GOOD AND

BAD PRACTICES

MANUAL TO IMPROVE THE QUALITY

AND REDUCE THE COST OF PV SYSTEMS

PV CROPS

Photo**V**oltaic **C**ost r€duction, **R**eliability, **O**perational performance, **P**rediction and **S**imulation

SEVENTH FRAMEWORK PROGRAMME

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1. Introduction.

Grid-connected photovoltaic (PV) solar energy is a technology which has come to play a significant role in the electricity generation and supply systems of many countries. Over a period of only 10 years, approximately 100 GW of PV capacity has been developed and constructed with close to 80 GW of that total having been built in the past 3 years. This represents an annual grown of close to 40%. For this reason, PV installations are the third most significant renewable energy source, behind hydro and wind energy in terms of capacity. Some European countries are meeting more than 5% of their annual electricity demand with PV energy (Germany and Italy)[1].

This exponential growth has been evident in Europe, where close to 70% of the worldwide grid-connected PV power is situated. European countries have promoted the use of renewable energy to meet the European Union requirements for reducing damaging greenhouse gas emissions from energy production in order to alleviate the associated climate change effects. Those requirements to limit emissions, coupled with the bonus associated with the deployment of “green energy”, have favoured this rapid development, accompanied by a gradual decrease of PV device costs. Consequently, in the south of Europe, PV solar energy can compete in cost terms with traditional energy sources (gas, coal, oil, nuclear, etc.), even without additional subsidies.

The PV sector is maturing and spreading rapidly elsewhere in the World. Evidence of this is that last year (2012) was the first year in which PV power installed in the rest of the word was almost at the same level as that installed in Europe. In order to continue with this growth, and to make PV solar energy more and more competitive, it is necessary to consider the best practices for PV installations. This involves avoiding the mistakes which occurred in the earlier installations. Thus, solving a priori the known errors, new PV installations will be more reliable, efficient and cost-effective and can recover the initial investment in a shorted time.

In essence, the objective of this manual is to show the good and bad practices which have been detected in existing PV installations. This represents a useful reference for when a new installation is being designed and built. The good practices will be examples of how to implement these projects to get each individual device operating properly and avoid premature degradation. The bad practices will be example of mistakes which have previously been made and should be avoided.

The fact that this manual shows bad practices should not to be interpreted as indicating that they are common in existing installations. On the contrary, PV installations are generally well constructed and are operating effectively, with good practices predominating. This manual tries to show those defects that have been detected and which can cause a reduction in the lifetime of the installation or in the resulting energy production. Therefore, such practices lead to a decrease in overall performance if they are not resolved.

We can differentiate between two types of grid-connected PV solar energy production systems: PV plants and building integrated PV systems (BIPV).

PV plants are characterized as having a large installation area or footprint, as having a power rating in the order of some hundreds of kilowatts to tens (even hundreds) of megawatts and as having modules which are carefully oriented to the sun (south-oriented in the north hemisphere; north-oriented in the south hemisphere) in order to maximize the energy production.

BIPV take advantage of space available, mainly on the roofs of houses and industrial buildings, to install PV arrays in the range from a few kilowatts to several tens of kilowatts. These systems can be added after building construction, although it is becoming more usual for such installations to be integrated from the beginning of the design and construction phases. As they are integrated into a house or a building, their orientation is limited by the characteristics of the building, so that the orientation and elevation used may not be optimal. This is particularly the case where the installations are added after the construction of the building.

The examples shown in this manual are related to both PV plants and BIPV. Most of the situations and examples presented here come from PV plants, but there are good and bad practices common in both installations. Those situations that are specifically related to BIPV will be highlighted in the accompanying text.

[1] Global market outlook for photovoltaics 2013-2017. May 2013. European Photovoltaic Industry Association (available in www.epia.org/news/publications/)

We have to point out that all the measures recommended here are worthless if after a PV installation is built, it is not properly maintained. Following the recommendations presented here will not guarantee a good performance from a PV installation. PV installations must meet the national electrical industry regulations and should include preventive and corrective maintenance to detect and quickly solve faults and failures that can appear during normal operation. It is advisable to install a monitoring system, operated by qualified personnel, that provides alerts in the event of faults in the PV installation during operation. A periodic review of the status and condition of the wiring, plugs, modules, inverters, etc. is essential. Only in this way will the installation operate properly, ensuring that it reaches its full design lifetime, a high availability level with high energy production and, consequently, lower costs for PV solar energy.

2. Organization of the manual.

Chapter 3 of this manual shows the good and bad practices which have been detected in existing PV installations. It is divided into 7 sections, each dealing with separate aspects of grid-connected photovoltaic installations, both PV plant and BIPV. These sections describe both typical good practice in terms of PV installations and some of the mistakes which can occur. The presentation is in the form of visual material, both photographs and diagrams, and a short text which describes the good and bad practice where relevant.

All of the photographs are from real installations in various parts of Europe and represent the common procedures which are used for the construction of PV installations. Avoiding bad practices and applying the examples of better practice will help to ensure that final PV installations will be free of premature degradation and frequent failure that will decrease the energy production of the system and, consequently, its profitability.

As noted above, each category is related to one of the main components or sub-systems of a PV system and is identified by a letter which indicates the aspect to which the figures refer:

- “C” for the civil works;
- “S” for the supporting structures;
- “W” for the connection boxes and wiring;
- “G” for the photovoltaic array or generator;
- “I” for the inverters;
- “M” for the monitoring devices and routines;
- “O” for those other aspects not dealt with in the other categories.

In order to a quickly and clearly highlight the nature of the situation being presented, the following symbols are associated with each of the figures:

For good practices

For bad practices

On occasion, a further symbol is used with figures in those situations which would not necessarily be classified as good/bad practice but where it could be possible for some improvement to be made:

For neither good/bad practices;
situations that could be improved

3. Good and Bad Practices.

3.1. Civil Works.

Feasibility study and initial planning

Tests must be carried out to adapt the foundations to soil properties.

It is fundamental that a feasibility study of the land on which the PV plant is to be installed be carried out. The objectives of such a study would be to determine the properties of the site before selecting the foundations to use as this selection is determined by the mechanical constraints and the soil quality. Foundations must accommodate the effects of weight and wind (as defined by the appropriate Eurocode norms). This study would also eliminate the possibility of unnecessary works.

Each type of foundation (concrete footing, pile, mini-pile, etc.) is suited to specific land-types. Shallow foundations, such as concrete footings, could be suitable in compacted and stable land (rocks, aggregates), while deep foundations, such as piles or mini-piles, could be suitable in un-compacted lands which might be prone to seasonal climactic variations (e.g. expansive clays, areas close to water table). Figures 1 to 3 show some situations in which this preliminary study has been carried out.

Figure 1.

Figure 2.

Figure 3.

Feasibility study and initial planning

Obstacles must be identified during initial planning phase.

An initial study of the relative locations of trackers, buildings, fences, walls, etc. must also be carried out to avoid later modifications to these elements that will increase the final cost of the civil works.

The pictures below show the consequences of bad initial planning; in Figures 4, 5 and 6 the shadow of monitoring systems or a wall is cast over the module. On the other hand, Figures 7 and 8 show trackers that are restricted to maintaining their horizontal position and cannot go through the full tracking range because of the close proximity of a building or a wall.

Figure 4.

Figure 5.

Figure 6.

Figure 7.

Figure 8.

General organization

PV plant must be enclosed with a fence or a wall.

This element of the installation has two objectives: to protect the installation against larceny and, more importantly, as a barrier to protects against electric shock by ensuring adequate distance between personnel outside the installation and the live electrical equipment inside. Poor installation of the fence or any breech in the fence will render it useless.

The Figure 9 shows a good fence installation which allows some small wild animals to enter the PV plant but not people (see also Figure 227 – practice O2, page 126). On the other hand, the remaining pictures show different faults in the fence. In Figure 10, the fence has a suitable gap at the bottom on the right side, but this too big on the left side and would allow a person to enter the plant. Something similar is shown in Figure 11, but at the upper side of the fence. Finally, Figure 12 shows a hole in a fence that means that it does not achieve its function.

Figure 9.

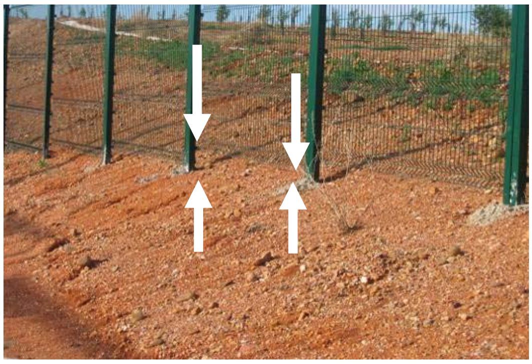


Figure 10.

Figure 11.

Figure 12.

General organization

A plan or map of the installation is needed to locate every element in the PV plant.

If signage is added to the trackers (Figure 14), structures (Figure 15), paths (Figure 16) and buildings, they will be easier to locate.

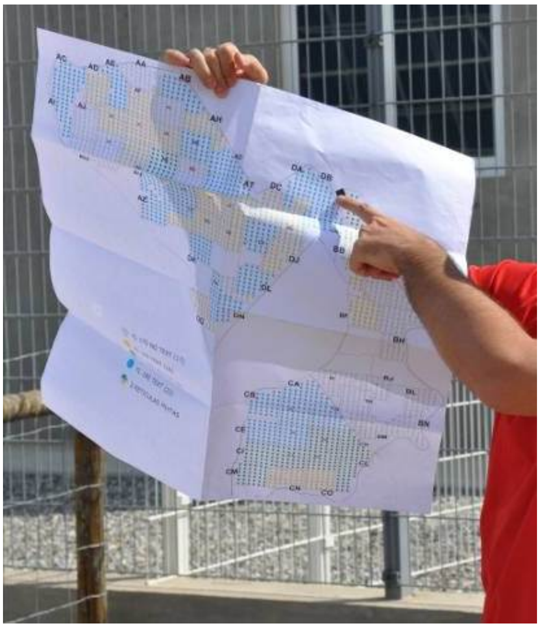


Figure 13.

Figure 14.

Figure 15.

Figure 16.

YES

Drainage and water protection

Foundations and drainage systems must be designed to accommodate floods.

Water can cause erosion and landslides which can leave concrete footings without earth support, as is shown in Figures 17 and 18, or cause fracture, as is shown in Figure 19. The fracture of concrete footings can also cause separation of structures, as shown in Figure 20, and the possibility of PV module breakage.

Figure 17.

Figure 18.

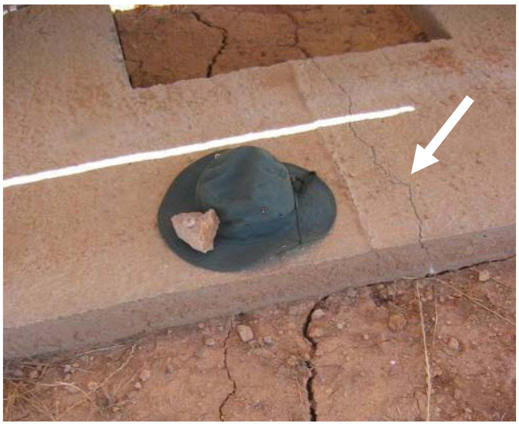


Figure 19.

Figure 20.

Drainage and water protection

Drainage systems must accommodate extreme events and be properly maintained.

The absence of correct drainage system can transform foundations, paths and buildings into dams and lead to flooding as shown in Figures 21 and 22.

Figure 21.

Figure 22.

Drainage system channels must be clear to allow water to flow easily (Figure 23). Otherwise, accumulation of vegetation, stones, sand, etc. could block drainage channels and cause flooding (Figure 24).

Figure 23.

Figure 24.

Drainage and water protection

Service buildings must be waterproof.

The service buildings which house inverters, transformers, monitoring systems and other equipment must be waterproof to avoid electrical faults and damage to equipment. The buildings have to be watertight to maintain integrity so that all possibilities for water ingress are sealed, as has been achieved in Figure 25. Water cannot enter the building because the hole has been sealed leaving the cables dry and clean (black). In contrast, Figures 26 and 27 show how water has entered the building through the roof because of a leak and through the floor or foundation, respectively. Figure 28 shows evidence of flooding as the cables are dirty with mud once the water had evaporated. This was because the entrances to the building were not sealed and water could enter through the pipes. This is avoided in the installation shown in Figure 25.

Figure 25.

Figure 26.

Figure 27.

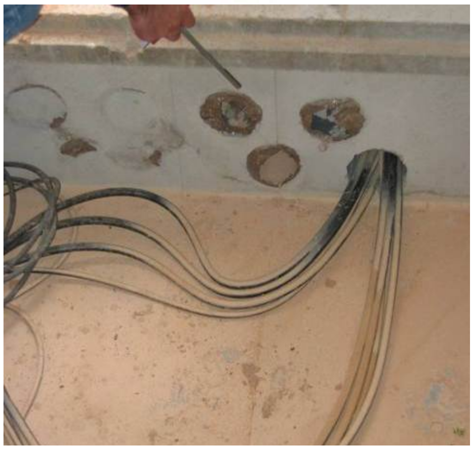


Figure 28.

Drainage and water protection

Cable entry points in buildings must be waterproof.

In BIPV installations, cable entry points in buildings must be waterproof; otherwise water can enter the building. Pipe or tubing entry points have to be sealed, unlike the arrangement in Figure 29. Apart from the sealing of pipes or tubes, other techniques can be used. Advantage can be taken of the “drop of water” principle for entry points on a vertical wall, with cables curving below the entrance (Figure 30) or curved sleeves for entry points on a horizontal roof.

Figure 29.

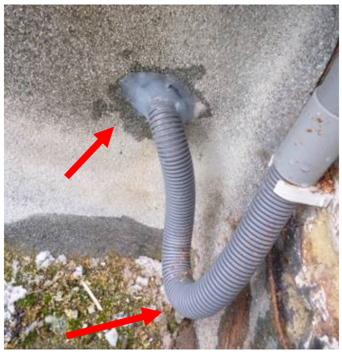


Figure 30.

Drainage and water protection

Doors of service buildings must be waterproof and dirt-proof.

Doors should protect the devices and equipment inside the building; they must resist corrosion and must be blocked when open to avoid damage due to wind gusts. Otherwise, doors can degrade prematurely, preventing them from meeting their intended function.

Figure 31 shows door hinges that are oxidized, with the right hinge bent. This is evidence of damage due to a wind gust because these doors do not have a blocking system. This can eventually lead to further damage of the door if the situation repeats.

On the contrary, the door in Figure 32 has a proper blocking system and is perfectly protected against oxidation.

Figure 31.

Figure 32.

Cables

Cables trays must be protected during construction phase.

The next pictures show the case of a PV plant in which the cables are located in trays on the ground (Figure 33). Unfortunately, those trays are close to drainage channels and during the construction of the channels, concrete has been allowed to flow into the cable trays (Figures 34 and 35). The concrete has also reached the cables situated in these trays. This could degrade the properties of the cable insulation and sheaths or other covering as a result of chemical reaction with the cement, decreasing its insulation properties or even its external resistance to environmental conditions (low or high temperatures, rain, frost, etc.) even though these cables were designed for external use.

Figure 33.

Figure 35.

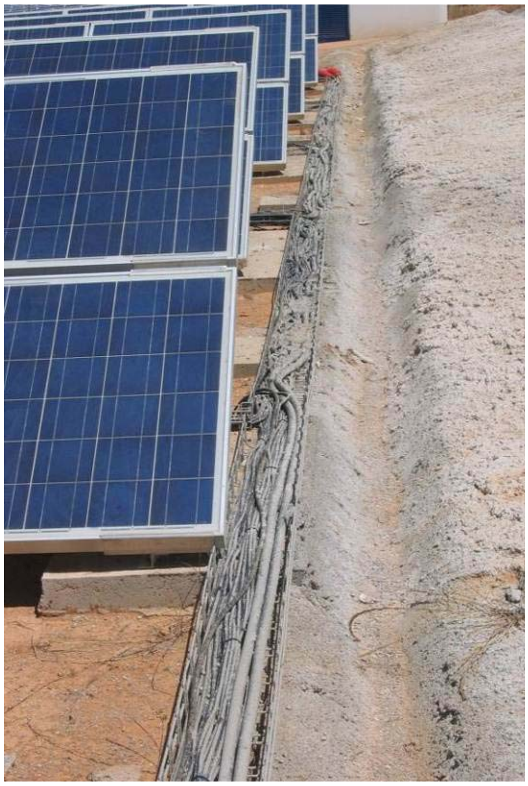


Figure 34.

Cables

Cables must be placed in cable trays.

Figure 36 shows current-carrying cables running from the connection boxes to the inverter in a particular installation. This presents a hazard as personnel could trip on the cables because of the manner in which they have been installed. In order to be able to locate and trace specific conductors and to avoid a trip hazard, cable trays as shown previously in Figure 33 (practice C10, page 22) should be used.

Figure 36.

Cables

Buried cables should be protected by rigid tubing or ducts.

Buried cables benefit from additional protection against mechanical damage. However, the cables should not be placed directly in trenches as they can be damaged by backfill. Also, some cable sheaths are made from organic material (for example, vegetable oil) that could be eaten or damaged by rodents or moles. Additionally, ducts or conduit allows easy replacement of cables if needed.

In the case shown in Figure 37, the cables between the connection boxes and the inverters are directly buried in the trench. A better solution would have been to locate the cables in tubes or pipes to protect them from moisture and from land animals which can damage or prematurely degrade the cables and cause excessive leakage currents or failure.

Figure 37.

It is also advisable to use different pipes to protect power and signal cables. In this way any interference from the power to the signal cables will be avoided.

Cables

Buried cables should be burried below freezing depth.

Trenches to accommodate buried cables should be deep enough, as the cables must be below the freezing depth. High temperature differences cause variation in cable length and this can lead to damage of cables if stretching is excessive. It is necessary to refer to local regulations and construction norms for more information on the minimum depth of cables.

Figures 38 and 39 show two trenches in the same installation. In this area the freezing depth is 60 centimetres (the freezing depth is location-specific). The cables in Figure 38 are not protected against freezing because the trench depth is not sufficient. On the other hand, the depth of the trench in Figure 39 is sufficient and consequently, these cables are unlikely to be exposed to stretching.

Figure 38.

Figure 39.

Manholes and chambers

Manholes and chambers must be properly installed.

Figures 40 and 41 show damage in the installation of manholes or chambers and consequently the protection afforded by the manhole is lost. This allows water, soil, dust or rodents to enter the manhole and from there into the pipes connected to the manhole (as these pipes are located at the bottom of the manhole and are unsealed).

Figure 40.

Figure 41.

Figures 42 and 43 show the proper construction and installation of manholes or chambers. The protection provided by the manhole is guaranteed, preventing the ingress of material or rodents. There is also a gap between the bottom of the manhole and the entry point of the pipes and the pipes themselves are sealed.

Figure 42.

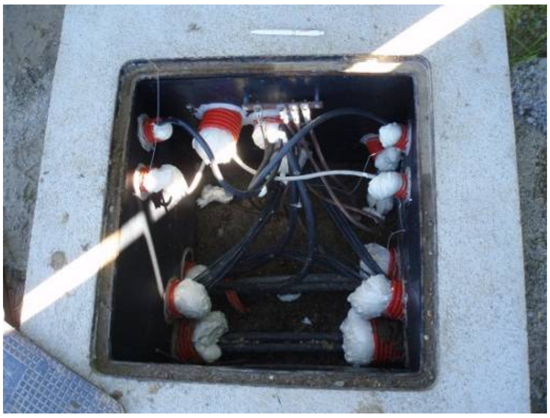


Figure 43.

Manholes and chambers

Manholes should be raised above the ground for additional protection.

Sometimes manholes or chambers are broken because heavy machinery has been driven across them as shown in Figure 40 (practice C14, page 26). A good option to avoid this is to raise the manholes or chambers some centimeters from the ground level, as is shown in the Figures 44 and 45. Another option is to avoid installing manholes on paths or any other routes used by heavy machinery which can cause this damage.

Figure 44.

Figure 45.

Supporting roofs

Supporting roofs must be in good condition.

