Manufacturing tolerance of 3 %
- Inverter efficiency of 93 %
- Derating factor for operating temperature: 0.82
- Derating factor for system cables: 0.97
- Derating factor for dirt build-up: 0.94

$$E_{sys} = 4200 \times 0.97 \times 0.94 \times 0.82 \times 1570 \times 0.93 \times 0.97$$

$$E_{sys} = 4{,}447{,}511\ Wh$$

$$E_{sys} = 4{,}448\ kWh$$

Specific Energy Yield

The specific energy yield of a PV power system represents how many kWh are produced per rated kW of the PV system. Specific energy yield can be calculated using the following equation:

$$SY = \frac{E_{sys}}{P_{array\_STC}}$$

Where:

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SY	=	Specific energy yield in kWh per kW
E_{sys}	=	Energy yield in watt hours (Wh)
P_{array_STC}	=	Rated output power of the array under STC in watts (W)

Worked Example – Specific Energy Yield

Following on from the previous worked example, estimate the specific energy yield of the system.

$$SY = \frac{5{,}250{,}695}{4200}$$

$$SY = 1{,}250\ kWh/kW$$

Performance Ratio

The performance ratio of a PV power system gives a good indication of the overall effectiveness and quality of the system design, installation and performance. The performance ratio can be calculated using the following equation:

$$PR = \frac{E_{sys}}{E_{ideal}}$$

Where:

PR =	Performance ratio
E_{sys} =	Energy yield in watt hours (Wh)
E_{ideal} =	Ideal energy yield in watt hours (Wh)

The ideal yearly energy yield can be determined using a number of methods. The simplest one is to use the following equation:

$$E_{ideal} = P_{array\_STC} \times H_{tilt}$$

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Where:

E_{ideal}	=	Ideal energy yield in watt hours (Wh)
P_{array_STC}	=	Rated output power of the array under STC in watts (W)
H_{tilt}	=	Total yearly irradiation for the selected site in kWh/m^2

Worked Example – Performance Ratio

Following on from the previous worked example, estimate the performance ratio of the system.

$$E_{ideal} = 4200 \times 1{,}570$$

$$E_{ideal} = 6{,}594{,}000\ Wh$$

$$\text{PR} = \frac{5{,}250{,}695}{6{,}594{,}000}$$

$$\text{PR} = 0.796$$

PV System Software

It should be noted that there are a variety of apps and software packages available to assist with the design and evaluation of PV power systems. Common features include:

- Estimation of solar access.
- Optimal positioning of PV arrays.
- Estimation of energy yield and system performance.

Monitoring PV Power Systems

Monitoring tools allow consumers to see the operating parameters and performance of their PV systems. The ability to review and analyse this data allows them to quickly identify system errors/problems, and also to optimise their energy usage.

Storage water heaters, for example, have traditionally been arranged so that the elements are energised at night, taking advantage of the cheaper "off-peak" energy tariffs. For the owner of a grid-connected PV system, however, it will likely be more cost effective to operate the elements during the middle of the day – consider the following scenario:

- The Network Provider pays a feed-in tariff of 5 c/kWh to the owner for each kWh they export to the network.
- The Network Provider charges 11 c/kWh for energy used between 10 p.m. and 6 a.m.
- The consumer needs to operate their 6 kW water heater for 5 hours (6 x 5 = 30 kWh).

So if the consumer operates their water heater during the off-peak period, then the net cost will be $1.50:

Associated Charges = 30 x 11 = 330 cents

Associated Income = 30 x 6 = 150 cents

Net Cost = 330 – 180 = 150 = <u>$1.50</u> **?**

However, if the consumer operates their water heater during the middle of the day (i.e. using solar energy), then the net cost will be $0.00:

Associated Charges = 0 cents

Associated Income = 0 cents

Net Cost = $0.00

This principle can have a significant impact on the return on investment (ROI) for both domestic and commercial premises.

PV System Monitoring Tools

There are a number of different PV monitoring systems available that provide different degrees of detail and functionality. For many modern systems wireless technology streams real-time data to cloud-based software. The software collates and presents data in various lists, tables and charts for analysis, and can be accessed from computers and smartphone apps using an appropriate login.

Depending on the sophistication of the system, monitoring can take place at the overall level, string level, or even at the individual module level for micro-inverter systems. Some typical features and functions are outlined in the following table.

PV System Monitoring Tools	
Weather conditions	• Most commonly ambient temperature and irradiation, and in some cases air pressure and humidity.
Operating parameters	• Real-time output voltage, current and power at the array/module. • Real-time input and output voltage, current and power at the inverter. • Energy import/export values.
Fault detection and alerts	• Identifies faults/errors at the array or inverter. • Can be configured to send notifications in the event of a fault, e.g. via email.
Data logging and reporting	• Records and stores data for collation and analysis. • Reports can be generated manually and/or automatically to view operation and performance over time.
Public screens/ displays	• A screen is sometimes provided in a public place to show the performance of the system, sometimes used by commercial premises for promotional/educational purposes.

This learning activity consists of 6 parts designed to develop your understanding of how to estimate and monitor PV system performance and energy yield.

Topic 6.2 Learning Activity

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In this skills practice, you are required to select and size wiring systems and control and protection equipment to suit a given grid connected PV power system scenario, and to determine the energy yield and performance of the arrays. *It is recommended that this Skills Practice is carried out in conjunction with TSP05.2.*

Topic 6.2 Skills Practice

Undertaking this topic quiz will help you to confirm your understanding of the factors to consider when selecting Balance of System (BoS) equipment for PV power systems, including wiring, switchgear and controlgear.

Topic 6 Content Quiz

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Introduction

In this topic you will learn the various factors, standards and safety practices associated with the installation of grid connected PV power systems, including working on roofs, and installation labelling and identification requirements.

Workplace Health & Safety

The health and safety considerations for working on roofs are outlined in the following table:

Hazards	Risks	Control Measures
Working at heights.	Falls from heights, dropping tools/equipment.	Safety harness, non-slip footwear.
Manual handling.	Strains, sprains, cuts, abrasions.	Gloves, safe lifting methods, mechanical handling equipment.
UV radiation.	Sunburn, heat stroke, skin cancer.	Sun-cream, UV protected clothing, polarised safety glasses.

