Guidelines on Rooftop Solar PV Installation for Solar Service Providers

REVISION 1

September 2022

Public Utilities Commission of Sri Lanka

Preface

This document provides a general guideline and best practices guide for the installation of rooftop solar PV systems in Sri Lanka. The guide was prepared based on the applicable international standards and best industry practices around the world. This document would provide a guideline to plan and install a rooftop PV system for a solar system service provider. This would provide a guide for a utility to assess the technical compatibility and quality of installation of a proposed or installed solar PV system.

List of Abbreviations

AC	Alternating Current
BS	British Standard
DC	Direct Current
ER	Engineers Recommendation
I	Current
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
PV	Photo Voltaic
PUCSL	Public Utilities Commission
RCD	Residual Current Device
SPD	Surge Protective Device
STC	Standard Test Conditions
V	Voltage

List of Definitions

AC side: Part of a PV installation from the AC terminals of the PV Inverter to the point of connection of the PV supply cable to the Electrical Installation.

Array: Mechanically and electrically integrated assembly of PV Modules, and other necessary components, to form a DC power supply unit.

Array Junction Box: Enclosure where PV Strings of any PV Array are electrically connected and where devices can be located.

Array Cable: Output cable of a PV array

Class II Equipment: Equipment that does not include a means for connection to an Earth Conductor, and which provides supplementary insulation in addition to the basic insulation of the equipment such that a breakdown of the basic insulation will not present a dangerous Voltage on Exposed-Conductive-Parts (also known as Double Insulated Equipment).

Connection Point (CP): The point which defines the boundary between the Owner's Electrical Installation installed at a Premises and the main cable or equipment owned by the Distribution Company.

Customer: Any person, corporate body, or company who has an agreement with a Distribution Company for the supply of electricity.

Cell: Basic PV device which can generate electricity when exposed to light such as solar radiation.

DC side: Part of a PV installation from a PV cell to the DC terminals of the PV Inverter.

Distribution Company: A company or body holding a distribution license, granted by the PUCSL.

Earthing or Earthed: A general term used to describe the connection of conductive parts of an Electrical Installation or an appliance to earth.

Electrical Installation: An Electrical Installation comprises any fixed or temporary cable, switchgear, or other electrical equipment or apparatus within a premise or other place where there is an electricity supply (including outdoor locations). Fixed or portable electrical appliances are not considered part of the Electrical Installation.

Electrical Installation Certificate: A certificate in accordance with the Electricity Wiring Regulations used by the Licensed Contractor after completion of work on an Electrical Installation and provided to the Customer or Owner of the Premises.

Low Voltage (LV): An AC voltage between 1000V between phases, or below 600V between any phase and earth, or; a DC voltage below 1500V between conductors, or below 900V between any conductor to earth.

Main Distribution Board (MDB): The Distribution Board which accepts the main incoming LV supply from the Distribution Company or Owner's transformer.

Owner: The legal owner of the Premises in which an Electrical Installation is installed.

Qualified Person: One who has skills and knowledge related to the construction and operation of the Solar PV electrical equipment and electrical installations and has received safety training to recognize and avoid the hazards involved.

CONTENTS

1. INTRODUCTION

1.1 SCOPE & PURPOSE

The scope of this guideline is to provide solar PV system designers and installers with information to ensure that a grid-connected PV system meets latest standards and best practice recommendations. This provides information for the installation of solar PV system including PV modules, inverters, and corresponding electrical system on roof of an existing structure.

The directions are provided herein shall be followed by the all the solar PV system installers in Sri Lanka.

1.1.1 APPLICABLE STANDARDS AND REGULATIONS

IEC 60364: 2017	Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – PV power supply systems Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems
IEC 61727, 2nd Ed. (2004)	Photovoltaic (PV) systems - Characteristics of the utility interface
IEC 62116, 2nd Ed. (2014-02),	Utility-interconnected photovoltaic inverters – Test procedure for islanding prevention measures
IEC 62109-1, 1st Ed. (2010-04),	Safety of power converters for use in photovoltaic power systems – Part 1: General requirements
IEC 62109-2, 1st Ed. (2011-06),	Safety of power converters for use in photovoltaic power systems – Part 2: Particular requirements for inverters

IEC 62109-3:2020	Safety of power converters for use in photovoltaic power systems - Part 3: Requirements for electronic devices in combination with photovoltaic elements.
IEC 61730-1:2016	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction.
IEC 61557	Electrical safety in low voltage distribution systems up to 1000 V AC and 1500 V DC – Equipment for testing, measuring, or monitoring of protective measures
IEC 60755: 2017	General safety requirements for residual current operated protective devices
IEC 62423:2009	Type F and type B residual current operated circuit-breakers with and without integral overcurrent protection for household and similar uses
IEC 60947	Low-voltage switchgear and control gear
IEC 62305	Protection against lightning
DIN EN 63027	DC arc detection and interruption in photovoltaic power systems
IEEE 519 (2014),	Recommended practice and requirements for harmonic control in electric power systems
IEC 61000	Electromagnetic Compatibility
BS 7671 – 18th Ed (2018)	Section 712 – Solar Photovoltaic (PV) power supply systems

IEC 61427-1:2013	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application
IEC 61427-2:2015	Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications
IEC 62619:2022	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications

1.2 SAFETY

1.2.1 INTRODUCTION

The solar PV system provider shall carefully evaluate the potential hazards and systematically devise methods to minimize the risks. The service provider shall consider both mitigating potential hazards present during and after the installation phase.

The service provider shall be knowledgeable of the that the supply from PV modules cannot be switched off. Thus, special precautions should be made to ensure that live parts are either not accessible or cannot be touched during installation, use and maintenance. The standard practise needs to be followed at all the time when designing protection system to the PV system.

PV systems include DC wiring, generally competency of electrical installers in DC systems are lower. Other important point is that the installation of PV systems presents a unique combination of hazards – due to risk of electric shock, falling and simultaneous manual handling difficulty. All these hazards are encountered as a matter of course on a building site, but rarely all at once. While roofer may be accustomed to minimizing risks of falling or injury due to manual handling problems, they may not be used to dealing with the risk of electric shock. Similarly, Electricians should be able to handle large object at heights.

The PV service provider shall thoroughly study the potential risk and prepare a detailed mitigation plan. The developed risk mitigation plan shall be strictly followed by all the personal involved in system design, installation and operation and maintenance.

It is then important to ensure that the long-term safety of the system is not compromised by a poor installation or subsequent poor maintenance. Much of this comes down to the quality of the installation and system inspection and testing.

Therefore, to ensure the safety of solar PV systems, all involved parties should ensure the following:

- Selection of the correct system components that conform to the appropriate international standards as provided in this guideline. (i.e. Modules, Inverters, cables, connectors, junction boxes, isolators etc.);
- Correct Design and Installation of the solar PV system; and
- Correct operation and maintenance of the solar PV system.

All key safety issues affecting the design and installation process must be addressed including following typical issues.

- The supply from PV modules cannot be switched off, so special precautions should be made to ensure that live parts are either not accessible or cannot be touched during installation, use and maintenance.
- PV modules are current-limiting devices, which require a non-standard approach when designing fault protection systems, as fuses are not likely to operate under short-circuit conditions.
- PV systems include DC wiring. DC wiring has few differences than AC wiring.
- The installation of PV systems presents a unique combination of hazards – due to risk of electric shock, falling and simultaneous manual handling difficulty. All of these hazards are encountered as a matter of course on a building site, but rarely all at once.

1.2.2 MAIN HAZARDS

The following is a summary of some of the main hazards that may be encountered during the construction, operation, and maintenance of a Solar PV Systems:

- PV Modules produce electricity during daylight and cannot be turned off. Therefore, it is expected that during installation work, installers will be working on live modules and a risk of direct or indirect contact with electricity will be high. Measures should be taken to inform installers of such risks and use of proper insulating materials (e.g. gloves, insulated shoes, proper harness , and etc.) to minimize the risk of electric shock.

- PV Modules are current limiting devices with the short circuit current being not much higher than the operating current which in turn may not be detected by the overcurrent protection used as such minor faults may remain undetected for a long period of time which can develop into a fire hazard.
- PV Modules installed on roofs, affected by high wind may increase the risk of flying objects. As such, the mounting structure holding the PV Modules should take into consideration such risks during the design and installation phases.
- The majority of Solar PV systems would be installed at premises rooftops, the risk of falling becomes very high, as such measures should be taken to reduce such risks by using the appropriate scaffolding, suitable access provisions, safe lifting procedures, and suitable labelling and warning signs.
- Electric shock from PV Modules, cables, combiner boxes, and termination points. As indicated above Modules will produce electricity when subjected to sunlight, as such measures should be taken to eliminate the risk of exposed/damaged wires, cables, and connections.

1.2.3 STRUCTURAL SAFETY

To ensure safety, there are measures and steps that need to be taken or considered when installing a solar PV system onto a new or an existing building. The design of the structure must take into consideration the loading of the solar PV system installation, just like any other equipment mounted onto a building structure, all relevant building codes, and safety codes.

For existing buildings, a professional competent Structural Engineer or Consultant may be required for calculation of the structural loading. Check if the roof is able to withstand the loading of the solar PV system before commencement of the installation works. The design of a solar PV system mounting structure should allow for thermal expansion and contraction (e.g., thermal breaks and gaps). This is particularly important for large mounting structures.

The design and installation of a solar PV system should take into consideration the rainwater drainage from the roof top, this is to avoid creation of any pools of water on the roof during heavy rain fall. Also, the location of rain fall drainage should be considered in relation to the location of the modules to avoid overloading the drainage system during heavy rain fall.

Safe access to the mounting structure should be considered during the design of a solar PV system, this is particularly important for future access for maintenance, testing, troubleshooting and emergency purposes.

