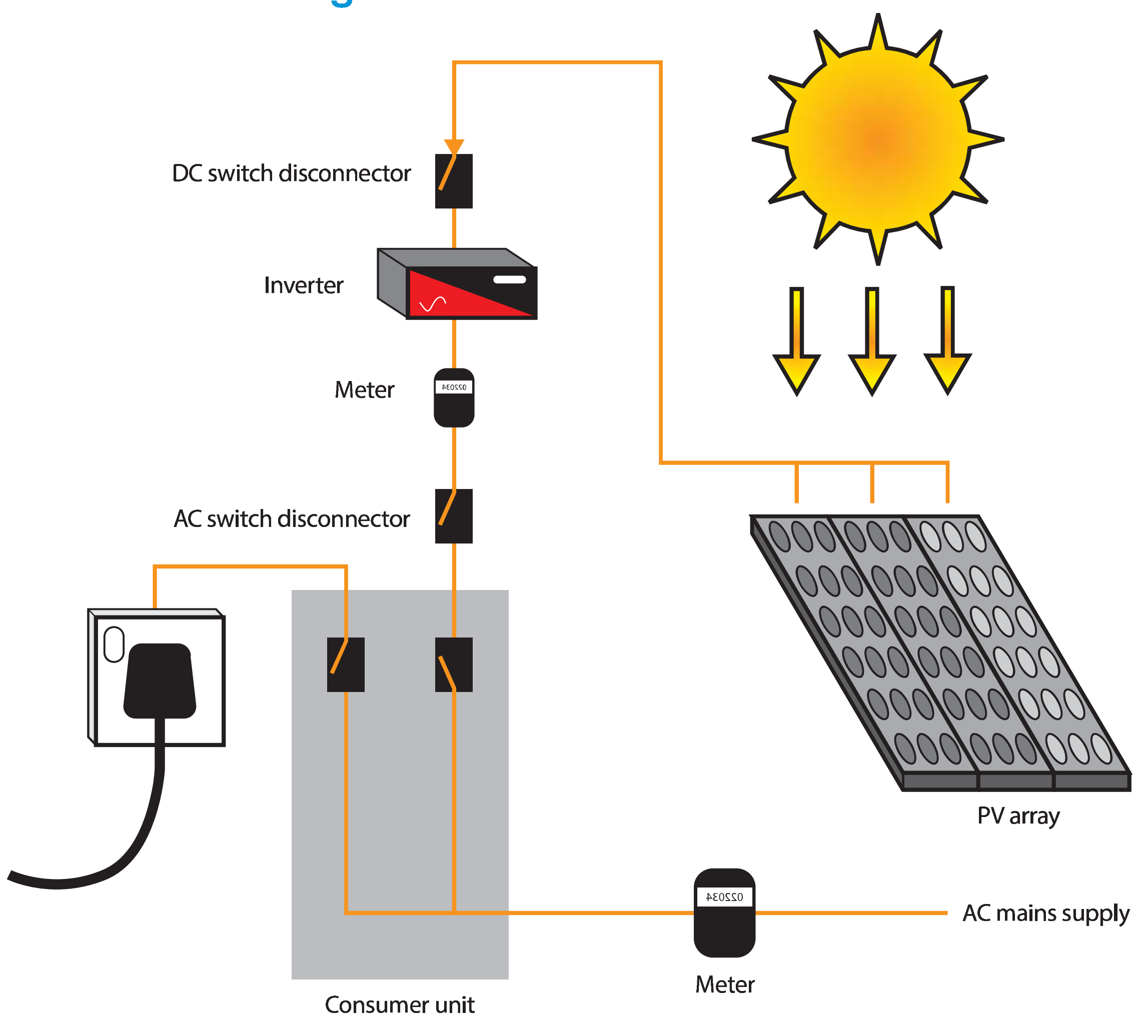
Contents

Module 1

Photovoltaic panels in context of renewable technologies

Module 1 – Photovoltaic panels in context of renewable technologies



What is a PV system?

PV *stands for* ***photovoltaic****. The definition is – The capability of a material to produce a voltage, usually through photoemission, when exposed to radiant energy, especially light.*

The process of converting light (photons) directly to electricity (voltage) is known as photovoltaic (PV). When photovoltaic materials absorb sunlight the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. Photovoltaic material is used to build solar cells, which are usually packaged in photovoltaic modules (also known as solar panels). Modules can be grouped together and connected to form a photovoltaic array.

