5

Inverters and Other System Components

In addition to the PV modules, a PV system requires other components in order to interact effectively and safely with the power grid. This chapter discusses inverters, PV combiner boxes and metering (net and gross). PV arrays are covered in Chapter 4 and the PV array frame is discussed in Chapter 6.

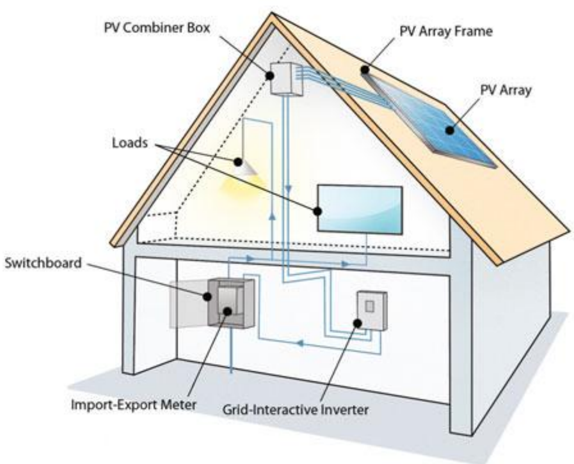


Figure 5.1 The primary system components are shown in this diagram (other configurations are possible). This is a net-metering arrangement where the electricity generated by the PV array and converted to AC by the grid-interactive inverter is either used on site or exported to the grid

Source: Global Sustainable Energy Solutions

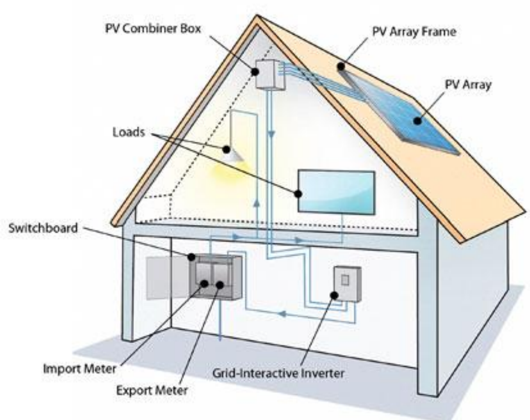


Figure 5.2 Alternative PV system using a gross-metering arrangement where all the power generated by the PV array is exported to the grid and all the power required by the loads is imported from the grid

Source: Global Sustainable Energy Solutions

Inverters

Photovoltaic arrays produce DC, while the typical electricity grid is AC and most electrical devices operate on AC power. To ensure that the power produced by a PV array will flow into the grid, it is necessary for an inverter to convert the DC power produced by the PV array to AC power.

The circuit design of inverters makes this conversion possible: the alternating current is created by the inverter's switching mechanisms, which rapidly open and close the circuit. Transformers, discussed later in the chapter, are then used to increase the voltage to the level required by the grid.

There are two main types of inverters: battery or power inverters, which use batteries as their power source, and grid-interactive inverters, which are used in grid-connected PV systems.

Battery inverters

Many people are familiar with using an inverter when operating standard AC appliances from DC power sources, such as a car battery or larger storage batteries. The inverter takes the DC battery power and converts it to AC for use in AC circuits and loads. These inverters are usually referred to as battery inverters or power inverters. Battery inverters have a wide range of applications and are used in stand-alone PV systems; they are very different from the type of inverter used in grid-connected systems (see Chapter 1). Normally these inverters range from 1kW to 5kW continuous output.

There are also inverter-charger products that are used in off-grid and back-up power systems and these are able to be connected to the grid and can function in a number of different ways: (1) can feed the PV power to charge batteries; (2) can feed power via the inverter to AC loads or to the grid; (3) can feed power from the batteries through the inverter to supply AC power; etc. The various operating options for these inverter-chargers are determined by the individual product and the specifications should be checked closely to confirm this type of product's suitability.

Grid-interactive inverters

This type of inverter, also known as a grid-tied inverter, is used in grid-connected systems and many different models are currently available. They receive the DC input from the array and match it to the AC output required by the utility grid. The inverter will only function when the grid is present and is working within a specific voltage and frequency range. Whether an inverter-charger feeds power back to the grid will be determined by the operating specifications of the unit itself, e.g. a US manufacturer of inverter-chargers has one model which is used only with mains or DC power input and cannot export to the grid and another model which has a software change to allow the inverted AC power to be exported to the grid.

All grid interactive inverters perform these basic functions:

- Convert the DC power from the PV array into AC power that can be used by appliances on site or fed back into the grid via the meter. Without a grid-interactive inverter it is impossible to export the electricity produced by a PV system into the grid.
- Ensure that the power being fed into the grid is at the appropriate frequency and voltage. If the inverter is unable to convert the DC power to match the grid's appropriate frequency and voltage, it will not release electricity to the grid.
- Use 'maximum power point tracking' (MPPT) to ensure that the inverter is finding the maximum power available from the PV array to convert to AC.
- The inverter has inbuilt active and passive safety protections to ensure that the inverter shuts itself down when the grid is not operating within acceptable voltage and frequency tolerances. This is discussed here in the section on inverter protection systems.

Grid interactive inverters may be different in a number of ways depending on:

- whether or not the inverter has a transformer;
- the switching frequency of the transformer used;
- how the PV array and inverter interface with each other;
- the inverter's rated capacity;
- whether the inverter has a single string or multiple string PV power inputs;
- whether the inverter is designed for single phase or multiple phase power supplies.

Transformers

Transformers are devices that use magnetic fields to increase or decrease the voltage of a power source. Traditionally all grid-interactive inverters incorporate

Figure 5.3 An electrician tests a grid-interactive inverter

Source: Global Sustainable Energy Solutions

transformers of varying types, e.g. high- or low-frequency switching. As electronics have improved rapidly, many transformer-less inverter models are now available. Although not widely used in the US, they are becoming popular in Europe and Australia. Transformer-less inverters offer the advantages of being lighter and having a higher efficiency than the traditional product. A transformer, however, can provide electrical isolation because the circuits are connected by a magnetic field (often referred to as 'galvanic isolation') rather than by physical wires as in transformer-less inverters. The disadvantage of transformer-less inverters is that they may inject a small amount of DC power into the grid due to the lack of electrical isolation. Sometimes a small isolating transformer is used to prevent DC injection.

Transformers used in inverters are either low frequency or high frequency. High-frequency transformers are more efficient and lighter than low-frequency transformers but are also more complicated to manufacture.