The solar PV system should be designed and installed taking into consideration the maximum expected wind speed encountered in the area.

Emergency Shutdown procedure should be clearly displayed.

1.2.4 FIRE PREVENTION CONSIDERATION

Most likely cause of a fire on a grid connected solar PV system is the development of a DC arc because of poor connections (module connectors, combiner boxes, Batteries) creating high resistance junctions or faulty DC disconnector switches or damaged cables resulting in a short circuit.

The design and installation of solar PV system should aim to minimize the risk of the system being the source of fire and minimize the risk to occupants or emergency services. The following are some measures for consideration:

- Specifying and installing the proper DC overcurrent protection.
- Properly securing DC cables in containments.
- Use of enclosures made from insulating materials with self-extinguishing properties.
- Ensuring the correct ratings are used for the DC cables, combiner boxes and switch disconnectors etc.
- Ensuring all connections are tightened and torqued in accordance with manufacturer specifications.
- Ensuring that used inverters have a built in DC arc detection capabilities. Otherwise, standalone detectors should be considered for PV systems operating 80V or greater.
- Ensuring that double insulated cables are used throughout the DC circuit to greatly minimize the risk of parallel arcs between conductors, or via an earth path.
- Minimize as much as possible the length of the DC cables from the inverters and avoid installing DC cables in walls or hidden in the building structure.

2. SOLAR PV DC SYSTEM DESIGN

2.1 DESIGN OF DC SYSTEM

DC system of a solar PV system shall include DC cables, isolators / disconnectors, surge protective devices switches, connectors etc. All DC component ratings of the system shall be derived from the maximum voltage and current of the relevant part of the PV array adjusted in accordance with the safety factors. The system voltage/currents of the series/parallel connected modules making up the array and maximum output of the individual modules shall be taken into account when calculating the component ratings.

The rating of all DC components of Solar PV system must be rated in consideration of the highest DC voltage and highest DC current the circuit will be subject to. This will include but not limited to all cables, switch disconnectors, and connectors used on the DC side of the Solar PV System.

An assessment of the highest DC voltage and highest DC current need to be made based on the PV Modules Open-Circuit-Voltage (Voc) and Short-Circuit-Current (Isc). This information is typically provided by the PV Module manufacturer under Standard Test Conditions (STC).

Standard test conditions (STC) refer to the following testing conditions:

Irradiance of 1000 W/m²;
25°C cell temperature; and
Air mass of 1.5

The temperature rise due to solar gain must be calculated for the relevant equipment (typically 10°C above ambient temperature), and this will have an impact on the output voltage and output current of PV Modules. Therefore, it is critical perform system design calculation taking into consideration the minimum/maximum temperatures that can occur where the system is being installed. Typically, module manufactures provide the required technical data sheets that will include temperature coefficients for V_{oc} and I_{sc} respectively and may include other information on the operation of modules during the first week of exposure to sunlight these must be taken into consideration

The DC components shall be rated for following minimum voltage and current when operating with PV modules. For other PV module types, the ratings shall be calculated case by case basis.

Voltage	**1.15 V_{oc}**
Current	**1.25 I_{sc}**

In a general system, PV array and string voltages exceed 120 VDC . Such DC voltage will exceed levels that are considered to reduce the risk to a minimum. Thus, double insulation shall be applied as the method of shock protection. In this instance the use of suitably rated cables, connectors, and enclosures along with controlled installation techniques becomes fundamentally important to providing this protective measure as defined in BS 7671- Section 412. Similarly, double insulation of the DC circuit greatly minimizes the risk of creating accidental shock current paths and the risk of fire.

Therefore, Double insulation (insulation comprising both basic & supplementary insulation) or reinforced insulation, appropriate barriers and separation of parts must be applied to all parts of the DC circuit to facilitate a level of protection equivalent to the protective measure “double or reinforced insulation” as defined in BS 7671- Section 412.

2.2 DC CABLE SYSTEM

To minimize the risk of faults, PV DC cable runs should be kept as short as practicable. “PV cables” which are specially designed for solar PV applications are readily available and those cable shall be used for the installations. The mentioned cable type is designed to withstand the extremes of the environmental, voltage and current conditions, under which they may be expected to operate. This will include heating effects of both the current and solar gain, especially where installed in close proximity to the PV modules.

The installer shall use following type of cables or cable installations for DC system.

- Single conductor “double insulated” cable which complies with IEC 62930:2017,
- Single conductor cable suitably mechanically protected conduit/trunking. Alternatively, a single core Steel Wire Armoured cable shall be considered as a mechanically robust solution,
- Multi core Steel Wire Armoured cables. Typically, only suitable for main DC cable between a PV array junction box and inverter position, due to termination difficulties.

PV array cables exclusively rely on double or reinforced insulation as their means of shock protection. Therefore, DC cables shall not be buried in walls or otherwise hidden in the building structure as mechanical damage would be very difficult to detect and may lead to increase instances of shock and fire risk.

In a situation where this cannot be avoided conductors should be suitably protected from mechanical damage, suitable methods may include the use of metallic trunking or conduit or the use of steel wire armoured cable in accordance with BS 7671.

Where multiple PV sub-arrays and or string conductors enter a junction box they should be grouped or identified in pairs so that positive (RED)and negative (BLACK) conductors of the same circuit may easily be clearly distinguished from other pairs.

Cable that are suitable for permanent outdoor use shall either have a black sheath in accordance with SLS 1282 or be suitable protected and tested by the manufacturer against exposure to UV.

2.3 DC CABLE SIZING

Cables should be sized in accordance with BS 7671. Guidance on a method of cable sizing including any de-rating factor requiring to be applied and typical current carrying capacities for common cable types are provided in Appendix 4 of BS 7671.

Cables should be designed such that the overall voltage drop, at array maximum operating power (STC), between the array and the inverter is <3%.

The DC system main components are shown in Figure 2-1.

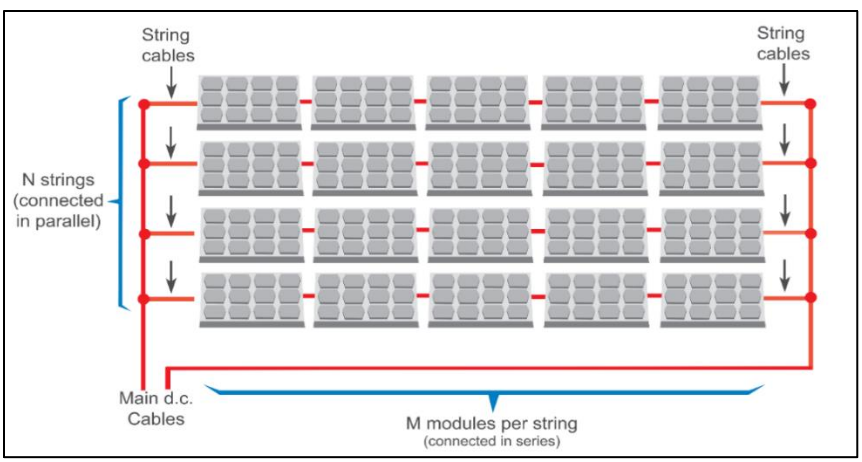


Figure2-1: DC system main components (For a system of N parallel connected strings, with each formed of M series connected modules)

In a PV array formed from a number of strings, fault conditions can give rise to fault currents flowing though parts of the DC system. Two key problems need addressing overloaded string cables and excessive module reverse currents, both of which can present a considerable fire risk. Up to two strings systems where it is determined that string fuses are not required for module protection (maximum reverse currents less than module reverse current rating), a common approach is to ensure that the string cables are suitably rated such that they may safely carry the maximum possible fault current.

2.3.1 SIZING OF MAIN DC CABLE

The main DC cables must be rated as a minimum as follows:

Voltage > V_{oc}(STC) x M x 1.15

Current > I_{sc}(STC) x N x 1.25

The cable Current Carrying Capacity (Iz) must be calculated according to the requirements of BS 7671to include cable de-rating factors to take into account factors such as cable installation method and grouping etc.

2.3.2 SIZING OF STRING CABLES

The string cables must be rated as a minimum as follows:

Voltage> V_{oc}(STC) x M x 1.15

Current> I_{sc}(STC) x (N-1) x 1.25

The cable Current Carrying Capacity (Iz) must be calculated according to the requirements of BS 7671 to include cable de-rating factors to take into account factors such as cable installation method solar gains and grouping etc.

Where a system includes string fuses, the cable size may be reduced, but in all cases the I_z after de-rating factors have been applied must exceed the string fuse rating and must exceed the I_{sc}(STC) x 1.25.

2.4 LOCATIONS OF PROTECTIVE DEVICES

Protection devices shall be placed as follows:

For string overcurrent protection –where the string cables join the sub-array or array cables in the string combiner box (refer to Figure 2-2 and 2-6).

For sub-array overcurrent protection –where the sub-array cables join the array cables in the array combiner box (refer to Figure 2-5).

For array overcurrent protection –where the array cables join the application circuit or the inverter (refer to Figure 2-2 and 2-5).

In LV arrays, overcurrent protective devices, where required, shall be placed in all current carrying conductors not directly connected to earth.