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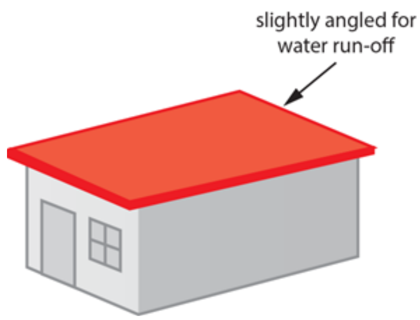
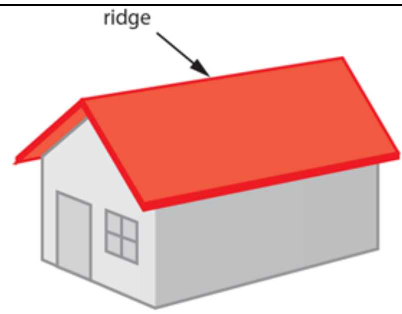
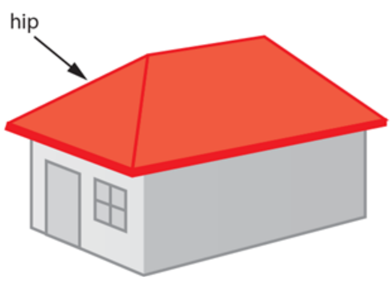
Energised parts (e.g. overhead services, consumer's mains and other LV cables).	Electric shock.	Exclusion zones around energised parts.
Asbestos.	Inhalation of asbestos fibres.	Removal of asbestos by an accredited contractor.

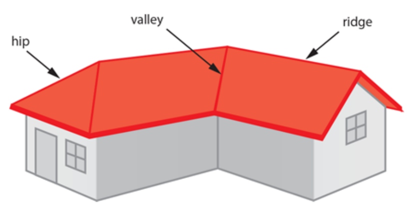
Roof Structures

In general, a roof structure will either be a concrete slab or consist of roofing material on a timber or metallic frame. There are a variety of common roof shapes, as shown in the following table:

<table>
<tr><th colspan="2">Basic Roof Structures</th></tr>
<tr>
<td>

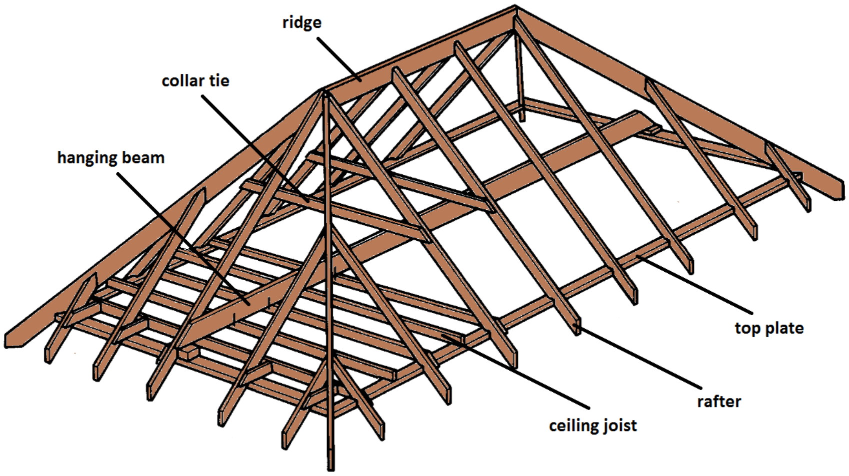
Flat Roof (slab or frame)</td>
<td>

Gable Roof (frame)</td>
</tr>
<tr>
<td>

Hip Roof (frame)</td>
<td>

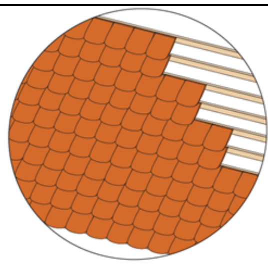
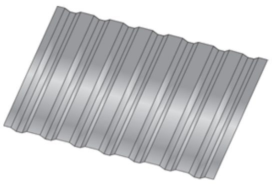
Hip and Valley Roof (frame)</td>
</tr>
</table>

Roof structures can be quite complex. The following diagram shows the basic arrangement of beams in a hip roof.



Roofing Materials

The type of roofing material will influence the method of mounting for a given PV array. Types of roofing materials that may be encountered in Australia are outlined in the following table.

Common Roofing Materials		
Type	**Appearance**	**Material**
Tiles		• Ceramic. • Concrete. • Clay. • Slate.
Shingles		• Asphalt. • Fiberglass. • Hardwood (older houses).
Sheet		• Flat steel. • Corrugated steel. • Corrugated asbestos.

PV Array Mounting Systems

PV array mounting systems can be classified into three main types: **?**

- Top-down rail systems.

- Racking systems.
- Pole mounting systems (top-of-pole/side-of-pole).

Top-Down Rail Systems

The following table outlines the features, advantages and disadvantages of top-down rail systems.

Top-Down Rail System	Features
	• Roof mounting system. • Feet are fixed to the rafters. • Aluminium rails fasten to the feet. • Clamps with stainless steel bolts fasten the PV array to the rails.
Advantages	**Disadvantages**
• Flexible configuration. • Fast and easy installation. • The array being parallel with the roof is typically more aesthetically pleasing.	• No tilt angle adjustment – roof tilt determines the tilt angle of the array. • Limited air circulation due to low roof clearance.

Racking Systems

The following table outlines the features, advantages and disadvantages of racking systems.

Racking System	Features
	• Roof mount, awning and free-standing types available. • Post type mounting feet are fixed to ground or roof surface. • Rails fasten to the array and posts. • Stainless steel bolts are used to fasten components in position.
Advantages	**Disadvantages**
• Rear posts offer tilt angle adjustment, clearance, and room for air circulation. • Generally, provide easy access to the rear of the panels.	• Less flexible mounting configuration – feet may need to be mounted at specific intervals. • Can result in poor aesthetics.

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Pole Mounting Systems

The following table outlines the features, advantages and disadvantages of pole mounting systems.

Pole Mounting System	**Features**
	• Free standing type. • Steel pole is mounted into the ground. • Array cross-brace assembly is fastened to the top of the pole with a mounting sleeve or to the side of the pole with a mounting bracket. • Stainless steel bolts are used to fasten components in position.
Advantages	**Disadvantages**
• Mounting sleeve offers tilt angle adjustment. • Maximum air circulation. • Easy access to the rear of the panels.	• More space required. • Generally, not aesthetically pleasing. • Excavation required for pole and cable trench.

