Chapitre P
Photovoltaic installations

Contents

1 Benefits of photovoltaic energy

1.1 Practical benefits

This technology enables the use of renewable energy from the sun. There are two types of solar energy:

- Thermal energy captured through an exchange between circulating fluid exposed to the sun and a load circuit (accumulation tank or heat pump).
- Photovoltaic energy, which uses the principle of the photovoltaic cell discovered by Edmond Becquerel in 1839 to produce electrical power.

It is particularly beneficial to use solar radiation reaching the earth since:

- This radiation remains stable (to within 10%) on average from one year to the next;
- At ground level, it supplies an average of 1000 Wh/m² per day although this depends on the following principal criteria:
  - The latitude
  - The angle of the surface and the direction faced
  - The degree of pollution
  - The time of year
  - The thickness of the cloud layer
  - The time of day
  - The shade

This radiation varies from 870 Wh/m² per day in the North of France to 1890 Wh/m² per day in Corsica (and up to 3125 Wh/m² per day in the Sahara).

1.2 Environmental benefits

By using solar energy, it is possible to reduce consumption of “fossil” fuels which are the likely cause of global warming and atmospheric pollution.
This contributes to sustainable development and is also in keeping with the policies of the European Council, which passed a decree in March 2007 setting the following targets to be met by 2020:

- Reduction of greenhouse emissions by 20%
- Reduction of energy consumption by 20%
- 20% renewable energy as a proportion of total energy consumption

2 Background and technology

2.1 The photovoltaic effect

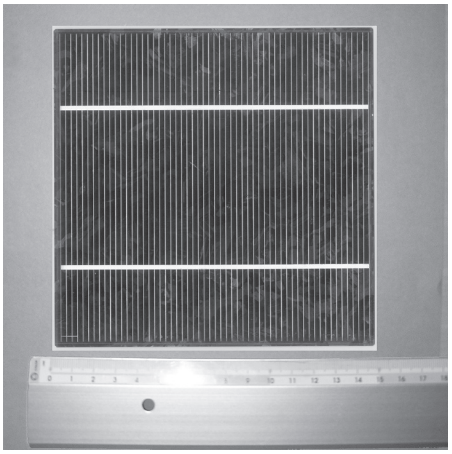


Fig. P1 : Photovoltaic cell manufactured in a silicon plate (source: Photowatt)

This is the ability to transform solar energy into electricity and is achieved by using photovoltaic (PV) cells.
A PV cell (see **Fig. P1**) is capable of generating voltage of between 0.5 V and 2 V depending on the materials used and a current directly dependent on the surface area (5 or 6 inch cells).
Its characteristics are shown in a current/voltage graph as shown in **Figure 2**.

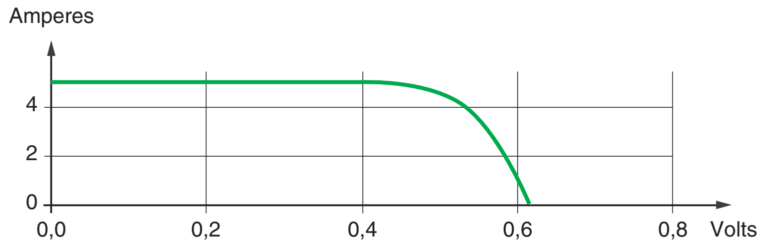


Fig. P2 : Typical characteristic of a photovoltaic cell

The photovoltaic effect is dependent on two physical values (see **Fig. P3**) – irradiance and temperature:
- As irradiance E (Wm²) increases, so does the current produced by the cell
- Conversely, as the temperature (T°) increases, the output voltage decreases.

In order to compare the performance of different cells, the standard has set out Standard Test Conditions (STC) for irradiance of 1000 W/m² at 25°C.

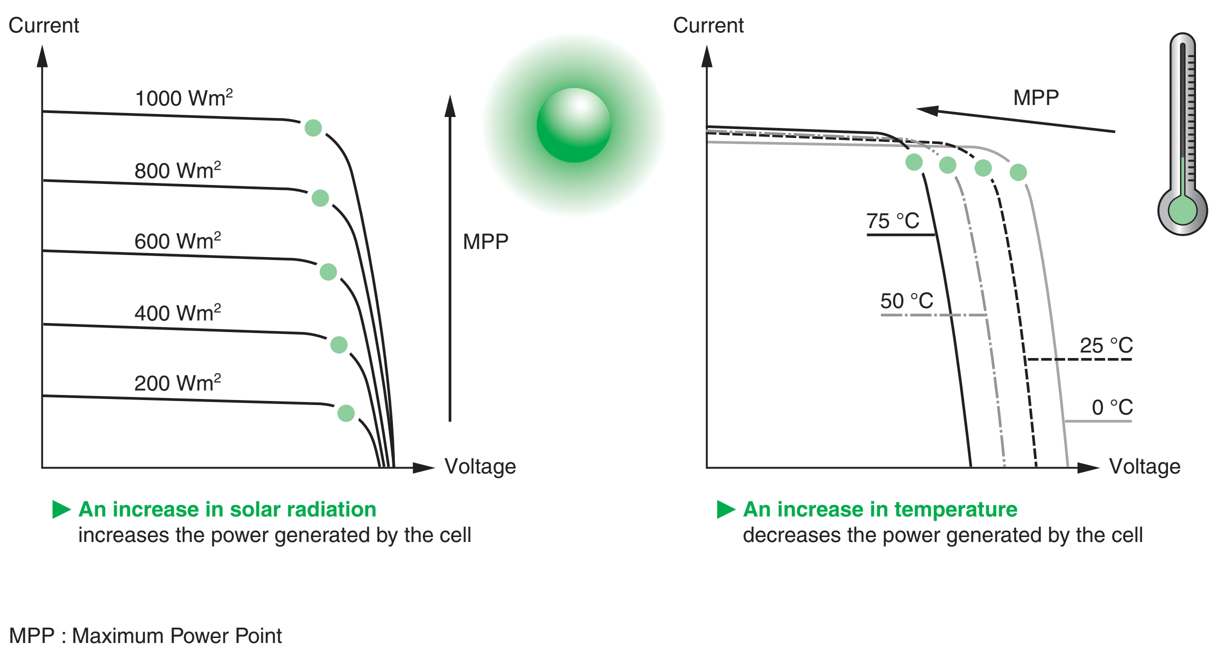


Fig. P3 : Irradiance and temperature influence the photovoltaic effect

To make it easier to use energy generated by photovoltaic cells, manufacturers offer serial and/or parallel combinations grouped into panels or modules.