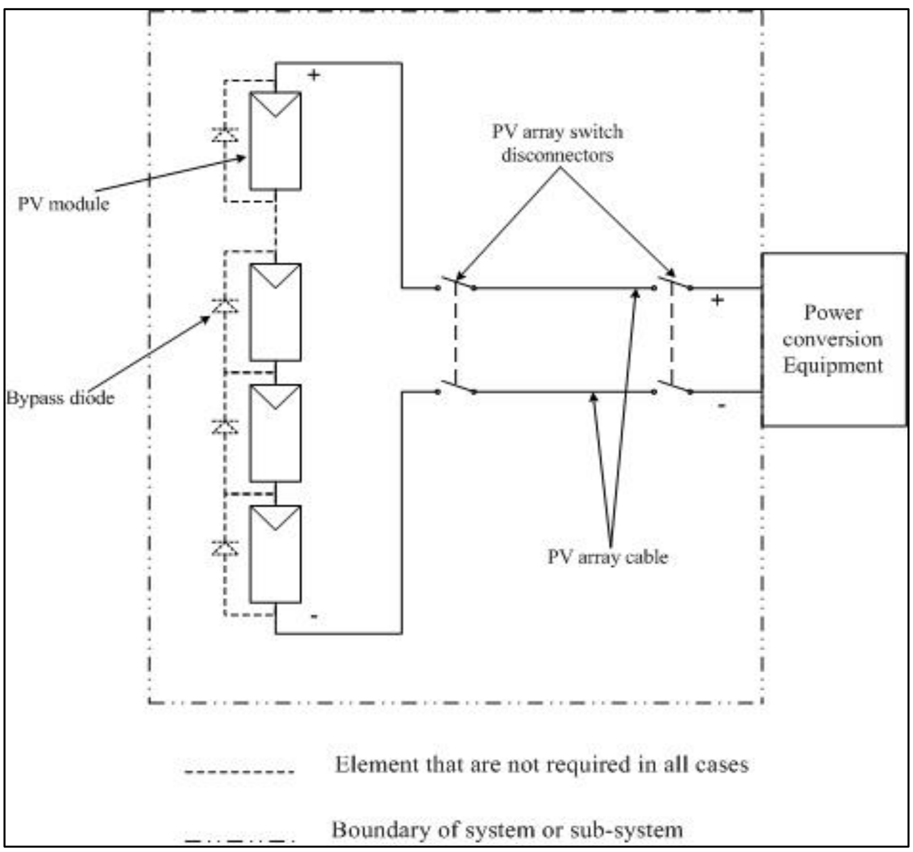


Figure 2-2: PV array diagram – single string case

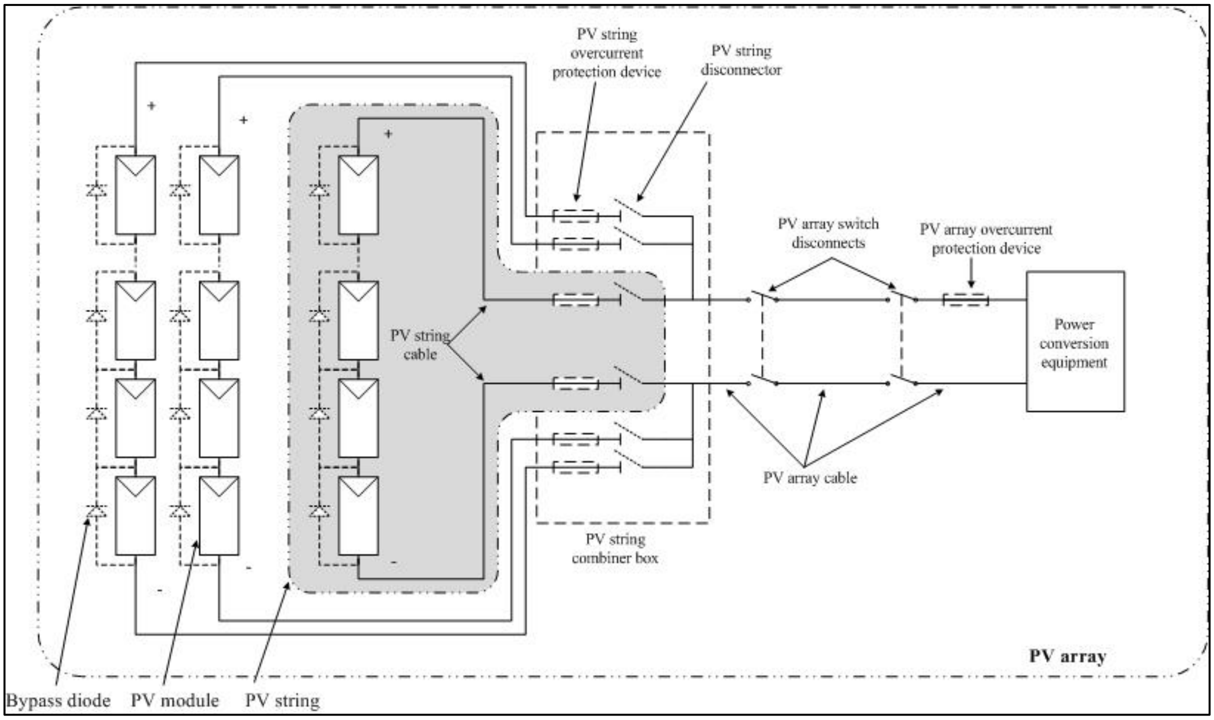


Figure 2-3: PV array diagram – multiple parallel string case

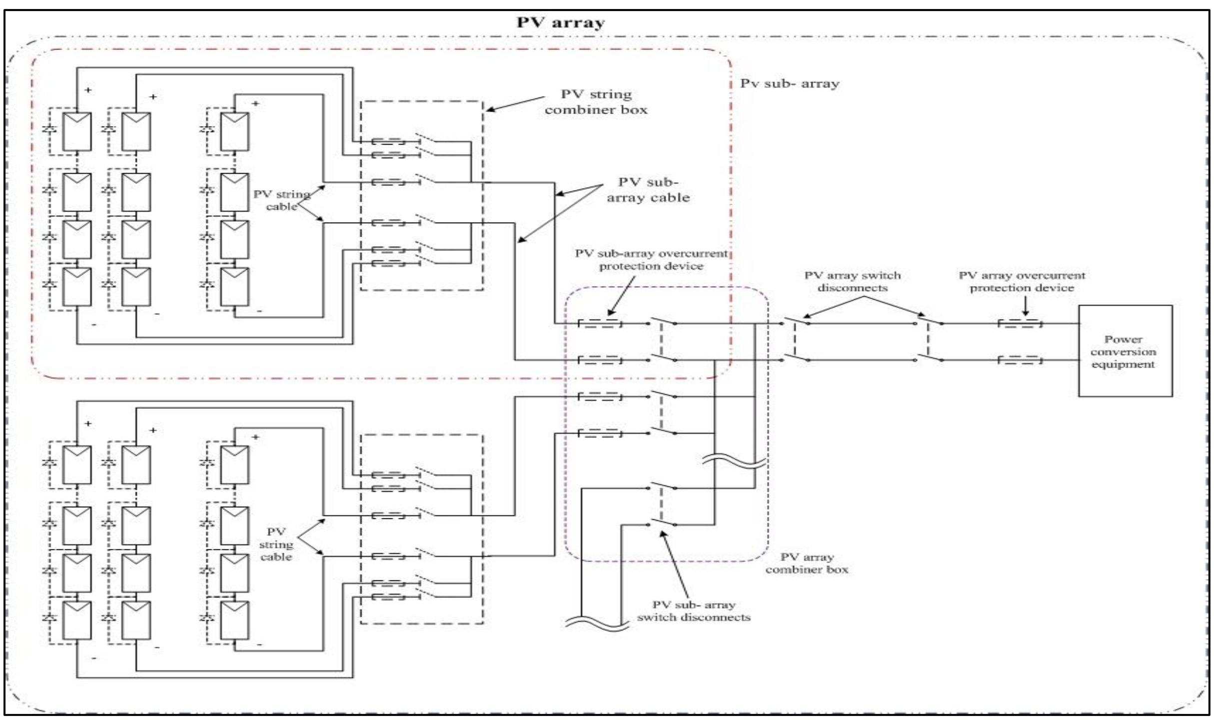


Figure 2-4: PV array diagram – multiple parallel string case with array divided into sub-arrays