A PV system will incorporate a number of pieces of equipment:

- Solar modules
- Mounting system
- Inverter/s (which may include power optimisers)

- AC/DC switch disconnector/s
- Generation Meter
- AC/DC cabling
- Consumer unit/distribution board

Benefits of a PV system

There are different kinds of benefits to consider when looking at a PV installation. The two main benefits of PV installations are economic and environmental.

The economic benefits of a PV system are actually considered to be an investment, where a PV system requires an initial cost to install and requires very little maintenance but will continue to generate electricity, which may be purchased from the client by the Distribution Network Operator (DNO).

Below are some examples of these benefits:

Economic

- Reduction in electricity bills: sunlight is free, so once the initial installation is paid for, electricity costs will be greatly reduced. On average, a typical home PV system can produce around 40% of the electricity a household uses in a year.
- Sell electricity back to the grid: if the system is producing more electricity than is need, or when it can't be used, someone else can use it – and the system could potentially generate an income.
- Store electricity for a cloudy day: with the prominence of battery storage systems being installed, system owners can utilise the energy which they've generated at a later time, saving money on importing electricity.

Environmental

- Reduction in carbon footprint: solar electricity is a green, renewable energy and doesn't release any harmful carbon dioxide or other pollutants. A typical home PV system could save around 1200kg of carbon dioxide per year – that's around 30 tonnes over its lifetime.
- Wildlife protection: At power stations large quantities of water are used for producing steam and for cooling systems. When power plants remove water from a lake or river, the fish and other aquatic life can be affected, as well as animals and people who depend on these aquatic resources. At the same time, pollutants build up in the water used by the power plant boiler and cooling system. If the water used in the power plant is discharged to a lake or river, the pollutants in the water can harm fish and plants. PV systems have no such processes.
- No waste material: Worldwide, the burning of coal creates solid waste, called ash, which is composed primarily of metal oxides and alkali. On average, the ash content of coal is 10%. Solid waste is also created at coal mines when coal is cleaned and at power plants when air pollutants are removed from the stack gas. Much of this waste is deposited in landfills and abandoned mines, although some amounts are now being recycled into useful products, such as cement and building materials. This is the same for nuclear-fuelled power stations, which create radioactive waste. This waste is radioactive for many thousands of years and must be stored in special locations either underground or kept in a concrete vault immersed in water or surrounded by steel. There is no exhaust or solid waste emissions from a PV system.

Disadvantages of a PV system

Below are some disadvantages of a PV system.

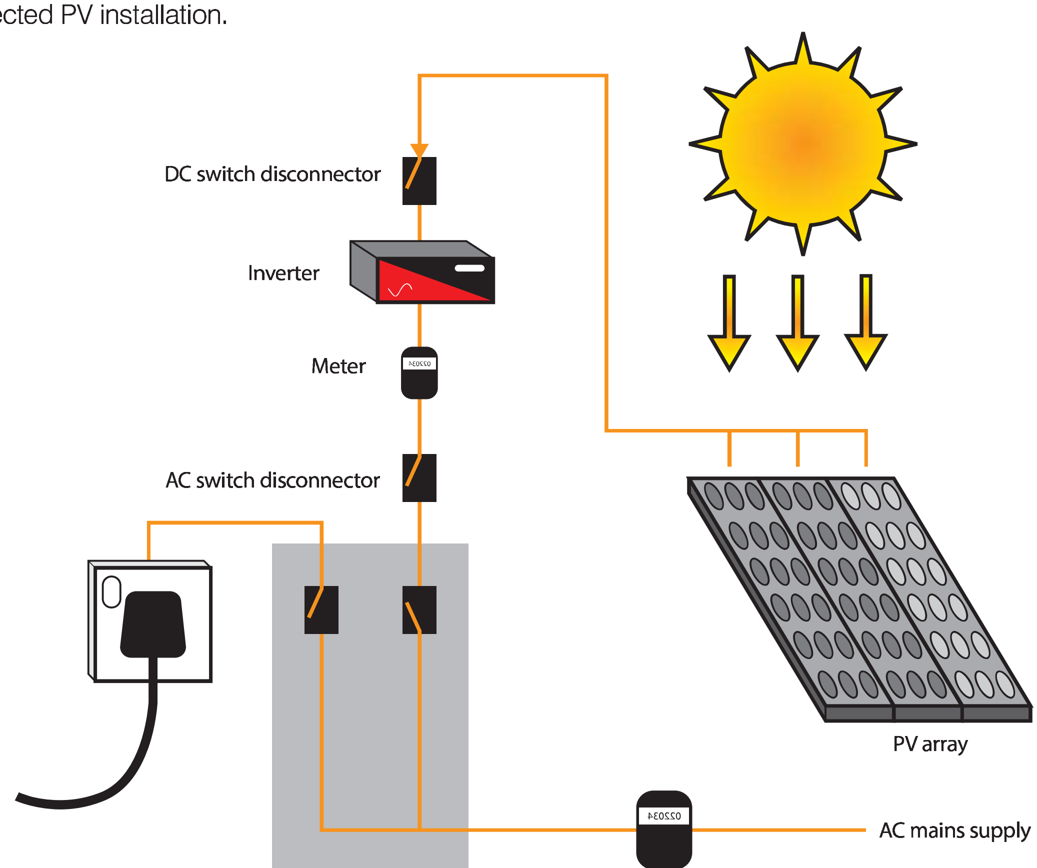
- Some toxic chemicals, like cadmium and arsenic, are used in the PV production process. These environmental impacts are minor and can be easily controlled through recycling and proper disposal.
- Solar energy is somewhat more expensive to produce than conventional sources of energy due in part to the cost of manufacturing PV devices and in part to the conversion efficiencies of the equipment. As the conversion efficiencies continue to increase and the manufacturing costs continue to come down, PV will become increasingly cost competitive with conventional fuels.
- Solar power is a variable energy source, with energy production dependent on the sun. Solar facilities may produce no power at all some of the time, which could lead to a shortage if a large proportion of the energy requirements are from solar power.