2 Background and technology

2.2 Photovoltaic modules

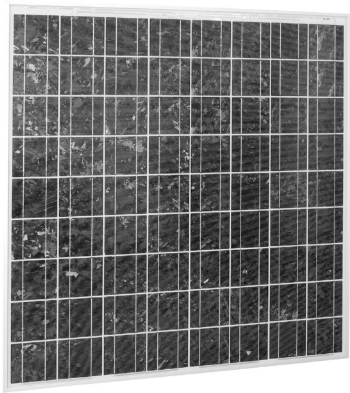


Fig. P4 : PW1400 photovoltaic module dimensions: 1237 x 1082 x 45 mm (source: Photowatt)

These combinations of cells (see **Fig. P4**) enable the voltage and current to be increased. To optimise the characteristics of the modules, these are made up of cells with similar electrical characteristics.

Each module providing a voltage of several tens of volts is classified by its power level measured in Watt peak (Wp). This relates to the power produced by a surface area of one m² exposed to irradiation of 1000 W/m² at 25°C. However, identical modules may produce different levels of power so the common standard variation for power is ±3% (see table in **Figure P5**). Modules with typical power of 160 Wp include all modules with power of between 155 Wp (160 -3%) and 165 Wp (160 +3%).
It is therefore necessary to compare their efficiency which is calculated by dividing their power (W/m²) by 1000 W/m².
For example, for a module of 160 Wp with a surface area of 1.338m² (*), the peak power is 160/1.338 which gives 120 Wp/m².
Therefore the efficiency of this module is: 120/1000 = 12%.

Encapsulation	Glass/Tedlar		
Cell size	125.50 x 125.5 mm		
Number of cells	72		
Voltage	24 V		
Number of bypass diodes	4 bypass diodes		
Typical power	150 Wp	160 Wp	170 Wp
Minimum power	145 Wp	155 Wp	165 Wp
Voltage at typical power	33.8 V	34.1 V	34.7 V
Current at typical power	4.45 A	4.7 A	4.9 A
Short circuit current	4.65 A	4.8 A	5.0 A
Open wire voltage	43 V	43.2 V	43.4 V
Maximum circuit voltage	1 000 V CC		
Temperature coefficient	α = (dI/I)/dt # + 0.032 %/°C β = dV/dt # - 158 mV/°C ς P/P = - 0.43 %/°C		
Power specifications at	1000 W/m²: 25°C: AM 1.5		

Fig. P5 : Electrical characteristics of a PW1400 module (source: Photowatt)

However when photovoltaic cells are connected in series, a destructive phenomenon known as the “hot spot” may occur if one of the cells is partially shaded. This cell will operate as a receiver and the current passing through it may destroy it. To avoid this risk, manufacturers include bypass diodes which bypass damaged cells. Bypass diodes are usually fitted in the junction box behind the module and enable 18 to 22 cells to be shunted depending on the manufacturer.

These modules are then connected in series to achieve the level of voltage required, forming chains of modules or “strings”. Then the strings are arranged in parallel to achieve the required level of power, thus forming a PV array.

A faulty module within a string must be replaced by an identical module and therefore it is important to choose a supplier which is likely to be in business in the long-term.

Since there are increasing numbers of PV module manufacturers throughout the world, it is important to consider the various options carefully when choosing equipment. Installers should also:
■ Ensure the compatibility of the electrical characteristics with the rest of the installation (inverter input voltage).
■ Ensure that they are compliant with the standards.
■ Select suppliers likely to be in business in the long-term to ensure that faulty modules can be replaced as these must be identical to those already installed.
This final point is important as installers are responsible for the warranty granted to their clients.

2.3 Additional equipment: inverters or chargers

Photovoltaic generators only supply energy as direct current and when there is sunlight.
Therefore, if this energy is to be supplied to the distribution network, the direct current must be converted into alternating current using converters or inverters, and if it is to be supplied permanently, it must be stored in rechargeable batteries using a battery charger.

(*) The dimensions of these modules (L x W x D) in mm are: 1237 x 1082 x 38.

3 Special equipment

3.1 Modules

Different technologies are currently being used to manufacture photovoltaic generators. These are divided into two categories - crystalline modules and thin film modules.

Crystalline modules

There are two main categories of crystalline modules – mono-crystalline modules and multi-crystalline modules.
Mono-crystalline modules are currently best in terms of performance, with efficiency of 16 – 18%. They are also more expensive.
The efficiency of multi-crystalline modules is between 12 and 14%. They are more commonly used, especially in the residential and service sectors.

These modules have a service life of more than 20 years. They lose some of their power over time (< 1% per year) but continue to produce electricity. Depending on the look required, bi-glass modules are available with two plates of glass which make the module semi-transparent, or Tedlar or Teflon glass modules which are less expensive but completely opaque.

Thin film modules

Extensive research is currently being carried out on thin film modules and current efficiency levels of 6 to 8% should increase in coming years. They are cheap and suitable for large areas provided that the surface is not a valuable part of the facility.
This category of thin film modules includes a number of technologies of which there are 3 main types:
- a-Si – thin film or amorphous silicon
- CdTe (cadmium telluride)
- CIS (copper indium selenide)

It should be noted that at present we do not yet have 20 years' experience of this type of technology and thus still do not know how these modules will age.
In their technical specifications, reputable manufacturers indicate initial and stabilised values.

The table in **Figure P6** provides a comparative overview of all these technologies.

Technologies	sc-Si mono-crystalline	mc-Si multi-crystalline	a-Si Thin film	CdTe Thin film	CIS Thin film
STC module efficiency					
Maximum	19 %	15 %	8.5 %	11 %	11 %
Average	14 %	13 %	6 %	8 %	8 %
Relative cost ($/Wp)	3	3	2	1	1
Temperature coefficient at the power peak (%/°C)	-0.3 / -0.5	-0.3 / -0.5	-0.2	-0.2	-0.3

Fig. P6 : Comparison of technologies used in photovoltaic generators

3.2 Connections

Photovoltaic installations require special cables and connectors. Since modules are installed outdoors they are subjected to climatic constraints associated with high voltages caused by the installation of modules in series.