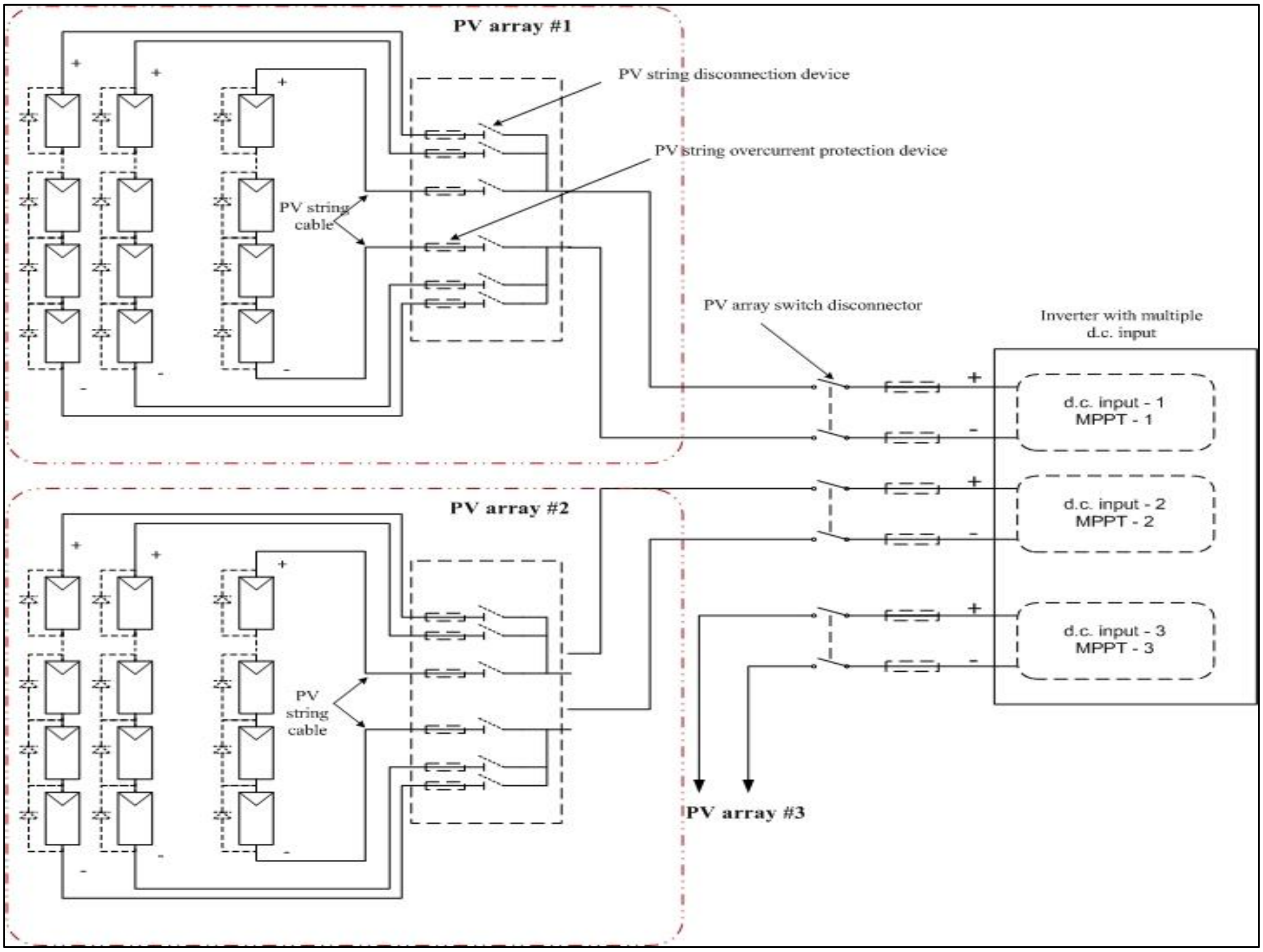


Figure 2-5: PV array using a inverter with multiple MPPT DC inputs

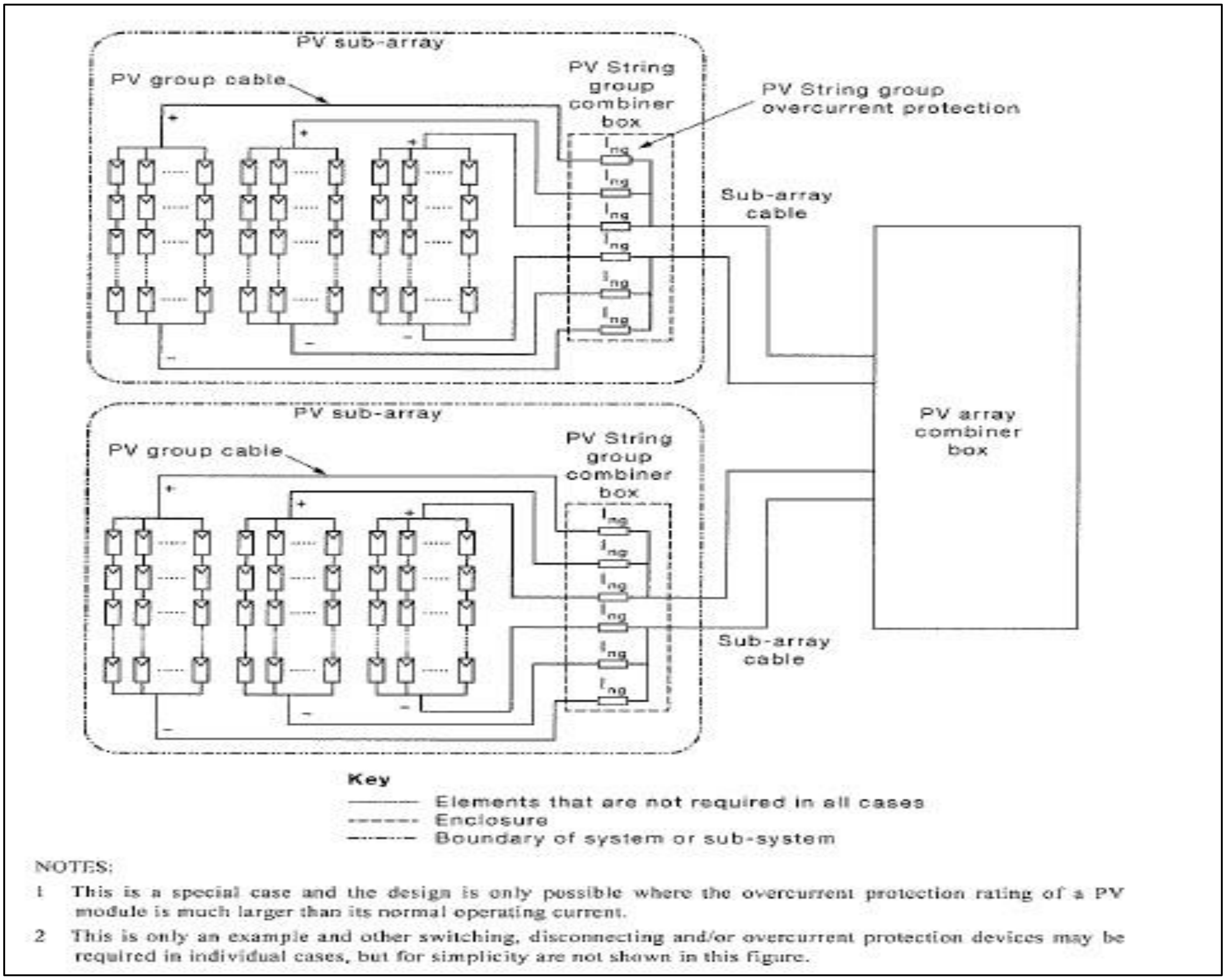


Figure 2-6: PV array diagram where strings are grouped under one overcurrent protection device per group

2.5 DC PLUG AND SOCKET CONNECTORS

PV specific plug and socket connectors are commonly fitted to module cables by the manufacturer. Such connectors provide a secure, durable, and effective electrical contact. They also simplify and increase the safety of installation works.

DC Plugs and socket connectors shall comply with the requirements of BS EN 50521. Different brands may only be interconnected where a test report has been provided confirming the compatibility of the two types to the requirements of BS EN 50521.

Connectors readily accessible to ordinary persons shall be of the locking type, requiring a tool or two separate actions to separate and shall have sign attached that reads: 'Do not disconnect DC plugs and sockets under load'. Cable connectors shall not be used as the means for DC switching or isolation under load since arcing can cause permanent damage to some connectors. Cable junctions shall either be by an approved plug and socket connector or contained within a DC Junction Box. Other types of inline cable junctions shall not be employed.

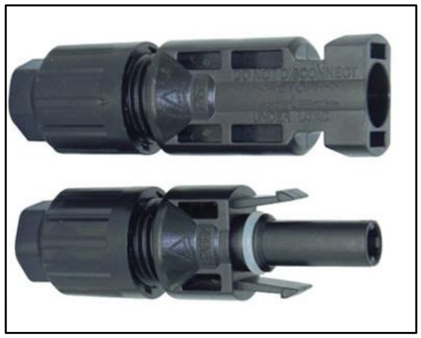


Figure 2 7: DC Connector

2.6 STRING JUNCTION BOXES

If there is more than two string in the system, a DC junction box (sometimes called a combiner box) shall be used as the point at which they are connected in parallel. The box may also contain string fuses and test points.

It is to be noted that PV system cannot be turned off. The terminals will always remain live during daylight hours the installer shall ensure that anyone opening an enclosure is fully aware of this fact. The short-circuit protection afforded by the cable installation throughout the rest of the DC circuit shall be maintained in the construction and makeup of the DC junction box.

In order to provide the short circuit protection, enclosure of the junction box shall be fabricated from non-conductive material. Positive and negative bus bars and terminals shall be adequately separated and segregated within the enclosure. Segregation shall be achieved by a suitably sized insulating plate. Further, the Cable and terminal layout shall be designed such that short-circuits during installation and subsequent maintenance are extremely unlikely. When mounting junction boxes, it is recommended to mount them so that the access to the junction box is made on the side of the junction box and not on a side facing up.

3 PV INSTALLATION PROTECTION

3.1 DC OVERCURRENT PROTECTION

The short circuit current of a module is little more than the operating current, so in a single string system, a circuit fuse would simply not detect or operate to clear a short circuit fault.

In systems with multiple strings some fault scenarios can result in the current from several adjacent strings flowing through a single string and the prospective fault current may be such that overcurrent protective devices are required.

Therefore, PV system shall be protected from overcurrent from the PV modules by means of fuses at the string combiner box. Since PV modules are connected in series in a string, the short-circuit current of the string is equal to the short circuit current of the PV module. Both the positive terminal and negative terminal of a string shall be protected with a fuse. The fuses shall be rated for minimum 1,000 VDC.

For a system of N parallel connected strings, the maximum module reverse current (I_R) to be experienced under fault conditions is:

$$\mathbf{I_R = (N - 1) \times I_{sc}}$$

Hence, overcurrent protection is required where $(N - 1) \times I_{sc}$ is greater than the module maximum series fuse rating.

In order to provide full protection of all cables and modules, string fuses are required in both the positive and negative legs of the string cabling.

The following requirements apply where the PV array provides the only source of fault current, such as in a typical grid connected system with no battery.

