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# Solar Photovoltaic: A global technical study for Design, Installation and High Performance

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**Abstract:** Solar energy is one of the possibilities for reducing the global carbon footprint. The solar is made up of two types of solar panels: the photovoltaic solar and the thermal solar. Solar thermal is mainly intended to produce hot water, while photovoltaic solar is intended for the direct production of electricity. This article is about photovoltaics. Its objective is to provide, after in-depth research, requirements on the design and installation of the elements of a photovoltaic system to guarantee optimum performance throughout the life cycle.

## Introduction

Solar energy is an energy source that depends on the sun. This energy makes it possible to produce electricity from photovoltaic panels or solar thermal power plants, thanks to the sunlight captured by solar panels.

This article defines the technical specification for the design, supply, installation, commissioning, and operation of the Solar Photovoltaic (PV) Systems.This article is structured in several part. Each part corresponds to important element (material or not material) to take under consideration.

The PV system must be installed by a qualified professional who is accredited by the local accredited body (if applicable). For having a performant installation, it is preferable to use new, unused, and in original condition.

Due to low energy yield of the PV systems, it is essential to transmit the produced energy to the consumers with minimum losses as possible. Therefore, it necessary to minimize these losses by eliminating the factors that cause the losses occurred in PV systems. Factors that may cause losses in PV systems are environmental factors such as shade, dust, snow, rain, temperature, and such losses due to system components such as cables, inverters and batteries. PV systems should be installed taking into account the losses and the produced energy should be consumed in local areas where it was produced as much as possible. Figure 1 shows some losses occurred in a PV system. [1]

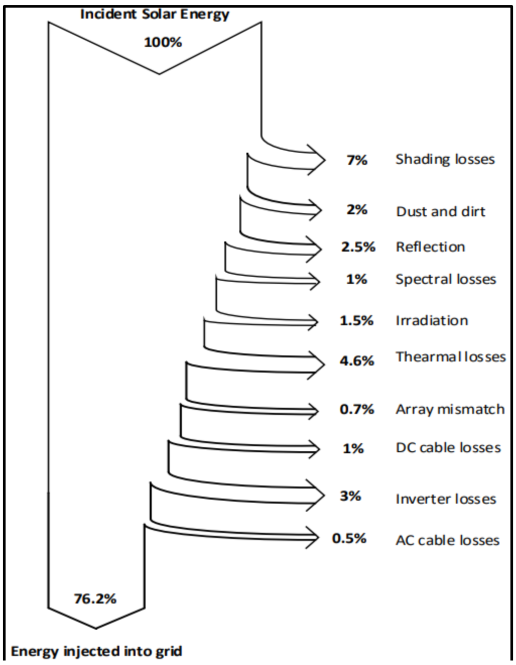


Figure 1:PV systems losses [1]

  

Technical specifications to reduce losses will be given later in this paper.

## Photovoltaic System Design

Figure 2 contains main element of a photovoltaic system.

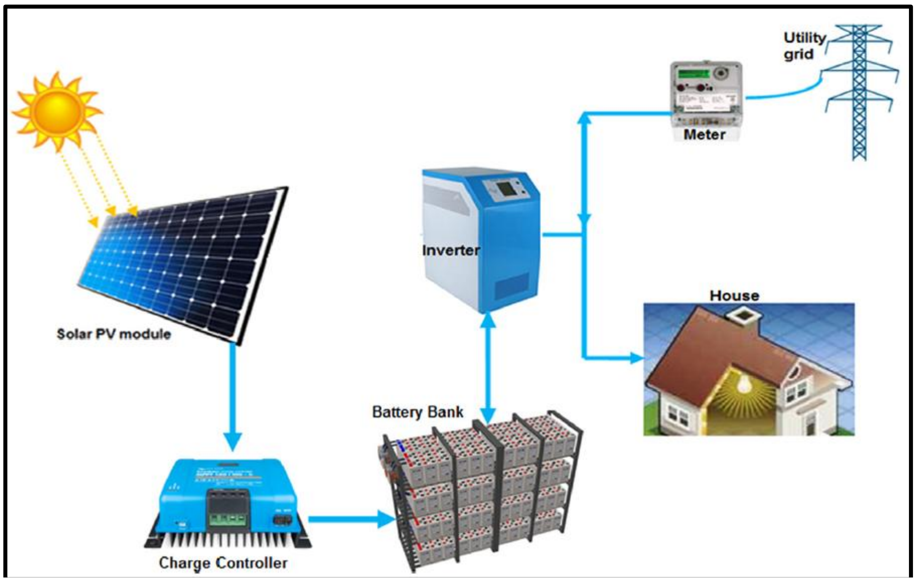


Figure 2:Standalone/off grid PV system [2]

All photovoltaicsystem design and installation works must be undertaken by a qualified professional who isaccredited by a local accredited body. The use of a non-qualified and notaccredited can havea huge impact on the performance and life-cycle of the photovoltaicsystem.