Waterproofing

It is important to ensure the integrity of waterproofing is maintained when installing PV arrays on roofs. All mounting points should be effectively sealed with a waterproof sealant. Where cables enter the roof space through a penetration in the roof structure, a suitable gland/device designed for that purpose should be used to ensure a proper seal. Note that the use of silicon sealant as the main method of sealing penetrations is not generally considered to be appropriate.

This learning activity consists of 6 parts designed to develop your understanding of PV array installation practices, considerations and safety requirements.

 **Topic 7.1 Learning Activity**

In this skills practice, you are required to identify a suitable roof mounting system for a given PV installation and undertake a risk assessment for the installation of a PV array on the roof of a building. You will also develop a Safe Work Method Statement (SWMS) for the job.

 **Topic 7.1 Skills Practice**

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Australian Installation Standards

In addition to AS/NZS 3000:2018, there are a number of Australian Standards containing requirements related to the installation of low voltage grid-connected PV power systems, including:

- AS/NZS 5033:2021 Installation and safety requirements for photovoltaic (PV) arrays.
- AS/NZS 4777.1:2016 Grid connection of energy systems via inverters – Installation requirements.

The intent of these standards is to ensure safety, correct functionality, long life and ease of maintenance for the system.

AS/NZS 5033:2021 Overview

Some of the main factors and requirements affecting the installation of PV arrays are summarised in the following table.

AS/NZS 5033:2021 Overview	
Installation Factors	**Summary of Requirements**
PV Array Characteristics	PV array mounting frames are required to be: • Resistant to corrosion, including that caused by contact between dissimilar metals. • Capable of withstanding the required mechanical load. • Capable of withstanding any expected weather effects such as wind, snow or ice. • Installed in accordance with applicable building codes, regulations and standards.
PV Array Configurations	Any domestic PV system must not exceed a maximum d.c. circuit voltage of 1,000 V d.c. (note that the 2016 edition of AS/NZS 4777.1 still limits the maximum d.c. voltage to 600 V for domestic installations). The standard also illustrates permissible connection configurations for arrays and grid-connected inverters, and sets out the need for: • Bypass diodes. • Blocking diodes. • Switch disconnectors.

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Electrical Protection and Earthing	The standard sets out specific requirements for isolation, overcurrent protection, earth fault protection, overvoltage protection, protective earthing, and equipotential bonding. Disconnectors (isolation switches or circuit breakers) are required for the a.c. and d.c. sides of the grid-connected inverter, and either a disconnector or disconnection point (non-load break d.c. disconnection device) is required for the PV array. This is to ensure that these components can be safely disconnected from one another and from the grid. Some of the main requirements for switch-disconnectors are that they must: • Have a utilisation category of DC-PV2. • Break all live conductors at the same time. • Be capable of being locked in the open position. • Be rated to break the PV array prospective fault current. • Have at least one pole per polarity and must **not** be polarised. Appendix H provides guidance and example calculations for selecting suitably rated PV system switch-disconnectors.
PV System Cable Selection	All PV system wiring must: • Be suitable for the environmental conditions (e.g. UV, wind, rain, temperature etc.). • Be rated for direct current (d.c.). • Be rated to withstand the maximum d.c. circuit voltage. • Have a minimum cross-sectional area (c.s.a.) of 4 mm^2. • Be double insulated (where the maximum d.c. circuit voltage exceeds 35 V d.c.). • Have minimum current carrying capacity in accordance with Table 4.2 and AS/NZS 3008.1:2017. • A temperature rating of 40^0C above ambient temperature should be considered for cables that will be in close proximity to PV modules.
PV System Low Voltage Wiring	Low voltage PV system wiring must be installed in accordance with the Wiring Rules (AS/NZS 3000:2018). Care must be taken to ensure that wiring systems installed on roofs don’t obstruct water drainage or cause the accumulation of debris (e.g. leaves). PV arrays must be wired using flexible cables, and must **not** be primarily supported by plastic cable ties. PV array d.c. wiring must be segregated from a.c. wiring, and any d.c. wiring within wall cavities, roof spaces, under a floor, or installed externally in an accessible location must be enclosed in metal or HDPVC conduit (or equivalent wiring enclosure).
Identification and Documentation	PV system documentation must be prepared and provided to the owner of the system in the form of a system manual. Clause 6.2 lists the information required to be included. There are several requirements for PV system signage and labelling of various components that will be explored further on Content Page 7.3.

System Commissioning	Clause 6.3 and Appendix E set out the minimum inspection and testing activities required for commissioning a grid-connected PV power system. Appendix F provides details of additional commissioning procedures that may be required in some circumstances.

AS/NZS 4777.1:2016 Overview

Some of the main factors and requirements affecting the installation of grid-connected inverter systems are summarised in the following table.

Overview of AS/NZS 4777.1:2016	
Installation Factors	**Summary of Requirements**
Equipment Selection	The inverter used in the installation must comply with the requirements of AS/NZS 4777.2. Inverter wiring must be selected in accordance with AS/NZS 3000, AS/NZS 3008.1.1 and AS/NZS 5033 as applicable.
Installation Requirements	Inverter system wiring and equipment must be installed in accordance with the requirements of AS/NZS 4777.1 and the requirements of AS/NZS 3000 (except where varied by AS/NZS 4777.1). Inverters must be installed: • In accordance with the manufacturer's instructions. • In a well-ventilated and readily available location. • In a way that allows safe operation, inspection, testing, maintenance and repair. • So that they are protected against external influences. Inverters are not permitted to be installed in a restricted switchboard location, as defined in AS/NZS 3000.
Control and Protection	Control and isolation devices must be provided to allow safe operation, maintenance, testing, fault finding and repairs. A main switch for the inverter supply must be provided on the connecting switchboard that: • Operates in all active conductors. • Is capable of being secured in the OFF position. • Is rated to break the rated current of the inverter system. Protection devices must be provided to protect inverter system wiring against overloads, short-circuits and excessive earth leakage.

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Inverter Wiring and Connection	The inverter system must be connected to a dedicated circuit on the connecting switchboard, using flexible cables and approved connectors/couplings that have been designed for that purpose. The a.c. and d.c. circuits must be kept segregated from one another. Within an enclosure, this must be by an insulating barrier (e.g. PVC conduit). Outside of enclosures, this can be by either: • A minimum 50 mm separation. • An insulating barrier.
Wiring Systems	The inverter system wiring must be: • Supported to prevent mechanical strain on terminations. • Protected against any external influences (wind, rain, snow, direct sunlight etc.). • Enclosed when installed along roofs or floors. Wiring enclosures and supports must have a lifetime that exceeds that of the inverter system
Commissioning and Documentation	A system manual must be provided with each installation. Section 7 provides a list the required information to be included. Compliance and functionality of the installation must be verified in accordance with AS/NZS 3000:2018. This is done by visual inspection, mandatory testing, and some specific operational testing. Note that there are some additional specific details and parameters that must be noted on the verification report, as detailed in Section 7.