In BIPV installations it is very important to consider the condition and the quality of the roof on which the generator is to be placed. An investigation of the condition of the roof before installing support structures and PV modules is required. Such installations will be in place for up to 25 years. Therefore, it is necessary to ensure that the roof does not require repair or replacement within that period. The roofs in Figures 46 and 47 are suitable for BIPV installation, while the roofs in Figures 48 and 49 must be repaired before a PV array structure and modules can be installed. Standing water on a flat roof is also a problem that must be resolved before the installation of BIPV as it creates additional weight on the roof and can cause degradation.

Figure 46.

Figure 47.

Figure 48.

Figure 49.

Supporting roofs

Total weight of the PV installation (structure + ballast + modules) must remain below the maximum load tolerated by the roof (including safety margins).

The total weight of the installation (structures, ballast and modules) must remain below the maximum load tolerated by the roof. This has to include safety margins because the mechanical load created by the new installation is going to be augmented by the intermittent loads caused by snow and wind on the roof. These safety margins (Ultimate Limit State and Serviceability Limit State, as defined in the Eurocode norms) should be calculated by a specialized engineering office. For the installation of BIPV, the roof structure should be reinforced if necessary, as in the Figure 50.

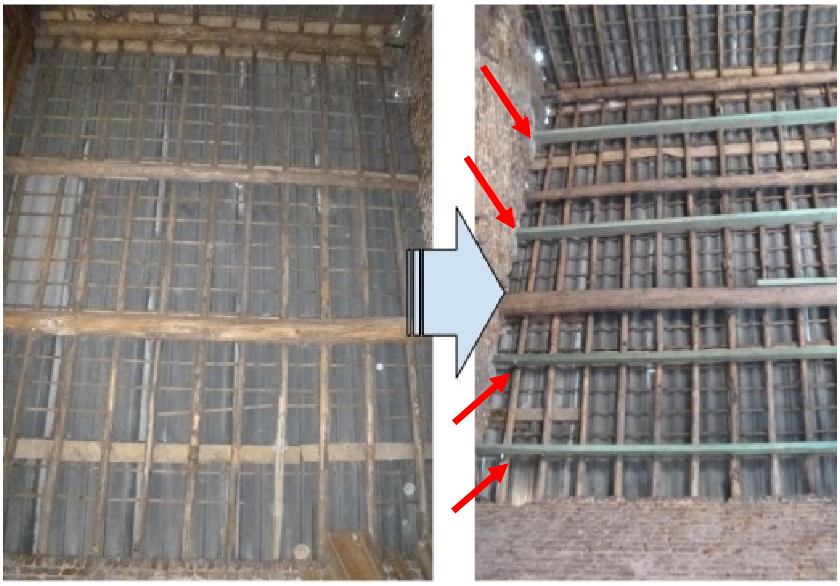


Figure 50.

3.2. Supporting Structures.

Grounding of the structures

All metallic parts of the structures must be grounded.

A good earth connection protects people and electronic devices against leakage currents. All metallic parts of the supporting structure, including those where direct contact cannot be made as they are separated by non-conductive material, must be interconnected or bonded and then grounded. This is in order to protect people against electric shock in the event of faults or electrical storms (Figures 51 and 52). Otherwise, the ungrounded components could reach dangerous voltage levels relative to ground. This could happen with the post in Figure 53 due to the black insulating layer.

Figure 51.

Figure 52.

Figure 53.

Grounding of the structures

Grounding wires must be clearly identified.

The earth connection wire of Figure 54 was screwed to the supporting structure to ensure the protection of people from electric shock. However, the wire has been cut and the protection is lost.

It is advisable to use conductors which are clearly distinguishable from the power cables for earthing structures. The ground conductor can be bare wire as in Figure 52 (practice S1, page 33) or with a covering of a different colour, usually yellow/green, as in Figure 70 (practice S10, page 42).

Figure 54.

Mounting PV modules

PV modules are usually fixed with clamps on the long edges. Fixing the PV modules on the short edges may be permitted for certain models and under certain conditions.

PV modules are usually fixed with clamps on the long edges (Figure 55). Fixing the PV modules on the short edges (Figure 56) may be permitted for certain models and under certain conditions. However, this practice reduces the ability to deal with climatic loads such as wind and snow. The maximum load due to extreme meteorological conditions depends on the location of the system and on its direct environment and should be compared to the permitted loading on the modules. These would typically be in the range of 2400 Pa to 5400 Pa.

Figure 55.

Figure 56.

Clamps must be symmetrically placed to avoid excessive distance between the PV module attachment point and the edge to achieve better attachment of modules to the structure, as shown in Figure 55, rather than Figure 57.

Figure 57.

It is important to refer to the PV module installation manual for additional information concerning the installation procedure and appropriate fixing points.

Mounting PV modules

Clamps must be used according to their specifications.

In Figures 58 to 61, the PV modules are fixed to the supporting structure by clamps designed to support PV modules. These clamps avoid shading as well as electrical corrosion, but they must fit perfectly to the PV module frame (i.e. the dimensions of the clamps must match the PV module) and they have to be properly tensioned to achieve good attachment, as shown in Figures 58 and 59. Otherwise, modules can become detached as a result of high wind loading, as has happened in the installations shown in Figures 60 and 61.

Figure 58.

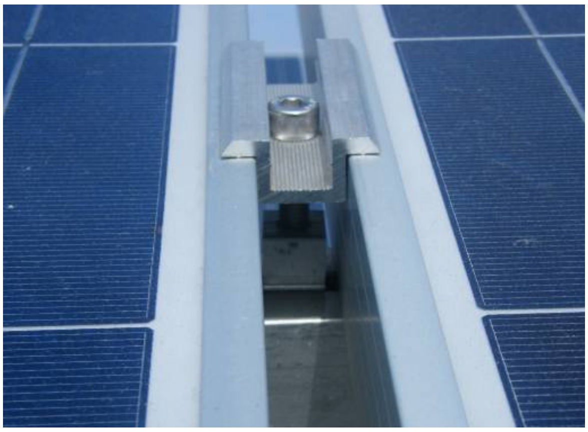


Figure 59.

Figure 60.

Figure 61.

Mounting PV modules

Clamps must match the size and shape of the modules.

In contrast to the previous pictures, Figures 62 and 63 show how the modules are ineffectively fixed to the supporting structure. The clamps used are not aligned and do not match the shape of the PV modules (Figure 62) or they are not correctly installed in the gaps between the PV modules because the washers do not fix the module properly (Figure 63). This could easily detach as a result of wind loads or thermal expansion.

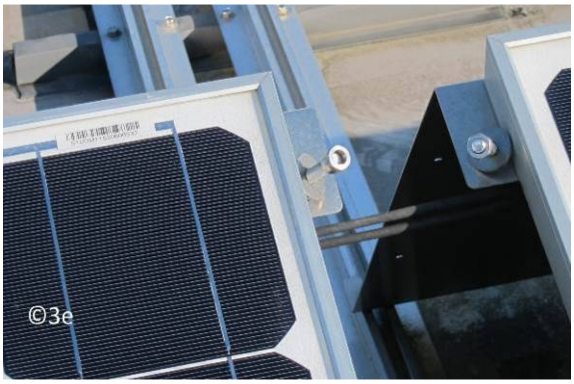


Figure 62.

Figure 63.

Mounting PV modules

Supporting structures must fit to the module frames.

In Figure 64, the PV module is not mounted in an appropriate manner since the supporting structure does not fit to the PV module frame. It is bent and incorrectly held by a threaded steel rod. The PV module may become detached during heavy winds or even be irreversibly damaged. As it has been said previously, the supporting structure and clamps have to be matched to the module thickness.

Also, the length of the screw is excessive and should be the correct length to avoid injury to personnel.

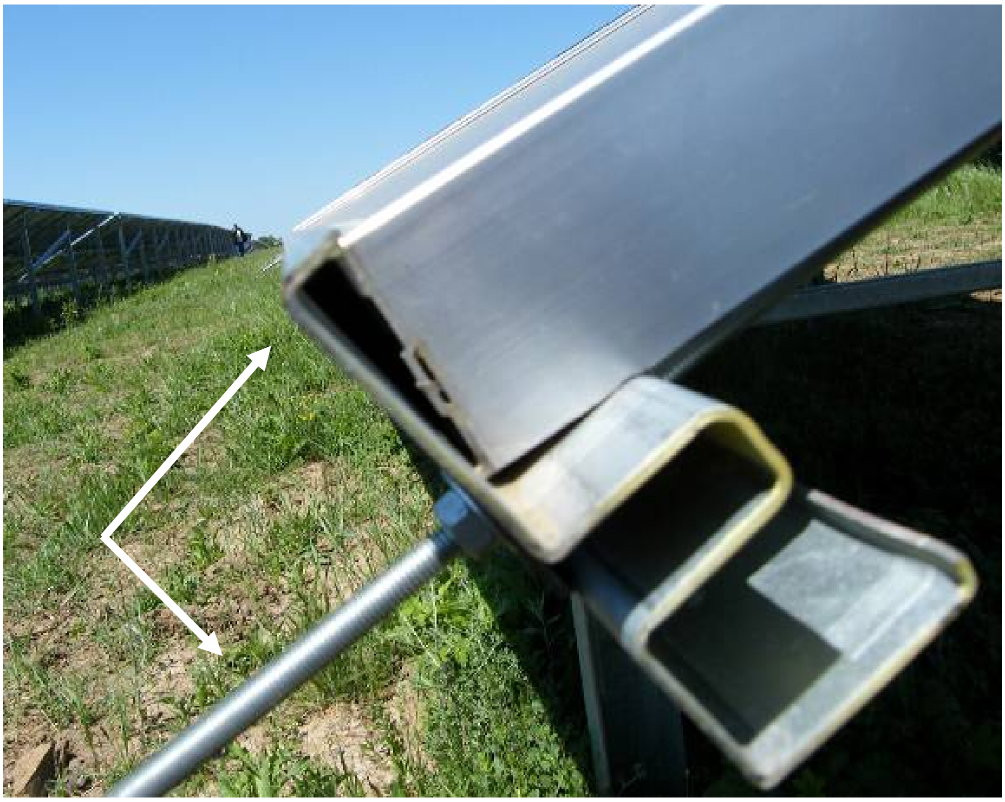


Figure 64.

Rigidity of supporting structures

Supporting structures and junctions must be rigid.

The support structures have to be attached in a rigid way to avoid loss of shape as in Figure 65. Small rods have been used to attach two structures but they are not strong enough to keep them straight. Figure 66 shows the proper way to attach them as it uses a rigid piece that fits perfectly, keeping the two structures straight, adding strength to the whole structure and preventing deformation in the future. This type of attachment could be used as a thermal expansion joint if it is fixed on one side only. Care should be taken to ensure that there is no loss of strength to the structure however.

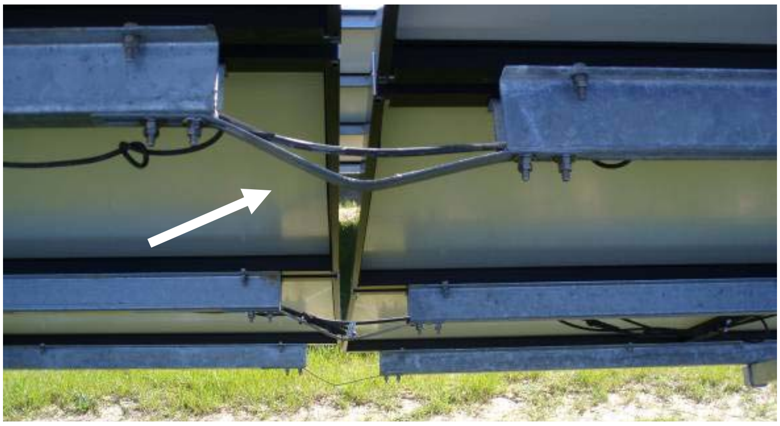


Figure 65.

NO

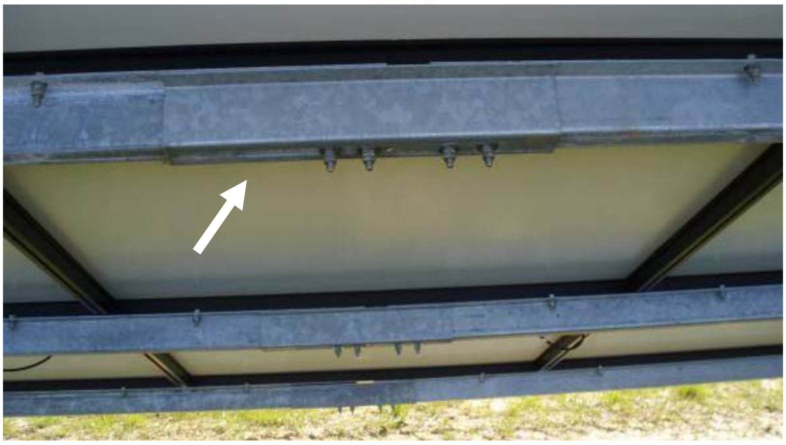


Figure 66.

YES

Assembly of structure elements

All parts of the structure must be correctly assembled.

The distance between the internal structure (tilt axis) and the external structure (orientation axis) is different at the opposite sides in Figure 67. It is due to the incorrect attachment between the structures as they are not perpendicular. As a consequence, the different rows of the foreground structure in Figure 68 (the right-hand row) do not have the same tilt. In fact, the effect of this mistake (a small error in the inclination) has almost no effect on the operation of the PV plant or on the final energy production. It only has a visual impact. Nevertheless, the proper attachment of structures would have achieved the same tilt of the rows and, consequently, a more harmonious view, as seen in the PV array in the middle of Figure 68.

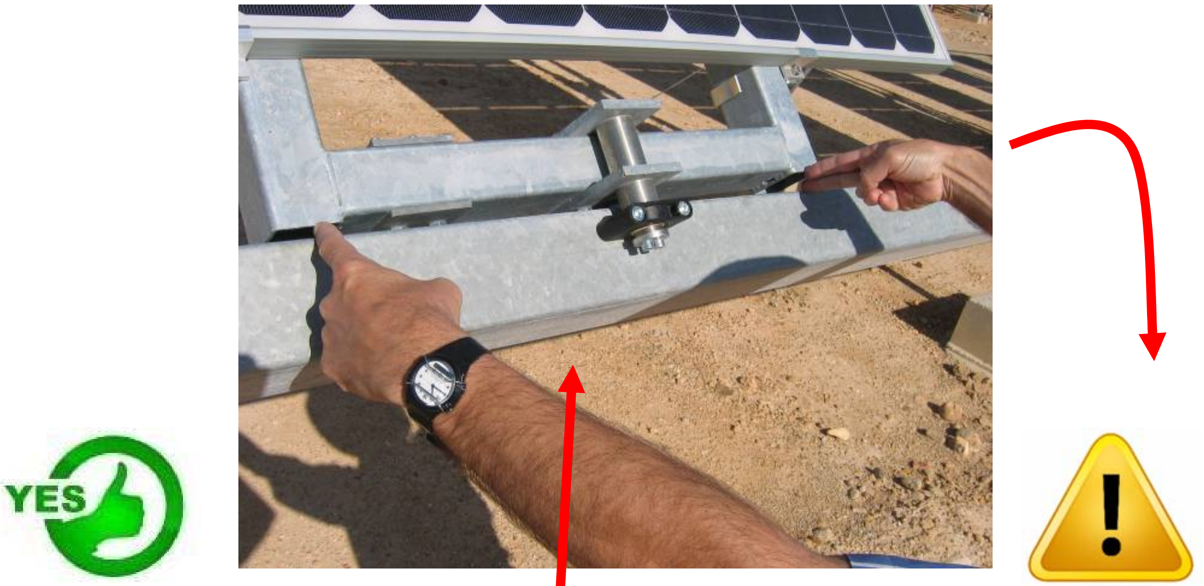


Figure 67.

Figure 68.

Assembly of structure elements

All parts of the structure must fit with each other.

In Figure 69 the tracker structure pieces do not fit properly. As a consequence, when they are attached, one of them has to deform to get a good grip. This modification of the original shape of the piece can cause faster degradation of the whole structure. This reduces the overall strength of the structure.

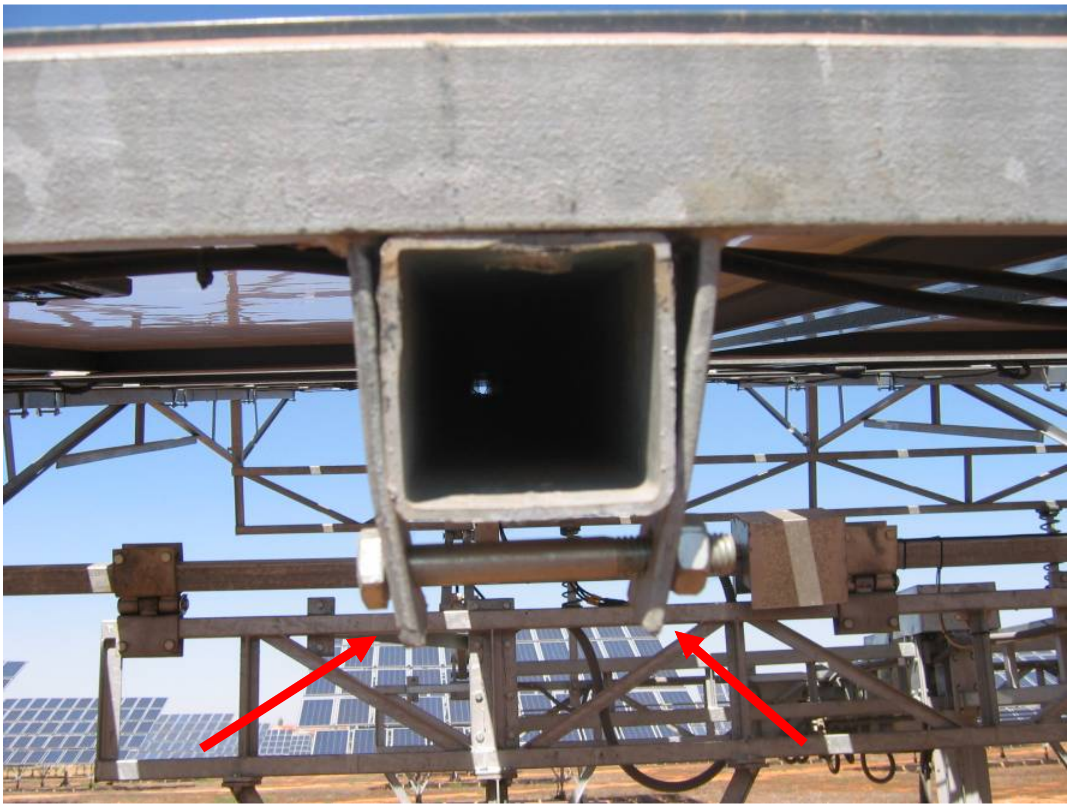


Figure 69.

Material compatibility

All material used in the structures must be compatible.

The metallic materials of the PV module frames, the supporting structures as well as screws, washers, nuts etc. must be compatible. Some materials are not compatible and should not be used in combination without the proper separation. Otherwise, galvanic corrosion may appear if incompatible materials are in contact, such as aluminium and stainless steel as shown in Figure 70.

Figure 70.

Resistance to outdoor climate conditions

Structures must resist to outdoor climate conditions (rain, salt, low temperature, sunlight).

The structures have to be constructed from stainless steel or be protected against degradation (mainly oxidation) with a treatment such as galvanizing or special painting. The strength of the structures could be reduced with time if this protection is not correct. Figures 71 to 77 show examples of good and bad practice. In Figures 71 to 75, galvanized or painted protection has not been applied or has been carried out incorrectly. Figures 76 and 77 show where the correct protection has been applied. Nevertheless, as they are painted or cold galvanized, they have to be monitored and repaired when required before the degradation becomes evident.

Figure 71.

Figure 72.

Figure 73.

Figure 74.

Figure 75.

Figure 76.