Besides being ingress protected, the equipment used must also be resistant to UV rays and ozone. It must furthermore display a high level of mechanical resistance and a high level of resistance to extreme variations in temperature.

Since it is dangerous to handle the cables connecting the modules, they must either first be disconnected or a DC isolator must be activated on the direct current circuit.

Câbles

The voltage drop between the PV array and the inverter must be calculated and this must not exceed 3% for nominal current (UTE recommendation: 1%).

The DC cables used should be double-insulated single wire cables and since these are not standardised, cables indicated by the manufacturer as being specifically for PV should be used.

Connectors

In general, photovoltaic modules are supplied with two cables equipped with one male and one female connector. Using these cables, it is possible to connect two modules installed side by side, thus creating a series without any difficulties. The male connector connects to the female connector of the following module and so on until the required level of direct current is attained.

These special connectors including the Multi-Contact MC3 or MC4 with locking systems offer protection if touched while they are disconnected. This protection is necessary since as soon as a photovoltaic module is exposed to irradiation, it supplies voltage. If the cables connecting the modules are handled (to alter or extend them) they must either first be disconnected or the DC isolator for the DC circuit must be activated at the input to the connection box.

It is also possible to use different connectors available on the market. These should be chosen carefully for their quality, contact and male-female mating to avoid any poor contact which may lead to overheating and destruction.

Fig. P7a : GT 500E inverter specifically designed for photovoltaic power supply (source Xantrex – Schneider Electric Group)

3.3 Inverters

These devices which convert direct current into alternating current are special inverters for photovoltaic power supply (see **Fig. P7a**). Various different types of photovoltaic inverters or “PV inverters” are available. They fulfil three main functions:

- Inverter function: Converts direct current into alternating current in the form required (sinusoidal, square, etc.)
- MPPT function: Calculates the operating point on the photovoltaic surface or array which produces the most power in terms of voltage and current - also known as the Maximum Power Point Tracker (see **Fig. P7b**).
- Automatic disconnection from the network function: Automatically commands the inverter to switch off and the system to disconnect from the network in the absence

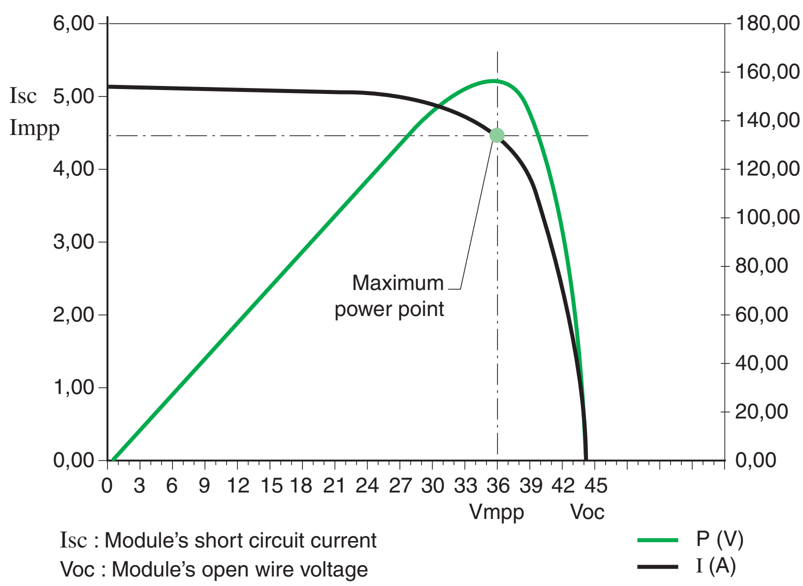


Fig. P7b : Operating point of a photovoltaic array which produces the most power, also known as the Maximum Power Point Tracker of voltage on the electrical network. This protects the inverter and any maintenance staff who may be working on the network.

Therefore, in the event of a network failure, the inverter no longer supplies energy to the network and energy produced by the photovoltaic modules is wasted. "Grid interactive" systems are nevertheless available which function in back-up mode. Batteries need to be installed for these systems as well as an additional control panel to ensure that the network is disconnected before supplying their own energy.

■ Different models

Some "multi-MPPT" inverters have a double (or triple, quadruple, etc.) MPPT function. This function enables PV supply to be optimised when the array includes strings facing in different directions. There is however a risk of total loss of supply if one inverter is faulty.
Nevertheless, it is possible to install one less powerful inverter per string, which is a more expensive solution but increases the overall reliability of the system.

"Multi-string inverters" are also available. These inverters are not necessarily multi-MPPT as described above. The name simply indicates that several strings can be connected to the inverter and that they are paralleled inside the inverter.

European efficiency

In order to compare the various appliances, a level of efficiency has been determined based on different operating points, simulating the average daily performance of an inverter. This "European efficiency" is calculated using the following formula:
$0.03 \times (\eta\ 5\%) + 0.06 \times (\eta\ 10\%) + 0.13 \times (\eta\ 20\%) + 0.1 \times (\eta\ 30\%) + 0.48 \times (\eta\ 50\%) + 0.2 \times (\eta\ 100\%)$

IP and operating temperature

We strongly advise against installing an inverter in a place exposed to the sun as this will considerably reduce its service life.

Ingress protection and temperature parameters are important when choosing an inverter.
Almost all manufacturers of inverters offer IP65 inverters which can be installed outdoors. However, this does not mean that they should be installed in full sunlight as most inverters operate in degraded mode in temperatures over 40°C (50°C for Xantrex inverters manufactured by Schneider Electric) and thus output power is reduced.
Installing inverters outdoors in full sunlight also incurs the risk of premature aging of some of the inverter's components such as the chemical condensers. This considerably reduces the inverter's service life from 10 years to as few as 5 years!

3.4 Battery chargers

In remote locations, batteries need to be charged to supply energy after sunset.
There are two types of chargers:
■ Current chargers – the voltage of the PV array must be the same as the charge voltage of the battery and is regulated in terms of current.
■ MPPT chargers – these chargers operate at the maximum power point. They manage the charge of the battery, limit the current and voltage, and control floating. This type of charger is more expensive than the type mentioned above but allows an optimal number of PV modules to be installed and reduces the overall cost of the installation.