Types of PV systems

Photovoltaic-based systems are generally classified according to their functional and operational requirements, their component configuration, and how the equipment is connected to the other power sources and electrical loads (appliances). The two principal classifications are grid-connected and stand-alone systems.

Grid connected systems

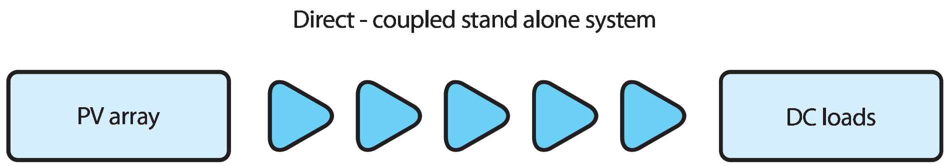
Grid-connected PV systems are designed to operate in parallel with and are interconnected to the electricity grid. The primary component is the inverter. The inverter converts the DC power produced by the PV array into AC power consistent with the voltage and power quality required by the grid. The inverter automatically stops supplying power to the grid when the grid is not energised, for example, a power cut. Below is a typical grid connected PV installation.



Off grid systems (stand-alone systems)

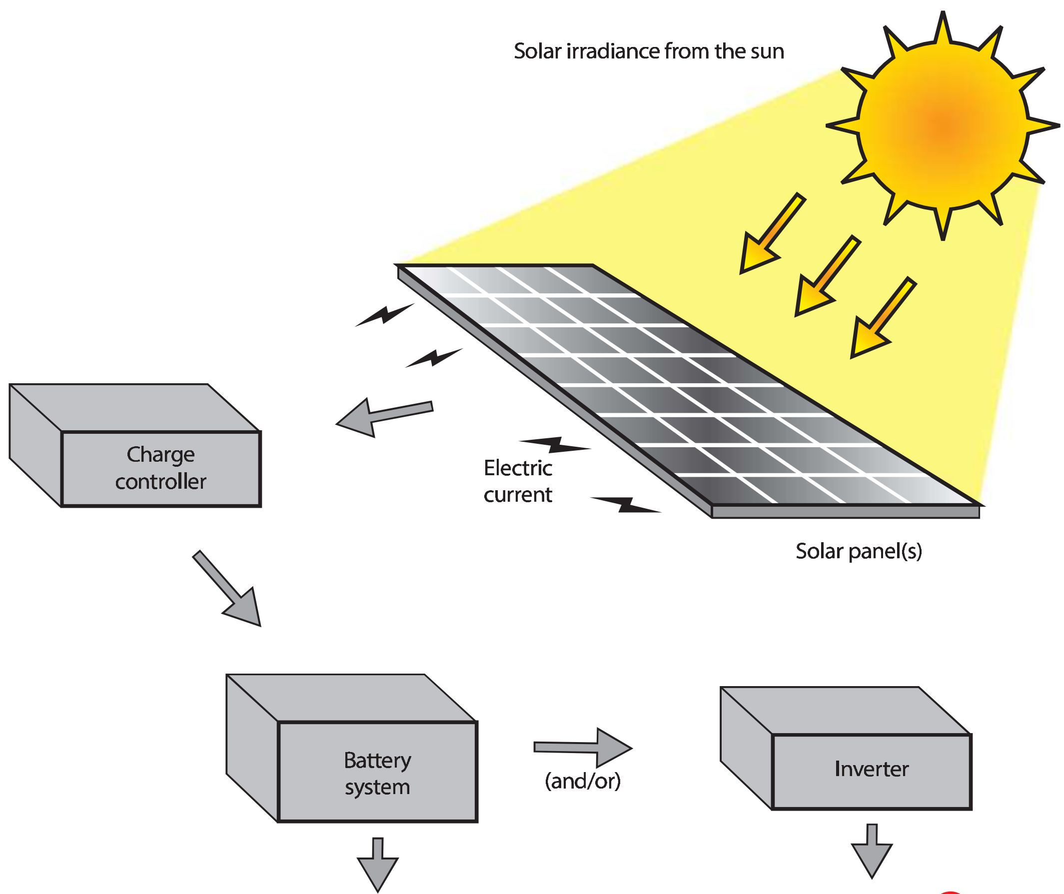
Stand-alone system

Off-grid PV systems are designed to operate independently of the electricity grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. Off-grid systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as a backup power source in what is called a PV- hybrid system. The simplest type of Off-grid PV system is a direct-coupled system, where the DC output of a PV module or array is directly connected to a DC load.



Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems. Matching the impedance of the electrical load to the maximum power output of the PV array is a critical part of designing well-performing direct-coupled systems.

In many stand-alone PV systems, batteries are used for energy storage. Below is a diagram of a typical Off-grid PV system with battery storage powering DC and AC loads.



Smart Export Guarantee

The UK Government financial incentive scheme for installation of renewables (Feed-in Tariffs) ended on 31st March 2019. Renewable Obligation Certificates (ROC's) ended on 31st March 2017.

In effect, all financial subsidies from the UK Government for installation of micro-renewables, solar PV included, have now been closed.

However, the UK government have introduced an alternative arrangement for paying owners of small-scale low carbon technologies who export excess energy back to the grid. The Smart Export Guarantee (SEG) came into force on 1st January 2020 and requires all licensed electricity suppliers to offer export tariffs to anaerobic digestion (AD), hydro, onshore wind, and solar photovoltaic generators with a total installed capacity up to 5MW.