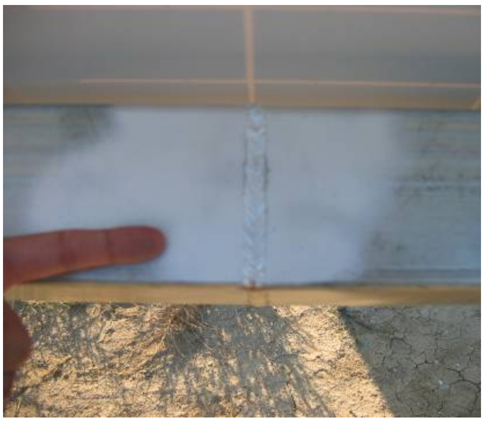


Figure 77.

Resistance to outdoor climate conditions

Structures must resist to outdoor climate conditions (rain, salt, low temperature, sunlight).

Supporting structures are not made only from metallic materials but other materials such as wood can be used. Wood has to be varnished to protect it against the environment. In Figure 78, the wood has not been treated and this will easily degrade and fail, causing damage to the installation.

Figure 78.

Resistance to outdoor climate conditions

Mounting systems must allow for thermal expansion of all the system components.

The mounting systems must allow for thermal expansion of all the system components (both longitudinal and transversal expansion). PV modules or fasteners such as bolts and nuts, for example, may fail if the mounting system does not allow for this expansion.

In the case of longitudinal thermal expansion, it is typical to use expansion joints with a maximum distance of 6 to 10 meters between two consecutives joints (Figure 79). They should be placed so that the structure could expand without creating additional mechanical stress (for example, joints should not be placed inside a rigid triangle, as in Figure 80).

Figure 79.

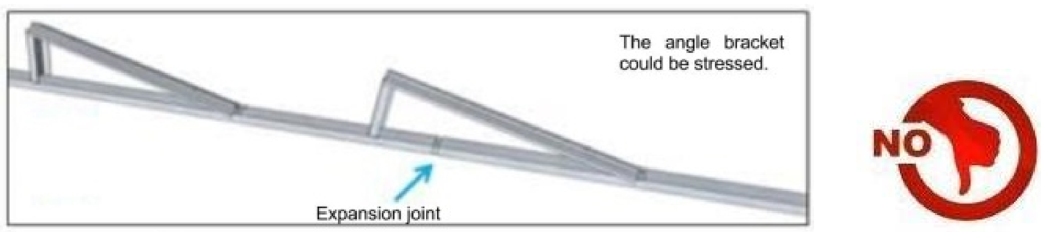


Figure 80.

In the case of transversal expansion, a typical solution involves inserting gaps every 10 to 15 meters, as shown in Figure 81.

Figure 81.

Resistance to outdoor climate conditions

PV installations on flat roofs must be grouped together or blocked by stops. If not, they may move in the direction of the slope due to successive thermal expansions.

In the case of BIPV installations, some support structures cannot be rigidly fixed on the roof because of the risk of damage to the waterproof layer. Consequently they must be blocked by grouping adjacent structures which are located on opposite slopes, as is shown in Figure 82, or by adding stops, for example, on parapets.

Figure 82.

Resistance to outdoor climate conditions

PV arrays placed on flat roofs must allow the thermal expansion of the supporting structure.

In BIPV installations, the original seal of the roof has to be protected. An interface between the roof and the supporting structures and ballast has to be installed. This interface has to be flexible because the thermal expansion of aluminum supporting structures is significantly higher than the expansion of the typical waterproof covering material used on flat roofs. In this way, the shear stress between the structure and the roof is reduced. Additional characteristics that this flexible interface must accomplish for the lifetime of the installation include: to be resistant to ultraviolet light and weather conditions; be chemically neutral to both the roof and the structure; have a high friction coefficient to ensure the stability of the support structure on the roof (see also Figure 84 – practice S16, page 48).

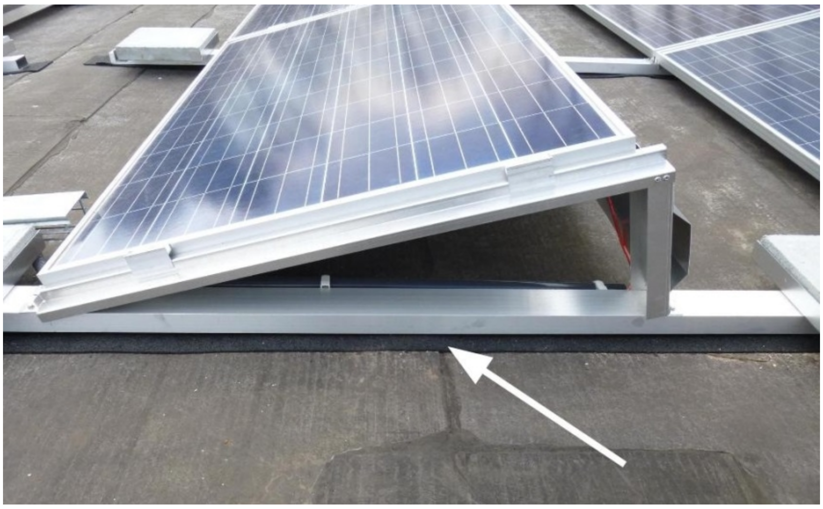


Figure 83.

Resistance to outdoor climate conditions

Supporting structures placed on flat roofs without rigid fixing system must be ballasted due to mechanical constraint induced by wind on the PV modules.

As a consequence of the difficulty in fixing support structures rigidly to roofs, additional weights (or ballast) must be used to prevent displacement and damage of the PV modules caused by wind (the sail effect). The ballast required must be calculated according to the Eurocode norms.

Figure 84.

Resistance to outdoor climate conditions

PV installations on roofs must allow rapid water drainage in case of heavy rain.

Poorly designed PV support structures could act as small dams during heavy rains, holding a significant mass of rainwater and/or dirt on the roof. The water represents an additional weight which may be unanticipated and that can cause damage the structure. The support structures should allow quick drainage in the case of heavy showers, as shown in Figure 85 and 86.

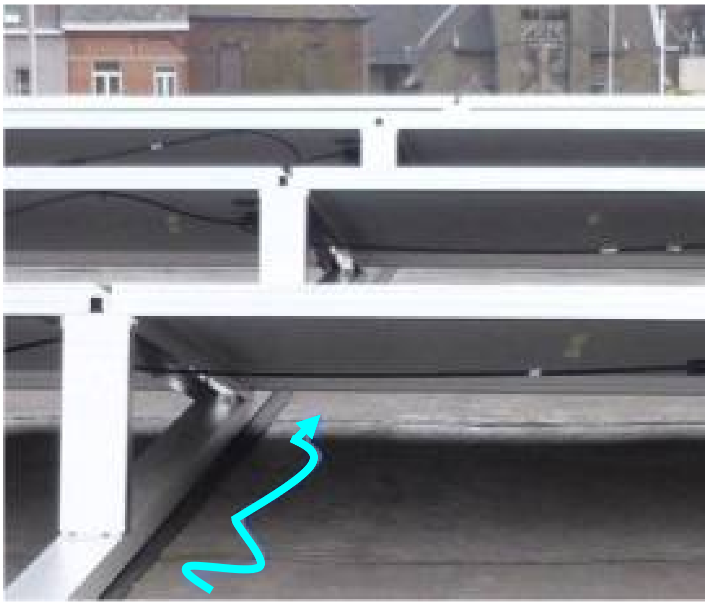


Figure 85.

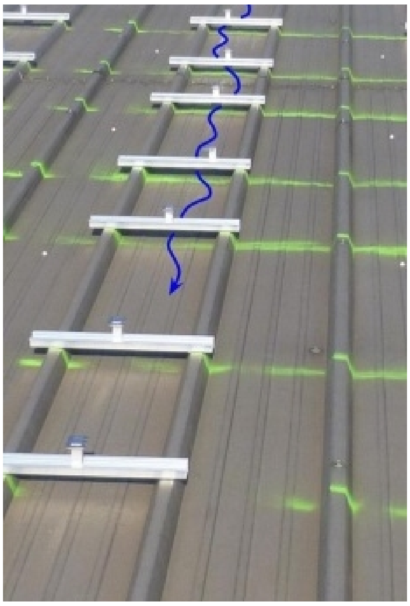


Figure 86.

Protection from vegetation

PV modules must be protected from vegetation.

The structures of Figures 87 to 89 are of such a height that low vegetation can reach the lowest PV modules. As a result of this, vegetation casts shadows over the panels that decrease the production of the installation and, at worst, can accelerate the degradation of PV modules causing hot spots (see Figures 141 to 143 –practice G10, page 80). Arranging the structure at a greater height would have avoided this situation. With appropriate monitoring of the installation, the vegetation could be cut before it reaches modules and this option is shown in Figure 90. Care needs to be taken to ensure that during ground maintenance, equipment with rotating blades or string cannot cause small stones to be projected which might damage the PV modules.

Figure 87.

Figure 88.

Figure 89.

Figure 90.

Safety of workers

All structural elements should be clearly identified.

The moorings and tensioners of the trackers should be appropriately signed. Otherwise they might not be visible and maintenance staff walking around the PV plant could accidentally collide with them.

Figure 91.

3.3. Connection Boxes.

Labeling electrical components

All active electrical components must be identified with adapted labels.

The boxes in Figures 92 to 94 have fixed labels warning of the risk of electric shock. This is important information, alerting people to the existence of live connectors, busbars, fuses and other electrical components in the boxes. This enables technical and maintenance staff to be alerted and take preventive measures before opening the boxes.

Figure 92.

Figure 93.

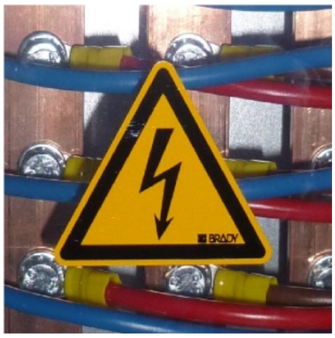


Figure 94.

Waterproofing of connection boxes

Connection boxes should have and respect the proper Ingress Protection rating (IP) selected according to the environment.

Figures 95 to 101 show examples of connection boxes that have original Ingress Protection rating (IP degree) above IP43 (IPXY: the “X” figure is related to the protection against the infiltration of solid foreign objects; “Y” figure is related to the protection against the entry of water). Although the original boxes meet these specifications, incorrect installation can drastically reduce the degree of protection.

As shown in Figure 95, the connection box has been drilled to provide an entry point for the cable. However, the excess space has not been properly sealed to prevent dirt or water entering the box. This results in the loss of the original IP degree.

Figure 96 shows that the box cover has been deformed and the box cannot be closed. Therefore its IP degree is lost as a result of this fault and solid objects or water can enter the box.

Figure 95.

Figure 96.

Waterproofing of connection boxes

Connection boxes should have and respect the proper Ingress Protection rating (IP) selected according to the environment.

In Figure 97 the tube which carries the cable is not fixed to the sealing gland and water or other material which could enter the tube which can prematurely damage the cable and the connections in the box. Figure 98 shows the correct way to fit tubes and sealing glands.

Figures 99 to 101 show a box with a label fixed to the outside which states that the IP degree protection is IP65. That is, total protection against dust and protection against water projected with a nozzle from any direction. However, sealing glands have not been installed, resulting in dust or water coming from underneath can enter the box.

Figure 97.

Figure 98.

Figure 99.

Figure 100.

Figure 101.

Waterproofing of connection boxes

Cable entering connection boxes must be correctly installed and sealed.

The cables entering a connection or junction box must pass through a sealing gland of the correct cross-sectional area which prevents the ingress of moisture or water into the box. When sealing glands are installed in such a way that cables enter the box from the top of the box, the possibility of water or moisture ingress is higher. Therefore the rubber seal must be in perfect condition and the nut seals have to be adequately tightened. Otherwise, water or moisture could enter the box, as in Figure 102. In this figure, the metallic tracks are oxidized and the cover is white, which is evidence that water has entered the box.

It is better to install the sealing gland in the sides or the bottom of the box to reduce the risk of the entry of water or other particles (Figure 103).

Top of the module

Figure 102.

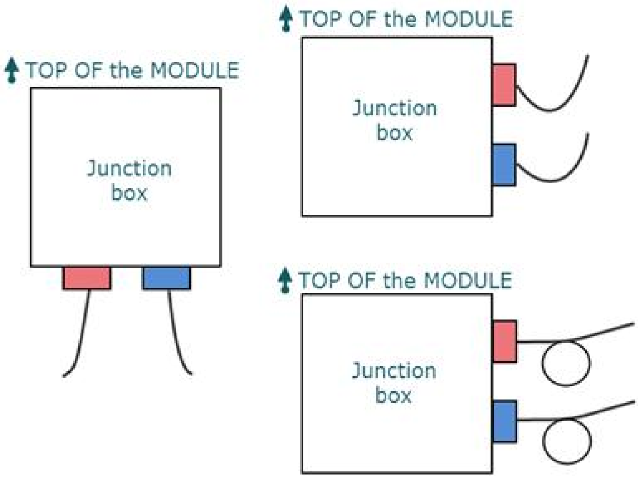


Figure 103.

Waterproofing of connection boxes

Doors and covers must resist to chemicals (grease and others) and must be blocked when open to avoid damage due to wind gusts.

The doors and covers of the connection boxes have to serve to prevent the ingress of water or soil (as described by the IP rating) and protect cables and electronic devices. They must resist or be protected from degradation due to water or grease. Figure 104 shows boxes which are damaged because of reaction between grease and the box material. The doors or covers must be blocked when open to avoid damage due to wind gusts (Figure 105). Otherwise the boxes can degrade prematurely, deteriorate and leave their content unprotected (Figure 106).

Figure 104.

NO

Figure 105.

YES

Figure 106.

NO

Quality of connections

All connectors must be correctly crimped and fastened to avoid overheating.

Another situation which can cause switches or cables to overheat or burn is when conductors are not correctly terminated to the connector by the fixing screw (or when conductors are badly crimped at the terminals). The thermographic pictures show two different situations. In Figure 107 a cable is not properly terminated with the fixing screw and the electrical contact is poor. This poor connection may also cause an internal electric arc. As a consequence, its temperature is higher than would be expected (in this particular case, more than 30°C higher than neighbouring cables). This increases wiring losses and the risk of fire. When proper contact is made, all conductors (with the same cross-sectional area and current) have the same temperature, as in Figure 108. A good practice to ensure that the bolts/screws are properly fastened is to seal them as shown in Figure 109 (yellow seal). Only a visual inspection is needed to identify a loose fastening (see also Figure 189 –practice I8, page 102– and Figure 190 –practice I9, page 103). This verification must be carried out each year during regular maintenance as temperature variations can cause loosening of bolts or screws.

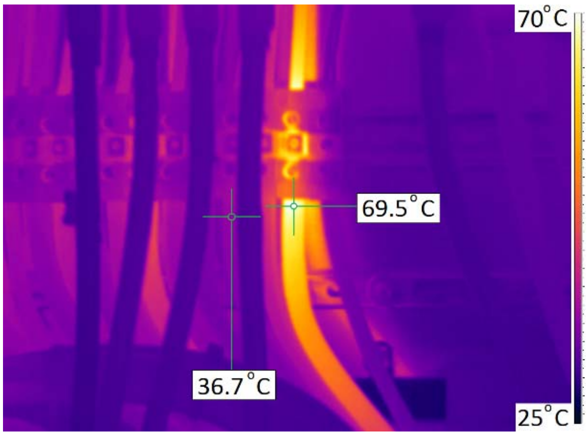


Figure 107.

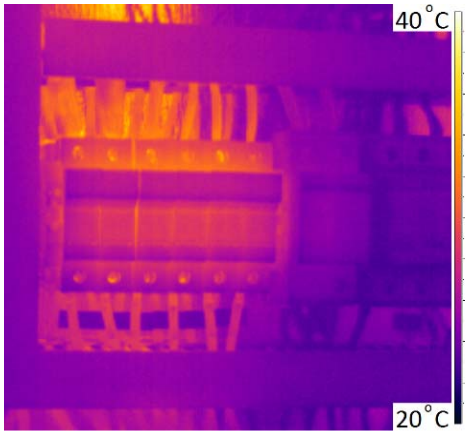


Figure 108.

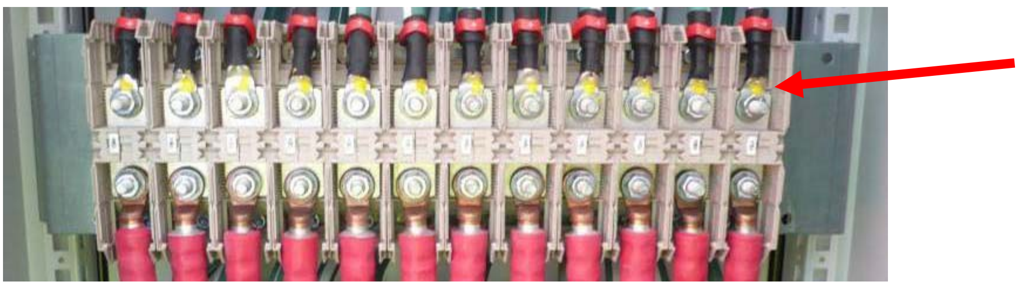


Figure 109.

Control of temperature in boxes

Boxes must be cooled and/or heated when they contain electronic components sensitive to the temperature.

When a box contains electronic devices and thermal switches it is important to consider if cooling or heating the box is required, as is the practice with computer equipment. Some of the devices will not operate properly at very low or high temperatures or will simply be switched off when a threshold temperature is reached. To avoid such occurrences, temperature sensors, heaters and fans can be installed, as it is shown in Figure 110.

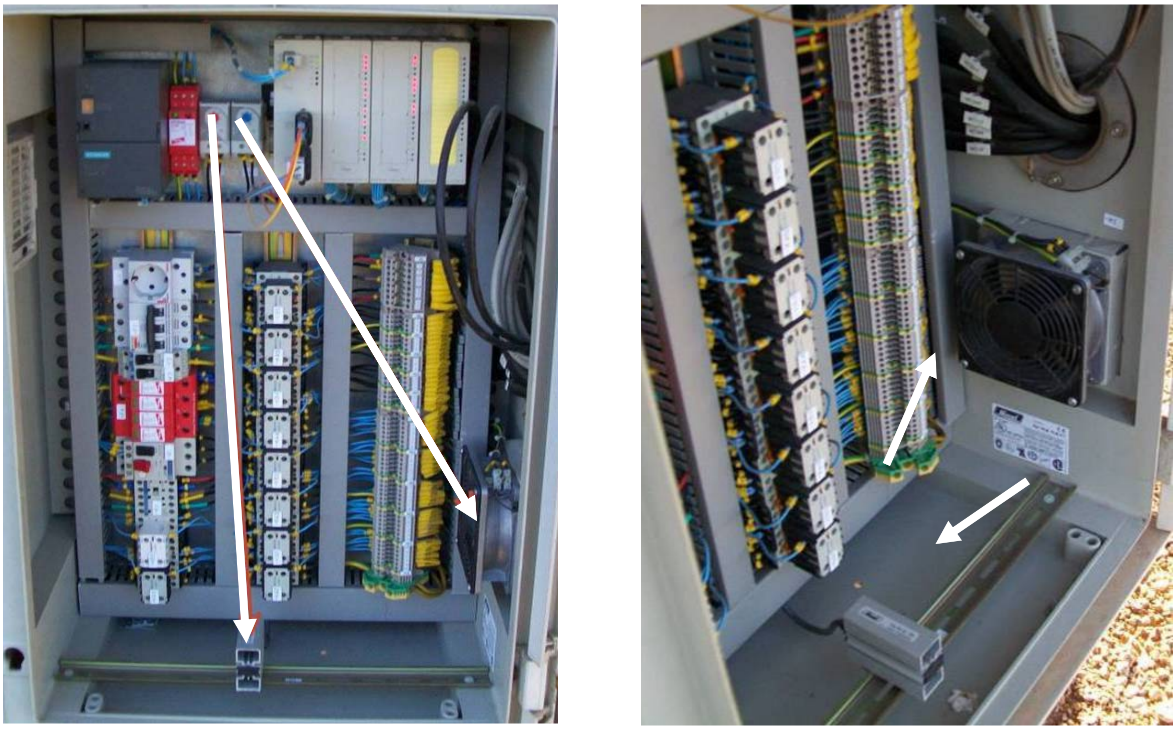


Figure 110.

Fuses and fuse holders

Fuses must be properly oversized to avoid overheating and premature degradation.