Figure 5.4 A transformer-less inverter is generally smaller, lighter and more efficient than an inverter of the same size (in kW) with a transformer

Source: SMA Solar Technology AG

Figure 5.5 Inverters with transformers are still the dominant technology in many locations; in the US they are used in almost all PV systems

Source: SMA Solar Technology AG

The maximum array power output the inverter can receive

Array voltage must not exceed this value

Array current must not exceed this value

Inverter efficiency

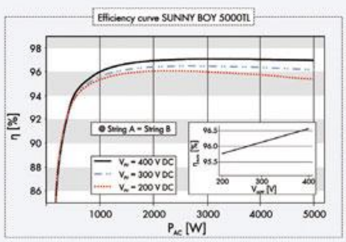
Physical details

Inverter must be installed in this temperature range

Indicates what environment the inverter can be installed in

Warranty

Technical data	Sunny Boy 3000TL	Sunny Boy 4000TL	Sunny Boy 4000TL/V	Sunny Boy 5000TL
Input (DC)				
Max. DC power (@ cos φ =1)	3200 W	4200 W	4200 W	5300 W
Max. DC voltage	550 V	550 V	550 V	550 V
MPP voltage range	188 V - 440 V	175 V - 440 V	175 V - 440 V	175 V - 440 V
DC nominal voltage	400 V	400 V	400 V	400 V
Min. DC voltage / start voltage	125 V / 150 V	125 V / 150 V	125 V / 150 V	125 V / 150 V
Max. input current / per string	17 A / 17 A	2 x 15 A / 15 A	2 x 15 A / 15 A	2 x 15 A / 15 A
Number of MPP trackers / strings per MPP tracker	1 / 2	2 / A: 2, B: 2	2 / A: 2, B: 2	2 / A: 2, B: 2
Output (AC)				
AC nominal power (@ 230 V, 50 Hz)	3000 W	4000 W	3680 W	4600 W
Max. AC apparent power	3000 VA	4000 VA	4000 VA	5000 VA
Nominal AC voltage; range	220, 230, 240 V; 180 - 280 V	220, 230, 240 V; 180 - 280 V	220, 230, 240 V; 180 - 280 V	220, 230, 240 V; 180 - 280 V
AC grid frequency; range	50, 60 Hz; ± 5 Hz	50, 60 Hz; ± 5 Hz	50, 60 Hz; ± 5 Hz	50, 60 Hz; ± 5 Hz
Max. output current	16 A	22 A	22 A	22 A
Power factor (cos φ)	1	1	1	1
Phase conductors / connection phases	1 / 1	1 / 1	1 / 1	1 / 1
Efficiency				
Max. efficiency / Euro-eta	97.0 % / 96.3 %	97.0 % / 96.4 %	97.0 % / 96.4 %	97.0 % / 96.5 %
Protection devices				
DC reverse-polarity protection	●	●	●	●
ESS switch-disconnector	●	●	●	●
AC short circuit protection	●	●	●	●
Ground fault monitoring	●	●	●	●
Grid monitoring (SMA Grid Guard)	●	●	●	●
Galvanically isolated / all-pole sensitive fault current monitoring unit	–/●	–/●	–/●	–/●
Protection class / overvoltage category	I / III	I / III	I / III	I / III
General data				
Dimensions (W / H / D) in mm	470 / 445 / 180	470 / 445 / 180	470 / 445 / 180	470 / 445 / 180
Weight	22 kg	25 kg	25 kg	25 kg
Operating temperature range	-25 °C ... +60 °C	-25 °C ... +60 °C	-25 °C ... +60 °C	-25 °C ... +60 °C
Noise emission (typical)	≤ 25 dB(A)	≤ 29 dB(A)	≤ 29 dB(A)	≤ 29 dB(A)
Internal consumption: (night)	< 0.5 W	< 0.5 W	< 0.5 W	< 0.5 W
Topology	transformerless	transformerless	transformerless	transformerless
Cooling concept	Convection	OptiCool	OptiCool	OptiCool
Electronics protection rating / connection area (as per IEC 60529)	IP65 / IP54	IP65 / IP54	IP65 / IP54	IP65 / IP54
Climatic category (per IEC 60721-3-4)	4K4H	4K4H	4K4H	4K4H
Features				
DC connection: SUNCLIX	●	●	●	●
AC connection: screw terminal / plug connector / spring-type terminal	–/–/●	–/–/●	–/–/●	–/–/●
Display: text line / graphic	–/●	–/●	–/●	–/●
Interfaces: RS485 / Bluetooth	○/●	○/●	○/●	○/●
Warranty: 5 / 10 / 15 / 20 / 25 years	●/○/○/○/○	●/○/○/○/○	●/○/○/○/○	●/○/○/○/○
Certificates and permits (more available on request)	CE, VDE 0126-1-1, DK 5940, RD 1663, G83/1-1, PPC, AS4777, EN 50438*, C10/C11, PPDS			
* Does not apply to all national deviations of EN 50438				
● Standard features ○ Optional features – not available				
Data at nominal conditions				
Type designation	SB 3000TL-20	SB 4000TL-20	SB 4000TL-20/V 0159	SB 5000TL-20



Accessories

www.SMA-Solar.com

SMA Solar Technology AG

Figure 5.6 Just like PV modules all inverters come with a data sheet outlining important information; see also Chapter 9

Source: SMA Solar Technology AG

Mainstream inverter technologies

Here are the general categories of grid-interactive inverters. Within each category there are numerous inverter brands and models available in varying sizes and features. It is very important to use the correct inverter, as discussed in Chapter 9.

Box 5.1 Maximum power point trackers

The maximum power point tracker (MPPT) uses electronics so that the PV array operates to produce the maximum amount of power possible. The MPPT is not a mechanical tracking system, but an electronics-based system that can vary the electrical operating point of the modules to ensure optimum performance and therefore maximum output.

The MPPT tracks the maximum power point (P_{mp}) of the array at regular intervals throughout the day (i.e. because of differing irradiance conditions or shading). The sophisticated electronics of the inverter then convert the maximum power from the array into 220V AC.

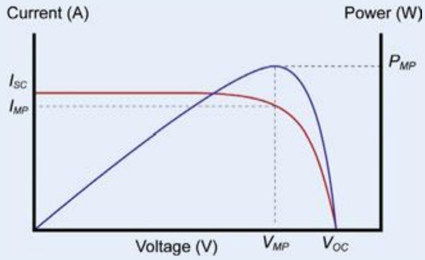


Figure 5.7 I-V curve with the power curve superimposed to find I_{mp} and V_{mp}

Source: Global Sustainable Energy Solutions

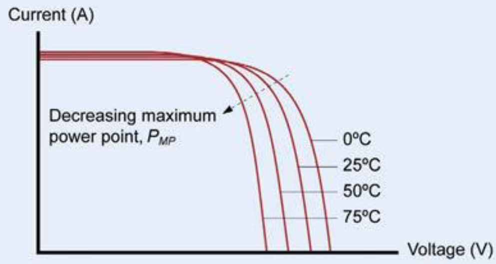


Figure 5.8 The maximum power point falling as temperature increases

Source: Global Sustainable Energy Solutions

String inverters

String inverters are used in small systems ranging from 1kWp to 11kWp. String inverters will all have one maximum power point tracker (MPPT) and the DC input voltages could vary from extra low voltage (ELV) right up 1000 volts DC (low voltage, LV). String inverters can be connected in a variety of ways as shown in Figures 5.9, 5.10 and 5.11.