For a system of N parallel connected strings, with each formed of M series connected modules:

- String fuses must be provided for all arrays where: $(N - 1) \times I_{sc} >$ module maximum series fuse rating,
- Where fitted, fuses must be installed in both positive and negative string cables for all strings,
- The string fuse must be of a type gPV, according to IEC60269-6
- The string fuse must be rated for operation at V_{oc}(STC) x M x 1.15
- The string fuse must be selected with an operating current I_n such that:

$$\mathbf{I_n > 1.5 \times I_{sc}(STC)}$$

$$\mathbf{I_n \leq 2.4 \times I_{sc}(STC)}$$

$$\mathbf{I_n \leq \text{Maximum series fuse value}}$$

3.2. DC ISOLATION AND SWITCHING

Isolation is a function intended to cut off for reasons of safety the supply from all, or a discrete section, of the installation by separating the installation or section from every source of electrical energy (from BS 7671). Isolation shall be provided in both positive and negative cables and all isolation measures shall be readily accessible.

The following table describes the requirements for both isolation and switching in the DC side of the PV array circuit:

DC Circuit	**Switching**	**Isolation**
String	Not required	Readily accessible means of string isolation
Sub array	Optional	Readily accessible means of sub array isolation
Array	Readily accessible load break switch disconnector on DC side of inverter	

Note: An additional DC switch or isolating device may be used for systems with long DC cable runs (typically at the point of cable entry into the building), so as to provide a means of isolating the cable for safety reasons or maintenance works

A switch disconnector installed on the DC side shall have the following features:

- The switch must isolate all live conductors (typically double pole to isolate PV array positive and negative conductors),
- The switch must be rated for DC operation at the system voltage maximum as calculated,
- The switch must be rated for DC operation at the system current maximum as calculated,

- The switch must be labelled as '***PV array DC isolator***', with the ON and OFF positions clearly marked. Switch enclosures should also be labelled with ***'Danger - contains live parts during daylight'***. All labels must be clear, easily visible, constructed and affixed to last and remain legible for as long as the enclosure.
- Shall comply with the requirements of IEC 60947 (series).
- Have a utilization category at least DC-21B of IEC 60947-3.
- Voltage ratings of both poles together of the isolator/switch disconnector shall be at least the PV array maximum voltage.
- All equipment exposed to the outdoor environment shall be of an appropriate IP rating in accordance with SLS 963 and shall be UV resistant.

The roof-mounted isolator shall be mounted such that the switch is in a sideways position (see Figures 3-1).

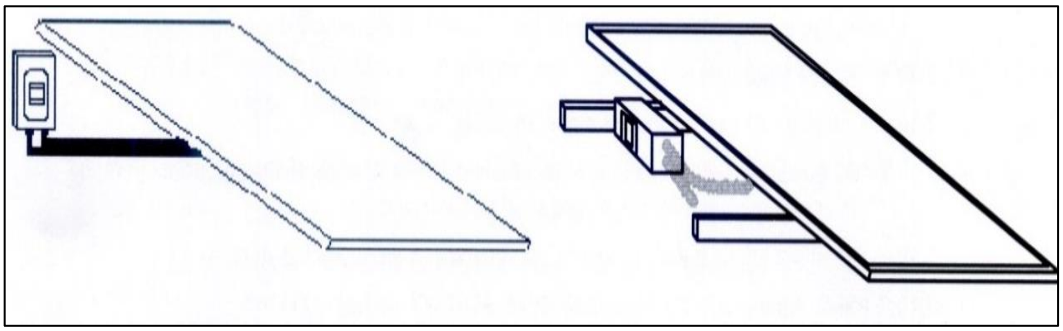


Figure 3-1: Recommended Roof Mounted Isolator mounting arrangement

NOTE

Ensure that the switch does not shade the array.

NOTE: A circuit breaker may also be used provided it meets all the above requirements.

Array Switch Disconnector shall be a readily accessible load break switch disconnector on DC side of the inverter. This array switch disconnector shall be a physically separated switch-disconnector mounted adjacent to the inverter.

For inverters with an integrated switch-disconnector: a separate switch-disconnector is not required at the inverter if the switch-disconnector is mechanically interlocked.

3.3 AC SYSTEM

Each solar PV system connected to the Distribution network must be designed, installed, and tested to be compatible with distribution network performance requirements with respect to frequency, voltage, control capabilities, protection coordination requirements, and phase voltage unbalance.

The PV system inverter(s) should be installed on a dedicated final circuit to the requirements of BS 7671 in which:

- No current-using equipment is connected to the circuit, and
- No provision is made for the connection of current-using equipment, and
- No socket-outlets are permitted.

Note: For the purposes of this guide a data logger is not considered current-using equipment and can be connected into the same final circuit as the PV system.

An inverter must not be connected by means of a plug with contacts which may be live when exposed and AC cables are to be specified and installed in accordance with BS 7671.

The AC cable connecting the inverter(s) to the consumer unit should be sized to minimize voltage drop less than 3%. (*1% drop or less is recommended. However, in larger installations this may not be practicable or economic due to the very large size of cable resulting. In this case the designer should minimize voltage drop as far as possible, but not exceeding maximum voltage drop of 3%*).

Note: The recommendation for a 1% voltage drop is due to two reasons:

when generating, the voltage at the inverter terminals is higher than the voltage at the supplier's cut out, during periods of high-power output this voltage drop must be kept to a minimum in order to prevent the inverter nuisance tripping on overvoltage.
the requirement ensures losses from the PV system are minimized.

3.3.1 RESIDUAL CURRENT(RCD) PROTECTION

Where an electrical installation includes a PV power supply system that cannot prevent DC fault currents from entering the AC side of the installation, and where an RCD is needed to satisfy the general requirements of the electrical installation in accordance with BS 7671, then the **selected RCD should be a Type B RCCB as defined in IEC 62423**.

If the inverter manufacturer has provided written statement claiming that a Type B RCCB as defined in IEC 62423 is integrated into the inverter, shall be exempted from having additional Type B RCCB in the installation.

If the inverter manufacturer has provided written confirmation that no smooth DC residual current can occur because of the use of his PV inverter, a Type A RCCB may also be sufficient.

3.3.2 AC ISOLATION AND SWITCHING

Isolation and Switching of the AC side of the installation shall also comply with the requirements of BS 7671. This is to include the provision of an isolator adjacent to the inverter to disconnect the inverter from the source of supply (AC).

The PV system shall be connected to an isolation switch that fulfils the following conditions:

- Isolate phase(s) and neutral conductors
- Be securable in the OFF position
- Located in an accessible location

This switch shall clearly show the ON and OFF positions and be labelled as '***PV system – Main AC isolator***'

3.3.3 AC CABLE PROTECTION

Protection for the cable from the inverter(s) must be provided at the distribution board. This protective measure shall be specified and installed in accordance with the requirements of BS 7671.

In very many cases the current limiting nature of the PV array and inverter(s) omits the requirements for overload protection and therefore the designer only need to consider fault current protection.

The protection afforded at the origin of the circuit (the distribution board) in accordance with BS 7671, means there is no requirement for additional overcurrent protection to be installed at the inverter end of the AC installation.

3.4 EARTHING, EQUIPOTENTIAL BONDING, SURGE AND LIGHTNING PROTECTION

3.4.1 SYSTEM EARTHING AND EQUIPOTENTIAL BONDING

Earthing shall be required for all exposed conductive parts PV module frames, array structures, power, communication and protective equipment and enclosures for protection. Earthing systems of AC side and DC side shall be connected at the earth electrode. It is to be noted that DC system is considered to be energized even when the system is disconnected from the grid side.

All the frames in a raw shall be connected to one continuous earthing conductor when earthing PV modules. Bare copper conductor or copper tape shall be used for this purpose as shown in Figure 3-2. Use of small pieces of jumper cables to connect frames of consecutive modules shall be avoided. A separate continuous earthing conductor shall be laid to connect the individual earth cables of each raw and that shall be connected to grounding conductor. Further, star-type washers shall be recommended when bolting the lugs of earthing cable with the module frame that can scratch the anodization of the module frame to contact its aluminium.

Figure 3-2: Earthing of PV Modules

The earthing conductor shall be rated considering safety factor of 25 % and albedo factor of 25 % to protect from any unaccounted external reflection onto the PV modules increasing its current. Thus, the conductor shall be rated for 1.56 times the maximum short circuit current of the PV array. However, bare copper earthing conductor size shall not be less than $6mm^2$. Resistance between any point of the PV system and earth should be as smaller as possible and it is recommended to have a value less than 10Ω at any time.

Equipotential bonding is a protective measure used where the connection of Extraneous-Conductive-Parts within Premises using designated conductors such that potential touch voltages are kept to safe value during the passage of earth fault current.

The first safeguard to put in place is a medium that ensures equipotential bonding between all the exposed conductive parts of a PV installation. The aim is to bond all grounded conductors and metal parts and so create equal potential at all points in the installed system is shown in Figure 3-3.

A connection to earth of any of the current-carrying DC conductors is not recommended. However, earthing of one of the live conductors of the DC side is permitted if there is at least simple separation between the AC and the DC side.

Where a functional earth is required, it is preferable that where possible this be done through high impedance (rather than directly). The PV installation designer of must confirm whether the inverter is suitable for earthing of a DC conductor. Transformer less inverters will not be suitable, and an earthed conductor may interfere with the inverter's built-in DC insulation monitoring. Hence, if an earthed DC conductor is required, it should be done in accordance with guidance from the inverter manufacturer.