4 Installation requirements

4.1 Off grid installation

Historically, these were the first places in which photovoltaic systems were used, supplying telecommunication relay stations or remote settlements which were difficult to access and could not be connected to the network.
They remain one of the only means of supplying electricity to 2 billion people who currently do not have access to it.
In order to size these installations correctly, it is first necessary to identify the load curve required and the number of days where the installation will not be exposed to sunlight in order to identify how much energy needs to be stored in the batteries. This information is used to determine the size and type of batteries required.
Then, the surface area of the photovoltaic sensors must be calculated to ensure that the batteries can be recharged in the worst case scenario (shortest day of the year).

Specific issues

This method entails over-sizing the system to ensure continuity once or twice a year. As a result, this type of installation is very expensive!
It should be noted that according to the EPIA (European Photovoltaic Industry Association) this type of installation will account for 20% of the photovoltaic market in 2012 and 40% in 2030.

Storage

Storage is crucial to this type of installation.
Several types of batteries are available:

- Lead batteries

These batteries operate in cycles (charge/discharge). Open batteries are recommended to prevent inflating which may occur due to excessively rapid charging and large emissions of hydrogen.
Their purchase price is certainly their main advantage although they have short service lives. This is influenced by the depth of discharging but they last no more than 2 or 3 years at a discharging rate of 50% and above. Furthermore, deep discharging may “kill” the battery. Therefore, when operating such equipment at a remote site, the batteries should be changed on a regular basis to maintain their charging performance.

- Ni-Cd or Nickel Cadmium batteries

These batteries have the advantage of being much less sensitive to extreme temperature conditions and deep charging or discharging. They have a much longer service life (5 to 8 years) but are more expensive to purchase. However, the cost of the Wh stored over the service life of the installation is lower than that of lead batteries.

- Li-ion batteries

These are the batteries of the future for these types of operations. They are insensitive to deep discharging and have a service life of up to 20 years. At present, they are prohibitively expensive but prices are set to fall by 2012 with the start of mass production. They will therefore become the most economic variety for this type of usage.

4.2 Connected to the public network

Owners of power generation systems connected to the network have 2 options:

- Sell all the power they produce (option known as “total sale”). For this option, a separate connection must be established to the network, apart from the connection for consumption. This also requires an administrative declaration.

- Use the power they produce locally as required and only sell the excess (option known as “sale of excess”) which has two benefits:
  - The difference in the rates payable by the producer (purchase) and the consumer (sale)
  - It is not necessary to establish a new connection which may be expensive and requires an administrative declaration.

Since different rates are charged, a profitability analysis should be carried out to choose the best option.

Installations connected to the network – 3 important points

The following points are important to note with regard to installations connected to the network:

■ In contrast to independent installations, no correlation is required between consumption for the building and output.

For the “total sale” option, the two elements are completely independent.

For the “sale of excess” option, the network will compensate when production does not cover consumption.

■ The network must be present in order to supply and sell energy. Furthermore, energy distributors require automatic disconnection systems to be in place in case of incidents on the network. When activated, these stop supply and therefore sales. Reconnection occurs automatically when the network returns to its nominal operating conditions.

■ As a general rule, no provision is made for local storage using batteries or other means. This is true for mainland France where there is a high quality network with the capacity to absorb all the energy produced.

However, the system does have one fault. If the network fails, owners of installations who are also generally consumers are left with a power generation facility which they cannot use (see previous point). In countries or towns with frequent network incidents, systems are being developed which include batteries. Xantrex, a subsidiary of Schneider Electric, is the leading provider of these systems worldwide.

4.3 Safety devices

Protecting people and property against electrical hazards

■ In terms of direct current, a DC isolator is compulsory as, even though a connector can be disconnected when live, an electric arc may occur and damage the connectors if photovoltaic modules are exposed to light. There are currently two methods for installing these DC isolators. They can either be integrated into the PV inverter or placed in an external enclosure.

If more than three strings need to be paralleled for the same inverter input when installing a PV array, the statutory safety devices are much more complex. Indeed, current reversal may occur in a string which would be destroyed under the combined power of all the other strings.

Schneider Electric also supplies paralleling enclosures for strings as well as protection units which include a general load break switch enabling work to be carried out safely upstream of this unit even in daylight.

■ In terms of alternating current, a more standard range of safety devices is available. The cable between the inverter and the network must be protected since any fault in this connection would be exposed to the short circuit power of the network. A safety device protecting against short circuits should therefore be positioned close to the network connection, and the inverter should disconnect automatically in the absence of voltage in the authorised range. Schneider Electric supplies enclosures including upstream and downstream safety devices.

Protecting PV installations against the effects of lightning

Overvoltage may occur in electrical installations for various reasons. This may be caused by:

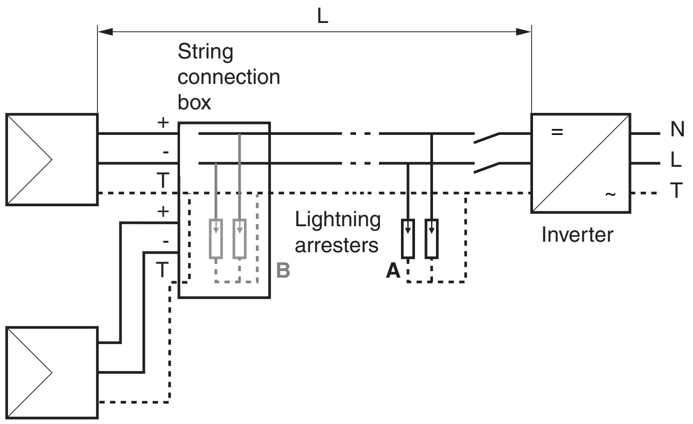
■ The distribution network as a result of lightning or any work carried out
■ Lightning bolts (nearby/on buildings and PV installations, or on lightning conductors)
■ Variations in the electrical field due to lightning.

Like all outdoor structures, photovoltaic installations are exposed to the risk of lightning which varies from region to region.