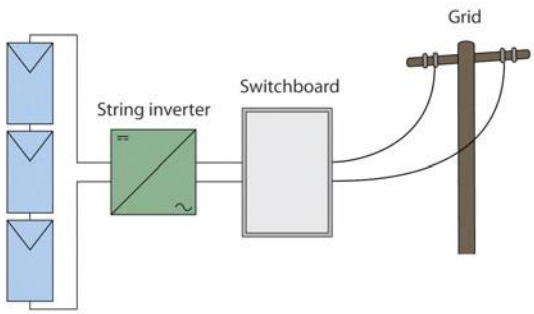


Figure 5.9 String inverter connected across one string of PV modules. The PV array comprises two parallel strings with a single input to the inverter, which means the inverter is only receiving power from the one combined PV string; this is a more stable set-up as there is no potential for interference from other strings

Source: Global Sustainable Energy Solutions

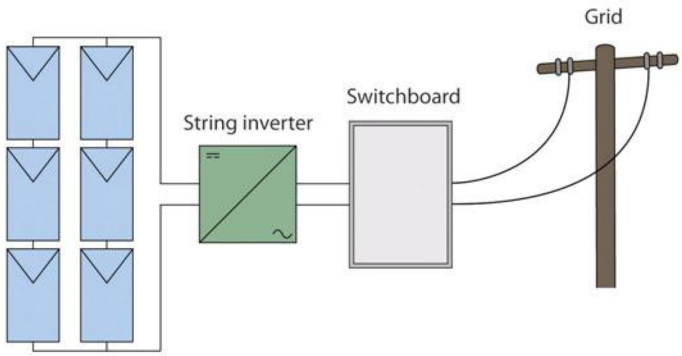


Figure 5.10 It is possible to connect multiple strings across the same string inverter, but if one string has a lower output (due to shading or damage) it will affect the output of the entire array

Source: Global Sustainable Energy Solutions

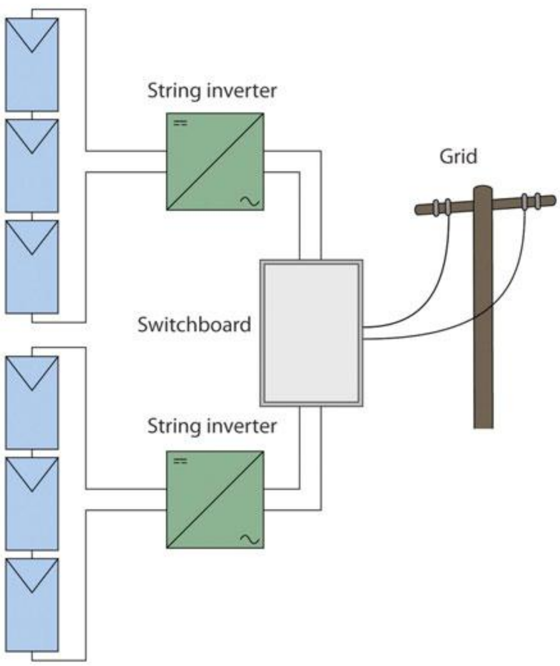


Figure 5.11 Multiple inverters can be used to increase the reliability of the system; if one inverter malfunctions, the others will still work and the system can continue to export power

Source: Global Sustainable Energy Solutions

Multi-string inverter

A multi-string inverter is a single inverter appliance, but it has a number of MPPT inputs. Therefore the PV array can be divided into multiple strings and a suitable combination of strings connects to each one of the inverter's MPPT inputs.

These inverters have the advantage that if the modules are facing different directions then the array could be divided into strings so that modules in the same string are all facing the same direction. These individual strings then connect to a dedicated MPPT so that the energy yield from the system will be

Figure 5.12 Multi-string inverters installed by Solgen Energy on Cockatoo Island for Sydney Harbour Federation Trust

Source: Solgen Energy

greater than if the strings were connected to an inverter with only one MPPT. A multi-string inverter is generally cheaper than using a number of individual inverters and can offer the advantage of higher energy output for arrays where parts of the array face different directions or experience different levels of shading.

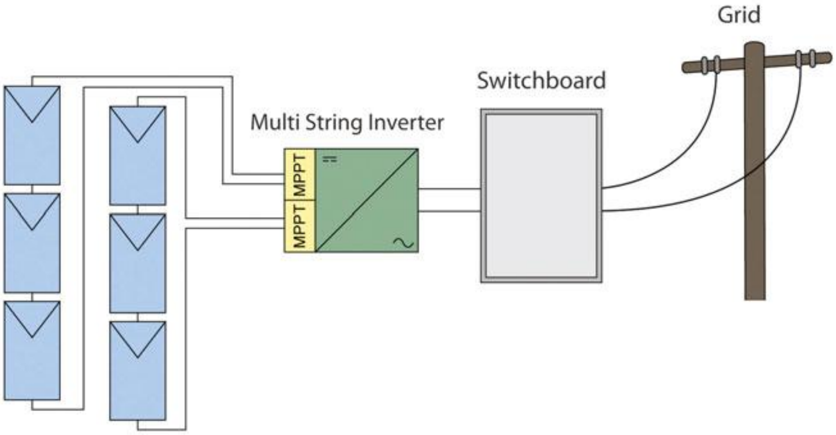


Figure 5.13 Two strings are each connected to different MPPTs so that if one is shaded it will not reduce the output of the other

Source: Global Sustainable Energy Solutions

Central inverter

A central inverter is very similar to the string inverter with multiple strings – the difference is that central inverters are generally used for a large system (>10kWp). In these systems the array could be divided into a number of sub-arrays, each comprising a number of strings.

In some systems there is just one large inverter suitable for the whole array or the single central inverter might be a single enclosure housing several smaller multi-string inverters combining to represent a single, electrical output. In others there will be a number of inverters, for example 5 × 20kW inverters for a 100kW system.

Some manufacturers of these large central inverters have rationalized their design: e.g. a central inverter can comprise multiples of smaller inverters that can operate selectively depending on the amount of power that can be produced from the available sunlight. This configuration improves the operating efficiency of the central inverter unit, especially when required to operate at less than peak load.

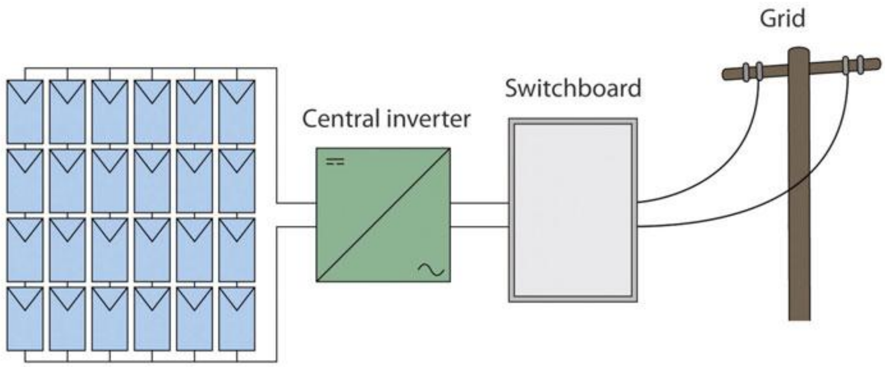


Figure 5.14 Connecting multiple strings to a central inverter

Source: Global Sustainable Energy Solutions

Figure 5.15 For very large installations a whole room of central inverters may be required. These are SMA Sunny Mini Central inverters

Source: SMA Solar Technology AG

Modular inverters

Modular inverters (also known as micro-inverters) are small transformer-less inverters (some will have an isolating transformer to minimize DC injection currents) designed to be mounted on the back of the PV module.

Over the years there have been a number of modular inverters manufactured in the range 100–300W. This product has re-emerged during 2009 for the grid-connect PV market. Two main advantages of the modular inverter are that they remove the requirement for DC cabling from the array as each module has an AC output and these AC cables can be paralleled at each module and then connected to the grid at the appropriate location. These inverters are also small and easy to handle, and they have the advantage of being modular (just like PV modules), which means that more modules and inverters can be added to the system in future at minimum cost.