Battery Banks

It is becoming increasingly cost effective for consumers to include battery storage into their PV power systems. Battery technology is a large and quickly evolving field within the renewable sector, which is explored in depth in the other units of competency, including:

- UEERE0060 – Design grid-connected battery storage systems.
- UEERE0077 – Install battery storage equipment power conversion equipment to grid.
- UEERE0078 – Install battery storage to power conversion equipment.

This learning activity consists of 6 parts designed to develop your understanding of the installation requirements and standards that apply to grid-connected PV power systems.

Topic 7.2 Learning Activity

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PV System Identification

Where an electrical installation includes a low voltage grid-connected PV power system, a variety of signage and labels must be provided to ensure the safety of personnel who may need to isolate and/or work on the installation.

Section 6 of AS/NZS 4777.1:2016 sets out the minimum standards for these signs and labels. Appendix A provides further guidance and examples of compliant signs. The following items are required to be clearly identified:

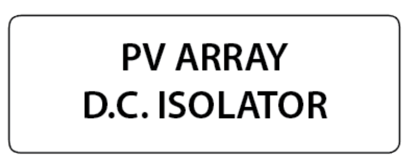
- The wiring between the PV array and the inverter.
- The inverter.
- The connecting switchboard.
- The inverter system main switch.
- The normal supply main switch (in the connecting switchboard).
- All intermediate switchboards between the connecting switchboard and the main switchboard.

Identification of Wiring

Wiring between the energy source and the inverter must be labelled at least every 2 m to indicate the type of energy source (e.g. 'SOLAR' or 'BATTERY'). An example of a compliant labelling, designed to be attached with cable ties, is shown below:

Inverter Signage

The a.c. and d.c. isolators installed adjacent to an inverter must be clearly identified. The following images show typical examples of these signs/labels:



Switchboard Signage

There are several items that must be identified at the switchboard to which the inverter directly connects (i.e. the connecting switchboard), as shown in the following table.

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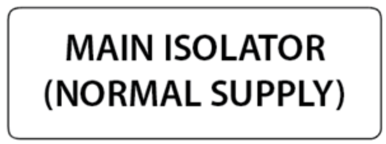
Connecting Switchboard Signage Requirements	
Signage Requirements	**Example**
A warning sign must be provided indicating that there are multiple supplies.	
The main switch for the inverter system must be clearly labelled.	
The main isolator/switch for the normal supply must also be labelled.	 (where the connecting switchboard is the main switchboard)  (where the connecting switchboard is a distribution board)
If the inverter is not installed next to the switchboard, then its location must be indicated.	

In the case that the connecting switchboard is a distribution board, then a warning sign must be provided at the main switchboard, and at each intermediate switchboard. The sign must indicate where to isolate the inverter supply. An example is shown below:

In larger installations, it may be necessary to indicate the locations of inverters on a building layout drawing, provided at the main switchboard and/or fire panel.

Shutdown Procedure Signage

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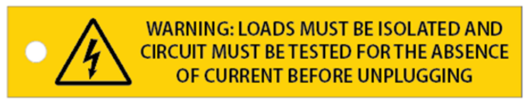
Signage indicating the shutdown procedure for the inverter system must be provided adjacent to the relevant switchgear to be operated.

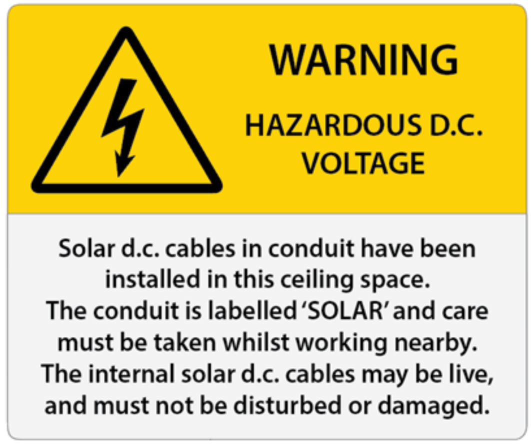
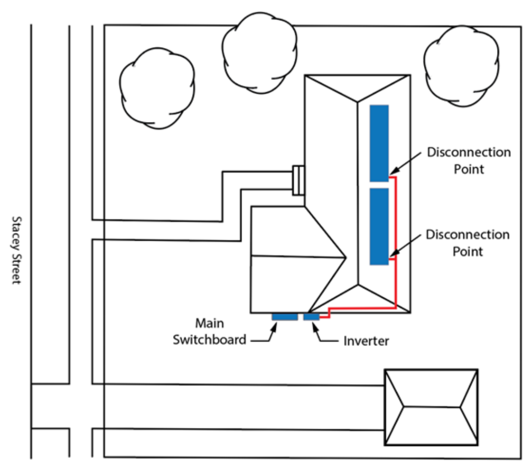
Consideration also needs to be given to the risks posed to emergency services workers. If the building has a fire panel, a warning sign must be provided that indicates the location of the shutdown procedure signage and switchgear.

Other Signage

Further AS/NZS 4777.1 signage requirements apply to installations containing multiple inverter supplies and energy sources, and for multimode inverters. See Section 6 for further details in these instances.

AS/NZS 5033:2021 also sets out several labelling and signage requirements for grid-connected PV systems, as summarised in the following table.

Additional PV System Signage Requirements (AS/NZS 5033:2021)	
Signage Requirements	**Example**
Disconnection points are required to be clearly labelled to ensure they are readily identifiable and will not be disconnected under load conditions.	 Sign for disconnection point
	 Sign for PV string disconnection point
	 Sign for system with multiple isolation/disconnection points, required adjacent to the PCE
PV d.c. wiring system junction boxes must be identified with a warning label.	

Entries to ceiling spaces or accessible floor spaces containing PV d.c. wiring systems must be identified with a warning label explaining the presence of the d.c. wiring system.	
A green circular sign must be placed on the main switchboard to warn emergency services that a PV supply exists. The sign must indicate the isolation arrangement: • DP – disconnection point • SW – load-break disconnector • AC – microinverters	
The layout of the solar system must be identified on a plan that shows the locations of the array and PCE, to be located either at the main switchboard, meter box or fire panel.	