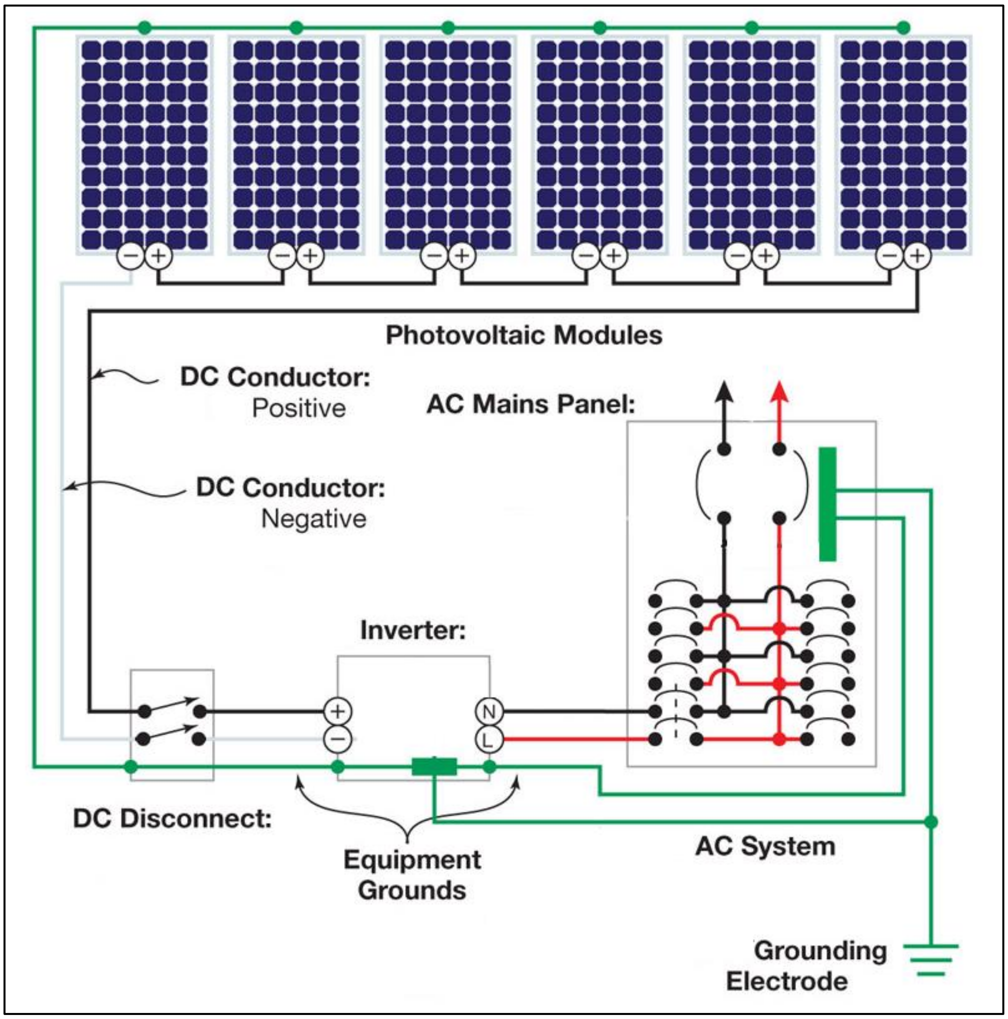


Figure 3-3: Earthing of Solar PV System

Connection components of Lighting Protection and Earthing

Connection components, or often simply called clamps, are used as lightning protection components to connect conductors (down conductor, air-termination conductor, earth entry) to each other or to an installation. Depending on the type of clamp and clamp material, a lot of different clamp combinations are possible. Below Table shows materials which may be **combined without causing contact corrosion.**

	Steel	**Aluminium**	**Copper**	**Stainless Steel**	**Titanium**	**Tin**
Steel	Yes	Yes	**NO**	Yes	Yes	Yes
Aluminium	Yes	Yes	**NO**	Yes	Yes	Yes
Copper	**NO**	**NO**	Yes	Yes	**NO**	Yes
Stainless Steel	Yes	Yes	Yes	Yes	Yes	Yes
Titanium	Yes	Yes	**NO**	Yes	Yes	Yes
Tin	Yes	Yes	Yes	Yes	Yes	Yes

3.4.2 SURGE PROTECTION

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

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

Like all outdoor structures, PV installations are exposed to the risk of lightning which varies from region to region. Preventive and arrest systems and devices should be in place. SPDs are particularly important to protect sensitive electrical equipment like AC/DC Inverter, monitoring devices and PV modules, but also other sensitive equipment powered by the 230 VAC electrical distribution network.

The requirement of surge protection is evaluated by the risk assessment as per the IEC 62305-2.

DC side of the inverter shall be protected with surge protective device (SPD) of IEC 61643-1 Type 2 “Low Voltage Surge Protective Devices”.

The following method of simplified risk assessment, which is based on the evaluation of the critical length L_{crit} and its comparison with L, the cumulative length of the DC lines shall be used to select DC surge protective devices.

Type of Installation	Individual residential premises	Terrestrial production plant	Service/Industrial/ Agricultural/ Buildings
L_{crit} (in m)	$115/N_g$	$200/N_g$	$450/N_g$
$L \geq L_{crit}$	Surge prospective device(s) compulsory on DC side		
$L < L_{crit}$	Surge prospective device(s) not compulsory on DC side		

Where,

- N_g is lightning density (number of strikes/km²/year)
- L is the sum of the sum of distances between the inverter(s) and the junction box(es), considering that the lengths of cable located in the same conduit are counted only once, and the sum of distances between the junction box and the connection points of the photovoltaic modules forming the string, taking into account that the lengths of cable located in the same conduit are counted only once.
- N_g can be estimated as $N_g=0.04\ T_d^{1.12}$
- Where T_d is the number of thunder days per year (Isokerunic Level) which is given in Annex A.

If the inverter is equipped with an in-built DC surge arrestor, additional SPD may not be required for the inverter DC end. The SPD shall be rated to a minimum continuous operating voltage (U_{cpv}) of 1.25 times the open-circuit voltage, V_{oc} (STC) of the PV string, maximum protective voltage (U_p) of 1.5 kV and a minimum flash current of I_{imp}=50 kA for Class I (Class B) and I_n=40 kA for Class II (Class C). The SPD shall protect both the positive and negative terminals of the system as shown in Figure 3-4.

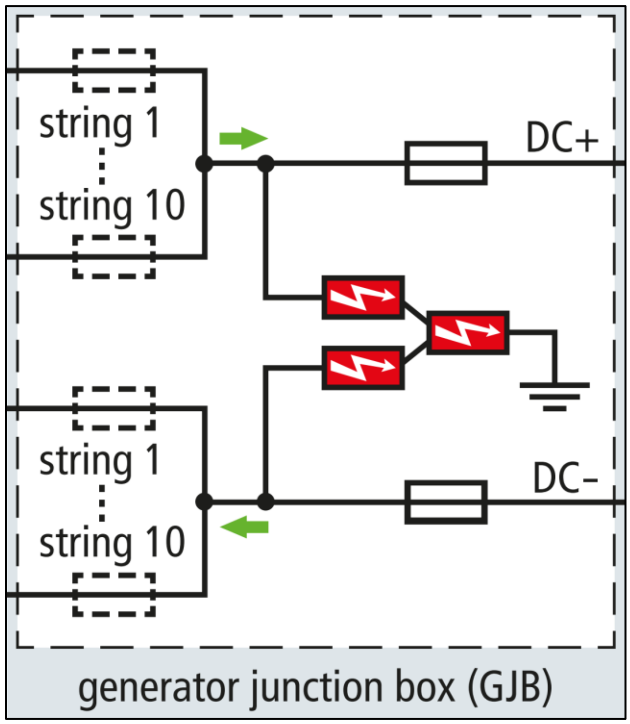


Figure 3 4: : DC SPD connection

The number and location of SPDs on the DC side depend on the length of the cables between the solar modules and inverter. The SPD should be installed in the vicinity of the inverter if the length is less than 10 metres. If it is greater than 10 metres, a second SDP is necessary and should be located in the box close to the solar modules, the first one is located in the inverter area.

It is recommended that a specialist entity in lightning protection be consulted to determine the appropriateness of installing a surge protection and Lightning Protection system. Simplified selection guide is given below;

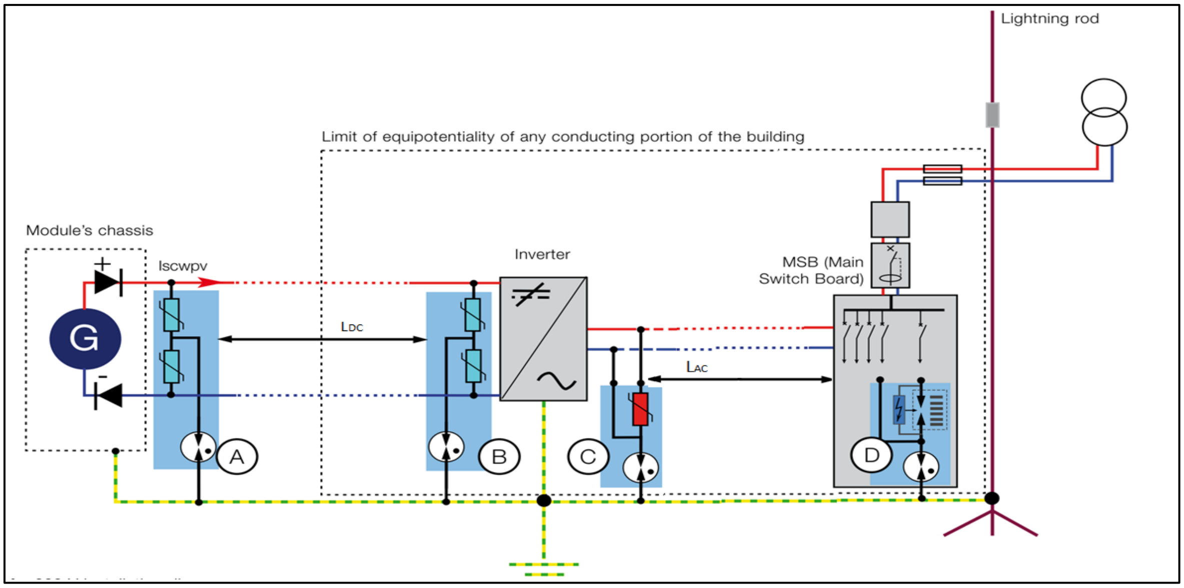


Figure 3 5: Recommended SPD locations of PV installation

	Location	PV Module or Array A		Inverter DC Side B	Inverter AC Side C		Main DB D
	Criteria	**L_{DC} <10 m and U_p< 0.8 U_w**	**L_{DC} >10 m**		**L_{AC} <10 m**	**L_{AC} >10 m**	
External LPS	No	No need	Class II	Class II	No need	Class II	Class I or Class II
External LPS	Yes –Isolated/ with sufficient separation	No need	Class II	Class II	No need	Class II	Class I
External LPS	Yes –Non Isolated/ with sufficient separation	Class I	Class I	Class I	Class I, **except inverter is located inside the main DB**	Class I	Class I

For more details, please refer IEC 61643-32: Surge protective devices connected to the DC side of photovoltaic installations – Selection and application principles.