In the past, modular inverters were generally more expensive, i.e. the cost per unit of power ($ per W) was higher than other inverters; but the latest modular inverters on the market are a similar cost $/watt to installing a single inverter for a PV installation.

The disadvantages of modular inverters are related to the fact that they are installed on the back of PV modules. If the inverter fails, repairing or replacing it involves removing the modules from the array to access the inverter behind it. In addition, designers may be wary of using modular inverters in hot climates. As discussed in Chapter 4, PV modules heat up considerably during

Figure 5.16 Micro-inverter attached to the back of a module

Source: Global Sustainable Energy Solutions

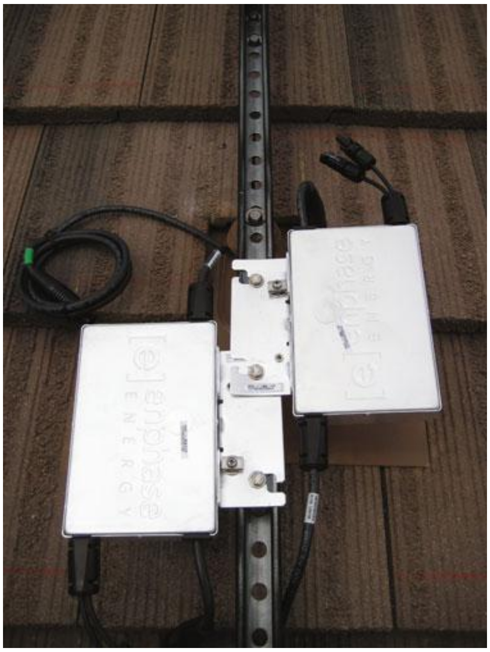


Figure 5.17 Micro-inverter available on the US market

Source: BMC Solar

the day, so the inverter will operate at a higher temperature than it would be if it were located on a shaded wall or indoors, increasing the risk of inverter failure. The operating characteristics of modular inverters under high temperatures should be provided by the manufacturer.

These latest micro-inverters offer similar data logging and communications features as other inverters on the market either via the AC power system at the location or via a website.

Table 5.1 Inverter types and characteristics

Inverter type	Modular	String	Multi-string	Central
Power range	100–300W	700–11,000W	2000–17,000W	10,000–300,000W
MPPT	Yes	Yes	Multiple	Multiple
Typical efficiency	95%	93–97%	97%	97%
Advantages	No DC cabling; easy to add more modules	Readily available	Multiple MPPTs; readily available	Lower $/W cost; one location for maintenance
Disadvantages	Replacing a faulty inverter can be difficult	Only one MPPT		No redundancy if inverter fails

Inverter protection systems

Grid-connected inverters will only work if the AC grid is functioning and is within the grid's predetermined operating conditions. If these conditions are not met, the grid-connected inverter will disconnect and will not output any power from the PV array at all. The inverter is set up to mirror the function of the grid itself. The MPPT software in these inverters allows the PV output to be optimized to best match the grid specifications at the time of power output. Grid-interactive inverters will typically incorporate two types of protection: active and passive. Both forms have the inverter switch off on over/under frequency or over/under voltage. This protection is intended as self-protection for the inverter if extreme conditions occur and protection for the grid itself, so the inverter will disconnect if it cannot see the grid, e.g. if there is a blackout.

Self-protection

Inverters incorporate protection mechanisms for a variety of problems:

- Incorrect connection: if an inverter is incorrectly connected to the PV array (e.g. with reverse polarity) it will not work and will in most cases be damaged. Even though some inverters protect against incorrect connection, the warranty for most inverters does not cover such damage.
- Temperature: inverters are sensitive to temperature variation and manufacturers will specify a temperature range within which they must operate. Some inverters reduce their power output or turn themselves off when temperature increases past the manufacturer's operating specification. Although the inverter might have over-temperature protection, it is important that the inverter has sufficient ventilation and cooling; over-temperature can cause damage to the inverter.

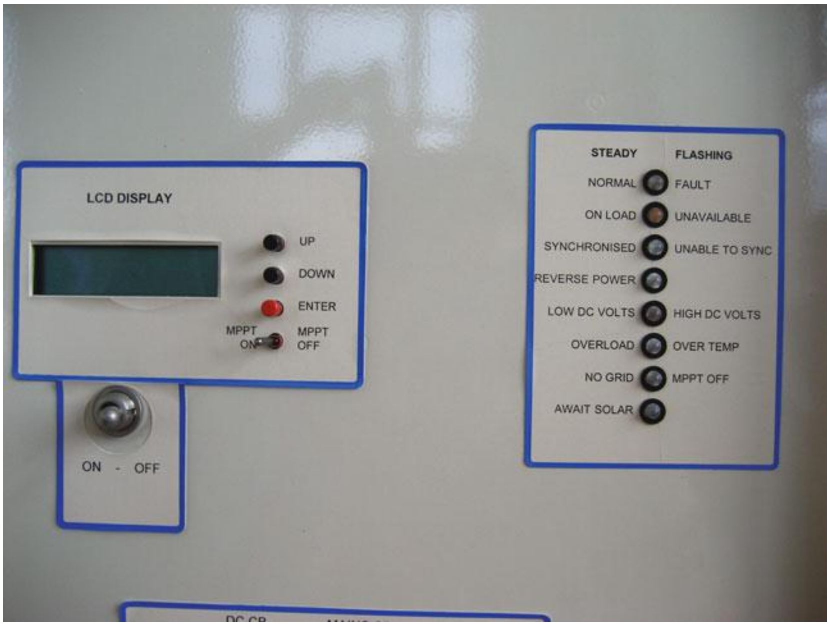


Figure 5.18 The front panel of an inverter will commonly display array faults

Source: Global Sustainable Energy Solutions

- DC voltage too high: all grid-connected inverters will have a specified voltage range within which they operate correctly. Some inverters switch off to protect their electronics if the maximum DC voltage they can tolerate is exceeded, but the inverter could still be damaged; other inverters have no such protection.

Grid protection

Grid-interactive inverters must be able to disconnect from the grid if the supply from the grid is disrupted or the grid itself is operating outside the preset parameters (e.g. under/over voltage, under/over frequency). In both these cases, the inverter disconnects to avoid continuing to output power to the grid when the grid itself is not operating.

There has always been concern that, if there were a sufficient number of inverters connected to the grid in an area and the grid supply to that area failed (e.g. a car hitting pole and cables breaking), the inverters would interact with each other, meaning that the voltage and frequency will become a reference to each other (i.e. an inverter would still think the grid was 'on' and continue exporting electricity to the grid). In this circumstance the passive protection, which switches the inverter off when the grid is operating outside the required voltage and frequency, may not operate, and power would continue to be exported onto a grid that is not operating. This phenomenon is known as 'islanding'. Therefore active as well as passive protection is required. 'Islanding' is a serious safety concern for electricity utilities, e.g. if the grid shuts down and technicians are working on it, there must be certainty that all grid-connected PV systems are also disconnected from the grid. Islanding obviously poses a significant risk of electrocution to workers trying to repair power lines and may damage transmission equipment.

The 'islanding' issue is met by the inverter's active and passive protection. Many standards require grid-interactive inverters to have both these features. Passive protection is provided by the inverter's ability to detect the grid's voltage and frequency, i.e. if the inverter detects that the grid is either over or under voltage and over or under frequency, it will shut down. Active protection is provided by the inverter detecting any frequency instability, frequency shift or power variation that would vary the voltage that the inverter detects. The inverter will shut down via this active protection if it detects any of these conditions.