The fuses used in this PV plant are designed to carry up to 12 amps, as can be seen in Figure 111, while the PV installation delivers close to 9 amps under Standard Test Conditions (i.e. STC of global irradiance of 1000 W/m^2 and cell temperature of 25°C). Current levels of above 12 amps can be reached on sunny days with some clouds acting as small light concentrators. Under these circumstances, such fuses would disconnect the circuit quite frequently. Also, fuses can overheat the fuse holders, which can degrade quickly in the first years after installation. Figure 111 shows a fuse holder that has become yellow after only two years. The installation of higher rated fuses avoids this premature degradation and maintains the holders close to their original condition (Figure 112). Furthermore, this degradation of fuse holders due to the high temperature of fuses can cause a short-circuit to its neighbouring holders and possibly result in a fire, as it has happened in the box in Figure 113. A better practice is to use fuses rated close to twice the current they must conduct under STC to avoid undesired and frequent operation.

Figure 111.

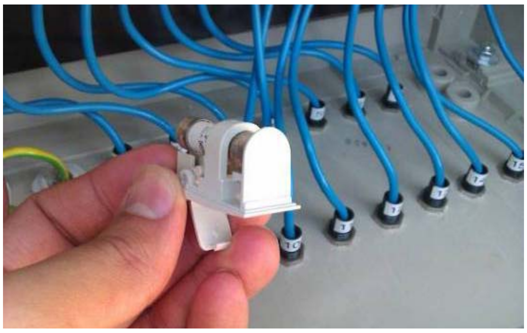


Figure 112.

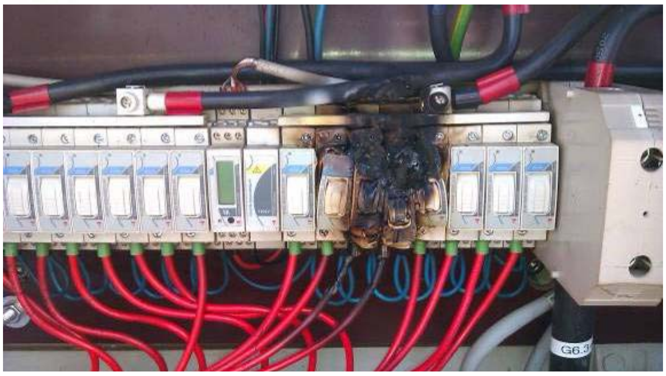


Figure 113.

Fuses and fuse holders

Each individual string must be protected, at least, by a fuse.

The connection box in Figure 114 has fuse holders for each individual conductor. This is the correct method of installation as it allows the connections from the busbars to the parallel arrays to be totally isolated from connecting cables and operate them safely. Fuses are only included in the positive terminal fuse holder; the negative terminal holder contains only a cylindrical conductor ("dummy" fuse). In this way each string is protected in the event of high currents and the number of fuses required is reduced by half. Consequently, locating blown fuses is quicker and the cost of the connection boxes is reduced.

Note: if the fuse holders with the “dummy” (or real) fuses are not included and they are replaced by bridging wires, the associated busbar cannot be isolated from that pole of the PV array.

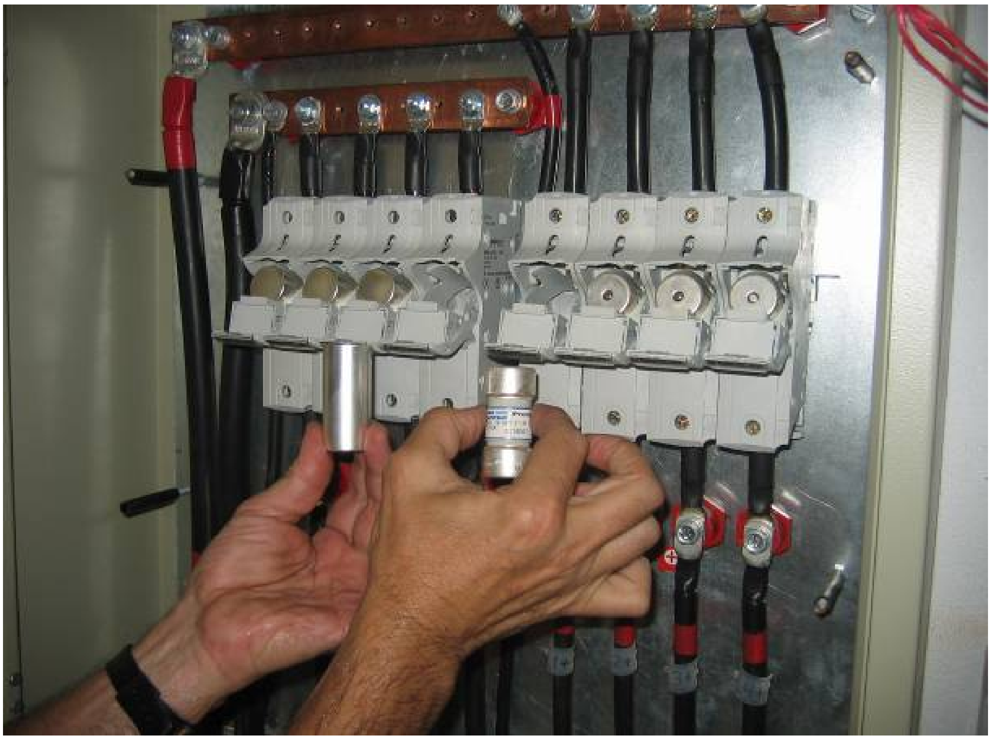


Figure 114.

Fuses and fuse holders

DC components like fuse holders must NOT be open when DC circuits are switched ON.

A very poor practice involves opening a fuse holder under load as this creates a serious risk of electrical shock and destruction of equipment. DC circuits must de-energised before any intervention is made. Figure 115 shows the consequence of opening a fuse carrying a DC current of approximately 40 amps. An electric arc developed between the fuse sides and caused a fire inside the box, leading to the destruction of the connection box. Fuses are a form of protection which cannot be opened under load and therefore special load breaking switches that are designed to open the circuit under load are used (see next pages).

Figure 115.

Cables and components

Cables in connection boxes should be correctly arranged and not too long.

The cables should be arranged neatly in the connection box and the length of cables should be slightly longer than the required length to facilitate repairs which might be required. Operators should be able to quickly identify each cable in the event of a fault. Figure 116 shows a connection box in which insufficient care has been taken in its wiring and where the cables are disordered and are of excessive length. Therefore it is difficult to find a specific cable. This arrangement also increases the wiring losses and the final cost of the installation.

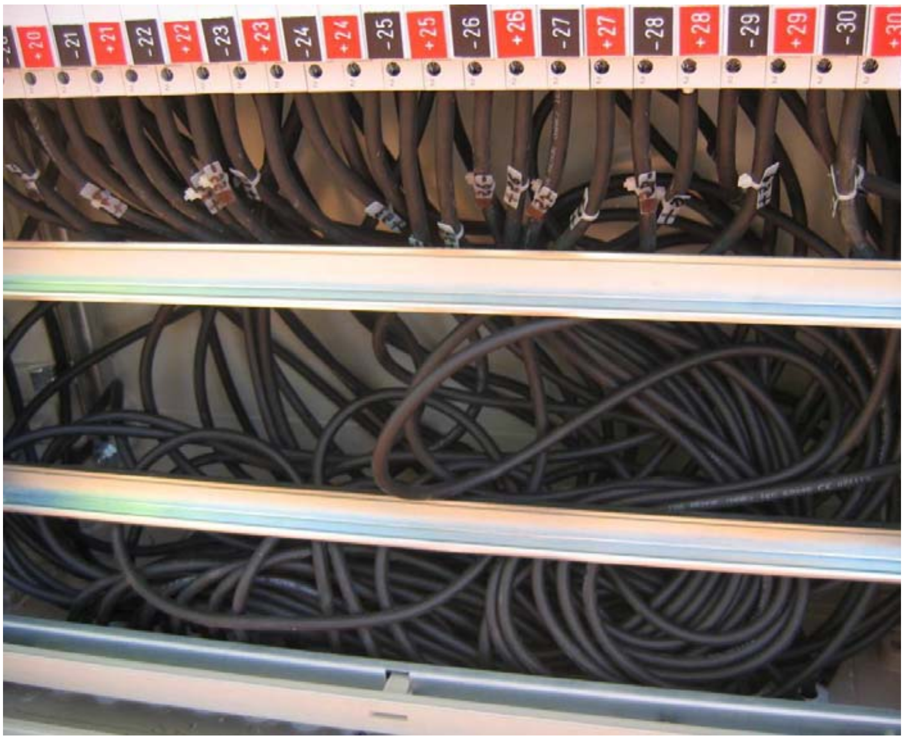


Figure 116.

Cables and components

Cables and busbars of different poles should be properly far away each other.

Figure 117 shows that the active cables from the positive and negative terminals of the modules enter the connection box through the right and left sides indistinctly. This results in cables passing behind the positive and negative busbars. Over time, due to vibration and thermal cycling, continuous contact between cable conductors and copper busbars can damage the cable insulation/sheaths and cause short-circuits. A better solution would have been to connect all the cables from the positive terminals through one side of the connection box and the negative ones through the opposite side. This is a more secure design because it results in positive and negative cables and busbars being adequately separated. This is similar to the red and blue cables which enter through the base of the connection box in Figure 120 (practice W14, page 68).

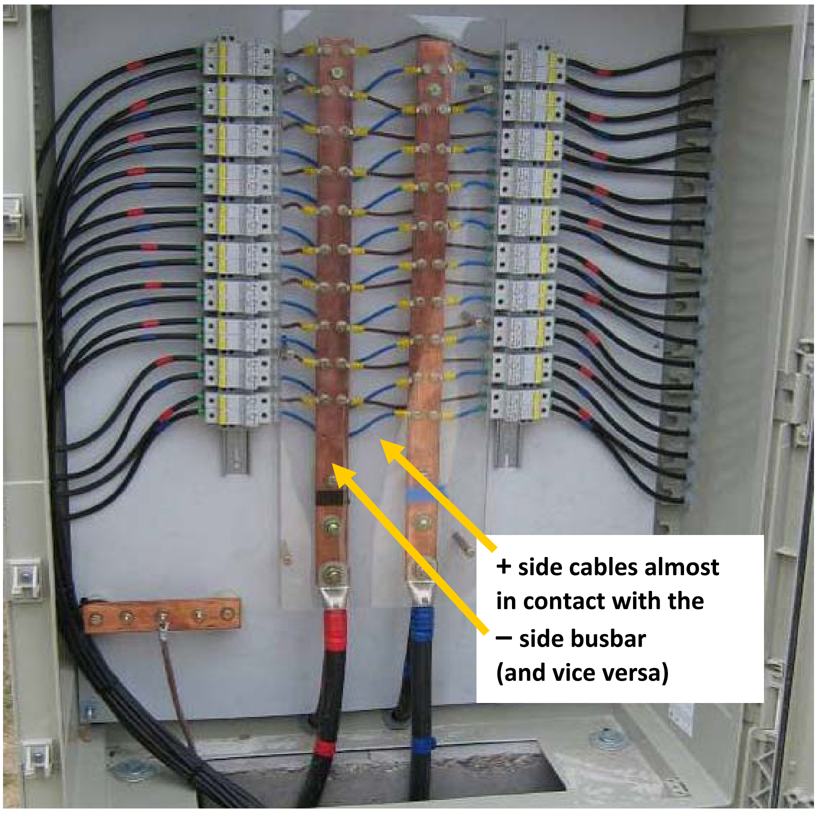


Figure 117.

Cables and components

Connection boxes must contain all needed elements.

Figures 118 and 119 show the primary and secondary connection boxes respectively of a PV installation. They are properly labeled to warn of the risk of electrical shock. The cables are arranged properly inside the boxes and each single cable is also identified with an individual label. (If all electrical components are properly identified with labels, the possibility of incorrect connections is considerably reduced.) Fuse holders are installed in both active poles for each cable as well as surge arrestors which are required to protect electronic devices. Positive and negative busbars are identified with labels and are adequately separated with a methacrylite sheet to avoid direct contact. There are also labels warning of the risk of electric shock.

Nevertheless, three improvements can be made (see Figure 120 – practice W14, page 68). Firstly, there is no information sheet to provide detail of the location of modules and strings that are connected in this box. Secondly, in the primary box, the positive and negative cables from modules are too close with inadequate separation to avoid short-circuit and there is a risk of direct contact in the event of a fuse holder failure or cable movement. Thirdly, in the secondary box there is no load-breaking switch which is required for disconnection under load. Despite these possible improvements, these boxes are very close to the optimal arrangement.

Figure 118.

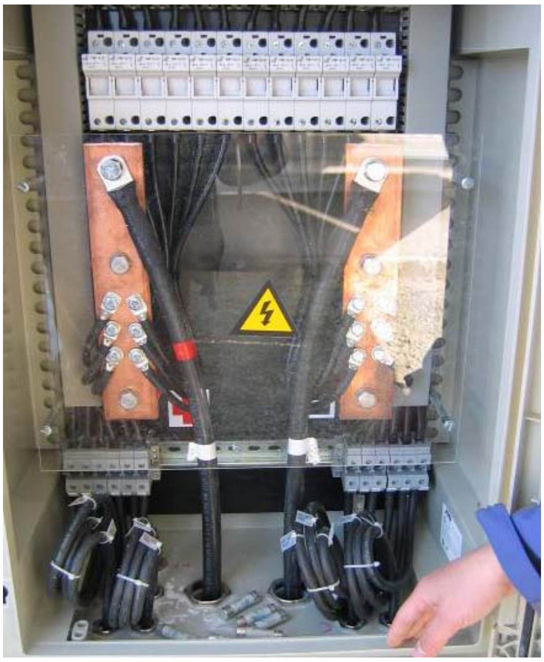


Figure 119.

Cables and components

Connection boxes must contain all needed elements.

The box shown in Figure 120 incorporates the improvements described above. There is a map in the inside cover that presents clearly the locations of the PV modules connected to the box. Positive and negative cables are easily identified by colour and are adequately separated to avoid short-circuits or faults and to allow for safe adjustment. Finally, there is a load-breaking switch (the grey/white device on the right of the box) which allows the circuit to be opened under load. The only improvement which could be made to this box is to include fuse holders in the negative cables also, to allow for the isolation of each individual string at both poles (see Figure 114 –practice W9, page 63– and Figures 118 and 119 –practice W13, page 67).

Figure 120.

3.4. Photovoltaic Array.

Modules quality and integrity

Light Induced Degradation (LID) effect must be taken into account in production forecasts.

Defects in solar cells and PV modules during the manufacturing process can cause subsequent degradation of the PV panel performance. After a few years (or even months or weeks) of PV module operation, hidden defects in solar cells can appear. One of these defects is Light Induced Degradation (LID). It involves a reaction between oxygen atoms (present as residue in the silicon crystal lattice) and boron atoms (resulting from silicon doping) that causes a reduction in the nominal power of typically between 1% to 4%. This can occur after the first few hours of exposure of the PV modules to the solar radiation. This effect is typical for p-type cells doped with boron and cannot be avoided (n-type cells are not affected by LID). Therefore, this degradation must be taken into account in predicting panel performance, as shown in Figure 121.

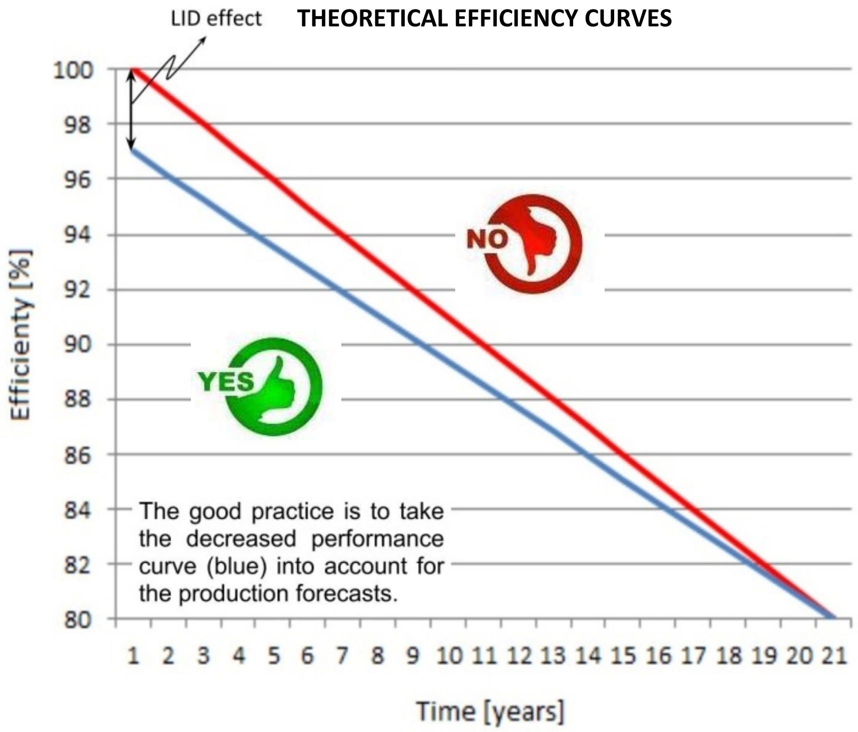


Figure 121.

Modules quality and integrity

Manufacturer warranty should include damages caused by PID on PV modules.

Another defect is Potential Induced Degradation (PID). Depending on the cell technology and encapsulation material, migration of Na^+ from the glass surface can cause the reduction of PV module performance. Manufacturers of PV modules should perform ageing tests in a test laboratory to determine the sensitivity of their products to PID and the module warranty should state potential damage caused by PID. Figure 122 shows the electroluminescence image of a module severely affected by PID. The completely black cells are shunted cells due to PID. This phenomenon can be prevented in installed PV modules by grounding the negative pole of the inverter (if modules affected are traditional silicon modules; other types of modules could need grounding the positive pole) using galvanic isolated inverters. External systems can reduce the effects of PID, but their efficiencies have yet to be confirmed. The implementation of such a corrective solution should be validated by a specialized engineering office.

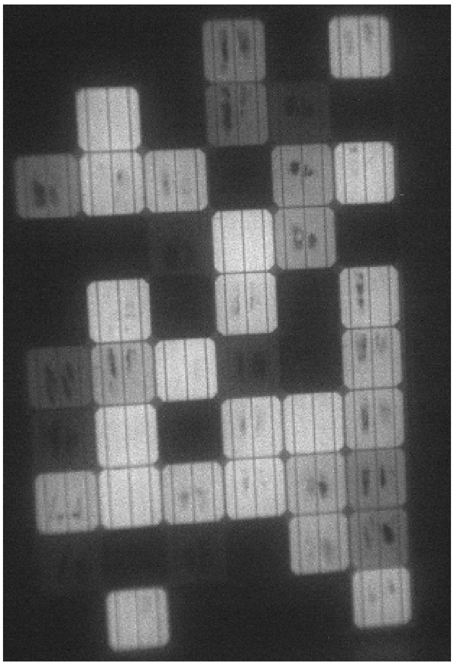
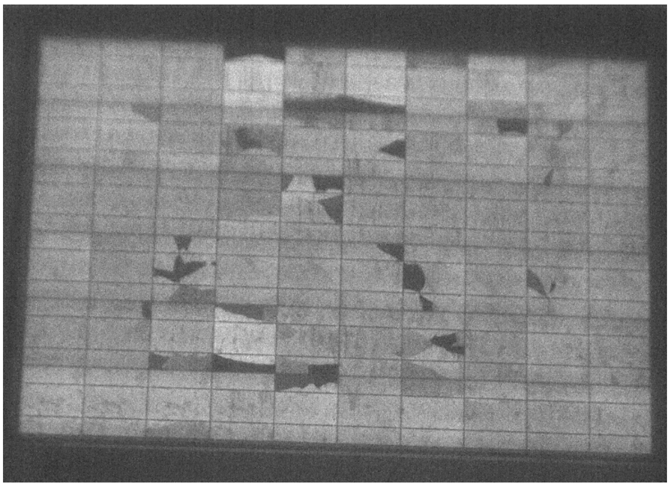


Figure 122.