Multimode Inverters – Additional Requirements

Additional risks are posed by grid-connected PV systems incorporating a multimode inverter that is capable of operating as a stand-alone power supply. The following additional requirements apply to multimode inverters:

- A main switch shall be provided for the stand-alone port of the inverter.
- The stand-alone port main switch shall be labelled "MAIN SWITCH (STAND-ALONE SUPPLY)".
- The inverter must provide an earth referenced a.c. supply when operating in stand-alone mode.
- The main switchboard shall be provided with a warning sign stating that neutral and earthing conductors may be live when the installation is operating in stand-alone mode.
- All final subcircuits supplied by the inverter must be RCD protected in accordance with AS/NZS 3000:2018.
- It is not permitted to protect the inverter grid-interactive port submain with an RCD.

There are also some additional requirements for multimode inverters stated in *AS/NZS 4777.2:2020 Grid connection of energy systems via inver' Inverter requirements*. When the multimode inverter is operating as a standalone supply:

- All active conductors must be isolated from the grid-interactive port, but the neutral conductor must not be interrupted (i.e. the grid protection should operate in the active conductors only).
- The total harmonic distortion (THD) of the standalone supply must not exceed 5%, and no individual harmonic may exceed 5%.

This learning activity consists of 6 parts designed to develop your understanding of the standards and requirements for identification and labelling of grid-connected PV power systems.

Topic 7.3 Learning Activity

Undertaking this topic quiz will help you to confirm your understanding of the standards and safety practices for installing grid connected PV power systems.

Topic 7 Content Quiz

Last modified: Tuesday, 12 September 2023, 12:56 PM

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Mark as done

Introduction

This unit cluster consists of 8 topics, exploring the design and installation of grid-connected photovoltaic (PV) power systems, including components, arrangements and configurations, standards and requirements, and associated safe working practices.

Each topic includes technical explanations, diagrams and activities designed to help you develop and reinforce your understanding. Topic skills practices give you the opportunity to practice the hand skills you'll need on the job, such as selecting PV equipment and installing system components. Finally, a quiz at the end of each topic allows you to check your progress against the topic requirements.

When you feel you have achieved the knowledge and skills in each topic, ask your teacher/trainer if you can sit the clustered unit tests. The Clustered Knowledge Test (CKT) is designed to determine your understanding of the unit concepts, whilst the Clustered Skills Test (CST) gives you the opportunity to demonstrate the planning, carrying out and completion of the practical tasks in the clustered units.

The experience you gain in the workplace can contribute to the completion of this unit. This can be achieved through the use of a compliant profiling system such as *Exemplar Profiling*. If you are using Exemplar Profiling, remember that it's important to review and discuss your progress regularly with your teacher/trainer.

Unit of Competence:

This course has been designed to facilitate blended delivery of the knowledge and skills contained in the Competency Standard Units:

- UEERE0061
- UEERE0080
- UEERE0081

Unit Learning Plan

The **Cluster Learning Plan** (CLP) specifies the assessment requirements, and defines the depth and breadth of knowledge and skills required for the Unit. It lists related learning and assessment resources, and provides a structured framework for delivery that is suitable for both traditional and blended approaches.

LMS Learner Components

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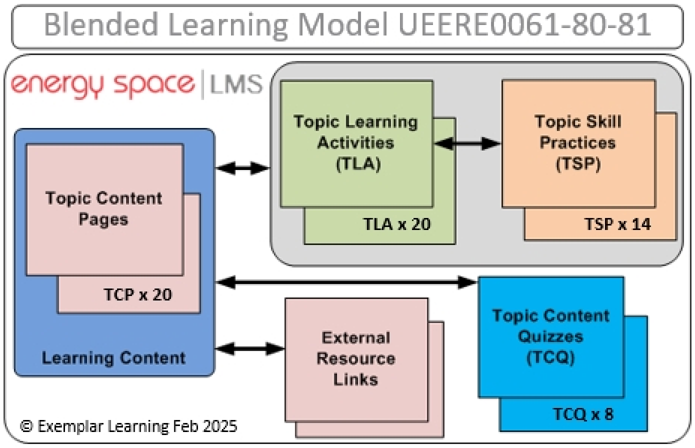

Topic Content Pages present the topic technical content using simple explanations, diagrams and interactive objects. These pages also provide links to external resources, learning activities, skills practices and quizzes, positioned like 'checkpoints' throughout the learning journey.

Load the Activity **Check Your Progress** activities provide short answer, drag and drop, and other interactions designed to assist in understanding the content.

External Resource Links and videos provide related information from external sources. All links to third party content are correct at the time of this course's publication.

Topic Learner Activities are intended to work in combination with RTO activities to support and reinforce learning..

Topic Skills Practices provide structured opportunities for the learner to develop their skills in an RTO or workplace environment.

Topic Content Quizzes provide the student with a way to confirm their understanding of the topic in preparation for the Unit Knowledge Assessment. The Topic Content Quiz contains multiple choice, matching and calculation questions that cover all aspects of the topic knowledge content. It is recommended that each Topic Content Quiz is completed prior to progressing to the next topic, and all quizzes should be completed prior to attempting the Unit Knowledge Assessment.

The Performance Indicator light will show according to your Topic Content Quiz score:


Score below 65%


Score between 65% and 85%


Score over 85%

Course Navigation

Navigate course content by selecting the required sub topic pages from the Home page, clicking on a link within the left hand navigation pane, or by clicking on the page navigation icons within each sub topic page, as per example below:

Previous

Home

Next

Get Started

Last modified: Tuesday, 4 February 2025, 12:56 PM

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online resources

Unit Learning Plan

UEERE0061 – Design grid-connected photovoltaic power supply systems

July 2023
Release No. 1.0

A division of ENERGY SKILLS AUSTRALIA ABN 22 070 582 017

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A. Overview

<table>
<tr><td>Competency Standard Unit (CSU)</td><td colspan="2">UEERE0061 Design grid-connected photovoltaic power supply systems</td></tr>
<tr><td>CSU Application</td><td colspan="2">This unit involves the skills and knowledge required to design grid-connected photovoltaic (PV) power supply systems.
It includes designing grid-connected PV power supply system, following design briefs, utilising data/information from site survey to determine design requirements, ensuring safety and performance standards and functional requirements are met, documenting and obtaining approval for design.
This unit is appropriate for Licenced Electricians or Electrical Engineers with responsibility for designing grid-connected photovoltaic power supply systems.
Licensing, legislative or certification requirements that apply to this unit may differ between jurisdictions and system types. They should be checked prior to commencing this unit.</td></tr>
<tr><td>Purpose of ULP</td><td colspan="2">The purpose of the Unit Learning Plan (ULP) is to define the depth and breadth of the knowledge and skills required to address the Competency Standard Unit (CSU) Assessment Requirements. It also indicates the recommended sequence and duration for the structured learning program, and provides a list of resources suitable for the delivery of the material using a blended approach.
In the context of this ULP, the term 'structured learning program' encompasses both the imparting of knowledge and skills and the completion of evidence gathering activities designed to address the Assessment Requirements. The structured learning program is generally undertaken off-the-job in a controlled learning environment.</td></tr>
<tr><td rowspan="3">Unit aspects addressed in this ULP</td><td>PC-UEERE0061</td><td>Performance Criteria</td></tr>
<tr><td>PE-UEERE0061</td><td>Performance Evidence</td></tr>
<tr><td>KE-UEERE0061</td><td>Knowledge Evidence</td></tr>
<tr><td rowspan="5">Suggested Durations</td><td>Completion of ULP topics 1 to 7</td><td>52 hours</td></tr>
<tr><td>Completion of Unit Knowledge Test</td><td>2 hours</td></tr>
<tr><td>Completion of Unit Skills Test</td><td>6 hours</td></tr>
<tr><td>Total duration of structured learning program</td><td>60 hours</td></tr>
<tr><td colspan="2">Note: These durations do not include the necessary workplace experience and final assessment of all evidence that must occur before competence can be determined.</td></tr>
<tr><td>Sequence</td><td colspan="2">Before undertaking this ULP a learner is to have completed the following Competency Standard Units or equivalent:
• UEERE0054 Conduct site survey for grid-connected photovoltaic and battery storage systems</td></tr>
</table>

	AND • UEEEL0039 Design, install and verify compliance and functionality of general electrical installations* **OR** • UEERE0051 Apply electrical principles to renewable energy design *Note that the following units are pre-requisites of UEEEL0039 (but are missing from the pre-requisite chain of UEERE0061 as shown on training.gov.au): • HLTAID009 Provide cardiopulmonary resuscitation • UEECD0007 Apply work health and safety regulations, codes and practices in the workplace • UEECD0016 Document and apply measures to control WHS risks associated with electrotechnology work • UEECD0019 Fabricate, dismantle and assemble utilities industry components • UEECD0020 Fix and secure electrotechnology equipment • UEECD0051 Use drawings, diagrams, schedules, standards, codes and specifications • UEEEL0003 Arrange circuits, control and protection for general electrical installations • UEEEL0005 Develop and connect electrical control circuits • UEEEL0008 Evaluate and modify low voltage heating equipment and controls • UEEEL0009 Evaluate and modify low voltage lighting circuits, equipment, and controls • UEEEL0010 Evaluate and modify low voltage socket outlets circuits • UEEEL0012 Install low voltage wiring, appliances, switchgear and associated accessories • UEEEL0014 Isolate, test and troubleshoot low voltage electrical circuits • UEEEL0018 Select wiring systems and cables for low voltage general electrical installations • UEEEL0019 Solve problems in direct current (d.c.) machines • UEEEL0020 Solve problems in low voltage a.c. circuit • UEEEL0021 Solve problems in electromagnetic devices • UEEEL0023 Terminate cables, cords and accessories for low voltage circuits • UEEEL0024 Solve problems in alternating current (a.c.) rotating machines • UEEEL0025 Test and connect transformers • UEEEL0047 Identify, shut down and restart systems with alternate supplies • UETDRRF004 Perform rescue from a live LV panel **AND** • UEECD0043 Solve problems in direct current circuits **OR** • UEECD0044 Solve problems in multiple path circuits • UEECD0046 Solve problems in single path circuits

B. Knowledge and Skills Delivery

1 Grid Connected PV Systems

Purpose:	In this topic you will learn about the arrangement and operational features of grid connected PV power systems, including functions such as synchronisation, safety and control features. You will also learn about how to determine the solar resource available at a given location, and the factors to consider when planning out a PV system.
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.

Knowledge and Skills Specification Content Areas	Unit Mapping[1]			Energy Space Resources
	KE	PC	PE	
1.1 PV System Features				
Knowledge				
Describe the basic installation configurations for a grid connected PV power systems.	7.2, 14	-	-	Topic 1 Content Quiz Topic 1.1 Learning Activity
Describe the operation of grid interactive PV systems including: • Synchronisation. • Safety features. • Power flow control. • Passive and active anti-islanding. • Metered energy.	10	-	-	
Skills				
Draw the block diagram of a PV grid connected system.	10, 14	-	-	Topic 1.1 Skills Practice
Draw schematic diagrams of common grid connected inverter circuit configurations including metering arrangements, isolation and connection with respect to RCDs in accordance with AS/NZS 4777.1.	7.2, 14	-	-	

1 Grid Connected PV Systems				
1.2 Solar Resource				
Knowledge				
Define the following terms: • Sunshine hours. • Irradiance. • Irradiation. • Latitude. • Azimuth and altitude angles. • Tilt angle.	1.1	-	-	Topic 1 Content Quiz Topic 1.2 Learning Activity
State the units and symbols for irradiation and irradiance.	1.1	-	-	
State the types and features of commonly available solar data.	1.2	-		
1.3 Array Positioning				
Knowledge				
Describe how radiation varies throughout the year on the surface of a fixed collector.	1.3	-	-	Topic 1 Content Quiz Topic 1.3 Learning Activity
Explain the factors affecting the optimal tilt and orientation of PV arrays	1.4	-	-	
Explain the principle and effect of solar tracking.	1.5	-	-	
Skills				
Determine the solar access for a given site.	1.2, 18, 19, 21	1.2	1, 2	Topic 1.3 Skills Practice
Select an appropriate location and tilt angle for a PV array at a given site.	1.4, 13, 18, 19, 21	2.1	1, 2	
Determine whether any shading will occur at a given site, and estimate its effect on the system.	18, 19, 21	1.2	1, 2	

1 Grid Connected PV Systems				
Estimate the solar resource for a given site.	1.2, 18, 19, 21	1.2	1, 2	
Present system design to teacher/trainer/assessor and finalise any alternations if necessary.	20, 21	2.3, 2.4	3	

Reference Text:

- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.
- Pethebridge, K. and Neeson, I., Electrical Wiring Practice, McGraw-Hill.