When the condition that caused the protection device to activate is removed and the inverter synchronizes again with the grid, the inverter will reconnect to the grid after a period of time, e.g. in general at least one minute. Some countries require inverters sold in their territory to have a minimum time delay between the inverter detecting a stable grid and the inverter reconnecting. This time delay is generally programmable within the inverter.

Balance of system equipment: System equipment excluding the PV array and inverter

In addition to the PV array and inverter, a system requires a variety of other components in order to function. These are known collectively as the balance of system equipment (BoS) and often must comply with local and/or national codes and regulations. The BoS equipment is composed of the components required to connect and protect the PV array and the inverter. This equipment includes cabling, disconnects/isolators, protection devices and monitoring equipment. The key balance of systems components are given below, and are described in further detail:

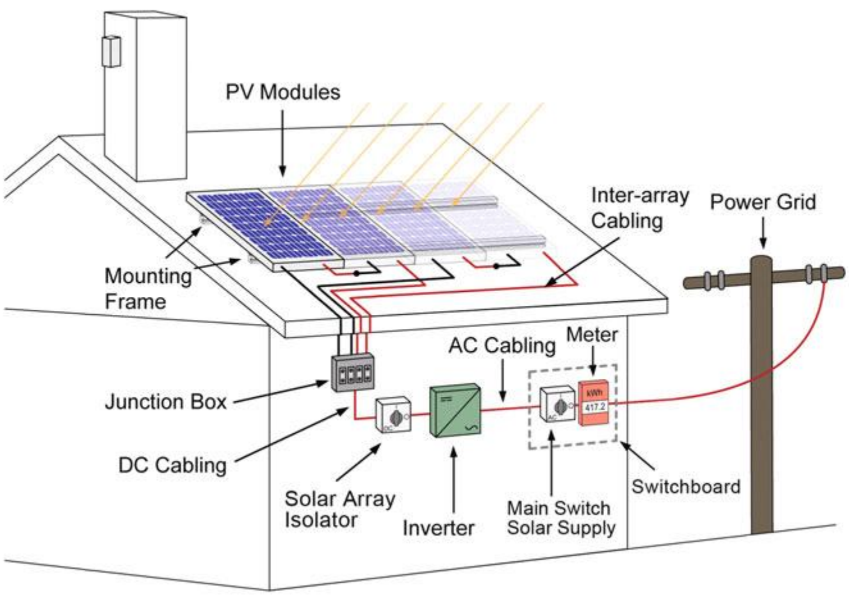


Figure 5.19 Key balance of system components shown excluding grounding/earthing

Source: Global Sustainable Energy Solutions

- DC cabling including the inter-array cabling (cabling used to connect the various modules and strings together to form a PV array), the cable from the PV array to the PV combiner box (if required) and the cable from the PV combiner box to the inverter.
- PV combiner box, normally only required when the PV array has more than one parallel string (see Chapter 4) and is located between the PV array and inverter.
- Module junction boxes located at the back of each module; they normally bring together the wires used to connect the PV cells to form a module.
- Protection and disconnect devices, such as the DC and AC main disconnects/isolators, are often required by many local standards and codes.
- Lightning and surge protection.
- Metering: the building will already have an electricity meter used to measure electricity flows in and out of the building. Installers may incorporate this meter into the new PV system or install a new meter, depending on whether the current meter meets the requirements of the system. Meters are either gross or net; the differences are important and are discussed below.
- AC cabling connecting the inverter to the meter, and the meter to the utility grid.
- Grounding/earthing cables for the array.
- Monitoring: most PV systems incorporate some kind of monitoring so that the owner is able to see the outputs of their system and any problems, such as a decrease in power output, can be quickly identified.

Cabling

During the 1990s, with increasing interest in grid-connected PV systems, ways to the make the installation time shorter and easier were investigated. A number of manufacturers developed plug and socket connections that are now very commonly used.

These have a positive and negative plug which minimize the risk of incorrectly interconnecting modules in series. They will typically have a locking mechanism so that they are not easily disconnected by pulling on the cable.

Many module manufacturers now supply their modules with the cables and plugs already connected into the junction box (see below) on the back of the

Figure 5.20 Example of solar cable plugs

Source: Multicontact

Figure 5.21 Another example of solar cable plugs

Source: Multicontact

PV module. The cable and the plugs can also be individually purchased so that the cables can be made to a length to suit the actual installation; longer cables are often required for certain installations.

It is important to select a cable that meets the output current and output voltage of the PV array and minimizes voltage drop. Typical cable sizes available include: 2.5mm^2, 4mm^2 and 6mm^2. These sizes are suitable for the majority of installations. Selecting cable sizes is discussed in Chapter 10. The AC and earthing cables used for small-scale grid-connected photovoltaics are the same as those typically used in buildings.

PV combiner box

If the array is composed of a number of parallel strings, then the cables from the array strings may be interconnected in a PV combiner box, sometimes called an array junction box or DC combiner box. Even if the array has only one string, PV combiner boxes can be used to interconnect the output cables from the array to the array cable to the inverter, particularly if the array cables are larger in diameter than those used for interconnecting the actual modules within the array.

If there are multiple parallel strings then the PV combiner box will facilitate the combining (connection) of the positive and negative cables from the different strings on links (or similar) allowing only one positive and negative array cable to interconnect with the inverter (via the DC main disconnect/isolator).

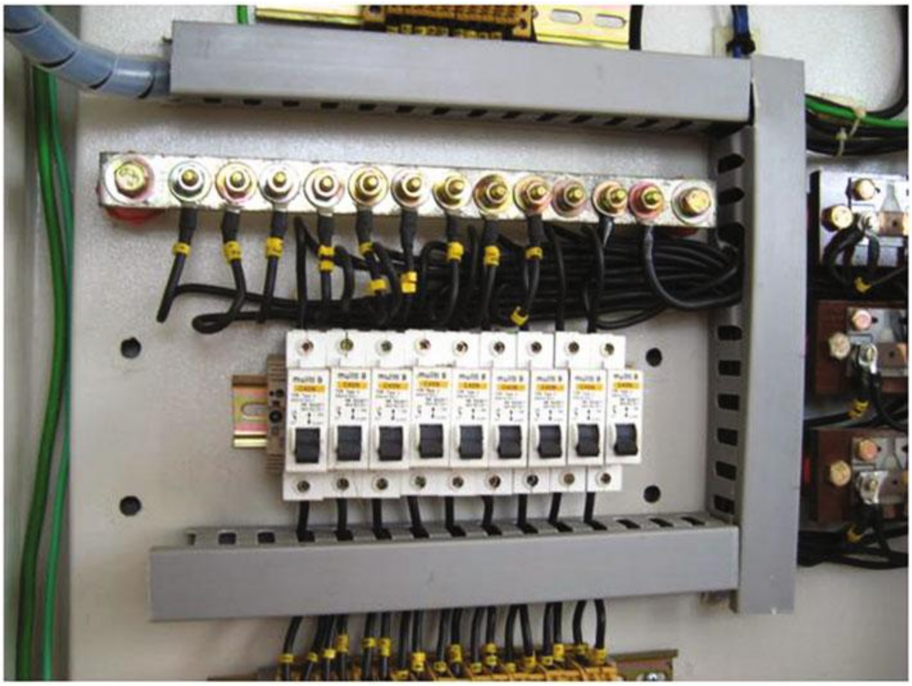


Figure 5.22 PV combiner box with over-current protection devices, in this case circuit breakers. Mounting them in the PV combiner box provides easy access

Source: Global Sustainable Energy Solutions

Figure 5.23 PV combiner box showing string fusing provision

Source: DKSH Australia

Module junction box

In some standard PV modules the wiring connections are enclosed in a module junction box attached to the back of the modules. These boxes include knock-outs where either cable or conduit glands can be installed. Cables can then be directly installed into the terminals of the junction box. In some PV modules, the module junction box is permanently sealed in the back.