The systemmust also be:

- Completed in compliance with the structural and geotechnical engineering reports,
- Designed and installed to comply with all relevant electrical requirements andwith the Distributed Network Service Provider (DNSP) connection agreement,
- Undertaken and completed in accordance with all engineering certifications, reports, applications, or sign-offs required by the connection agreement, local or state government authorities or any other statutory authority.

## Photovoltaic Modules

**Requirements**

Solar PV technology is one of the renewable technologies which have a potential to shape a clean, reliable, scalable, and affordable electricity system for the future [3].

To reach the goals mentioned above, photovoltaic modules shouldhave the following requirements:

- Have valid approval by local photovoltaic industry regulator at the time of project award, installation, and system commissioning.
- Be monocrystalline or polycrystalline silicon.
- Have a module efficiency greater than 15%.
- Be aluminumor stainless steel framed.
- Be constructed and tested in accordance with IEC 61215 ed 2 & IEC 61730 ed 2.
- The solar panels, frames and converters are expected to function under harsh environmental conditions such as high ambient temperature (>45°C) and humidity variations (0% - 100%).
- Have a manufacturer’s material and workmanship warranty of no less than 10 years.
- Have a manufacturer’s performance warranty that linearly decreases from at least 97% of rated power in year 1 and has a minimum warrantied value of no less than 80% of rated output in year 20.

  

- Be supported by the manufacturer with a dedicated service team located within country of installation.
- All module warranties must be valid for installation conditions at the site of installation.

**Installations**

Shading from adjacent buildings, roof-mounted plant, vegetation, or other obstructions must be avoided. Modules that are electrically in the same string shall all be installed at the same tilt angle and orientation[4].

## Inverters

**Requirements**

An inverter transforms the direct electric current produced by the solar panels into alternating current to allow the electricity to flow and be consumed. Choosing the right solar inverter is crucial because it has an impact on the electricity production of solar panels and their performance [5, 6].

Inverters shall meet the following minimum performance requirements and specifications:

- Approved by relevant local photovoltaic industry regulator.
  Have an efficiency of more than 97% at expected Vmp((Maximum Power Voltage) and full rated output.
- Provide three phase output (unless the system size is less than 5kWp and a three-phase connection is not practicable).
- Be rated for outdoor installation.
- Be capable of full rated output at an ambient temperature of 45°C.
- Include an earth fault alarm in compliance with IEC 61727, IEC 62116.
- Include monitoring and control capability over RS485 and/ or Ethernet.
- Shall be supplied with replaceable surge diverters on all inputs, including but not limited to DC, AC and communications wiring.
- Be supported by the manufacturer with a dedicated service team located within the installation country.
- Have a standard manufacturer’s warranty of no less than 10 years.
- Be programmed and configured to comply with the (Distributed Network Service Provider) connection agreement.

Ensure the inverter has an appropriate IP rating for the installation conditions.

**Installations**

Inverters shall not be installed in direct sunlight. Provide a shade structure if required.

Provide mechanical protection for inverters, e.g., bollards, if there is a reasonable risk of mechanical damage to the inverters, e.g., if inverters are located in a carpark. Position inverters to minimize the risk of access being blocked.

Verify that each inverter has adequate clearances and ventilation to avoid inverter derating due to ambient temperature rise. Provide additional ventilation/cooling if required.

## Cable Sizing, Voltage Drop and Protection

**Requirements**

Cables are important in the electricity systembut on the other hand one of the sources of energy losses. In the PV system, losses due to wires are DC losses in the string of solar panels and AC losses at the output of an inverter [7].

To ensure good performance, the followings point must be considered on voltage: A Direct Current (DC) voltage drop for all photovoltaic strings that not exceed 2% of Vmpat Standard Test Conditions (STC)and a voltage drop from the point of supply to the terminals of each inverter less than 2%.
Cables shall be sized in accordance with the requirements of relevant local or industry standard.

DC and AC Cables must:

- Have an insulation temperature rating of at least 90°C,
- For AC circuits, be copper or aluminum conductor,
- For DC circuits, be copper or aluminum conductor,
- be fully supported over the entire length of the cable route, including changes in direction and entry into enclosures.

  

It is very important that each equipment issized to withstand the prospective short circuit fault current at the point ofinstallation.

Circuit breakers must be sized to account for the effect of ambient temperature on the nominal ratings and overload protection shall also be set at the lowest level required to guarantee reliable system operation under expected ambient thermal conditions. Set the short circuit to minimize the fault energy to a level as low as reasonably practicable.