Standards:

- AS/NZS 4509 Stand-alone power systems.
- AS/NZS 5033 Installation and safety requirements for photovoltaic (PV) arrays.

2 PV Technology				
Purpose:	In this topic you will learn about the various terminology used in relation to the various types of photovoltaic modules and operating principles of the photovoltaic modules.			
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.			
Knowledge and Skills Specification Content Areas	**Unit Mapping[1]**			**Energy Space Resources**
	KE	**PC**	**PE**	
2.1 PV Cells and Modules				
Knowledge				
Define the following terms: • Cell. • Module. • String. • Array.	2.1	-	-	Topic 2 Content Quiz Topic 2.1 Learning Activity
Explain the different types of PV technology and their applications, including monocrystalline, polycrystalline and amorphous.	2.2, 17	-	-	
Describe the mechanical and electrical features necessary for the long life of a PV module under a wide range of operating conditions	2.3	-	-	
Skills				
Draw an equivalent circuit for a PV cell, labelling each of the elements and the polarity of the terminals.	2.1	-	-	Topic 2 Content Quiz Topic 2.2 Skills Practice
2.2 PV Module Characteristics				
Knowledge				
Define the following terms: • I-V curve. • Operating point.	3.1, 17	-	-	Topic 2 Content Quiz Topic 2.2 Learning Activity

2 PV Technology				
• Maximum power point (MPP). • Power and voltage temperature co-efficient. • Standard test conditions (STC). • Nominal operating cell temperature (NOCT).				
List the major ratings of a PV module as specified in manufacturer's data.	3.2, 17	-	-	
Skills				
Draw and label a family of I-V curves for a PV module, labelling major points.	3.1, 17	-	-	Topic 2.2 Skills Practice
Determine the major ratings of a PV module from the manufacturer's data.	3.2, 17	1.2	-	
Determine the electrical characteristics of a PV module.	3.1, 17	1.2	-	

Reference Text:
- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.

Standards:
- AS/NZS 5033 Installation and safety requirements for photovoltaic (PV) arrays.

Equipment:
- Manufacturer's catalogues.

3 PV Arrays				
Purpose:	In this topic you will learn about the arrangement of PV arrays, including series and parallel module configurations, and the arrangement of blocking and bypass diodes. You will also learn about BIPV products, and the factors to consider when selecting PV modules for a given installation.			
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.			

Knowledge and Skills Specification Content Areas	Unit Mapping[1]			Energy Space Resources
	KE	PC	PE	
3.1 PV Module Arrangements				
Knowledge				
Describe the configuration of a typical PV array, including the function, placement and ratings of blocking and bypass diodes.	3.3, 6.2	-	-	Topic 3 Content Quiz Topic 3.1 Learning Activity
Explain the effect of partial shading of a PV module or array, the impact of bypass diodes and the significance of their configuration on output current in typical operating conditions.	3.4	-	-	
Skills				
Specify a PV array wiring plan for series connected modules to minimise power loss due to shading at a particular site.	3.3, 3.4, 21	2.1, 2.2, 2.3	2	Topic 3.1 Skills Practice
Determine the minimum and maximum number of PV modules required in a string to achieve a specified operating voltage.	6.2, 21	2.1, 2.2, 2.3	2	
3.2 PV Array Selection				
Knowledge				
State the WHS/OHS requirements and risk management for selecting PV equipment.	18, 19	-	-	Topic 3 Content Quiz

3 PV Arrays				
Explain the factors that need to be considered and documented when selecting and sizing a PV array for a grid-connected inverter system, including: • Verification of site survey data. • Annual energy demand. • Budget constraints. • Architectural constraints. • Limitations on available inverter sizes.	5, 6.1, 13, 20, 21	-	-	Topic 3.2 Learning Activity
Skills				
Select and size a PV array for a grid-connected inverter system based on annual energy demand, budget constraints, architectural constraints and/or inverter limitations.	5, 6.1, 17, 18, 19, 21	1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3	1, 2	Topic 5.2 Skills Practice
Present system design to teacher/trainer/assessor and finalise any alternations if necessary.	20, 21	2.3, 2.4	3	

Reference Text:
- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.

Standards:
- AS/NZS 4509 Stand-alone power systems.
- AS/NZS 5033 Installation and safety requirements for photovoltaic (PV) arrays.

Equipment:
- Manufacturer's catalogues.

4 Basic Inverter Principles

Purpose:	In this topic you will learn about the purpose and basic operation of inverters. You will also have the opportunity to connect an inverter and measure the input and output parameters.
Duration:	This topic represents around 6.7% of the knowledge and skills specification contents, and should take the learner approximately 4 hours to achieve the topic requirements.

Knowledge and Skills Specification Content Areas	**Unit Mapping[1]**			**Energy Space Resources**
	KE	**PC**	**PE**	
4.1 Introduction to Inverters				
Knowledge				
List the different types of inverters used in grid connected systems.	9.1	-	-	Topic 4 Content Quiz Topic 4.1 Learning Activity
Describe the basic function of an inverter.	9.2	-	-	
Skills				
Draw the Australian standard symbol for a low voltage inverter.	9.1	-	-	Topic 4.1 Skills Practice
Draw a simple block diagram of a typical inverter used in a grid connected system.	9.2	-	-	
4.2 Inverter Operations				
Knowledge				
Explain the basic principle of operation of a single-phase inverter bridge.	9.3	-	-	Topic 4 Content Quiz Topic 4.2 Learning Activity
Describe the function of PWM techniques in square wave, modified square wave and synthesised sine wave inverters.	9.3	-	-	
Skills				
Connect a grid inverter and measure the inverter parameters for various loads.	9.3	-	-	Topic 4.2 Skills Practice

4 Basic Inverter Principles

Reference Text:

- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.
- Pethebridge, K. and Neeson, I., Electrical Wiring Practice, McGraw-Hill.

Standards:

- AS/NZS 4777 (Series) Grid connection of energy systems via inverters.

Equipment:

- Grid-connected inverter.
- d.c. supply.
- Variable a.c. load.
- a.c. and d.c. voltmeters.
- a.c. and d.c. ammeters.
- Cathode ray oscilloscope.
- PV array.
- PPE and hand tools.
- Connection leads.

5 Grid-Connect Inverters				
Purpose:	In this topic you will learn about the types of inverters that are suitable for grid connected applications, and the factors to consider when selecting grid connect inverters.			
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.			