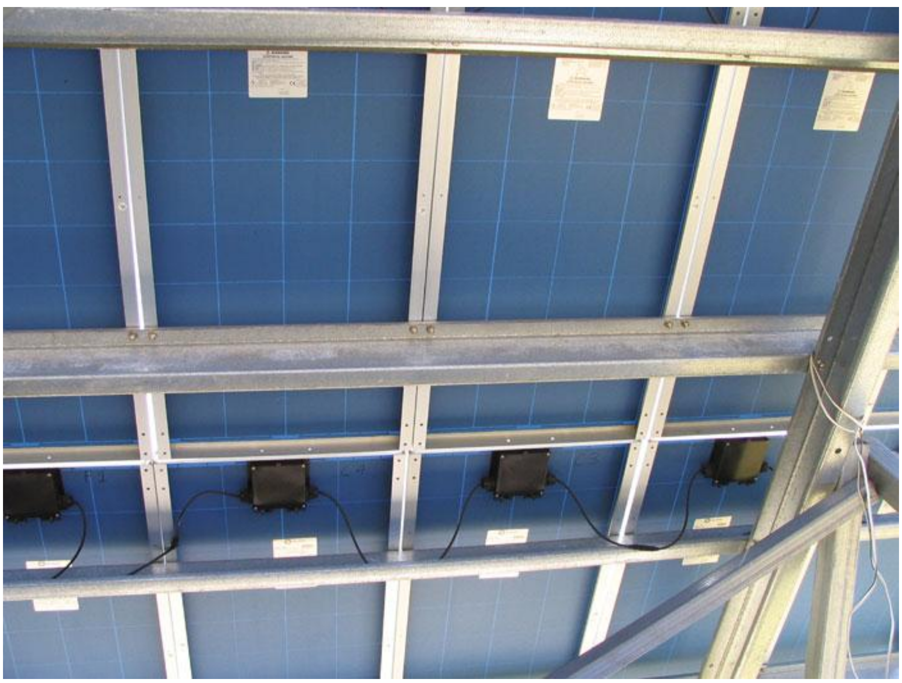


Figure 5.24 Module junction boxes on the back of modules in a PV array

Source: Global Sustainable Energy Solutions

Circuit breakers and fuses

Fuses and circuit breakers are commonly used as over-current protection in PV systems. National codes should specify over-current protection requirements. Normally either DC fuses or DC circuit breakers are used on the array side of the inverter and AC fuses or AC circuit breakers on the grid side. DC fuses may be required by codes in PV systems and they are very different from the AC fuses used in regular appliances. It is much more difficult to break a direct current, so it is important to make sure that any fuses used for DC applications are DC-rated. Most DC-rated fuses can be used in AC applications (manufacturers will generally state this), but DC fuses are more expensive. Likewise, AC circuit breakers are not compatible with DC circuits and vice versa. It is also important to note that DC fuses and DC circuit breakers in a PV system operate very differently to AC fuses and AC circuit breakers in AC systems, because PV is a current-limited source (i.e. the maximum current an array will produce is its short-circuit current I_{sc}). In an AC system, fuses and circuit breakers will blow/open very quickly because the current produced under fault conditions is very large, whereas in PV systems the current produced under fault conditions (I_{sc}) is not much higher than the normal operating current (I_{mp}) and so may not be interrupted by the string fuses and circuit breakers. It is imperative that those installing a PV system are qualified to work with electrical systems (specifically PV systems) and are familiar with local codes governing the choice of over-current protection and its installation.

A fuse is a device fitted to protect against excessive current flows that could damage conductors in a circuit, and to reduce the risk of fire due to overheating of conductors. This will commonly consist of a short section of conductor of sufficient size to carry the load current mounted in an insulating enclosure; under fault conditions the fuse will open the circuit. Fuses may be either rewireable or a cartridge high rupture capacity (HRC) style. Rewireable fuses are no longer considered sufficient to protect a wiring system, so cartridge fuses should be used at all times. Fuses normally feature a current rating, i.e. the amount of current that can pass through the fuse before it melts. Circuit breakers are mechanical devices that will open the circuit under fault conditions and the switch can be manually flipped to close the circuit and restore current flow when the fault has been removed. Currents in excess of the fuse or circuit breaker rating will cause the device to operate (open) and prevent any current from flowing.

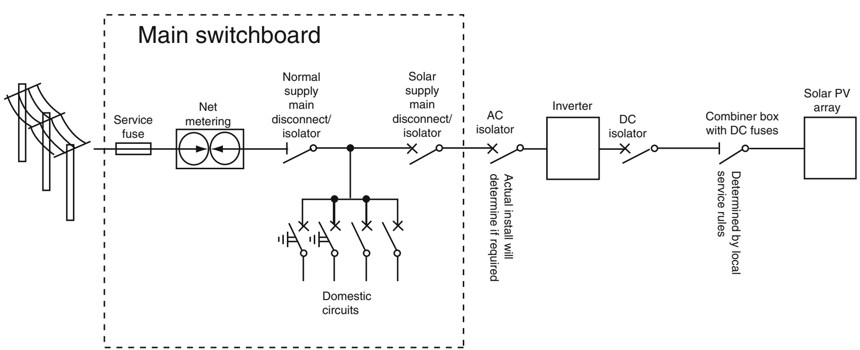


Figure 5.25 When considering possible array wiring, always check that potential designs conform to local wiring codes/standards

Source: Global Sustainable Energy Solutions

Figure 5.26 Circuit breakers in a grid-tied PV system

Source: Global Sustainable Energy Solutions

Fuses and circuit breakers may be used, not only as fault (excess)-current protection, but also as disconnect devices, as explained below. Fault-current protection is found on the DC side of the system (arrays, sub-arrays and strings), as well as on the AC side of the system (there is usually a circuit breaker on the utility side of a PV installation). Over-current protection requirements and ratings vary by country so it is important to check national codes.

PV main disconnects/isolators

A disconnect/isolator isolates equipment from electricity and power sources and allows the power in a circuit to be shut down. Disconnects/isolators should be installed on both the DC (typically DC circuit breakers are used) and AC sides of the inverter as shown in Figures 5.27, 5.28 and 5.29.