■ Equipotentiality
Equipotentiality is the first safeguard to put in place and entails connecting all conductive elements and metal conductive parts in the photovoltaic installation using an equipotential conductor.
The minimum section for this conductor is:
□ 4 mm² in the absence of a lightning conductor or if a lightning conductor is in place but not connected to the installation
□ 10 mm² if the installation is connected to the building’s lightning conductor (this must be connected by a cable of 10 mm² if the lightning conductor is less than 2.5m from the installation)

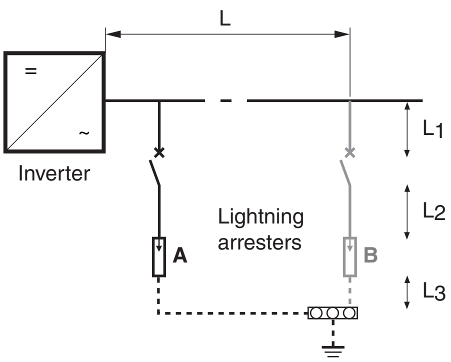
■ Lightning arresters

The positions of lightning arresters are explained by **Figures P10** and **P11**.



If L ⩽ 30 m: only lightning arrester **A** is required.
If L > 30 m: Both lightning arresters **A** and **B** are required.

***Fig. P10** : Positions of lightning arresters in the DC part stipulated in Guide UTE C 15-712*



If L ⩽ 10 m: only lightning arrester **A** is required.
If L > 10 m: Both lightning arresters **A** and **B** are required.
To increase the effectiveness of the lightning arresters: L1 + L2 + L3 < 50 cm

***Fig. P11** : Positions of lightning arresters in the AC part stipulated in Guide UTE C 15-712*

5 Installation

5.1 Installation precautions

A PV array is made up of a number of modules in series or parallel, corresponding to the input characteristics of the inverter. However, since these modules are interconnected, the array is very sensitive to shade or differences in terms of the direction faced.
By following a few simple cabling rules, supply can be optimised and any operating problems may be avoided.

Position of the panels

If, when installing a PV array on a roof, panels need to face in different directions, it is essential to assemble at least one string per direction and ensure each string is facing in just one direction to ensure optimised supply. Each string must be connected to a specific inverter (or to inputs of a multi-MPPT inverter - see Section 3).
If this instruction is not observed, the array will not be damaged but supply will be reduced, thus increasing the time needed for a return on investment.

Shade

Besides the risk of destruction of shaded modules within a PV array due to the "hot spot phenomenon" as described in Paragraph 2.2 for which manufacturers have devised solutions, research conducted by the Institut National des Energies Solaires (INES – France's national institute for solar energy) suggests that shading of 10% of the surface area of a string may cause more than a 30% reduction in output!
It is therefore important to eliminate direct shading. However, in many cases this is difficult (trees, chimney, neighbouring wall, pylon, etc.).
If a PV array includes several strings:
- If possible, shaded modules should be included in a single string
- Otherwise, a technology should be chosen which responds better to diffuse light than direct light

Eliminating loops

When connecting components, the first precaution to take is to avoid loops in the cabling within strings.
Even though direct lightning strikes on arrays are relatively rare, currents induced by lightning are much more common and these currents are particularly destructive where there are large areas of looping. **Figure P13** shows how to improve an array including a large loop.

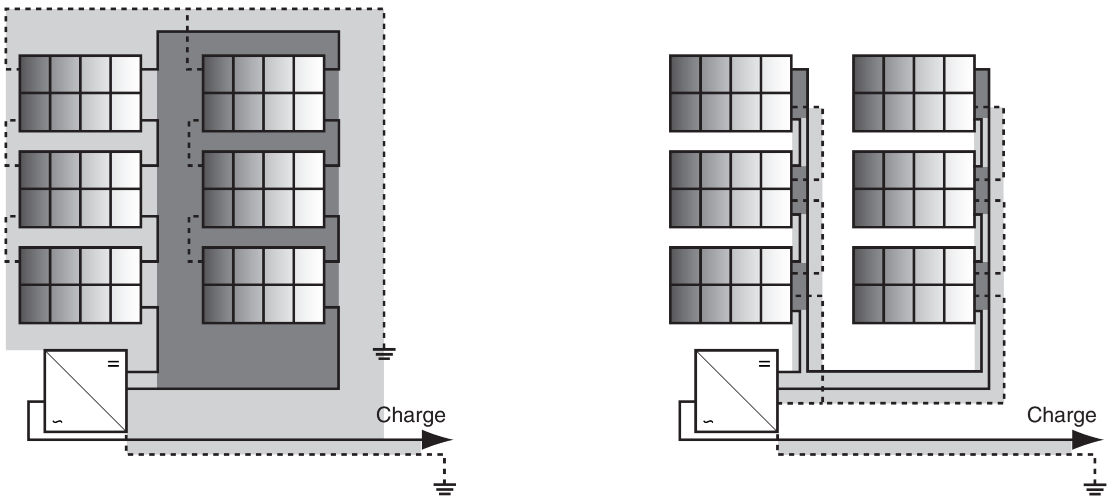


Fig. P13 : Avoiding loops when cabling strings

5.2 Architectures for installations connected to the network

General Rules

Where photovoltaic installations are connected to the network and energy is sold, it is necessary to optimise efficiency and reduce installation costs. With this in mind, a relatively high DC operating voltage of between 200 and 500 V is often used for residential applications, with up to 1000 V being used for applications requiring a higher level of power.
All the modules in a PV array should be identical (same brand and same type) and selected to supply the same level of power. For example, in the PW1700 range, they should all be 180 W, even though there are three power levels (170 W, 180 W and 190 W) in this range manufactured by Photowatt.
In practice, the protection units (DC and AC units) should be positioned close to the inverters for ease of maintenance.

PV array with a single string of modules

This is the simplest configuration (see **Fig. P14**). It is used for small PV arrays with peak power of up to 3 kWp depending on the modules deployed. In most cases, it is used for residential PV operations.