Connections of a SPD to the loads should be as short as possible in order to reduce the value of the voltage protection level (installed U_p) on the terminals of the protected equipment. The total length of SPD connections to the network and the earth terminal block should not exceed 50 cm as shown in Figure 3-6 .

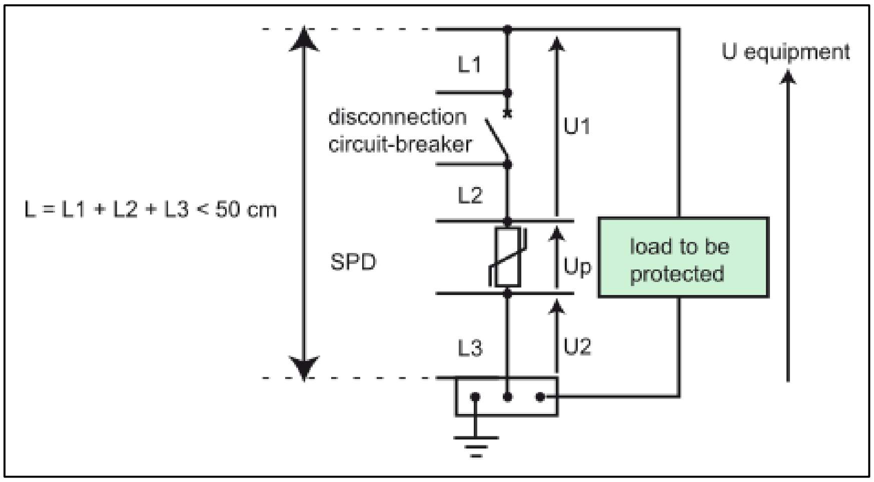


Figure 3 6: Connections of a SPD L < 50 cm

3.4.3 DIRECT LIGHTNING PROTECTION SYSTEM

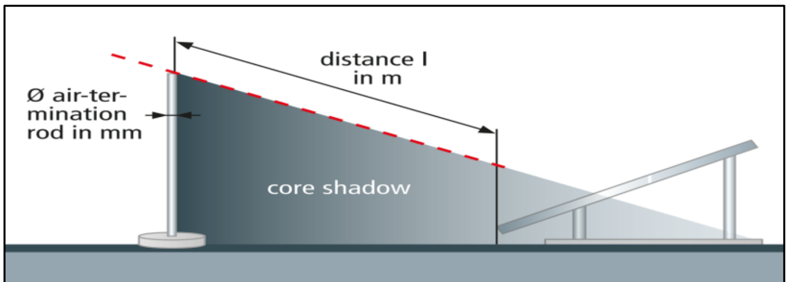
PV systems shall be equipped with a dedicated lightning protection system as per IEC 62305, which includes air terminal, down conductor, and earth termination. For this, the existing lightning protection of a building shall be used, provided it adequately protects the installation area and is assured of functioning throughout the life of the PV system.

A certain separation distance s must be maintained between a lightning protection system and a PV system as per IEC 62305-3 (EN 62305-3). It defines the distance required to avoid uncontrolled flashover to adjacent metal parts resulting from a lightning strike to the external lightning protection system.

To prevent direct lightning strikes to the electrical systems of a PV power plant, these systems must be located in the protected volume of air-termination systems. Positioning of air terminal system shall be done as per IEC 62305-3 (EN 62305-3).

The distance between the solar generator and the external lightning protection system is absolutely essential to prevent excessive shading. Diffuse shadows cast do not significantly affect the PV system and the yield. However, in case of core shadows, a dark clearly outlined shadow is cast on the surface behind an object, changing the current flowing through the PV modules. For this reason, solar cells and the associated bypass diodes must not be influenced by core shadows. This can be achieved by maintaining a sufficient distance.

The recommended distance between the module and the air-termination rod required to prevent core shadows is shown in below figure.



Ø air-termination rod	x factor	= distance l
10 mm	108	1.08 m
16 mm	108	1.76 m

Figure 3-7: Distance between the module and the air-termination rod required to prevent core shadows