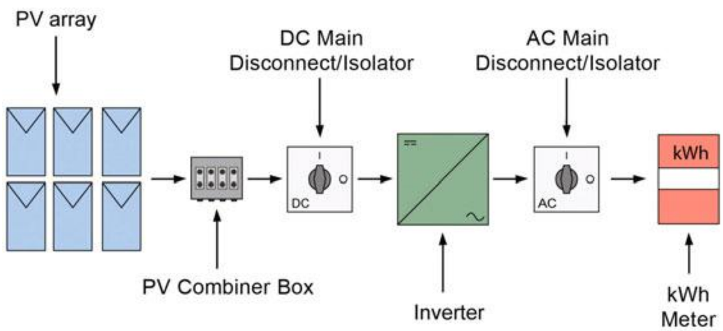


Figure 5.27 Locations of DC and AC disconnects/isolators

Source: Global Sustainable Energy Solutions

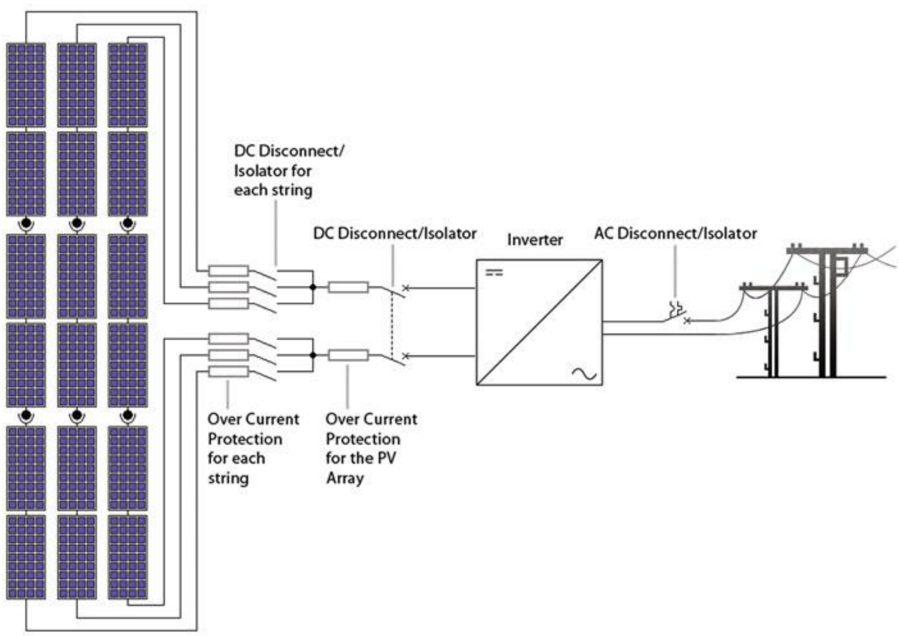


Figure 5.28 Diagram of a three-string PV system showing protection devices including AC and DC disconnects/ isolators and over-current protection

Source: Global Sustainable Energy Solutions

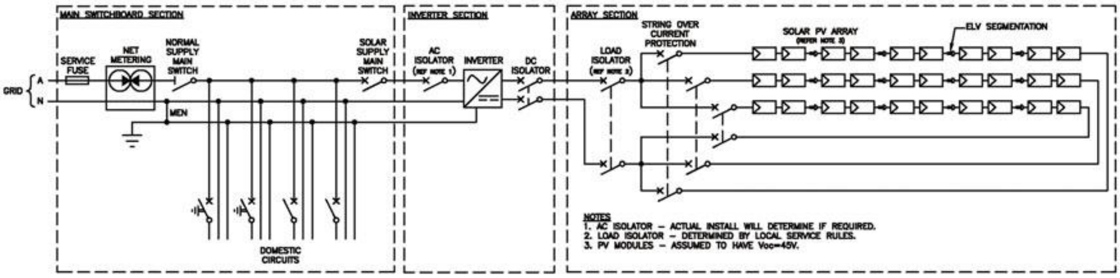


Figure 5.29 Schematic showing main disconnect/isolators and over-current protection. ELV segmentation is explained in Chapter 8

Source: Global Sustainable Energy Solutions

Box 5.2 Utility external disconnect switch (UEDS)

Inverters sold in the US normally have a utility external disconnect switch (UEDS) as a means to disconnect the system on the AC side of the inverter from the grid when required, in addition to the AC circuit breaker in the switchboard. The UEDS is typically incorporated into or installed near the inverter, which is in a location easily accessible to utility personnel should they need to switch off the system for routine or emergency maintenance on the local grid. UEDSs were previously mandatory, but are no longer required by all utilities and states for small systems; they are not widely used outside the US. Local and national codes and regulations should be checked to determine if UEDSs are recognized as an approved AC isolator by utilities and regulators. Remember a properly functioning inverter will not operate when the grid is down, which is why many solar professionals consider these switches to be largely redundant.

Figure 5.30 These inverters are designed for the US market and incorporate a large UEDS beneath the inverter

Source: Global Sustainable Energy Solutions

Lightning and surge protection

Lightning and surge protection may or may not be required, depending on the system and local codes. If it is required then the devices may be required on both the DC side of the inverter (protecting from strikes on the array) and on the AC side of the inverter (protecting from strikes on the AC power grid).

The exact positioning of these protection devices must be in accordance with the protection device manufacturers' recommendations. It is common for

Figure 5.31 These miniature circuit breakers (MCBs) provide over-current protection for the inverter

Source: Global Sustainable Energy Solutions

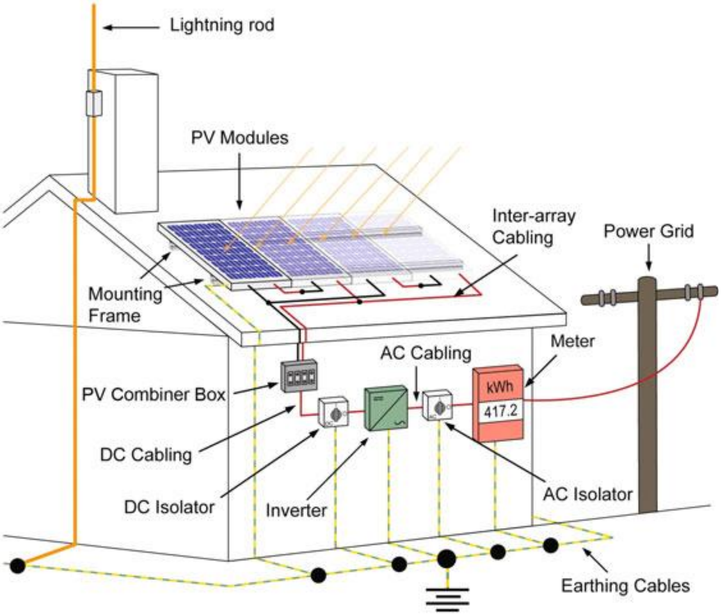


Figure 5.32 System installation layout showing lightning protection and common grounding/earthing point as per Australian national codes; methods may vary by location and the national codes should always be followed

Source: Global Sustainable Energy Solutions

them to be located in the PV combiner box as the array wires are already required to be close to each other. In addition, if remote monitoring of the inverter is possible through a modem, then protection devices should be connected to the telephone line on the line side of the modem.

System monitoring

PV installations may use a data logger to measure and record information about the performance of a system. The information recorded may include the time, power, voltage and temperature of a system. This information might then be sent to a central website hosted by the inverter manufacturer, be displayed on a school or company website, or on a display somewhere.

Metering

An electricity meter records the electrical energy in kWh consumed by the loads within the building where the meter is connected. The meter records the number of units of energy consumed and a unit is typically 1kWh. The electricity consumer is then charged for this electricity based on the price set for that consumer. Electricity distributors will often have different rates for residential homes, industrial and/or commercial consumers.