There are criteria which must be met to be eligible to apply for these tariffs, such as:

- The installation and/or installer are suitably certified (MCS or equivalent or be in accordance with EN 45011 or EN ISO/IEC 17065:2012).
- Have an export meter (able to take half-hourly readings, can be read remotely and be located at the point where the installation connects to the distribution network/grid).
- Have an export meter point administration number (MPAN)

Existing installations which already receive a FIT payment can continue to receive the generation payment and also opt for the SEG. However, they must opt out of receiving FIT export payments first.

SEG guidance for generators is available on the Ofgem website.

Energy Storage is a new sector which would help consumers achieve self-consumption of the energy they generate but would be an additional on cost to the installation price of a solar PV system

Costs

The cost of installing a solar electricity system can vary – an average system costs between £3000 – £7000, depending on its size and type. This includes both materials and labour charges

In general:

- The more electricity the system can generate, the more it costs but the more it could save
- Solar tiles cost more than conventional modules
- Integrated PV roof tiles/panels are generally more expensive than non-integrated PV roof systems (retrofit systems),however, if major roof repairs are required, integrated PV roof tiles/panels can offset the cost of roof tiles.

Module 6

Maintenance and fault finding

Module 6 – Maintenance and fault finding

Maintenance and fault finding

As a general rule, PV arrays are normally fault free and very low maintenance. However, periodic maintenance checks should be carried out either by the system operator or the installer of the system to ensure that it continues to work efficiently and avoid potential faults. This is also a possible source of additional income for installers, who can offer maintenance contracts to the client. In the following module, the key points of a PV system will be looked at including checking and maintaining PV systems and possible remedy of any faults that may occur. BS EN IEC 62446-2 offers more details on the maintenance of PV systems.