The combined operation of protection devices shall not be relied upon when determining the faultwithstand level of equipment. Fuses may be relied upon to reduce downstream fault currents.

**Installations**

All AC, DC and communications/signal cables shall be:

- a continuous run with no joints or extensions acceptable,
- handled so as to avoid damage to insulation or sheathing (discard cable with insulation damage),
- supported to prevent sagging over the life of the cable and secured as to prevent damage to the cable in the event of a fault,
- segregated from all other cables to ensure signal integrity and reliable operation. If physical separation is impracticable segregation barriers on cable trays/ladders can be provided.
- not exposed to direct sunlight (and conduit also).

## Cable Ladders and Trays

**Requirements**

Cable tray and cable tray covers are to be galvanized.

Covers shall be provided on all external ladders, ducts and trays including bends, tees, and other connection pieces. Covers must be the same material, of an adequate strength and rigidity (installed to ensure water is unable to pool on any surface of the cable tray cover), and preferably from the same manufacturer as the cable support system.

Flat cable tray covers should not be used for external installation where the slope of the flat cover will be within 10 degrees of horizontal.

Cable trays and cable ladders have to meet the following minimum requirements:

- Trays up to 150 mm wide: 1.0 mm minimum steel thickness
- Trays from 150 mm to 300 mm wide: 1.2 mm minimum steel thickness
- Trays over 300 mm wide: 1.6 mm minimum steel thickness
- Folded edge: Minimum height 50 mm, radiused.
- Slotting: Normal or reverse with no burrs or sharp edges on the side to which cables are attached.

Cable ladder shall be manufactured to comply with standard NEMA VE1 and be constructed generally to form two folded steel side rails with cable support rungs between the two rails spaced at intervals of not more than 300 mm.

### Installations

Cable tray support system shall be positioned to give adequate access for inspecting, replacing, oradding cable. Treat all cut edges of galvanized material to protect them against corrosion e.g. cold gal spray.

## Energy Monitoring System (EMS)

**Requirements**

To monitor and continuously improve the performance of the photovoltaic system, it should be monitored by a dedicated monitoring system. The monitoring system in PV power plant is veryimportant and urgent in some cases for analyzing,troubleshooting and in decision making issues [8]. This system will also be a powerful tool to perform continuous energy management [9, 10]and to identify savings through energy audit[11, 12,13].

The monitoring system will be composed of equipment provided by the inverter manufacturer and/orthird-party equipment.Online portals shall be provided by the equipment manufacturer for all data logging equipment for the viewingand management of logged data.

Below, the list of system parameters to log at a minimum:

- Site Load in kW
- Solar power generated in kW
- Total energy consumption of each relevant metering point in kWh
- Solar energy consumption at each relevant metering point in kWh
- Solar energy exported for each relevant metering point
- MPPT (Maximum Power Point Tracking) andoptimizer, DC volts and DC amps
- Inverter AC (Alternative Current) volts and AC amps
- Inverter errors
- Inverter warnings
- Inverter alarms

For facilitating data treatment and having enough data to take actions, it is judicious to have a monitoring system that log up of data to several years (example 5 years)at minimum 1-hour intervals.Datashould be downloadable in CSV format for also facilitating data treatment.

The photovoltaic system monitoring can be performed by an EMS similar tothe blue'Log X-Series by Meteocontrolrepresented in figure3 and in addition to the inverter manufacturer's datalogger.


Figure 3:The blue'Log X-Series by Meteocontrol (EMS)

**Installations**

All devices comprising the monitoring system (e.g., dataloggers, modems etc.) will be powered from a dedicated sub-circuit such that a fault on the photovoltaicsystem or on equipment unrelated to the monitoring system will not affect the monitoring system. If the photovoltaic system is disconnected from the grid, the monitoring system must remain connected to the grid.

Ensure that the system monitoring is installed correctlywith all Current Transformers (CTs) installed in the correct polarity and all voltage references correct. Make also sure that all reported information is consistent and accurate, and that data is being transferred reliably to the relevant portal (including Client's FTP server if required).

## Weather Station

**Requirements**

The monitoring of the yield of a photovoltaic-type electricity production field is described in standardization IEC 61724. This standard includes the recording of several meteorological parameters, the recording interval, and recommendations on the positioning of the sensors. A weather station is used to manage data and communicate with measuring instruments[14, 15].