Modules quality and integrity

PV modules must be protected from shocks and vibrations to avoid micro-cracks.

The PV modules have to be free of micro or macro-cracks. Micro-cracks are created by vibrations and shocks and can reduce PV module performance over time. They are usually invisible to the naked eye and require electroluminescence tests to be detected. These are indicated by the dark areas on Figure 123. Poor handling or transport after manufacture of the modules can cause these micro-cracks on modules which were originally defect-free.



NO

Figure 123.

These micro-cracks initially may not have a direct effect on the energy production. But they can develop into hot spots inside the modules that could reach unanticipated high temperatures (possibility above 100ºC) in the first few months of operation. Such high temperatures can cause the glass cover to break as a result of stress caused by thermal expansion of different materials (Figure 124).

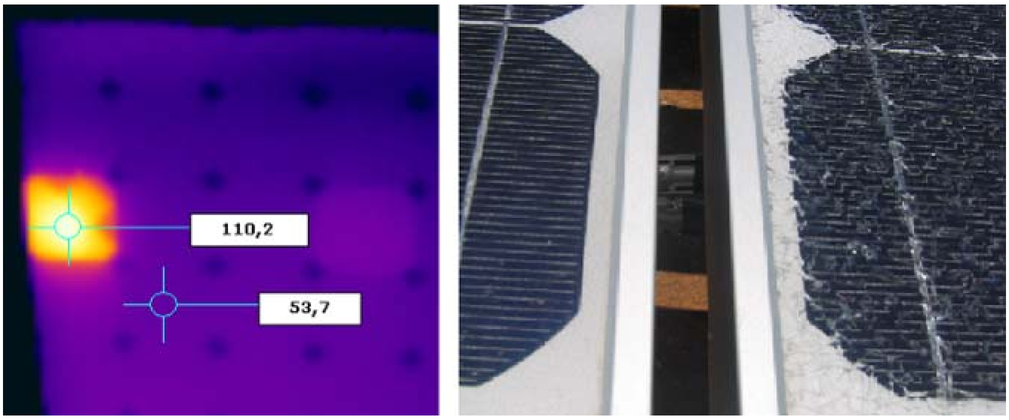


Figure 124.

NO

Modules quality and integrity

PV modules must be transported and installed in good conditions to prevent cracks and damages in the modules.

Macro-cracks usually occur before the PV panels are mounted on support structures during construction. Often, these breakages occur when PV modules are taken out of their protection packaging and stored carelessly, as in Figures 125 and 126. To limit the risk of macro-cracks it is recommended that modules be stored in their packaging until they are to be mounted on the support structures.

Figure 125.

Figure 126.

Modules quality and integrity

PV modules must be regularly inspected to check for potential damages.

Other defects that can be found in PV modules during the first months or years of operation are yellowing (Figure 127) and snail tracks (Figure 128). Sometimes (but not always as the real impact has not yet been quantified) these defects decrease the PV module performance and the energy production is reduced. Periodic site inspections must be carried out to check PV modules and seek replacements for those that do not meet the quality standard guaranteed by the manufacturer.

Figure 127.

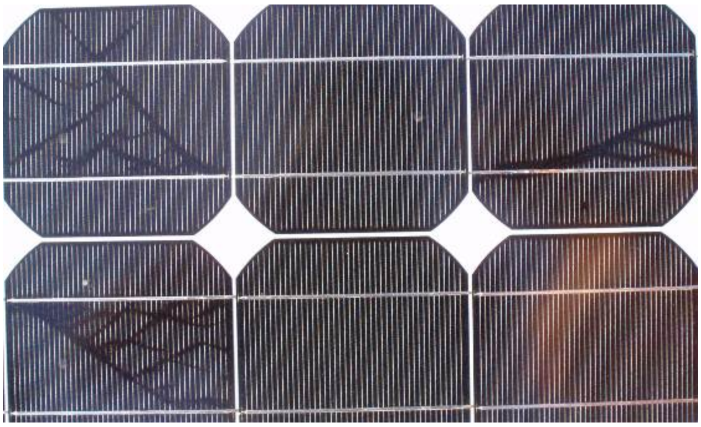


Figure 128.

Trackers and orientation

Trackers must be correctly oriented.

An alternative way to maximize the output energy from a PV plant is by mounting PV modules on trackers. The panels are continuously oriented in the optimal direction with respect to the sun. Consequently, they receive more solar radiation than static PV modules. In order to maximise the energy production, the trackers have to be appropriately oriented to the sun. Otherwise, they are not making the most of the tracking facility.

In Figure 129 (with blue sky conditions) it appears that each individual tracker has a different orientation. Therefore, only some can be correctly orientated to the sun. This means that a number of the trackers have additional power losses due to the fact that the panels are not perpendicular to the sun. In Figure 130 only three structures are not orientated correctly, but this mistake also causes additional losses due to shadows cast over the back trackers. In both situations the tracking routine must be revised to avoid these additional losses and ensure synchronization of all trackers.

Figure 129.

Figure 130.

Figures 131 and 132 show trackers that are appropriately orientated to the Sun. There little or no deviations between trackers and therefore the tracking routines are working properly.

Figure 131.

Figure 132.

Trackers and orientation

Simple tools can be used to check trackers orientation.

A simple look at the relative position of trackers is enough to detect erroneous tracking (as is shown in previous pictures). A more precise method is using a simple self-made device as shown Figures 133 to 135. When it is placed on a PV module of a tracker, the shadow cast by the screw on the table reveals whether the tracker is working properly or not. The smaller the shadow, the better the tracking routine.

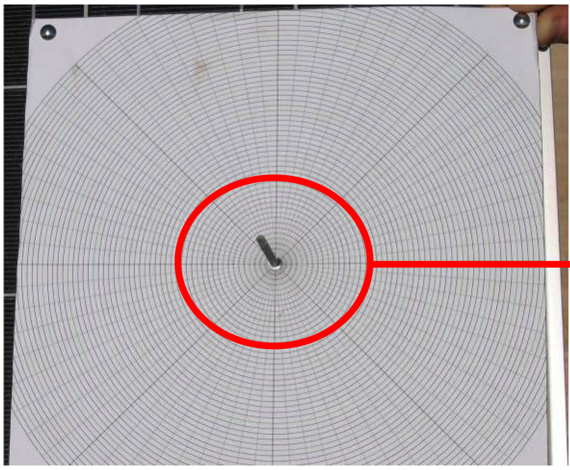


Figure 133.

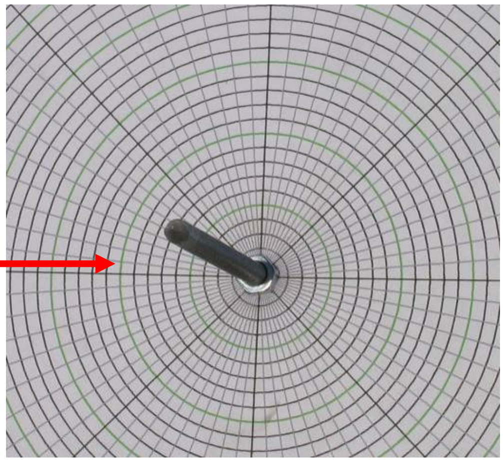


Figure 134.

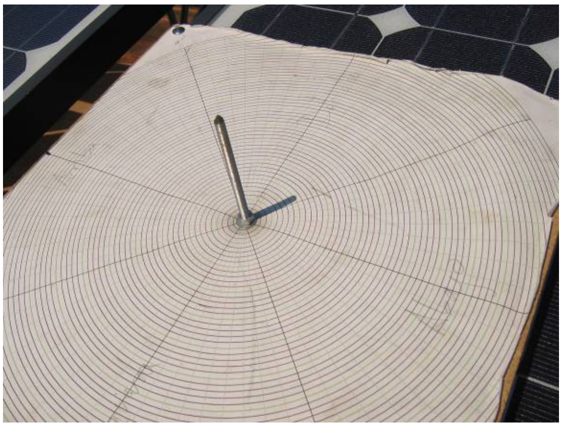


Figure 135.

Modules placement and shading

Distance between PV modules must be large enough to avoid shading between rows.

Shading is a phenomenon that has to be taken into account not only in tracking PV installations, but also in static installations before construction commences. The distance between rows has to be such that shading between PV rows has a minimum effect on the performance in terms of energy production. The performance can be reduced if the row separation and the row tilt are not correctly calculated. Figure 136 shows that for winter time at noon (the critical time for shading in static installations as the sun is lower in the sky) the front structures can cast a shadow over the panels behind them if the distance between rows is insufficient. The Figure 137 shows an installation where there is proper spacing between the rows, resulting in no shading between consecutive rows.

Figure 136.

Figure 137.

Obviously, there is a connection between row separation, land occupancy and productivity. The greater the separation, the larger the area required for a specific PV plant, but at the same time there will be less shading and higher productivity. Appropriate simulation tools can help to arrive at the optimal design.

Modules placement and shading

BIPV installations must be correctly place to avoid shading from surrounding environment.

BIPV installations are more prone to shading than PV plant installations. They require more accurate and detailed study in order to take into account not only shadows between rows of PV panels, but also shadows from the surroundings buildings, trees, facade elements, etc. If shade analysis is properly carried out before construction commences, the PV installation's performance will not be affected. Figure 138 shows a PV installation which is installed on a roof. The effect of the upper installation has not been taken into account and during the noon hours in summer time, shadows are cast over several modules in the last row on the lower building. Consequently, the performance of that PV installation is reduced, as shown in Figure 139. This graph shows the effect of partial shading. In addition to the diminution of energy production, the inverter could find the wrong maximum power point (MPP) which would further decrease the productivity. To avoid this situation, an inverter with the ability to scan the full operating range to find best MPP should be selected.

On the other hand, the graphic in Figure 140 relates to one of the front strings which is free of shadows.

Figure 138.

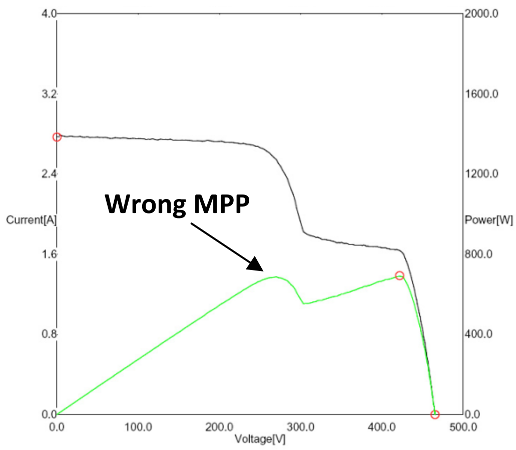


Figure 139.

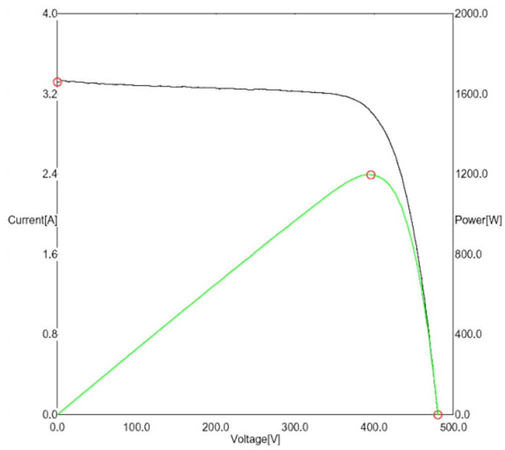


Figure 140.

Modules placement and shading

PV modules must remain clear of vegetation.

Small vegetation that grows to the base of the PV modules not only slightly decreases their productivity but also can accelerate the degradation of the module which is shaded. Figure 141 shows an example of a module that is shaded by a plant. Consequently, the shaded cell is hotter than the remaining cells of the module (by close to 20°C from the thermography image in Figure 142). If the situation is not rectified (by cutting or removing the plant, for example) this cell will degrade quickly and could reach higher temperature differences, even exceeding 100°C. This would certainly fracture the glass on the panel. When the plant is cut (thermography image in Figure 143) the cell recovers to its normal temperature after some minutes (the plants or vegetation that appear in the thermography image do not project any shadow on the module because they are in its back side and they act as a reference for better identification of the module).

Note: see also comments of Figures 87 to 90, practice S18, page 50.

Figure 141.

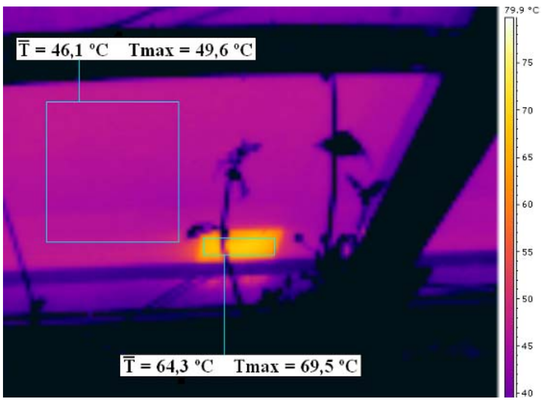


Figure 142.

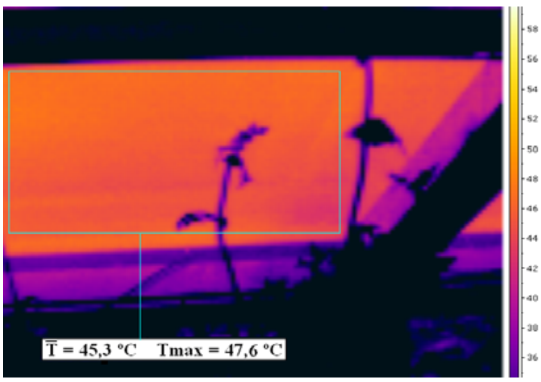


Figure 143.

Dust, sand and dirt

Cleaning of PV modules should be scheduled to optimize production.

Soiling of PV modules must be taken into account, mainly when a PV installation is close to a source of dust, such as a factory, or close to a beach or desert. Depending on the environment, rain might not be sufficient to keep the surfaces clean. The losses related to dust can reach 20% or greater as in Figure 144. This installation is close to a beach. In these cases, cleaning of the modules must be scheduled according to the accumulation of dust which significantly decreases the energy production. Figure 144 shows people cleaning the modules (in the background). However this cleaning should have been carried out earlier to reduce the impact of soiling. Chemical agents should not be used to clean modules, as they may interact with PV glass coatings and permanently damage them.

Figure 145 shows another case of soiling for an installation located close to a number of factories.

Figure 144.

Figure 145.

Dust, sand and dirt

Cleaning of PV modules should be scheduled to optimize production.

Unpaved or dirt roads inside the PV plant installation are a common source of soiling. When cars or trucks travel on these roads at high speeds, they raise dust or splash mud onto the modules. This situation increases the losses due to soiling. Therefore, the speed of vehicles inside the installation should be limited. When the unpaved roads are close to the installation but are not part of it, one way to reduce the soiling due to dust is to plant trees or other vegetation on the border of the PV plant.

Figure 146.

Figure 147.

Dust, sand and dirt

Modules should arrive from factory in a clean state, free of any particles or residues on the glass surface.

Figure 148 shows PV modules that have been installed whilst still having a silicone residue on the panel glass (creating a slightly tacky surface) from the manufacturing process. This silicone layer allows dust to stick to the glass surface of the module, increasing the soiling and, consequently, decreasing the quantity of light that reaches the PV cells. Modules should arrive from factory in a clean state, free of any particles or residues on the glass surface. If this is not the case and the modules are installed, they must be cleaned immediately to avoid soiling losses. The problem must also be raised with the manufacturer so that the problem is solved and a re-occurrence is avoided.

Figure 148.

NO

Dust, sand and dirt

PV installations with low tilt angle must be cleaned more often to avoid dust accumulation due to water evaporation.

PV installations on roofs sometimes have a low tilt angle. This can cause the accumulation of dust where rain or water collects on the panels and later evaporates. In these circumstances, dust settles on the surface of the PV module in a small area and some cells are partially hidden (see Figure 149 and Figure 150 enlarged). Besides the associated energy losses, there is the possibility of premature degradation of the shaded cells as a result of the development of hot-spots over time (see Figure 142 –practice G10, page 80). This problem can be minimised if the modules are installed in such a way that the side with the widest separation between the cells and the frame is at the bottom. It obviously also helps if the panels are periodically cleaned. In any case, minimum tilt angles of at least 15° are recommended.

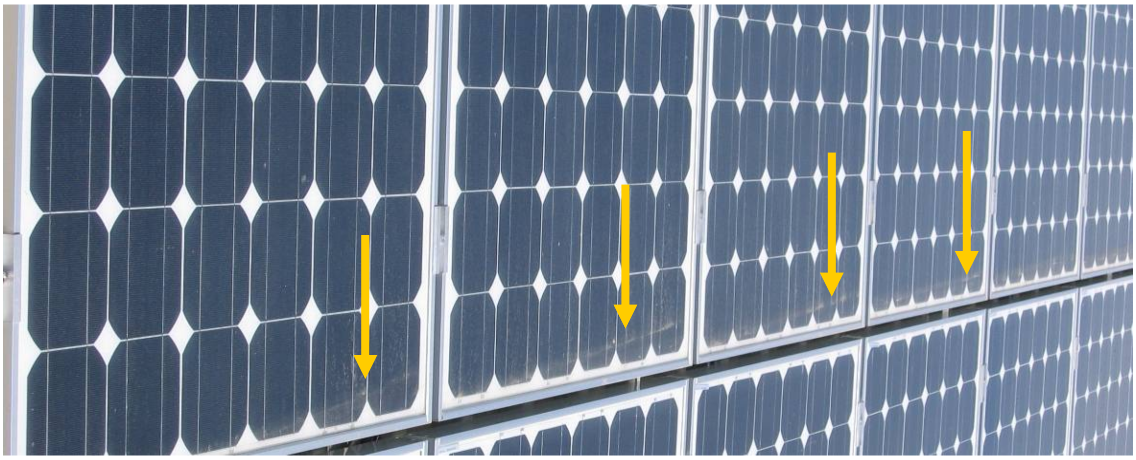


Figure 149.

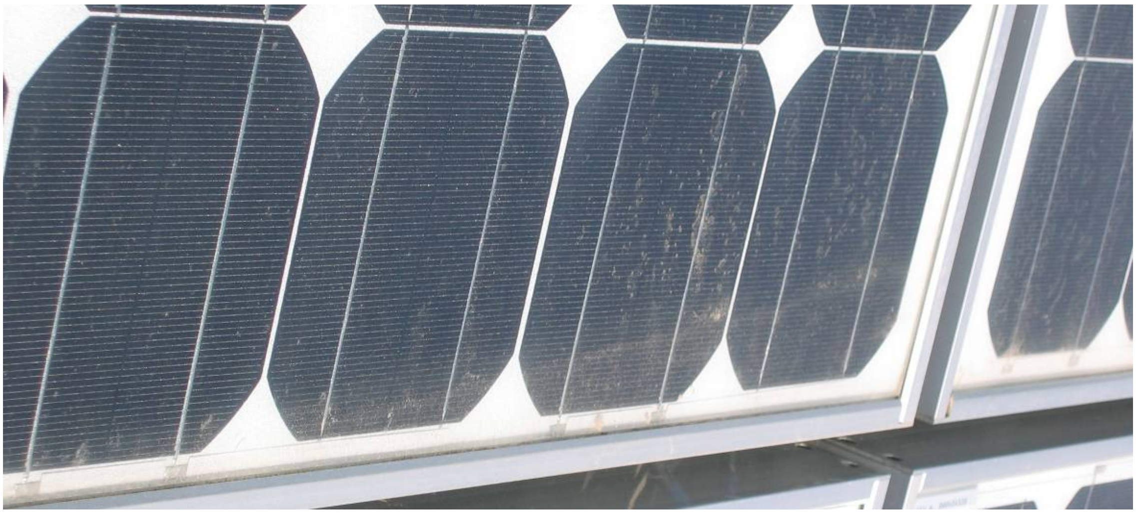


Figure 150.

Protection against birds

"Anti-bird" devices should be installed on top of the upper PV modules.

A good practice is to install "anti-bird" devices on the top of the upper PV modules of the installation to deter birds from perching on and dirtying them with their droppings. This practice is especially useful on trackers where the upper modules can be so high as to be difficult to clean, and also in BIPV installations where modules can be particularly difficult to access for cleaning. The Figures 151 and 152 show two different designs of “anti-birds” measures.