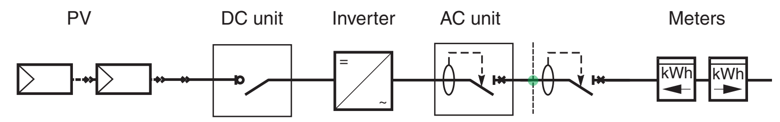


Fig. P14 : Diagram showing a single-string photovoltaic array

Modules are connected in series, supplying direct current of between 200 and 500 VDC in this instance. Optimal efficiency is obtained from the inverter within this voltage range.
A single DC line is fed through to the inverter. The PV array can be isolated from the inverter by means of a load break switch near the inverter.

PV array with several module strings in parallel

This configuration (see **Fig. P15**), mainly deployed on buildings or in small PV power plants on the ground, is used for PV installations of up to thirty strings in parallel with power output of some 100 kWp. This limit is imposed for technological and financial reasons. If exceeded, the required width of the main DC cable would be impractical.
Direct current can be determined based on the number of modules in series per string and in this instance is between 300 and 600 VDC. By paralleling identical strings, the power required for the installation can be attained. The strings are paralleled in a PV array box. This box includes the safety devices required for paralleling the strings and appliances used to measure the strings' current. A single DC cable connects these boxes to the inverter. The PV array can be isolated from the inverter by means a load break switch near the inverter.

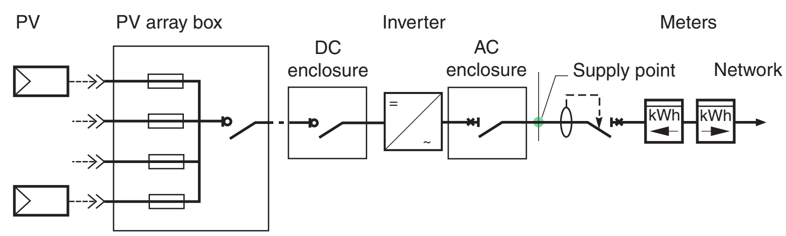


Fig. P15 : Diagram showing a multi-string photovoltaic array with one inverter

As a variation on this diagram, several single-phase inverters can be installed in a three-phase arrangement (see **Fig. P16**).

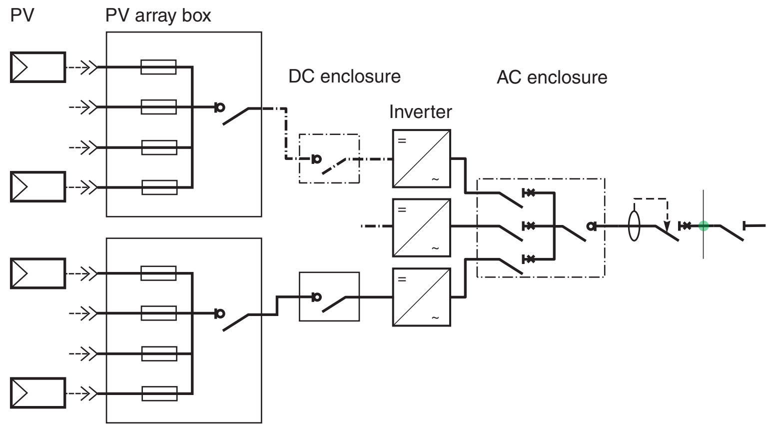


Fig. P16 : Diagram showing a multi-string photovoltaic array with several single-phase inverters connected in a three-phase arrangement

PV array with several strings divided into several groups

When power levels exceed 50 or 100 kW, photovoltaic arrays are split into subgroups (see **Fig. P17**) to make it easier to connect the various components. Strings are paralleled on two levels.

- Strings in each subgroup are paralleled in subgroup PV array boxes. These boxes are fitted with safety devices, the necessary measuring equipment and monitoring devices.
- The outputs of these boxes are paralleled in a PV array box near the inverter. This box is also fitted with the required safety devices as well as the measuring and monitoring equipment necessary for paralleling the subgroups.

The array can be isolated from the inverter using a load block switch which may or may not be fitted in the PV array box. The array's direct current is approximately 1000 VDC.

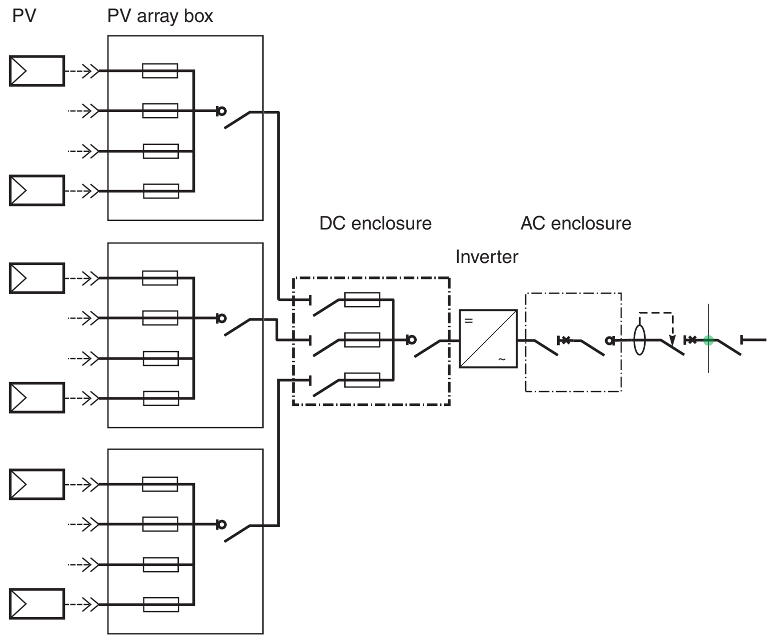


Fig. P17 : Diagram showing a photovoltaic array consisting of several groups

5.3 Sizing

Calculating a photovoltaic array

It is absolutely essential to take account of location (geographic location, latitude, altitude, shade, etc.) and installation factors (direction faced, angle, etc.).

Firstly, the approximate power output may be calculated based on the available surface area:
10 m² = 1 kWp
7140 m² (=football ground) = 700 kWp

The PV array should always be arranged around the inverter. The calculations involved should compare the characteristics of the modules and those of the inverter with a view to identifying the optimal configuration.