Maintaining a Solar Array
(Image courtesy of www.pasolar.ncat.org)

Maintenance

The following steps are only basic guidelines for common systems. Ensure that the manufacturer's instructions are read on the maintenance of their equipment. Before opening any equipment/apparatus, ensure safe isolation procedures are carried out (if applicable).

To ensure a high level of maintenance is achieved, the following information should be made available:

- All relevant certification (BS 7671) including:
  - Electrical Installation Certificate/Installation Condition Report.
  - Schedule of Inspections.
  - Schedule of Circuit Details and Schedule of Test Results
  - A diagram of the installation and location of key equipment.
  - When the system was installed.
  - Any alterations made to the system after the initial installation.
  - When the system was last serviced/inspected.

Before carrying out any maintenance work, a Schedule of Inspections should be undertaken.

Meter Reading A log of the meter readings should be taken and monitored. (This may not be applicable with systems for automatic recording and evaluating of operating data). Remove all sources of shade on the array and rinse the array to remove the build-up of dust, dirt and other debris. This may require additional time to remove bird droppings or tree sap.

DC/AC components The DC/AC components (switch-disconnectors, junction/combiner boxes, isolators, etc.) should be opened to inspect the connections. Also check for any insects or foreign bodies and signs of humidity. Use a voltmeter and DC ammeter (or appropriate DC test instrument) to measure and record the array's operating voltage and current level on the output side of the junction/combiner box. Note the irradiance level at the time. Remove the fuses (from DC junction/combiner box, if applicable) and record each string's Open-Circuit Voltage and current levels. Note any deviation between strings for future correction. You can also use these measurements to determine if the array's output is degrading over time.

PV array surface area and cabling

- Record the condition of the modules. Look for signs of degradation (this would include colour changes, fogged glazing, de-lamination, warping or water leaks etc), cracked glazing and the module frames being bent. Remove all sources of shade on the array and rinse the array to remove the build-up of dust, dirt and other debris. This may require additional time to remove bird droppings and/or tree sap.
- All nuts and bolts for the array frame and modules should be checked and tightened as required.
- Loose cabling from the modules should be secured and checked for degradation or damage from wildlife or adverse weather. Check for any cuts, gashes or worn spots and replace as necessary. Check all the connections between the modules are tight and have no damage to any shrouds or connectors. Replace as necessary.
- Check the frame earthing/bonding connections (if applicable).
- Check the building penetrations for adequate sealing and repair as required.
- Open the junction/combiner boxes and look for any dirty, loose or broken connections. Repair or replace as required. Check all connections inside the junction/combiner box and tighten them as necessary.

Inverter

The following checks should be carried out at the inverter:

- A voltmeter and DC ammeter should be used to check and record the inverters operating DC input voltage and current level. The same should apply to the AC output.
- Check the functionality of the inverter; ensure that LED's are in working order, readouts are working and displaying appropriate information.
- Record the total kWh produced since first start up (if possible). Use the readout to compare the system's production between inspections.
- Isolate the inverter and check for loose, dirty or broken connections. Check the casing for cracks or damage. Switch the inverter on and ensure that the start up operation is normal and that it is producing AC Electricity.

A repeat of the commissioning measurements (when required)

A repeat of the commissioning measurements and test may only be required for fault finding purposes, if the system is not performing as expected or the interval for periodic inspection has elapsed. This must only be carried out by trained personnel.

Inverters in outdoor applications

Check the inverter for signs of humidity or water penetration regardless of suitability for outdoor conditions. **This must only be carried out by trained personnel.**

The following checks should be employed if there is reason to suspect a fault.

If suspected

Modules, junction boxes and AC protective equipment

Peak output measurements should be taken. This must only be carried out by trained personnel. String fuses should be checked along with OCPD's.

Maintenance

Maintenance is a fundamental requirement of The Electricity At Work Regulations 1989. Although the regulations do not specifically state how this should be done for electrical installations, the current edition of BS 7671 provides further guidance on how to comply with this requirement. The requirement to maintain electrical systems involves keeping records of maintenance.