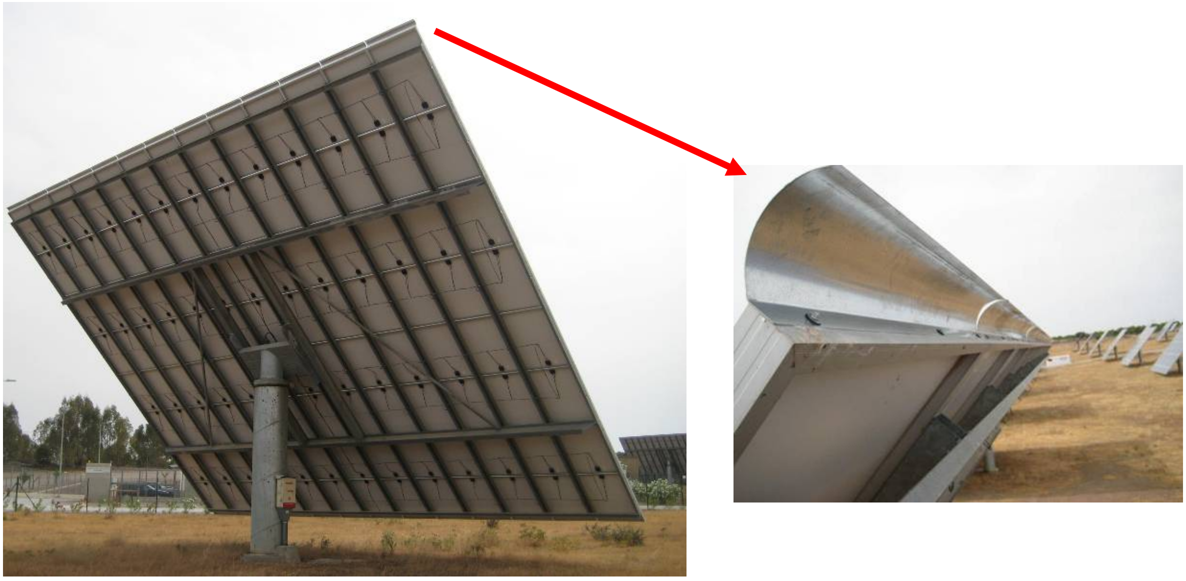


Figure 151.

Figure 152.

Grounding the modules frames

Each module frame must be independently connected to earth.

In order to achieve proper earth connection, the frames of the modules must be interconnected or boned using grounding wires fixed by screws and nuts to the prepared earthing holes on the frames. Otherwise, the coatings on the frames could prevent direct electrical contact. Simple physical contact between module frames and the support structure is not enough to ensure good earthing.

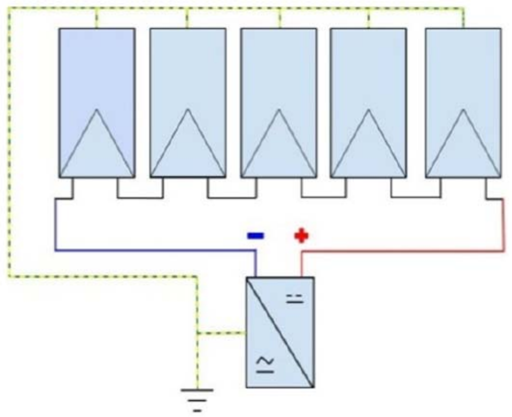


Figure 153.

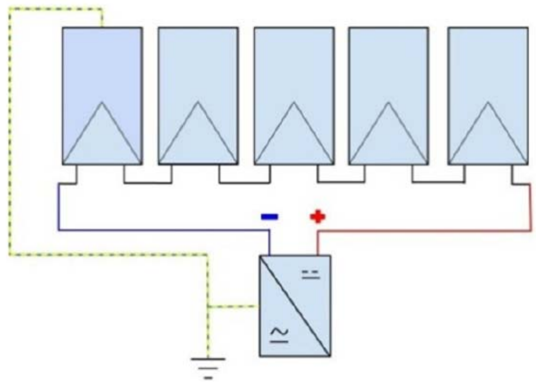


Figure 154.

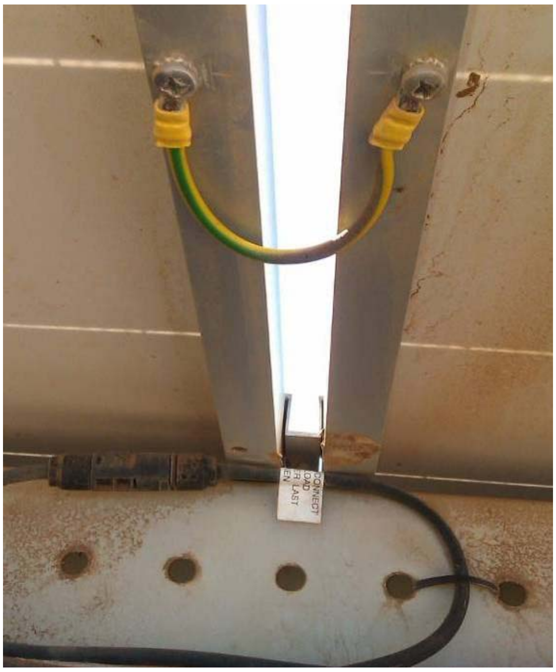


Figure 155.

Connection cables

Plugs must be from the same model to ensure good connections.

PV modules are interconnected using plugs which are crimped as part of the manufacturing process. The plugs have to be the same model and from the same manufacturer to ensure good connections. Although different model plugs might apparently fit, they can make poor connections internally and cause electric arcs that burn the plugs. This is the case in Figures 156 and 157. The modules have plugs from the same manufacturer. However, one module has round-type plugs and the other module has clip-type plugs. Although these plugs are not totally compatible, they have been used for interconnection of panels which gives rise to the risk of internal electric arcs (see next page).

Figure 156.

Figure 157.

NO

Connection cables

Connectors and plugs must be correctly crimped.

It is also important to ensure that the plugs and cables are properly crimped with the appropriate tool in such a way that live conductors are connected inside the plug. The size of the plugs must match the wire size to avoid ingress of water or dust that can reach live conductors and connectors. Otherwise, as DC voltages can be up to 1000 V, the protection offered by the covers is lost and the risk of intermittent power losses, leakage currents or electric shock is increased. Figure 158 shows an incorrectly crimped plug where the live conductor is exposed. The remaining pictures show examples of poorly-crimped plugs. Figure 159 shows a carbonized plug due to a poor connection. This is also most probably the result for the plugs in Figures 160 and 161 if the fault is not repaired. The picture and the thermography are related to a poorly crimped plug which caused a poor contact and, as a result, overheating of the cable and the plug above 100°C. This causes degradation of the plug and presents a real fire risk.

Figure 158.

Figure 159.

Figure 160.

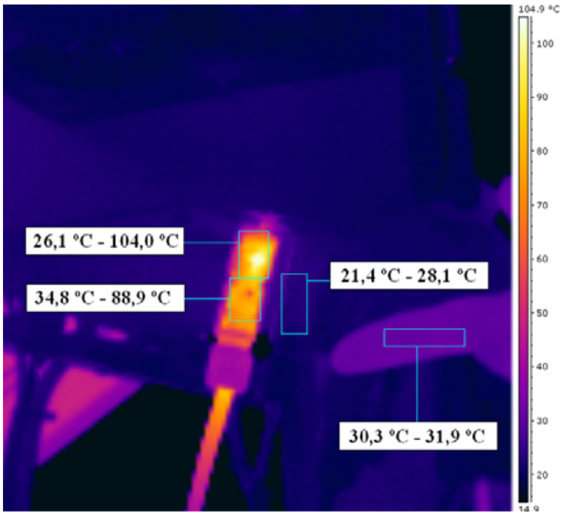


Figure 161.

Connection cables

Cables should not be too long or too short and should not support their own weigth.

Cables should be neither too short nor too long to ensure good operation of the PV plant installation. Short wires are under tension and plugs can be damaged if cables are stretched due to contraction when they are exposed to low temperatures (Figure 162). This could cause the same effect as incorrectly crimped connectors as shown in the previous figures.

Figure 162.

On the other hand, if the cables are too long (Figure 163) they cannot support their own weight and they must be attached to a fixed structure (see following figures). Otherwise, wind gusts can cause loose cables to rub against objects such as roof tiles or sharp structures that could damage their insulation. Connectors can also be damaged as a result of fatigue due to the continuous swinging and vibration of cables in the wind.

Figure 163.

Connection cables

Cables should not be too long or too short and should not support their own weigth.

In order to solve the problems described above, cables must be attached to support wires (Figure 164) or placed in trays (Figure 165). In this way, damage to the external protection of cables can be avoided. This includes cases where cables are compressed by sharp structures, (Figure 166), where cables have lost their external sheath protection (Figure 167) or where cables are so bent that can overheat or break (Figure 168).

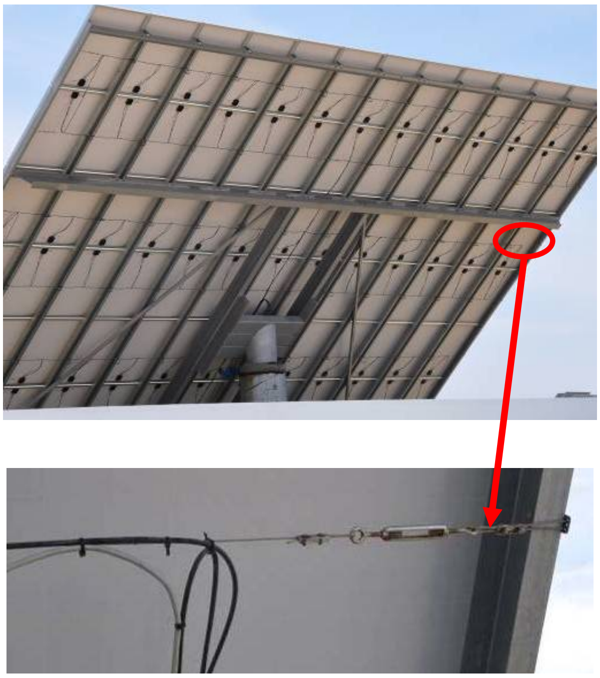


Figure 164.

Figure 165.

Figure 166.

Figure 167.

Figure 168.

Connection cables

Cable cross-section should be adapted to the maximal current values downstream of the Y-connectors.

The use of "Y" connectors can help reduce the number of DC connection boxes and their associated cost. However, a large number of these "Y" connectors increases the risk of poor connections. Moreover, the final cables should have a greater cross-sectional than the module cables to be appropriately rated to carry the total current to the inverter.

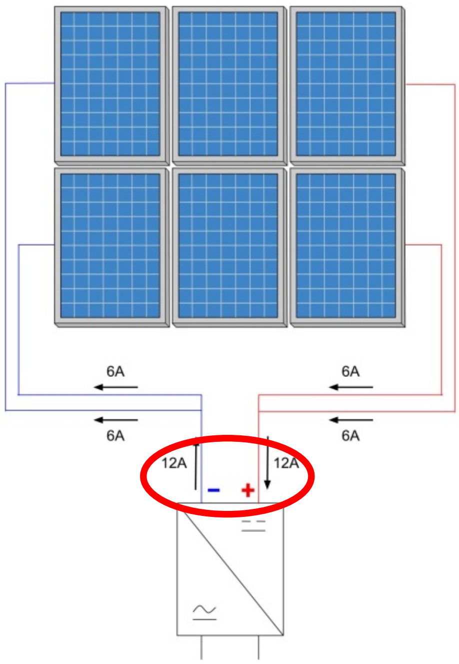


Figure 169.

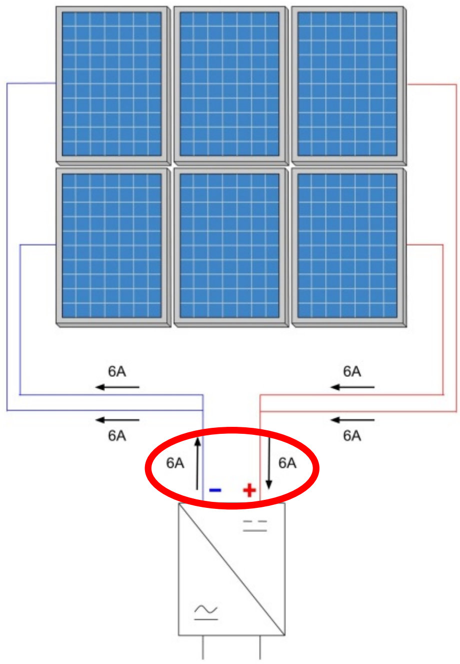


Figure 170.

Protection against indirect lightning effect in DC cables

Cables of both phases should be joined as much as possible to reduce size of loops of each string.

Positive and negative DC cables of a PV array should be installed in such a way as to reduce as much as possible the area of the loop of the array wiring, as shown in Figure 171. This is because the induced voltage due to the rate of change of the magnetic flux density enclosed by the loop is proportional to the area of the loop. It is possible to use protection devices against this induced voltage, such as surge arrestors. However, it is best to reduce the enclosed of the loop in order to minimize these induced voltages.

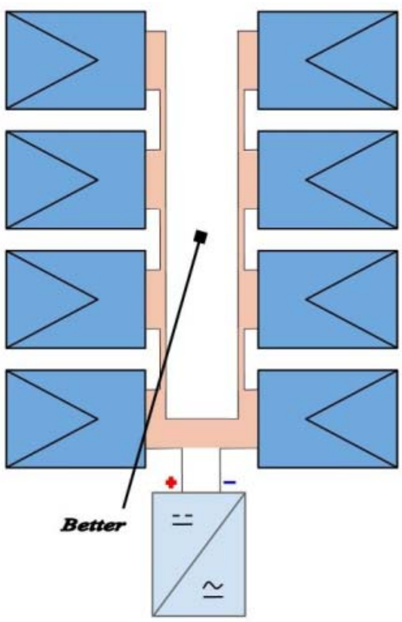


Figure 171.

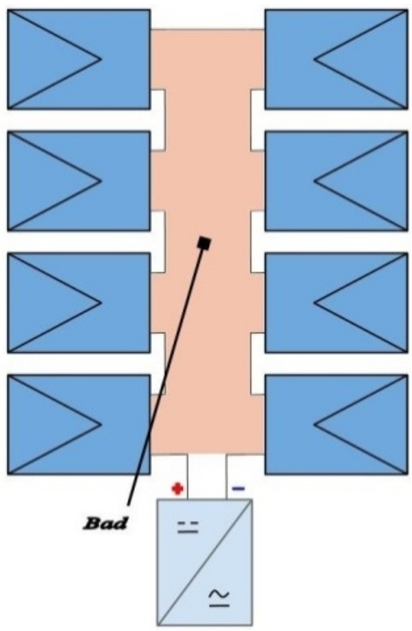


Figure 172.

3.5. Inverters.

Support and placement

Inverter support must be built in resistant and non-flammable materials.

The inverters must be placed on supporting walls which are adequate to carry the weight of the inverter over their entire lifetime (Figure 173). The weight of the inverter has to be taken into account in this determination, but also the weight of the on-board transformer (when required). The effects of the resulting vibrations need also to be considered. These devices can impose significant mechanical loads on the support structure. The supports must be built of non-flammable materials to avoid risks of combustion due to the heat released by the inverters. For example, as shown in Figure 174, the support was made of wood and, consequently the risk of fire is considerably higher.

Figure 173.

Figure 174.

Support and placement

Inverters cooled down by natural convection must be placed vertically in well ventilated areas and comply with clearances to walls and obstacles.

The temperature of inverters increases significantly when operating. Where inverters are cooled by natural convection, they must be placed vertically, in well ventilated areas with at least minimal clearance to walls, other objects and other inverters as specified by the manufactures (Figure 175). This is to ensure adequate air circulation to cool the equipment so that it operates properly. Failure to observe these guidelines may result in overheating, reduced efficiency and reduced life expectancy of the inverters (Figure 176 and Figure 177).

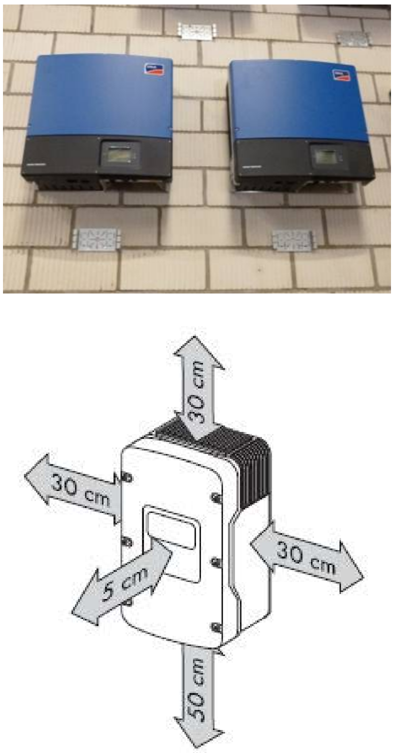


Figure 175.

Figure 176.

Figure 177.

Cooling

Inverters should not be modified without authorisation from manufacturer.

Figure 178 shows the consequences of inadequate ventilation of an inverter which was located in a room with limited air circulation. To improve ventilation, the PV plant operators decided to remove the grille from the top of the inverter. This improved the ventilation of the inverter and, consequently, its efficiency. However, the likelihood of damage to the inverter is significantly increased. The protection which the grille affords the inverter has been removed and dust infiltration is increased.

A better solution would have been to install an air circulation system comprising of fans, for example, in the inverter room.

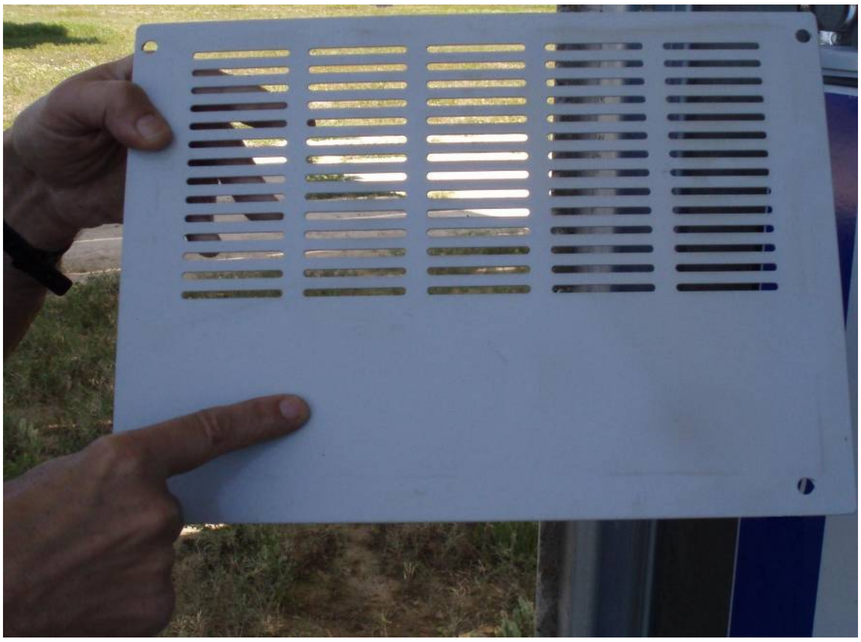


Figure 178.

Cooling

Inverters located in dedicated buildings must be properly cooled down. Fans and air ducts should be installed if necessary.

Buildings which house inverters generally operate at an elevated temperature and for this reason such building must have their own air circulation system. However, the air flow may not reach the internal sections of the inverter. Therefore, the temperature inside the inverter can be higher than the recommended value resulting in a reduction in its efficiency. Moreover, these high temperatures can cause an over-temperature alarm to be activated and the inverter turns off. A good practice is to add fans or air circulation systems which also cool the internal sections of the inverters.

In Figure 179, air ducts were added to the inverter building to expel the hot air generated within the building. Internally (Figure 180) it can be seen that these air ducts are directly connected to the inverter, so the hot air generated inside the inverter is transferred outside, reducing the operating temperature as much as possible and therefore achieving higher efficiencies.