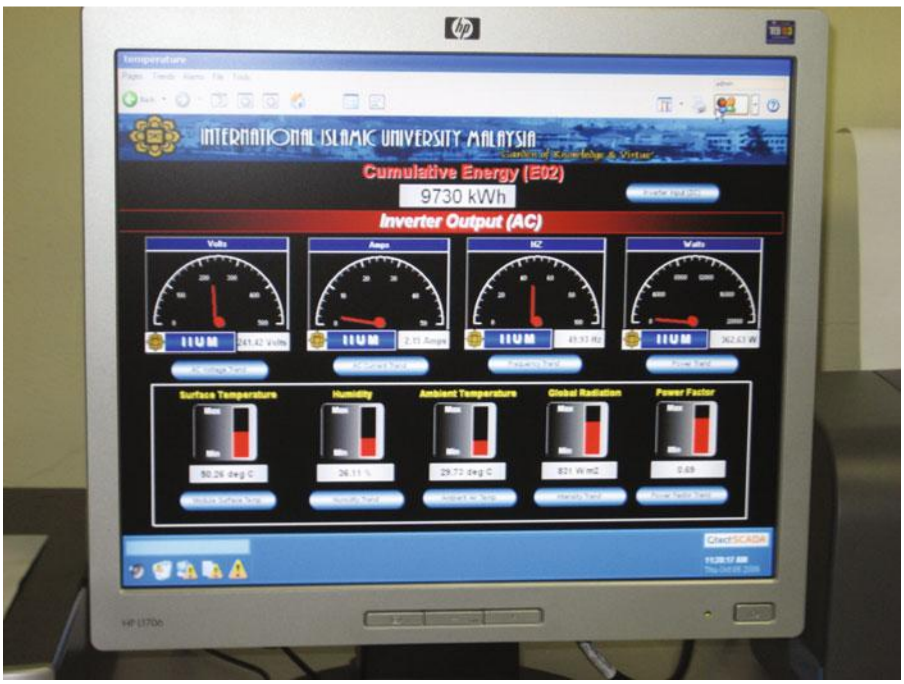


Figure 5.33 Example of a software data logger

Source: Global Sustainable Energy Solutions

Figure 5.34 Rotating barrel style meter, here shown accompanied by signage for a PV installation

Source: Global Sustainable Energy Solutions

Figure 5.35 A more complex digital meter also known as a smart meter; many governments and utilities have started to introduce smart meters, which are expected to be very widely used in future

Figure 5.36 The single rotating disc in the centre of this net meter is clearly visible: when electricity is consumed (by loads within the building) it rotates forwards and when electricity is produced (by the PV system) it rotates backwards

Figure 5.37 An electricity meter commonly used in the US

The simplest meter is a mechanical device with a calibrated rotating disc that spins when electricity is being consumed, as shown in Figure 5.36. A more complicated digital meter like the one in Figure 5.35 can record the time of day that the energy is consumed. This type of meter is used when electricity prices vary according to the time of day. The type of meter installed with a grid-connected PV system will depend on the electricity provider and the region.

Net metering

Net metering is a method by which a utility measures the difference between the consumption of a site and the generation at the site. In a typical residential system the electricity produced by the system will be exported to the grid during peak sunlight hours (usually 10.00am to 3.00 or 4.00pm) and the consumer will import electricity from the grid for use in the evening. If the generated energy is less than the consumed energy, then there is no net export and the customer pays the utility for the difference. If the generated energy is more than the consumed energy there is a net excess generation (NEG), the utility may pay the customer for their NEG or roll it over to offset the next month's bill. Net metering is widely used and is very common in the US where many states' utilities must make net metering available to customers with grid-connected PV systems.

The simplest metering method to achieve the net-metering effect is to allow the mechanical meter to operate in both directions. In this arrangement, electricity produced by the PV system either provides power directly to the loads or is exported to the grid, making the meter rotate backwards, reducing the actual number of units consumed as counted by the meter. In the evening, as the electricity for the loads is provided by the grid, the meter will rotate forwards, thereby increasing the number of units consumed as counted by the meter. In this arrangement the meter is effectively a net import meter and the customer is only charged for the units that are imported and thereby recorded on the meter.

The disadvantage of this metering arrangement is that it neither informs the user of the exact quantity (in kWh) that the PV system has produced nor the exact quantity that they have consumed. There is no record of the amount of electricity that is supplied directly from the PV system to the loads within the building.

It is recommended that if the local distributor requires this metering arrangement, then an installer should install a separate meter (if not included with inverter) that records the exact quantity of electricity produced by the PV system. This will allow analysis of system performance and comparison with the figures on the export meter (if used) to determine how much electricity has supplied loads directly within the building.

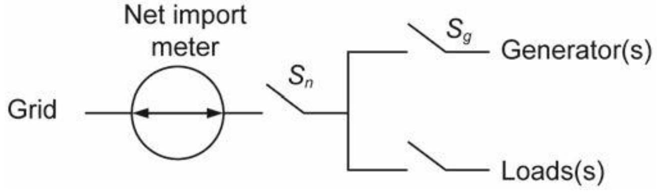


Figure 5.38 Diagram of a net import meter able to run in both directions

Source: Global Sustainable Energy Solutions

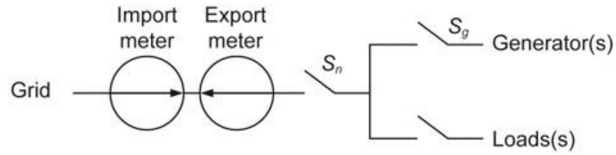


Figure 5.39 Diagram of a net import meter using two meters – one to measure import and the other to measure export. The NEG can be calculated simply by subtracting the number on the export meter from the number on the import meter

Source: Global Sustainable Energy Solutions

Gross metering

Gross metering is a method used by utilities to measure the entire solar energy production and electricity consumption separately for a site. This method is common in places such as Europe and Australia where gross feed-in tariffs are available (see Chapter 13). Gross meters either have two spinning discs (one for consumption and one for production) or two mechanical meters installed, which only operate (or rotate) in one direction. The export meter records the amount of electricity generated by the PV system exported to the grid during the day, while the import meter records the exact amount of electricity consumed from the grid.

In this arrangement the amount exported can be deducted from the import meter and the customer will be charged for the net imported (net metering) or exports and imports may be differentially priced, allowing the customer to make a profit. Gross metering can also be achieved by using a dual electronic import and export meter.

Figure 5.40 Two metering devices, one measuring the power generated and one measuring the power used

Source: Global Sustainable Energy Solutions

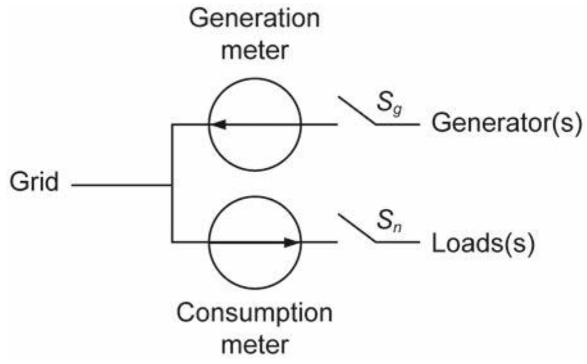


Figure 5.41 Diagram of a gross-metering system

Source: Global Sustainable Energy Solutions

Figure 5.42 Multiple meters are common, often for off and on peak demand metering and large appliances like ducted air-conditioning

Source: Global Sustainable Energy Solutions