The recording and reporting of maintenance is an essential process of keeping accurate and up-to-date information on the PV system. The company/competent person carrying out the maintenance should have a method of recording any measurements or conditions that are taken or observed. The measurements and observations should be used to construct a condition report, giving all details of the maintenance procedure and any recommendations for repairing or replacing faulty or inadequate equipment. The customer should receive a copy of the report once it has been completed.

It is regarded as good practice to regularly check the inverter fault display, if possible. If the system has automatic fault and operating data monitoring, this can make the system operator's task much easier should a fault occur.

Additional information on the maintenance and operation of PV systems can be found in the IET Code of Practice for Grid Connected Solar Photovoltaic Systems. A comprehensive list of maintenance items and intervals can be found in BS EN IEC 62446-2, maintenance of PV systems

Fault Finding

A PV system is expected to operate between 25 and 30 years. Due to exposure to the weather, various faults can occur within this time. Depending on the fault, it is always advisable that a visual check be carried out first, particularly of the PV array. Mechanical damage and soiling should be looked for and all wiring connections should be checked.

The following information should be made available when diagnosing and rectifying any faults:

- All relevant certification (BS 7671) including:
  - Electrical Installation Certificate/Installation Condition Report.
  - Schedule of Inspections.
  - Schedule of Circuit Details and Schedule of Test Results.
- A diagram of the installation and location of key equipment.
- When the system was installed.
- Any alterations made to the system after the initial installation.
- When the system was last serviced/inspected.
- The nature of the fault/how often it occurs/what happens to the system.

When troubleshooting a grid-connected PV system, common diagnosis includes:

- The inverter does not operate properly or not at all; or
- The array has low or no voltage/current

Inverter problems

A lack of power output from the inverter could be caused by a melted string fuse, broken cable, an earth fault or any of the inverter's internal disconnection tolerances (high and low voltage/current values).

With the inverter switched off (using the AC switch disconnector) check for and repair any earth faults before starting the inverter. Check for blown string fuses and replace as appropriate.

Fluctuations in the conditions affecting the array can alter the DC voltage/current values and if these are not within the inverter's tolerances, this can cause the inverter to shut down.

Array problems

Before looking at the array itself, measure and record the inverters input voltage/current level from the array. If there is no DC voltage/current value at the inverter, check all DC components. Check for any loose/broken cabling in the inverter. Replace damaged cabling, clean and tighten all terminations.

The array should be visibly checked for obvious damage to the modules or cabling. Repair and replace all damaged cabling as required.

If the output voltage is low, this would indicate that some modules in a series string are defective or disconnected and may need replaced. Blocking diodes (if applicable) may also be defective and need replacing.

Low current output could be caused by the conditions of the weather (cloudy), defective blocking diodes, damaged module, parallel connections between strings may be broken, loose or dirty. Replace any faulty modules and defective diodes. Clean and tighten any loose connections. Any sources of shading should be removed from the area of the array. Heavy soiling must also be removed.

The measurements required to find faults in a grid-connected system are essentially the same as those required for the commissioning of the system. Therefore, the fault-finding process should be taken from the testing procedure in Module 5.

- Some examples of common faults are listed below.
- Loss of full collection capacity
- Loss of output from inverter
- Loss of AC supply circuit to inverter
- No output from DC circuit
- Broken or damaged solar module
- Cable failure within DC circuit
- Dirty/partially covered/shaded modules

In order to diagnose these faults, a logical step-by-step process should be considered. There are some general guidelines which could apply to all of these faults which could be time saving.

1. Ask the person responsible for the system what the fault is. This can also extend to aspects of the fault, such as, how often the fault occurs? Does the fault occur at certain times of day? Has the system been regularly maintained?
2. Carry out a visual inspection of all the equipment including the PV array. Some faults can occur due to perhaps a build up of dust or some shading of the array which would not require the need for access equipment to the roof and can be easily seen from ground level.
3. Carry out safety and functional testing of the system. If you know what it is supposed to do at various stages of operation it is reasonably easy to tell where and what is at fault.

These points should be the starting point of any fault diagnosis.

Specific diagnosis of the faults above would be as follows:

- **Loss of collection capacity** – Having taken steps 1 to 3 above, the next step would be to record the output readings of the array at the inverter. These should be checked against the expected values for both the voltage and current output of the array. Shading could have occurred or a string cable could be loose or disconnected. There is also the possibility (if the array has four or more strings) that a string fuse has melted. These would result in a loss of a string which would decrease the power output of the array.
- **Loss of output from the inverter** – Having taken steps 1 to 3 above, the next step would be to check the display of the inverter. This display should indicate whether there is an output coming from the array and if the inverter is receiving an AC signal. If either of these inputs are not apparent, see the other faults listed here for guidance on diagnosis. If both signals are present, this may indicate an internal failure of the inverter or that the input characteristics of the inverter (voltage/current) from the PV array are not being met.