Knowledge and Skills Specification Content Areas	**Unit Mapping[1]**			**Energy Space Resources**
	KE	**PC**	**PE**	
5.1 GC Inverter Characteristics				
Knowledge				
List the characteristics that distinguish inverters suitable for grid connected photovoltaic array application from standard inverters.	9.4	-	-	Topic 5 Content Quiz Topic 5.1 Learning Activity
Outline the function and operation of a "grid protection device" as specified in AS/NZS 4777.	10	-	-	
5.2 GC Inverter Selection				
Knowledge				
State the key inverter ratings and specifications, including: • Continuous rating. • Half-hour rating. • Surge rating. • Operating window. • Efficiency. • IP rating.	11.1, 17	-	-	Topic 5 Content Quiz Topic 5.2 Learning Activity
Explain the factors that need to be considered and documented when selecting and sizing a grid connected inverter.	11.2, 17, 20, 21	-	-	
Skills				

5 Grid-Connect Inverters				
Determine the operating window of an inverter for given minimum and maximum effective cell temperatures.	11.1, 17, 18, 19, 21	-	-	Topic 5 Content Quiz Topic 5.2 Learning Activity Topic 5.2 Skills Practice
Select a grid connected inverter for a given PV array.	5, 11.1, 11.2, 17, 18, 19, 21	1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3	1, 2	
Present system design to teacher/trainer/assessor and finalise any alternations if necessary.	20, 21	2.3, 2.4	3	

Reference Text:

- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.
- Pethebridge, K. and Neeson, I., Electrical Wiring Practice, McGraw-Hill.

Standards:

- AS/NZS 4777 (Series) Grid connection of energy systems via inverters.

Equipment:

- Manufacturer's catalogues.

6 Other Design Factors	
Purpose:	In this topic you will learn about various other factors to consider in the design of PV power systems, including the selection of wiring and switchgear. You will practice selecting equipment for given scenarios, and also learn how to estimate the energy yield, specific yield and performance ratio of a given system.
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.

Knowledge and Skills Specification Content Areas	**Mapping[1]**			**Energy Space Resources**
	KE	**PC**	**PE**	
6.1 Wiring and Switchgear Selection				
Knowledge				
Explain the factors that need to be considered when selecting and sizing control and protection equipment for grid-connected inverter systems.	4, 5, 7.1, 17, 21	-	-	Topic 6 Content Quiz Topic 6.1 Learning Activity
List the factors to be considered when selecting and sizing wiring systems for grid-connected PV systems.	4, 5, 7.1, 17, 21	-	-	
Describe the other economic/financial, contractual/institutional, and legislative/regulatory factors that impact the design, installation and operation of grid-connected PV systems.	8.3	-	-	
Skills				
Verify the details for a proposed grid-connected inverter system from a given job specification.	5, 21	1.1, 1.2, 1.3, 1.4	1, 2	Topic 6.2 Skills Practice
Select and size a.c. and d.c. wiring systems for a given grid-connected PV system.	7.1, 17, 18, 19, 21	1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3	1, 2	
Select and size control and protection equipment for a given grid-connected PV system.	7.1, 17, 18, 19, 21	1.1, 1.2, 1.3, 1.4, 2.1, 2.2, 2.3	1, 2	

6 Other Design Factors				
Present system design to teacher/trainer/assessor and finalise any alternations if necessary.	20, 21	2.3, 2.4	3	
6.2 PV System Performance				
Knowledge				
Explain what is meant by the term 'energy yield' in relation to PV power systems.	8.1	-	-	Topic 6 Content Quiz Topic 6.3 Learning Activity
Explain what is meant by the term 'specific energy yield' in relation to PV power systems.	8.1	-	-	
Explain what is meant by the term 'performance ratio' in relation to PV power systems.	8.2	-	-	
State the factors affecting the need for monitoring PV system performance at a given site.	8.1, 8.2	-	-	
Skills				
Determine and document the energy yield, specific energy yield and performance ratio for the annual reduction in greenhouse gas emissions for a given grid-connected PV system.	8.1, 8.2, 21	2.3, 2.4	2, 3	Topic 6.2 Skills Practice

Reference Text:
- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.

Standards:
- AS/NZS 3000 Wiring Rules.
- AS/NZS 3008.1.1 Electrical installations – Selection of cables.
- AS/NZS 4509 Stand-alone power systems.
- AS/NZS 5033 Installation and safety requirements for photovoltaic (PV) arrays.

7 PV System Installations				
Purpose:	In this topic you will learn the various factors, standards and safety practices associated with the installation of grid connected PV power systems, including working on roofs, and installation labelling and identification requirements.			
Duration:	This topic represents around 13.3% of the knowledge and skills specification contents, and should take the learner approximately 8 hours to achieve the topic requirements.			
Knowledge and Skills Specification Content Areas	**Unit Mapping[1]**			**Energy Space Resources**
	KE	**PC**	**PE**	
7.1 PV Array Installation Practices				
Knowledge				
State the safety hazards, risks and control measures for working on roofs.	12, 18, 19	-	-	Topic 7 Content Quiz Topic 7.1 Learning Activity
Describe common types of roof-mounted and free-standing PV array frame construction, brackets, mounting and fixing methods.	12, 15, 17	-	-	
Skills				
Perform a risk assessment for installing a PV array on a roof at a given site.	18, 19	1.1	1	Topic 7.1 Skills Practice
7.2 Installation Requirements				
Knowledge				
State the major AS/NZS 4777 and AS/NZS 5033 installation requirements for grid-connected inverter systems to ensure correct operation, long life, safety and ease of maintenance.	4, 12, 15, 20	-	-	Topic 7 Content Quiz Topic 7.2 Learning Activity
7.3 Identification and Labelling				
Knowledge				

7 PV System Installations				
Outline the labelling and signage requirements for switchboards supplied with power from grid connected inverters, as set out in AS/NZS 4777.1.	16, 20	-	-	Topic 7 Content Quiz Topic 7.3 Learning Activity
Outline the additional requirements for the use of multimode inverters incorporating stand-alone (previously UPS) functionality, as specified in AS/NZS 4777.1.	16, 20	-	-	

Reference Text:

- Photovoltaic Power Systems – Resource Book, Commonwealth of Australia and Brisbane Institute of TAFE.
- Pethebridge, K. and Neeson, I., Electrical Wiring Practice, McGraw-Hill.

Standards:

- AS/NZS 5033 Installation and safety requirements for photovoltaic (PV) arrays.
- AS/NZS 4777 (Series) Grid connection of energy systems via inverters.

Legend:

KE	Knowledge Evidence	**PC**	Performance Criteria
PE	Performance Evidence		