- String composition:

NB: Number of modules x Voc (at t° min) < inverter Vmax
The no load voltage of the string (Voc x number of modules in series) at the minimum temperature of the installation location must be lower than the inverter's maximum input voltage.
=> This must be strictly observed. Otherwise the inverter may be destroyed.
Apart from the aforementioned rule for preventing destruction of the inverter Number of modules x Voc (at t° min) < inverter Vmax – two other limits must be observed:

- Number of modules x Vmpp (at t° max) > inverter Vmin

The operating voltage (Vm x number of modules in series at all temperatures at the installation location) should fall within the inverter's MPPT voltage range. Otherwise, the inverter will stall and energy supply will cease.

- Isc strings < inverter I max

The total Isc current for strings in parallel must be lower than the maximum input current for the inverter. Otherwise, the inverter limits the supply of energy delivered to the network.

Inverter specifications

- In Europe, the power level of the inverter must be between 0.8 and 1 times the power of the array:

0.8 < Pinverter / Parray < 1

- Below this (under 0.8 Parray), the inverter limits power significantly. The energy sold to the network will thus be inferior to that which the panels are capable of supplying and therefore it will take longer to secure a return on investment.
- Above this (over Parray), the inverter is too large for the power level of the array. Again, it will take longer to secure a return on investment.

- Single-phase or three-phase

A decision should be made over these two options in consultation with the local energy distributor based on the devices available in manufacturers' product ranges, often within the following limits:

- Inverter Pn < 10 kW => single phase inverter
- 10 kW < Pn < 100 kW => either three-phase inverter(s) or single-phase inverters split between the three phases and neutral. The management of unbalances between phases needs to be checked in this instance.
- Pn > 100 kW => three-phase inverter(s)

- Configuration software

Manufacturers of inverters help design offices and installers to size strings for residential and service sector installations based on the equipment available by supplying sizing software.

5.4 Installation type

The installation type is a factor which should not be neglected since, in countries including France, the purchase price for power supplied is dependent on this. Along with shading, it should be taken into account when choosing a module.
There are three installation types – building integrated, partially integrated and ground-based:

- Building Integrated PhotoVoltaic (BIPV)

This installation type fulfils a dual role (energy supply and roof waterproofing, shading, etc.).

■ Partially integrated
This is the simplest assembly to install and, most importantly, does not alter the water resistance of a roof. However, its major drawback is that, in France, operators cannot charge the highest rate for it. This installation type is most commonly used in Germany and Switzerland.

■ Ground-based
This installation type is used for power supply plants covering large areas (photovoltaic farms). Again, in France it is not eligible for the highest purchase price.

6 Monitoring

Since the profitability of photovoltaic installations depends mainly on them being operational, it is essential to ensure that they are permanently functional. The best way of ensuring this is to acquire a monitoring system for the installation. This system should notify all faults immediately and be capable of detecting drifts in output.

6.1 Types of monitoring

Several types of monitoring are available for installations:

■ Systems which communicate with the inverters and are able to monitor all electrical values relating to output from the installation as well as the condition of the inverters

■ Systems without communication protocols for the inverters but fitted with measurement inputs capable of monitoring photovoltaic output

■ Hybrid systems supplementing information from the inverters with measurements which are external to the installation such as solar radiation and temperature.

Information on the modules at the output of the inverters can only be correlated across the installation as a whole by systems capable of measuring solar radiation. Indeed, since output forecasts generally rely on meteorological statistics, it is quite difficult to interpret output data without correlating them to actual solar radiation. An abnormally low level of output may be caused by:

□ A low level of solar radiation over a certain period of time (and which is abnormal based on meteorological statistics)

□ A problem with the modules (clogging, shade, connection fault, etc.)

□ A functional problem with the inverter

It is only possible to identify these faults by equipping the installation with solar radiation and temperature sensors and comparing the output capacity with actual output.

Depending on the size of the installation, individual monitoring or monitoring by group of photovoltaic module strings may be possible in order to detect abnormal variations in output between strings.

6.2 Monitoring systems

These systems may be autonomous or include remote monitoring.

■ Autonomous systems (see **Fig. P18**)

Once data is collected locally, the system sends alerts directly to the maintenance operators as soon as they are generated.

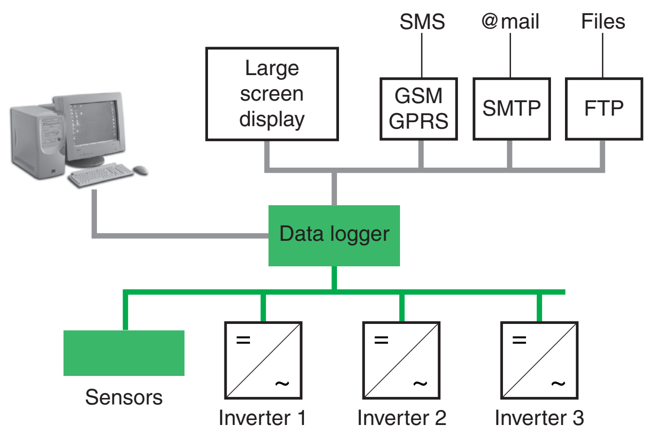
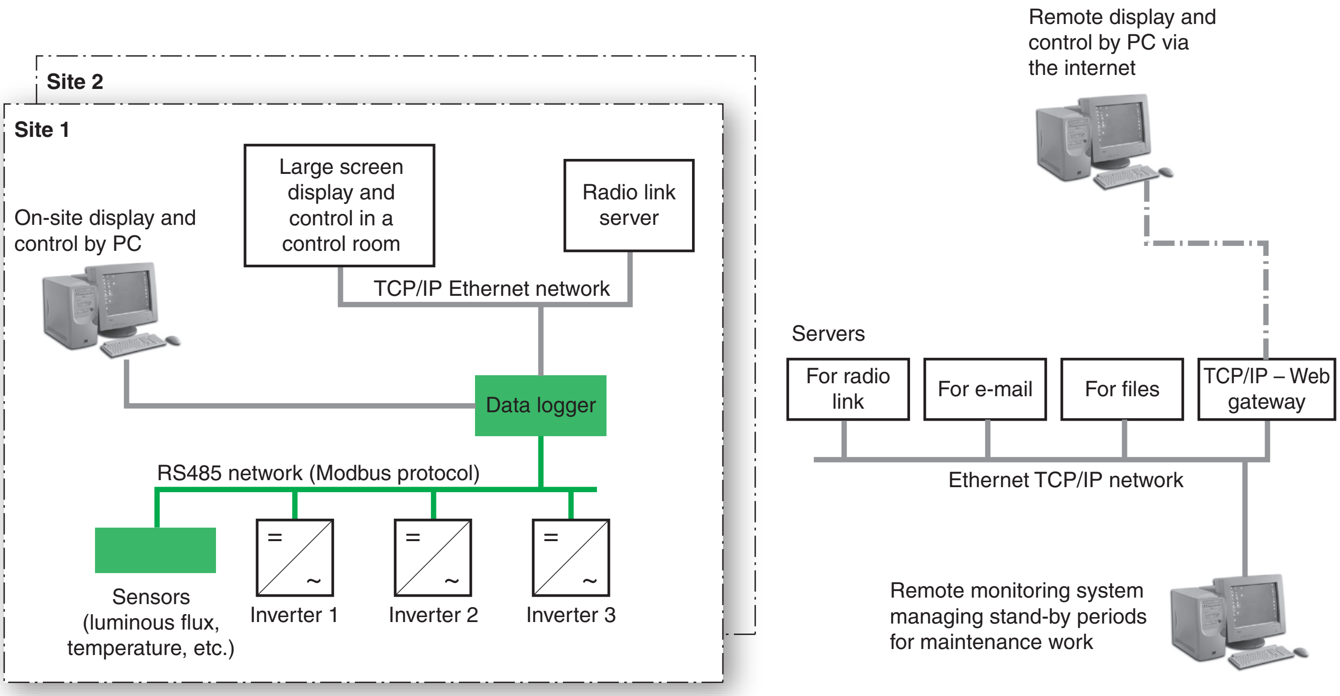