- **Loss of AC Supply circuit to the inverter** – Having taken step 1 above, the fault should be easily identified. Check the display on the inverter, which should display a fault message indicating that there has been a loss of AC input. (This is part of the anti-islanding requirements specified as part of the current edition of G98). This could indicate a loss of supply from the grid or could simply be that the OCPD has acted or the AC switch-disconnector could have been switched off.
- **No output from DC circuit –** After carrying out step 1, the fault should be easily identifiable. Check the display on the inverter, which should indicate that there has been a loss of supply from the PV array. There are many reasons for this type of fault: Main DC cable loose or disconnected, complete shading of the entire array, string fuses have melted or simply that the DC switch-disconnector has been switched off.
- **Broken or damaged solar module** – Carry out steps 1 to 3 above. There may need to be a comprehensive visual check carried out on the PV array which may require access equipment. The indication of this fault would be very similar to the first fault, where the damaged or broken module may result in a string not producing any power and loss of total collection capacity, indicated on the inverter display.
- **Cable failure within DC circuit –** Having carried out steps 1 to 3 previously, the indication of this fault can either be reduced collection capacity or no output from the DC circuit which would be shown on the inverter display. There is also the chance that some modules may still continue to function and so the PV system should be turned off. Reduced collection would indicate that there would be either a loose connection or cable damage to a string cable whereas no output from the array would indicate the same fault but on a main DC cable.
- **Dirty/partially covered/shaded modules** – Having carried out steps 1 and 2 previously, the indication of this fault can either be reduced collection capacity or no output from the DC circuit which would be shown on the inverter display. This type of fault is usually fairly simple to identify but shading is a little more difficult on cloudy or rainy days so you will have to imagine the passage of the sun. If the problem has occurred slowly it may be because no maintenance has been carried out or nearby trees have grown or new building has taken place. If it has occurred suddenly it may be fallen branches or wind blown materials that have landed on the modules.

Fault rectification

To rectify the faults given previously, we must diagnose the cause of the fault. Once this has been discovered, the following methods of rectifying these faults should be carried out:

- **Loss of collection capacity –** If shading has occurred, remove the object which is causing the shading effect (a well designed system should not have a permanent object which would cause regular shading effects on the PV array, such as a tree line or adjacent building). Check all connections and tighten or replace as appropriate. Replace any melted string fuses.
- **Loss of output from the inverter** – If internal failure of the inverter has occurred, the inverter must either be repaired (by a trained/competent person) or replaced. If the input characteristics are not within the inverter range, this maybe an indication of another fault present, such as broken or damaged module or DC cable failure, resulting in a reduced voltage/current output from the inverter. These will be rectified later in this list.
- **Loss of AC supply circuit to the inverter –** There are not many options open to rectifying this type of fault. Ensure that all points of switching and isolation are turned on. If this does not solve the problem, check the AC wiring from the consumer unit/distribution board to the inverter. The fault may have arisen from the loss of AC supply from the distributor, meaning that there is no rectification that can be carried out on the installed system.

- **No output from DC circuit** – Check that the DC switch-disconnector is in the ON position. Remove any objects causing the shading effect and tighten or replace any connections. Replace any melted string fuses.
- **Broken or damaged solar module –** There is no other way of rectifying this fault other than to replace the broken or damaged module. Please note that this string will be taken out of the array whilst the replacement is to be installed and simply connecting the two modules either side of the broken module should not be carried out. This would cause the string to be operating at a different voltage to any other strings on the array.
- **Cable failure within DC circuit** – Replacement of the cable that has failed is the only method of rectifying this fault.

Dirty/partially covered/shaded modules – Depending on what has caused the problem this will be easy or could be difficult to resolve. If it is lack of maintenance i.e. build-up of dirt or debris on the modules, fallen branches or other items blown onto the array etc., simply cleaning them or removing the debris should solve the problem. Shading could be more difficult to cure as it may involve other people's property such as cutting branches of neighbour's trees and so on. If a recent building is now causing shading, the only solution may be to relocate the array.