The monitoring system should be supplied with weather stations incorporating meteorological monitoring equipment of the following types and accuracy, in compliance with the following technical guidelines:

- In-plane irradiance, minimum accuracy 5%
- Horizontal global irradiance, minimum accuracy 5%
- Ambient temperature, minimum accuracy 1°C
- Module Temperature, minimum accuracy 1°C
- Wind speed, minimum accuracy ± 10%

Where the photovoltaic modules are installed in multiple orientations, each weather station have to include in-plane irradiance monitoring for each distinct photovoltaic module orientation.

Each weather station shall be a complete and integrated unit, with all relevant components securely mounted in a suitable location and orientation, and with suitable IP rating for installation in the open air or in an enclosure.

**Installations**

Where more than one weather station is required, they should be installed at opposite ends of theinstallation, as far as practicable.

Module temperature sensors shall be installed on the back of the module, at the center of the top third of the module, or according to the test unit manufacturer's instructions.

Shading of the array due to weather station masts should be considered in the placement of the masts and avoided where possible.

## Other important elements:

**Current Transformers for metering, Monitoring and Protection**

Current Transformers (CTs) are used for measuring electric current for monitoring or protection purpose. CTs need to beappropriately rated for the load and the monitoring of protection equipment, and the burden due to cable and devices.

CTs shall not be connected to more than one piece of equipment. If there is no space in an existing board for the necessary number of CTs, confirm from all relevant equipment manufacturers that the monitoring and or protection functions will operate as required under these specific installation conditions, and all necessary engineering calculations to provide that confirmation.

Do not install Power Factor Correction units on the generation side of any generation meters, i.e., on the same side of the generation meter as any inverter.

**Switchboards and Equipment Enclosures**

The switchboard shall comply with DNSP requirements and relevant local and Industry Standards and be of a standardized design and type tested.

All switchboards must be vermin and dust proof with a minimum degree of protection of IP54 inaccordance with the relevant local and Industry standards.Cable entries to switchboards must be made through the non-ferrous gland plates (3mm thick aluminum or brass) with correctly fitted glands to maintain the specified degree of protection.Moreover, sealed any unused penetrations to the switchboard enclosure.

The exterior paintwork should be by powder coating unless stainless steel. As a best practice, keep 20% spare space in all switchboards for future equipment installation. Separate cubicles shall be provided for electronic multifunction meters, monitoring equipment and photovoltaic system control equipment

The air temperature rises within switchboard compartments due to maximum ambient and operating conditions must not exceed maximum ambient temperature rating of any equipment in the switchboard.

Trough equipment selection for switchboard, provide short circuit protection coordination between supplied and upstream short circuit protection devices.

Issue Factory Acceptance Test results prior to the delivery of the switchboard or enclosure to site.

**AC and DC Isolators**

Outdoor DC isolator enclosures shall be weatherproof to IP66 or higher and shall maintain the IP rating after cables and conduits are terminated.

Rooftop DC isolators and AC isolators installed outdoors are to be protected from direct UV exposure and water ingress.

DC isolators should be rated to withstand worst case conditions of the installed environment

Implement minimum IP54 AC isolators if installed indoors, and minimum IP66 if installed outdoors. AC isolators shall be lockable in the open position.

AC isolator enclosures shall maintain the IP rating after cables and conduits are terminated.

Ensure that all control and protection equipment is installed and commissioned as required to comply with the connection agreement for that site.

### Mounting Frames

All mounting rails and associated joiners, clamps and brackets must be certified.All rooftop mounting structures shall be aluminum or stainless steel and all structures be highly durable and corrosion resistant.

The array frame has to be designed to prevent damage to the modules or roofing material due to the action of flora and fauna present at the site.

The mounting system must be selected to suit the existing roof type (i.e., penetrated, roofing clip,concrete), minimize penetrations where possible, and accommodate any additional fixing requirements imposed by the structural certification.

To prevent rust appearance, implement roof fixings (e.g.,photovoltaic, roof safety system) made with minimum 316 stainless steel or marine grade aluminum. Utilize existing roof fixing points wherever possible.

Sufficient clearance shall be provided to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris[16].

All cables (and conductors within multi-core cables) that share an enclosure with cables operating at a different voltage level (excluding HV) must be double insulated.

Roof penetrations must be avoided where possible. Suitably seal any roof penetrations to maintain the full waterproofing and fire rated integrity of the existing roof for the expected life of the system.

**Penetration with Existing Lightning Protection Schemes**

Include in the design an appropriate lightning protection system to protect the photovoltaic array as required under the relevant local or Industry Standard. Any modification to an existing lightning protection system must be designed and installed made in accordance with the local or industry standard.

## Conclusion

Through this article we can see that design and installation are key in the future performance. In fact, poor design and installation can decrease significatively the overall performance of the installation.Electronic components play a key role and must be deeply studied and adapted to the implantation location.

Ensure that the installation is done by qualified person andorganization.

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