Figure 179.

Figure 180.

Cooling

Inverters must remain protected from direct sun exposure to avoid overheating.

When installed outdoors, the inverters operate at a higher temperature and, consequently, their efficiency decreases if they are subject to direct sunlight (Figures 181 and 182). If inverters cannot be housed in cooled buildings and they have to be in the open, it is recommended that they be protected by adding roofs to avoid overheating due to sunlight, as in Figure 183. Ideally, the inverter should be oriented to the North[2] to avoid direct sunlight. This ensures that the production of electricity does not decrease. Obviously, when inverters are placed outdoors, their IP rating against water and dust ingress must be adequate.

Figure 181.

Figure 182.

Figure 183.

[2] In the northern hemisphere (oriented to the South in the southern hemisphere).

Dust, sand and dirt

Inverters cooling fans must remain clean and free of dust.

Some inverters have in-built fans to improve their cooling and therefore attain higher efficiencies. However, these measures are useless if they are not properly maintained as showed in the Figure 184. The room is full of dust and the filters of the inverter fans are clogged. Therefore, the inverter cooling and the efficiency are reduced.

Figure 184.

Terminal boards

Terminal boards in connection boxes should be properly placed to avoid loose fittings. Earthing wire cross-sectional area must be minimum 6 mm^2.

The AC cables in Figure 185 are rigid and they have not been properly fixed inside the inverter structure. Because the cables have different lengths and some of them are too short, the terminal boards are mis-aligned and the cables are not straight. This can cause overheating due to loose fittings (see Figure 107 –practice W6, page 60) or even fire inside the inverter due to electric arcs that ignite the terminal boards (see Figure 113 –practice W8, page 62–, Figure 115 –practice W10, page 64– and Figure 159 –practice G18, page 88).

The earthing wires of the overvoltage protection (surge arrestors) seem to be too small. A general rule is that the earthing wire cross-sectional area has to be the same as the earthing wire on the DC side, or a minimum of 6 mm^2.

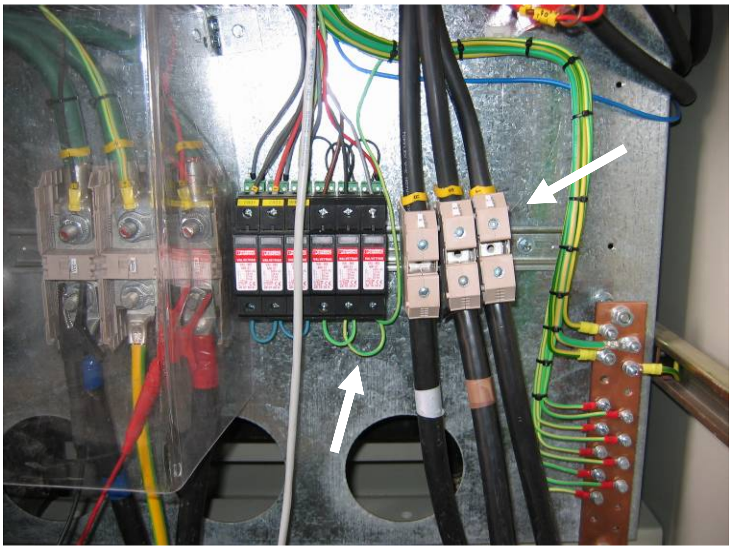


Figure 185.

Terminal boards

Cables and terminal boards must have compatible diameter and be correctly tightened.

Figure 186 shows that the cable entering the inverter terminal board has a cross-sectional area which obliges the use of a larger termination that does not properly fit and cannot be tightened by the nut.

Both the inverter terminal boards and the cable terminations must be compatible and of the same size to fit properly. Otherwise the connection can be unsatisfactory, resulting in degradation, overheating, discharges and even fire within the inverter.

Figures 187 to 189 show connection arrangements in which cables and terminal boards are compatible and are correctly tightened. Figure 188 also shows a methacrylate sheet to protect against direct contact with the active terminals. The screws are marked to check if any terminals have loosened after operating for some time (see Figure 109 –practice W6, page 60).

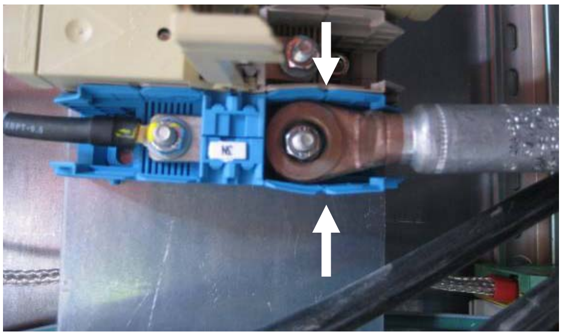


Figure 186.

Figure 187.

Figure 188.

Figure 189.

Terminal boards

Inverters terminal boards should include a toroid current sensor on DC side for checks and performance tests.

Figure 190 shows an inverter that includes a toroid current sensor to measure the input DC current. The output signal from the sensor is used for monitoring the inverter, but it can also be used for testing the inverter. Its availability and accessibility is good practice because it allows checking of the inverter and easily test its performance by an independent laboratory.

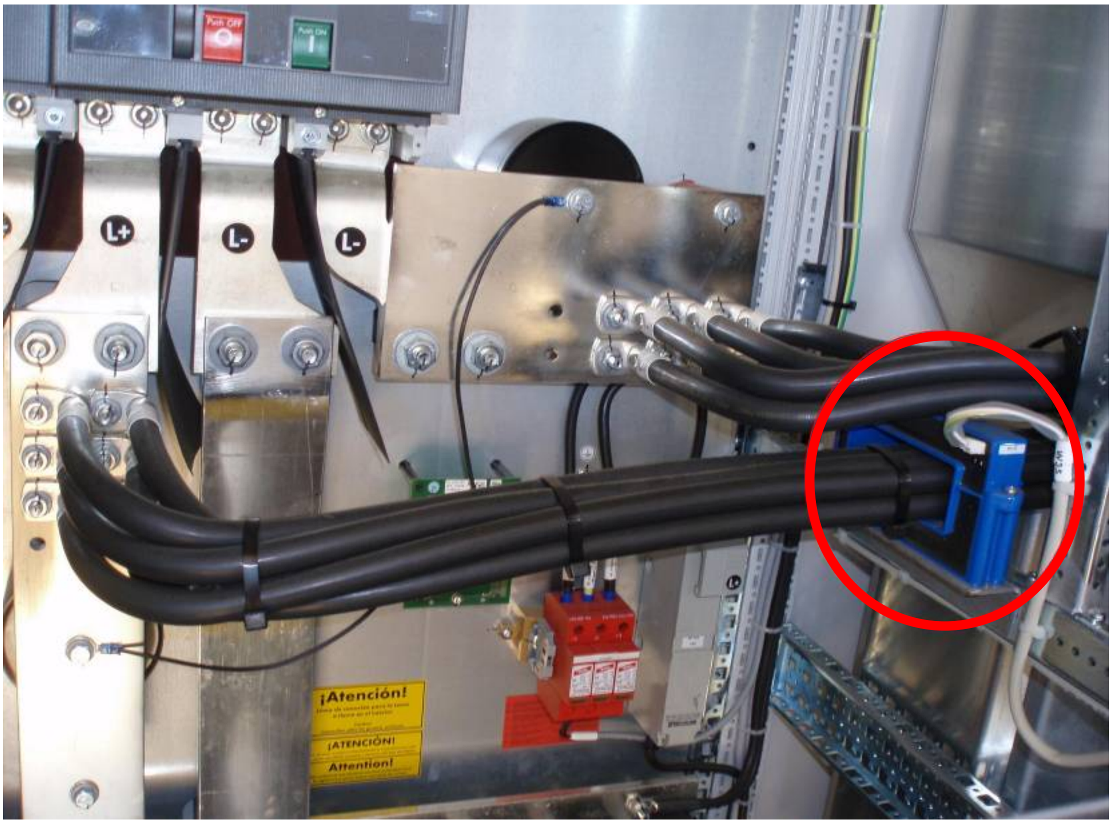


Figure 190.

Switching the PV installation ON and OFF

Switching the AC and DC sides of the PV installation must be done in the good order.

Whenever possible, the AC side should be switched off before the DC side due to the risk of the creation of an electrical arc. The DC switch of the inverter is normally designed to protect the operator but should be used with caution and only in the case of a real emergency. For large installations (and especially with Low Voltage/Medium Voltage transformers), special operating procedures must be developed for operators and they must be strictly followed. Usually, when switching on, the order is DC side first, AC side last. When switching off, the order is AC side first and DC side last.

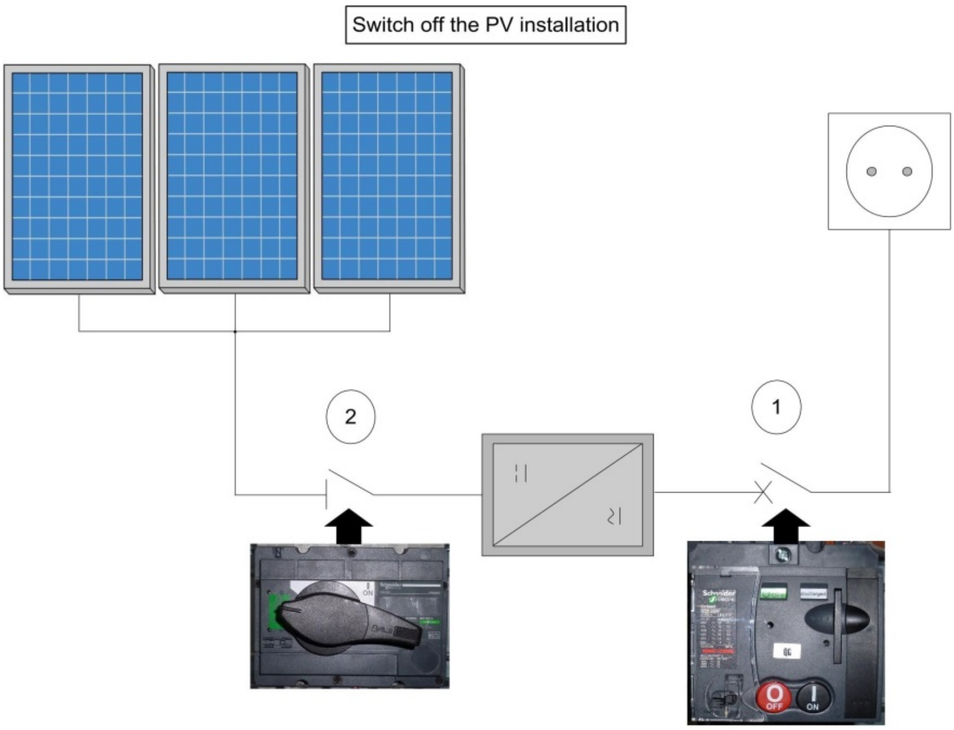


Figure 191.

3.6. Monitoring.

Irradiance sensor

Irradiance sensors must be installed in the same plane as the PV modules and without shading.

The irradiance sensor has to be fixed in the same plane as the PV modules in order to be correctly illuminated. Any shading should be avoided so that the solar irradiation in the plane of the PV generator is monitored properly.

Figure 192 shows the correct installation of an irradiance sensor which is free of shadows. Figure 193 shows the opposite situation where the sensor has been installed below the PV module plane. As a consequence, shadows from the modules are cast over the sensor during the afternoon and the irradiance values measured are erroneous and do not match the actual irradiance reaching the PV modules.

Figure 192.

Figure 193.

Irradiance sensor

Several irradiance sensors can be placed along the PV structure for advanced studies.

A good practice when installing an irradiance sensor is to locate it on top of the structure. This ensures that shadows only affect the irradiance sensor when the whole PV array is shaded. Another option is to locate several irradiance sensors along the height of the structure. In this way it is possible to analyze the difference between the irradiance at different levels of the array, as shown in the tracker in Figure 194.

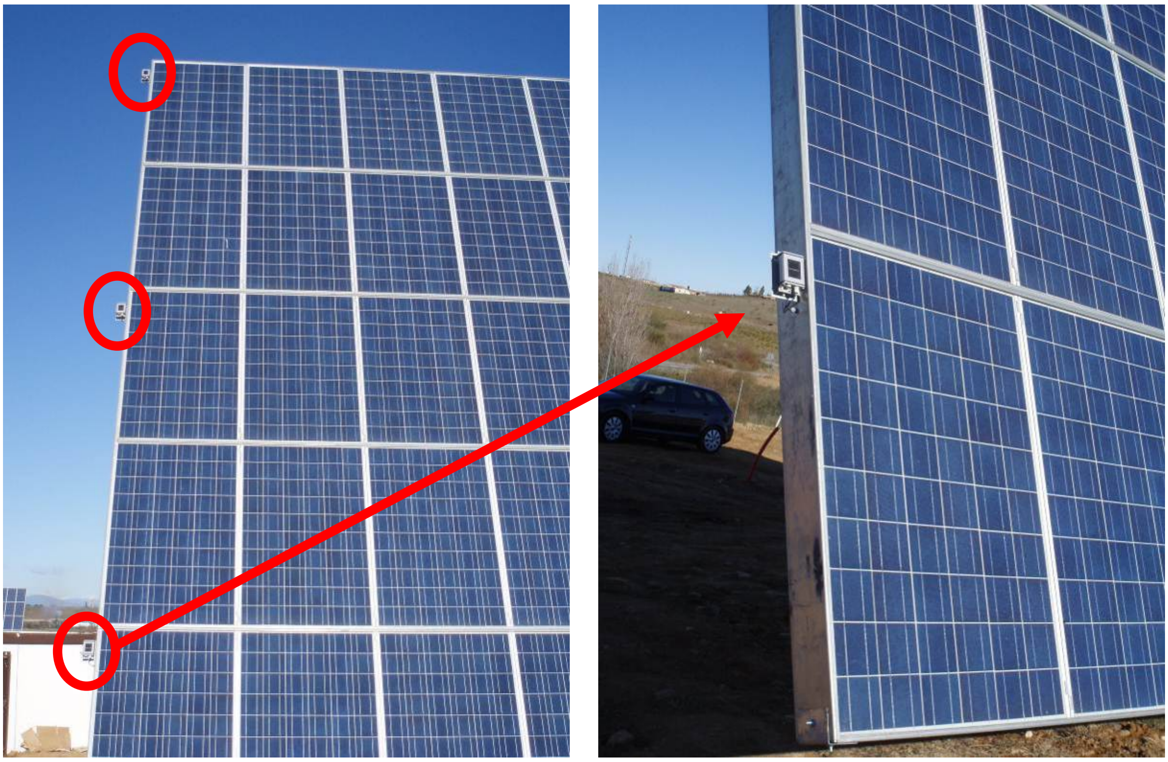


Figure 194.

Irradiance and cell temperature sensors

For improved accuracy, complete PV modules of the same technology as the PV array should be used as irradiance and cell temperature sensors.

It is usual that the irradiance sensor is a single cell of the same technology as the PV modules (Figure 195). However, it is better to use calibrated PV modules for better accuracy. The reason is very simple: the thermal, spectral and angular response of the array is closer to the response of a module than to that of a cell. The Figure 196 shows two PV modules acting as irradiance (upper) and cell temperature (lower) sensors.

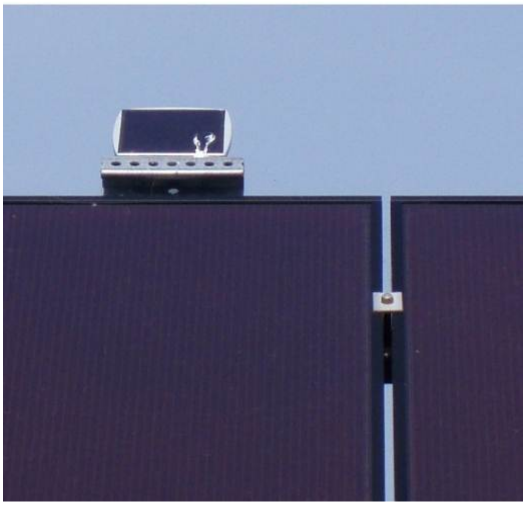


Figure 195.

Figure 196.

Irradiance and cell temperature sensors

For improved accuracy, complete PV modules of the same technology as the PV array should be used as irradiance and cell temperature sensors.

A PV module acting as an irradiance sensor is less sensitive to localised soiling than a PV cell (by bird excrements, for example, as shown in Figure 196). When the sensor is a single cell, the measured value is lower than the actual value. On the other hand, if the irradiance sensor is a PV module (consisting of several PV cells) the measured value (related to the current Isc) is the actual one. Figure 197 shows the I-V curve of a PV module without soiling (right), with homogeneous soiling (middle) and with homogeneous and localised soiling (left, with bird excrements). As can be seen, the Isc value of the I-V curve for the module with homogeneous soiling is slightly lower than the module which is clean; and this value does not change with localised soiling. As stated previously, a PV module acting as an irradiance sensor is less sensitive to localised soiling.

In any case, irradiance sensors should be free of localised soiling and must be re-calibrated periodically (every one or two years) to be sure of the accuracy of the measured values.

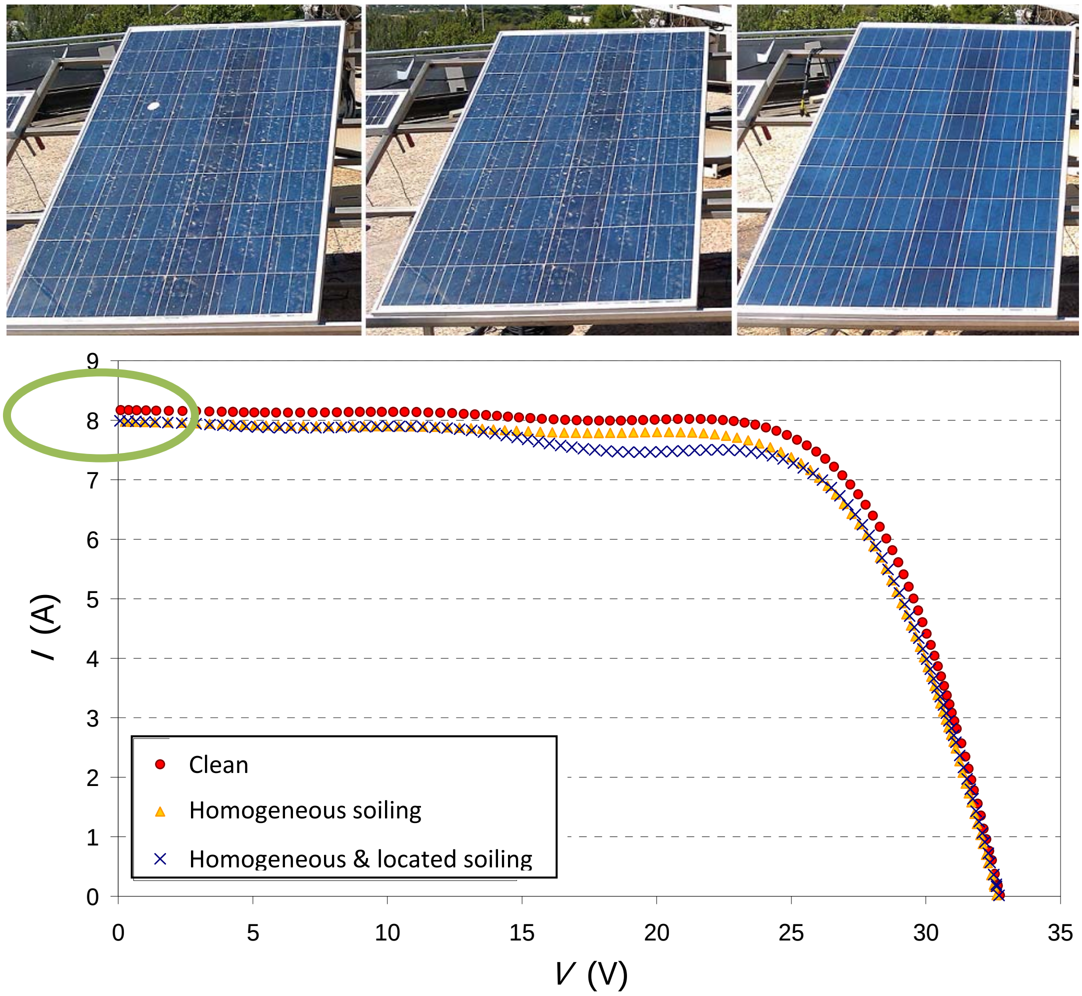


Figure 197.