Fig. P18 : Example of an autonomous monitoring system

■ With remote monitoring (see **Fig. P19**)

Once the data is collected locally, the system sends output data and alerts as soon as they are generated to a remote monitoring system capable of managing stand-by periods for maintenance work. This enables the installation to be monitored closely, which is essential for multi-site installations or where operators of photovoltaic installations are not necessarily the site occupants.



Servers:
- Data server for the radio link: using the GPRS (*General Packed Radio Service*) protocol – changes in the GSM standard
- E-mail server: using SMTP (*Single Mail Transport Protocol*)
- File server: using FTP (*File Transfer Protocol*)

Fig. P19 *: Example of a system for remote monitoring*

Fig. P20 *: Pyranometer – Kipp & Zonen*

6.3 Sensors

Sensors provide data to the monitoring systems and include:

- A sensor for measuring instantaneous luminous flux such as a pyranometer (heat flow sensor used to measure the quantity of solar energy in natural light (W/m²), see **Fig. P20**). This is the standard reference for the installation. It may be used to identify shifts over time and is recommended to all suppliers wishing to conduct comparative analyses and compile statistics for their installations.
- A temperature sensor – this is an important factor for photovoltaic power supply (see Paragraph 2.1). This sensor either serves as an external probe or is attached to the back of a module.
- A kilowatt hour meter

When selling power, only the kilowatt hour meter operated by the energy distributor purchasing the electricity may be used as a reference.
The other meters fitted within an installation (in the inverter or next to the official meter) are only indicators with their own specific levels of accuracy. Variations of more than 10% may occur between the values given by an installation's devices and that given by the official meter. However, these variations are not only due to different levels of accuracy. They are also caused by energy lost in the cables and safety devices downstream from the inverter.
It is therefore important to use cables of minimal length and clearly identify:

- The location where the installation will be connected to the network
- The locations where the energy distributor's meters will be connected

6.4 Monitoring the installation

Since modules are expensive and in some cases openly accessible, sites need to be monitored by security cameras.
NB – although this type of surveillance is authorised for private sites, filming of public highways is prohibited.

7 Additional Information

7.1 Installation costs (2009)

The following table (see Fig. P21) shows average installation costs estimated in 2008 by surface and module type.

Surface type	Module type	P/m²	No. m² /kW	Price/Wp for 10 kW	Price/Wp for 100 kW
Pitched roof (integrated)	standard	120 W/m²	9 m²/kW	7-8 €	5-6 €
Pitched roof (partially integrated)	standard	120 W/m²	9 m²/kW	6-7 €	5-6 €
Pitched roof (integrated)	Standard in a steel rack	65 W/m² (*)	15 m²/kW	8-9 €	6-7 €
Pitched roof (integrated)	Thin film	45 W/m²	22 m²/kW	5-6 €	4-5 €
Flat roof (non-integrated)	standard	120 W/m²	22 m²/kW	5-6 €	4-5 €
Glass roof (integrated)	standard	120 W/m²	9 m²/kW	13-15 €	9-10 €
Sun shade (integrated)	standard	120 W/m²	9 m²/kW	9-10 €	7-8 €

7.2 see (Guide de l'installation électrique)

7.3 see (Guide de l'installation électrique)

7.4 see (Guide de l'installation électrique)

7.5 True or false

- Solar panels produce less energy than is required to manufacture them.
False: The service life of a solar panel is over 20 years and only 18 to 36 months are required, depending on the direction faced, to generate the energy needed for its manufacture. Therefore, by the end of their service life, solar panels produce ten times the energy used to manufacture them.

- Intermittent supplies of renewable energy disrupt the networks
True: The power networks were set up as part of a three-tier system (distribution, transmission and supply) and are only equipped for the input of large quantities of power at very specific points in the transmission network. Networks are controlled vertically from suppliers to consumers. The connection of energy sources throughout the distribution network is changing current practices. However, since their power levels are relatively low, residential installations have no direct impact on the distribution network on an individual basis. It is due to the large numbers and disparity of these installations that the various networks need to be managed more carefully.

- One of the features of some forms of renewable energy (wind power and photovoltaic power) is the fact that power is supplied intermittently since output is dependent on the sun (or wind) which disappears in cloudy conditions or when night falls. Therefore, they are not reliable sources of energy and are not available on demand.
True – except in remote areas where extensive research has been conducted on charging storage batteries.
True – except when generators are connected to the network as the network supplements shortfalls in renewable energy.