Irradiance and cell temperature sensors

For improved accuracy, complete PV modules of the same technology as the PV array should be used as irradiance and cell temperature sensors.

Figures 198 and 199 show a static installation and a tracking installation, respectively, in which two PV modules have been installed as irradiance and cell temperature sensors.

In the static case (Figure 198), the PV modules have been installed in an empty space within the structure. This avoids shadows being cast over the PV modules, thereby ensuring that the measured values are correct. The PV module on the left is short-circuited with a shunt resistor to measure irradiance, while the one on the right has been open-circuited to measure cell temperature.

In the case of the installation with trackers (Figure 199), two additional structures similar to those used in the tracker have been installed to keep the PV modules in the same orientation and inclination as the other PV modules of the tracker.

In both cases, all the cables and a shunt resistor (a calibrated resistor with a very low resistance value) are inside a box as shown in Figure 200, which has the proper IP rating (i.e. free from moisture and foreign bodies).

Figure 198.

Figure 199.

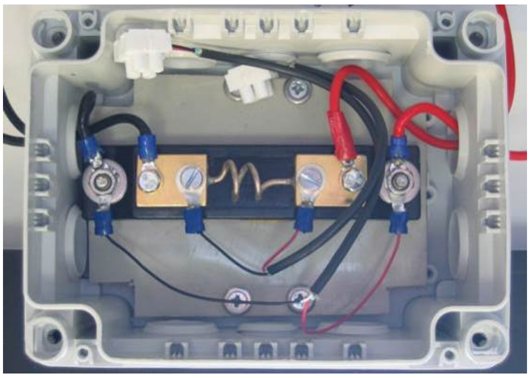


Figure 200.

Irradiance and cell temperature sensors

Irradiance and temperature sensors must remain out of shadows.

The location selected in the supporting structure to mount the modules should be in the same plane of the PV array in order to avoid shadows. Otherwise, measured values will be erroneous when shadows are cast over the sensor, as shown in Figure 201 where two modules have been installed as irradiance and cell temperature sensors. The upper module has been short-circuited by a shunt resistor to measure irradiance, while the bottom one has been open-circuited to measure cell temperature. The location selected is not ideal because in the afternoon there is a shadow cast over the PV modules from a tower in the surroundings (and even from the red tube). These elements have not been taken into account and affect the measured values (see also Figure 4 to Figure 6 –practice C2, page 14 – and Figure 193 –practice M1, page 107).

Figure 201.

Irradiance and cell temperature sensors

PV modules used as sensors must be fixed the same way than the PV array.

PV modules added as irradiance and cell temperature sensors have to be properly fixed to the supporting structure in the same way as the modules of the array. In this case, the fixing method is not appropriate as clamps have been used to attach the modules to the structure instead of the usual clips. The glass cover of the calibrated PV module was broken as a result of the high pressure caused by the clamps (Figure 202). Standard clips which hold the PV modules with no additional pressure should be used to avoid this problem as shown in Figure 203 (see also Figure 55 to Figure 63 –practices S3 to S5, pages 35 to 37).

Figure 202.

Figure 203.

Irradiance and cell temperature sensors

A single PV module can be used both as irradiance and cell temperature sensor.

Another good option is to use a single PV module modified to act simultaneously as both an irradiance and a cell temperature sensor. Taking advantage of the by-pass diodes, one part of the PV module has been short-circuited with a shunt resistor to measure irradiance; the remaining module has been open-circuited to measure cell temperature, as is shown in Figure 204 (circles represent cells).

Figure 205 shows an example of a PV module that has been installed in the middle of a tracker. This option is good when it is difficult to include a different structure for two additional PV modules. All the cables and the shunt resistor are inside a box with the proper IP rating (Figure 206).

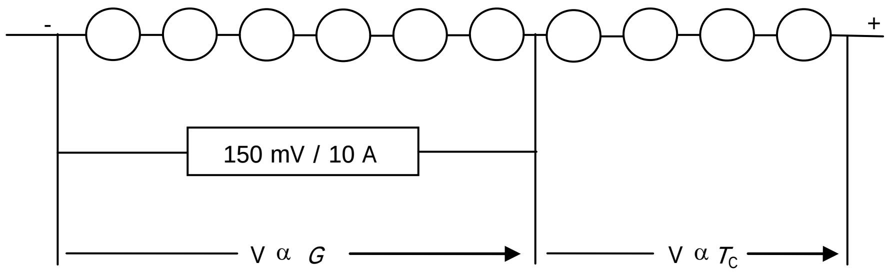


Figure 204.

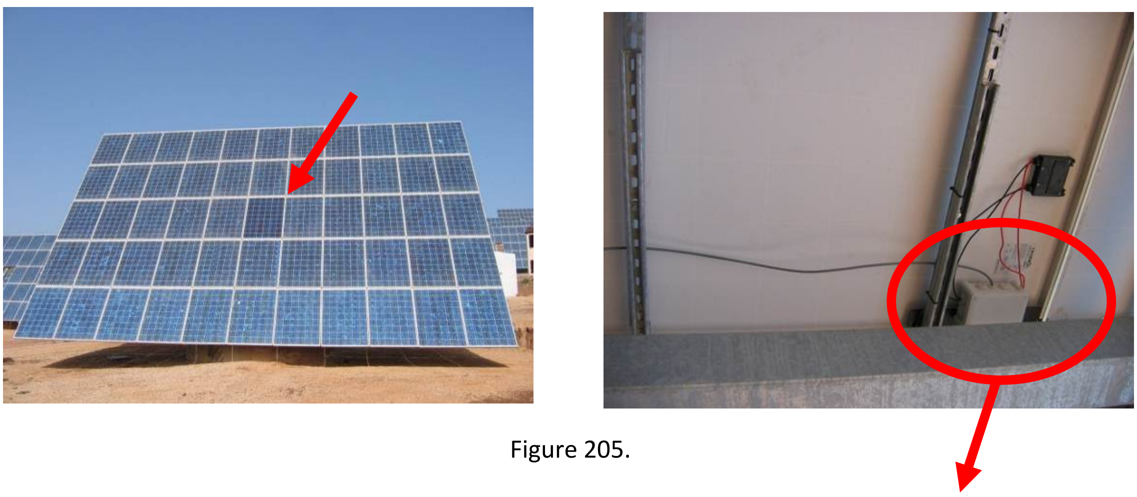


Figure 205.

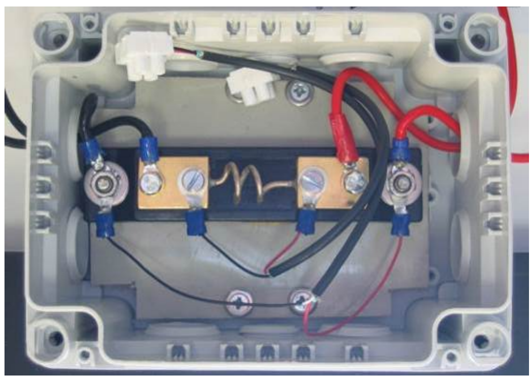


Figure 206.

Irradiance and cell temperature sensors

PV modules used as sensors must be in the same plane as the array modules.

Figures 207 and 208 show a PV module which has been added to a tracker and acts as both an irradiance and a cell temperature sensor. It can be noticed that the supporting structure for the added PV module does not ensure that the PV module is in the same plane as that of the array. Its orientation is wrong and, consequently, the effective irradiance measured by this device is different to the actual irradiance reaching the modules of the array. It is important to ensure that the irradiance sensor has the same orientation and tilt as the PV modules of the installation to ensure the accuracy of the measurements (see previous figures).

Figure 207.

Figure 208.

NO

Irradiance and cell temperature sensors

Electronic devices needed to use PV modules as irradiance sensors must be protected inside boxes with proper IP rating.

When a PV module is used as an irradiance sensor, it has to be short-circuited and the resulting current has to be monitored. The simplest way is to use a shunt resistor, which has to be protected from the environment to ensure that it is working properly (see previous figures). Figure 209 shows a case in which the shunt resistor and the cables used to short-circuit the PV module acting as an irradiance sensor are not inside a box with the proper IP rating to protect the contents from water and soiling effects. This causes the connectors and shunt resistor to deteriorate quickly.

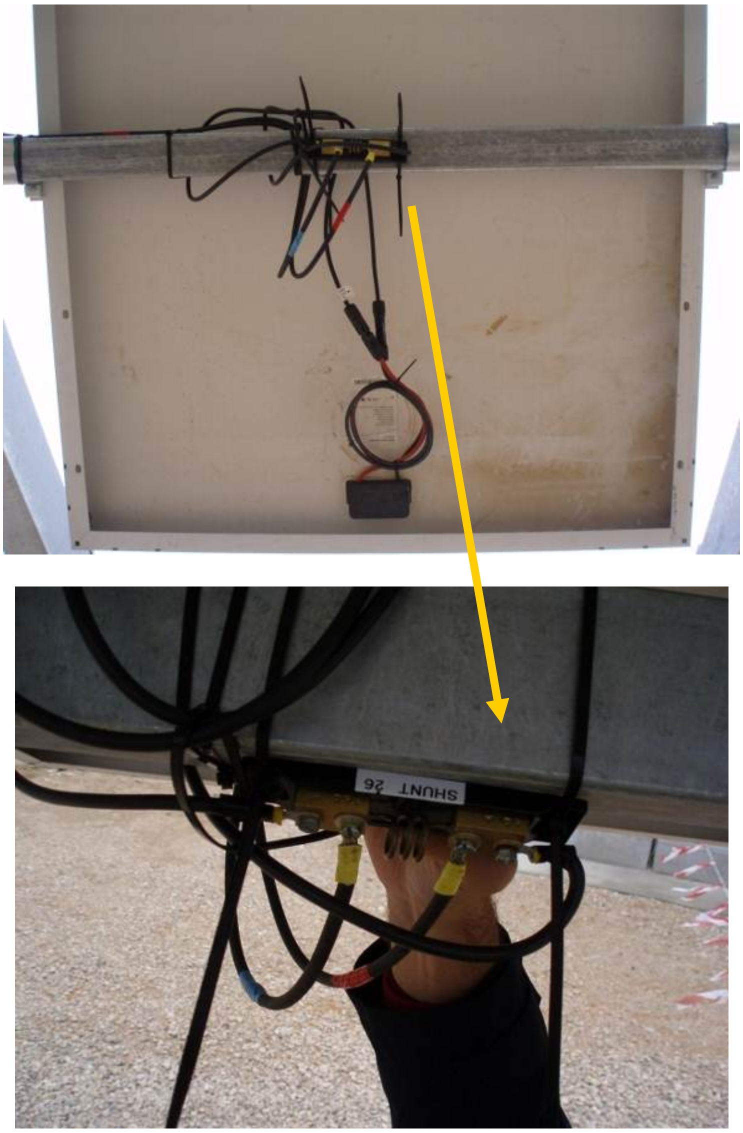


Figure 209.

Temperature sensors

Thermocouple sensors monitoring the module temperature must be properly installed and periodically reviewed.

The module temperature can be monitored with PT100, PT1000 or thermocouple sensors. If these devices are used, they have to be installed correctly on the rear of a PV module by properly fixing them on a cell with no hot spots or over-temperature (a thermographic inspection is required) and reviewing it periodically (if the adhesive surface of these devices wears down, they could register an erroneous temperature).

Figure 210.

Wind speed sensors

Wind speed sensors should not be installed just at the top of a tracker. Wind protection threshold must be carefully determined to prevent production losses (threshold too low) and material destruction (threshold too high).

Another important sensor in a PV installation, especially in tracking PV plants that can move the modules to horizontal position, is a wind speed sensor. When the speed monitored is above a safety threshold, an alarm is generated and the trackers move to the horizontal position in order to guarantee their physical safety against high wind gusts. It is very important to establish an appropriate threshold to avoid false alarms which will reduce the final energy production.

This sensor must be elevated above ground level. But when it is installed just at the top of a tracker, the wind speed measured is higher than the actual speed because of the hot air coming from the PV modules (Figure 211). This can cause an incorrect activation of the wind speed alarm and, consequently, cause trackers to switch to the horizontal position, resulting in a loss in energy production, as shown in Figure 212. A good alternative is to install the wind speed sensor on a separate tower (Figure 213).

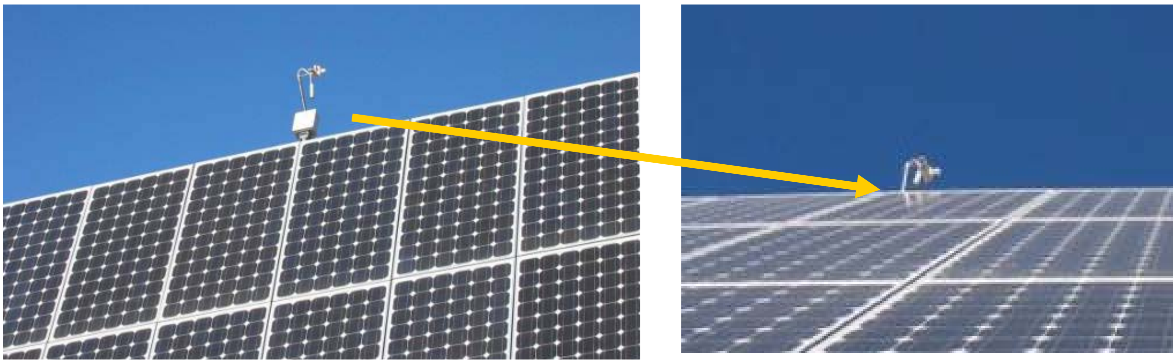


Figure 211.

Figure 212.

Figure 213.

Wind speed sensors

Towers supporting the wind speed sensors must be securely anchored to the ground.

In the situation shown in Figure 214, anchors or stays of the tower are incorrectly installed. To avoid the tower collapsing, the 3 anchor points have to be separated 120 degrees (Figure 215). If they are separated by 90 degrees, as in Figure 216, one more anchor point is required.

Figure 214.

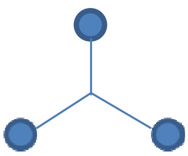


Figure 215.

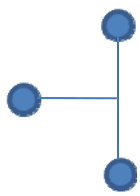


Figure 216.

Meteorological stations

A complete meteorological station can be useful to improve the estimated values of energy production.

A complete meteorological station (Figure 217) with a pyranometer on the same tilt as the supporting structure to measure global irradiance on the structure's plane, a pyrheliometer to measure beam irradiance, a horizontal pyranometer with a shading ring to measure diffuse irradiance and another horizontal pyranometer free of shadows to measure global horizontal irradiance can be very useful to study in detail the expected energy production of an array and compare the outcome with the result of the typical simulations studies, most of which are based only on global horizontal radiation. To achieve more accurate measurements, these devices must be frequently maintained, involving cleaning, checking that tracking of the pyrheliometer and movement of the stripe are correct. This also includes checking if the moisture sensors are operating and that the silica gel is in a good condition as shown in Figures 218 and 219. It is also important to periodically review the calibration values to avoid errors in the measurements.

Figure 217.

Figure 218.

Figure 219.

Centralized monitoring system

Centralized monitoring systems should be used in PV plants to report about defects and minimize their energy losses.

The monitoring system of a PV plant must instantaneously alert the operator of any defects so that they can be repaired immediately and energy losses can be minimized. A better option is to display all the monitored information on a screen as shown in Figure 220. This arrangement reports the condition of the installation and can be easily assessed with a single viewing.

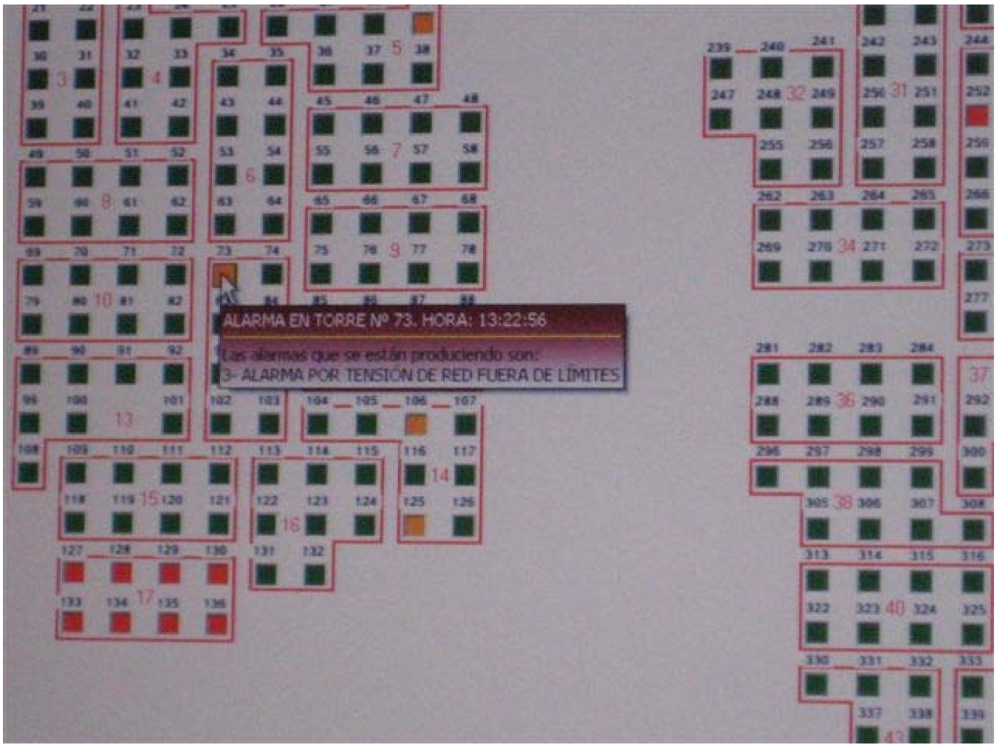


Figure 220.

3.7. Others

Integration and environmental impact

PV plants should be designed to minimize their environmental impact.

A PV plant installation must be sensitive to the environment where it is located. More and more, a good integration of a PV plant in its location is required and more valued. Figures 221 to 229 show PV plants that have been designed to minimize the environmental impact.

Figure 221 shows a tractor sowing seeds for typical vegetation of the region close to a PV plant. The first shoots of this vegetation are shown in Figure 222.

Figure 221.

Figure 222.

Figures 223 and 224 show how the natural habitat has been preserved around PV installations. The trackers have been installed in such a way that shadows are avoided.

Figure 223.

Figure 224.

Integration and environmental impact

Special efforts should be made to properly integrate PV plants in their surrounding environment and ecosystem.

Figure 225 shows sheep grazing in a PV plant installation. Co-existence between grazing animals and the PV installation is good because the animals eat the small vegetation, preventing it reaching the lower modules and casting shadows on the modules. The modules provide shading to the cattle on hot summer days. Figure 226 shows a drinking trough for cattle located within the region of the PV plant. Figure 227 shows an overflow channel which is closed with a fence but with sufficient spacing to allow animals to cross the installation and therefore the PV plant is not an unnatural barrier to their movement.

Figure 225.

Figure 226.

Figure 227.

Figure 228 shows an old well that has been restored and preserved and Figure 229 shows a small lake in which ducks are swimming serenely close to the trackers of a PV plant installation[3].

Figure 228.

Figure 229.

These pictures are very good examples how a PV installation can be well integrated in its environment without disturbing the natural habitat.

[3] These two pictures correspond to an installation with 1 axis azimuthal tracking and have been taken in a blue sky day at first hour in the morning. This is the reason of the shadows cast over the modules (those shadows disappear a few minutes later).

4. General links for PV.

www.pvcrops.eu

www.epia.org

www.pvgrid.eu

www.pvsunrise.eu

www.eupvplatform.org

www.iea-pvps.org

www.ises.org

www.eurobser-er.org

www.seia.org

www.setis.ec.europa.eu

www.solarweb.net

www.bdpr.fr