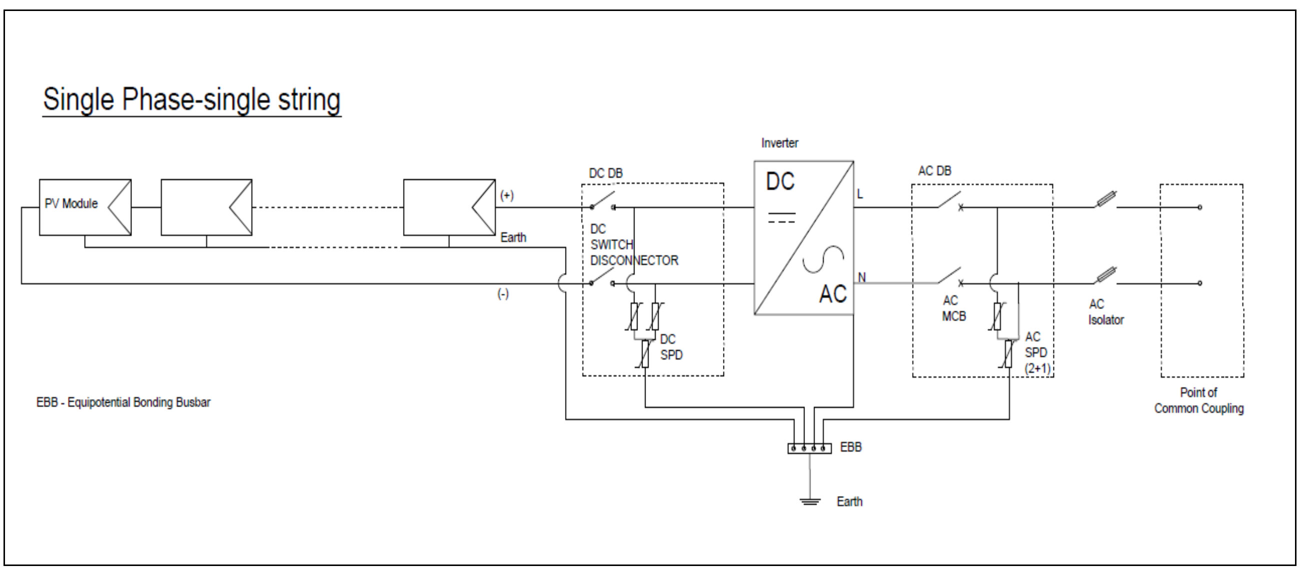


Figure 3-8: Connection diagram for Single Phase-Single String

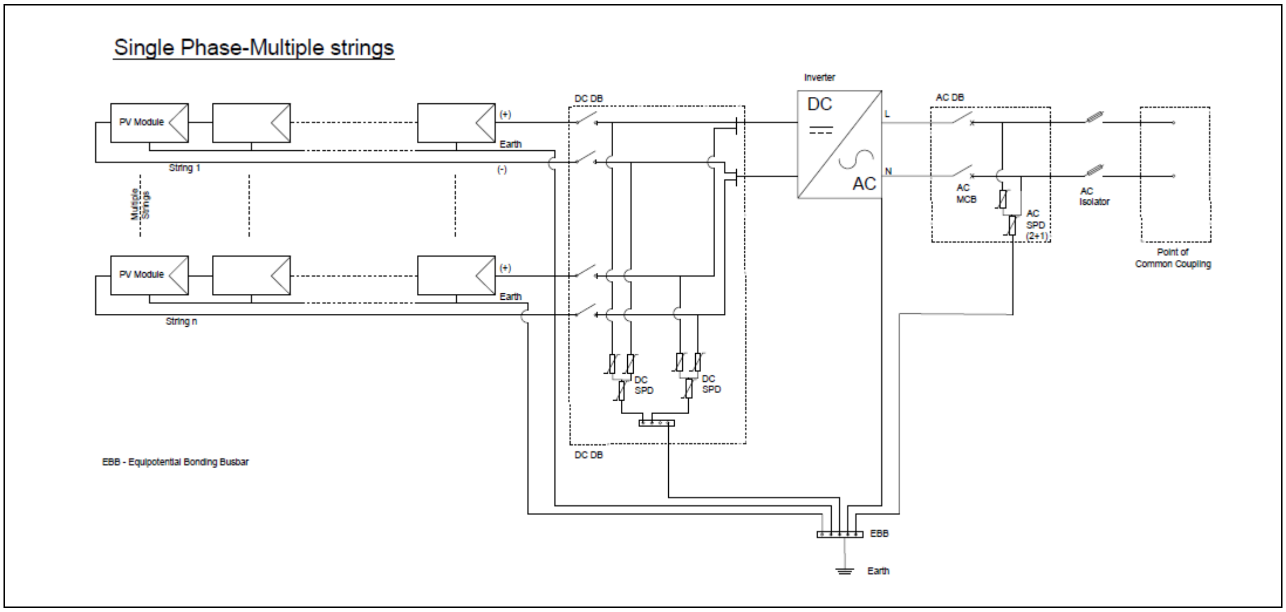


Figure 3-9: Connection diagram for Single Phase-Multi String

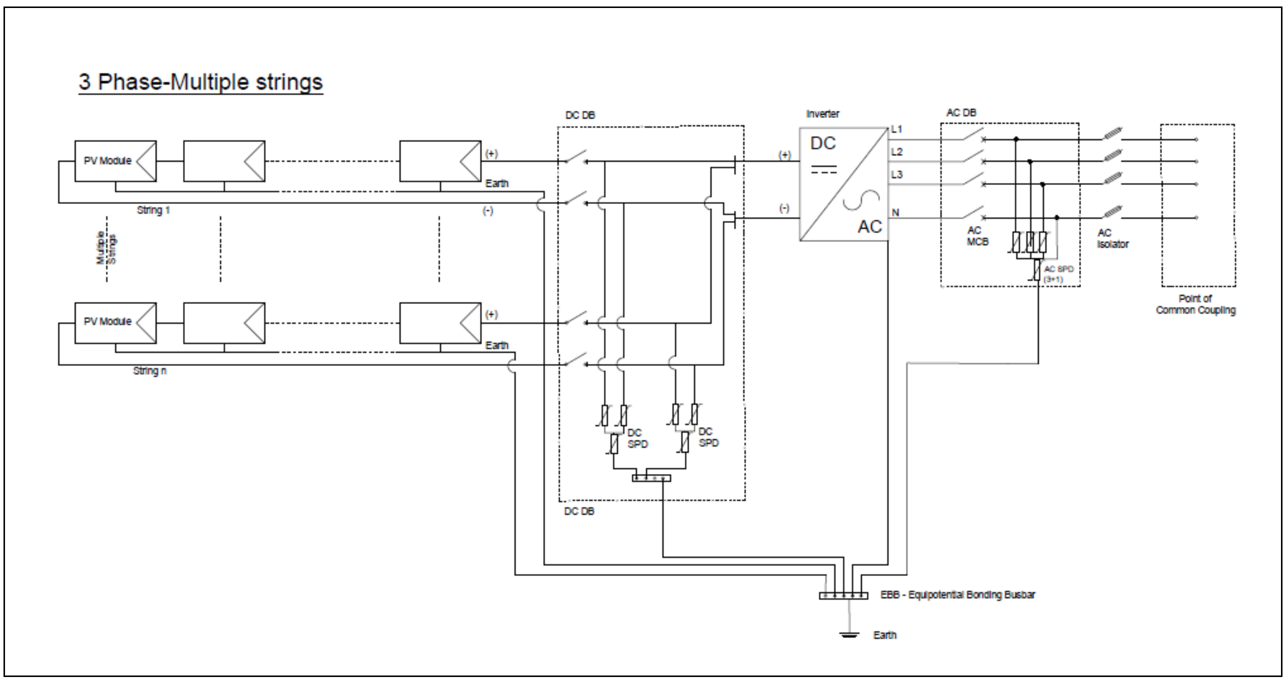


Figure 3-10: Connection diagram for Three Phase-Multi String

4. MOUNTING OF MODULES

4.1 PV SPECIFIC HAZARDS

When compiling a method statement and risk assessment for the installation of a PV system, there are a number of PV specific hazards that shall be addressed. These will be in addition to standard considerations such as PPE (Personal Protective Equipment), working at height, manual handling, handling glass and the application of the construction design and management regulations.

PV modules produce electricity when exposed to daylight and individual modules cannot be switched off. Therefore, unlike most other electrical installation work, the installation of a PV system typically involves working on a live system.

As current limiting devices, PV module string circuits cannot rely on fuse protection for automatic disconnection of supply under fault conditions, as the short-circuit current is little more than the operating current. Once established, a fault may remain a hazard, perhaps undetected, for a considerable time. Undetected, fault currents can also develop into a fire hazard. Without fuse protection to clear such faults, protection from this fire hazard can be achieved only by both a good DC system design and a careful installation.

Good wiring design and installation practice will serve to protect both the system installers and any persons subsequently coming into contact with the system from an electric shock hazard (operator, owner, cleaner, service engineers, etc.)

PV presents a unique combination of hazards – due to risk of shock, falling, and simultaneous manual handling difficulty. All of these hazards are encountered as a matter of course on a building site, but rarely all at once. While roofers may be accustomed to minimising risks of falling or injury due to manual handling problems, they may not be used to dealing with the risk of electric shock. Similarly, electricians would be familiar with electric shock hazards but will not be used to handling large objects at heights.

4.2 ROOF REQUIREMENTS

The installer shall specify the weight of the PV system per unit area. The weight shall include the weight of the PV modules and mounting structures. In a general case the weight of the system would not exceed 30 kg/m^3.

PV systems shall not adversely affect the weather tightness of the structure to which they are fitted. The system should be designed and installed to ensure this is maintained for the life of the system. For integrated systems, the weather tightness of the PV system should be the same or better than the roof or cladding systems they are replacing and should not adversely affect the weather tightness of the surrounding covering.

For the roof PV systems, the array fixing brackets should not affect the weather tightness of the roof they are fitted to. For example, systems attached to tile roofs should be designed and installed such that the fixing brackets do not displace the tiles and cause gaps more than naturally occurs between the tiles. Fixing methods must not subject roof coverings to imposed loads which may degrade their primary purpose of maintaining weather-tightness.

4.3 MOUNTING STRUCTURE

It is necessary to ensure that the suitability of the roof support structure and whether it can withstand additional loads (array frames structure, PV modules and wind load).

Galvanized iron (GI) or aluminium or similar low-corrosion or no corrosion materials shall be the material used for module mounting structures. The installer shall guarantee the rust free and safe lifetime of 10 years for the structure.

The mounting structure shall consist of two parallel rails anchored to the roof structure. The mounting system shall have minimum of four end clamps and two mid clamps per four PV modules. The suggested mounting structure is depicted in Figure 4.1.

Solar modules shall be attached to the array structure either using the mounting holes provided by the manufacturer or via clamps.

When using clamps solar module manufacturer's installation instructions shall be followed.

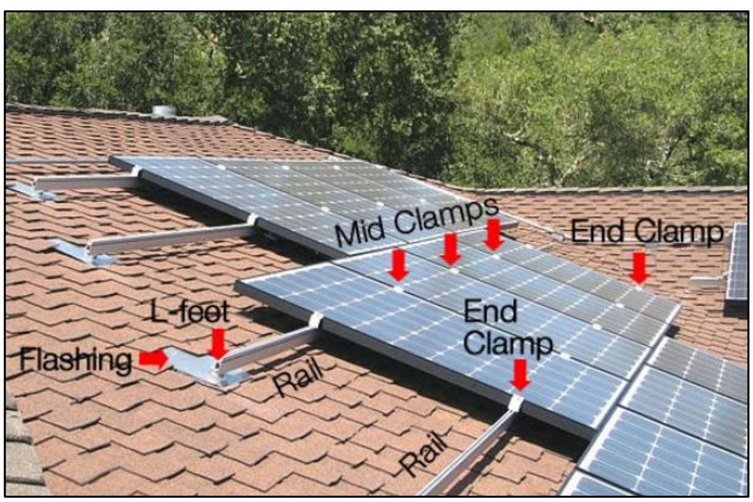


Figure 4 1: Mounting arrangement of PV modules

Any roof penetrations shall be suitably sealed and waterproof for the expected life of the system. (Refer to roofing manufacturer's guidelines.) If this is not possible then this shall be detailed in the system's Maintenance schedule.

It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris (Refer to roofing manufacturers guidelines). If possums and other fauna are a problem in the vicinity of the installation, then consideration shall be given to how to prevent them gaining access under the array.

4.3.1 INSTALLATION OF BUILDING INTEGRATED PV (BIPV) MODULES

The installation of modules that are being used as building material e.g., tiles, roofing materials, building walls, sun-screens shall only be installed by a person qualified to install that particular type of building element.

4.4 INCLINATION OF PV MODULES

The optimal angle of inclination of a flat plate solar PV module is approximately the latitude of the location of installation facing south. Minimum tilt of 10° is recommended to take advantage of self-cleaning during rain events.

The mounting structure shall be anchored to the roof structure. Mounting structures shall not the anchored to the roofing material such as asbestos or GI sheet.

The PV array shall be mounted above and parallel to the roof surface with a standoff of 100 mm for cooling purposes. All the roof penetrations shall be weather sealed.

4.5 DC CIRCUIT INSTALLATION

All persons working on the live DC cabling of a Photovoltaic (PV) system shall be experienced / trained in working with such systems and fully acquainted with the voltages present on that system in particular.

All DC wiring should, if possible, completed prior to installing a PV array. This will allow effective electrical isolation of the DC system (via the DC switch-disconnector and PV module cable connectors) while the array is installed; and effective electrical isolation of the PV array while the inverter is installed.

Typically, this would require an installation sequence of:

- DC switch-disconnector and DC junction box(es)

- String/array positive and negative cables - from the DC disconnect/junction box to either end of the PV string/array;
- PV array main cables from DC switch to inverter.

This shall be carried out in such a way that it should never be necessary for an installer to work in any enclosure or situation featuring simultaneously accessible live PV string positive and negative parts.

Where it is not possible to pre-install a DC isolator (e.g. a new-build project where shall be put temporarily into an isolation box and suitably labelled.

4.6 SAFE WORKING PRACTICES

Always the presence of voltage of parts shall be tested before touching any part of the system.

An electric shock may be experienced from a capacitive discharge – a charge may build up in the PV system due to its distributed capacitance to ground. Such effects are more prevalent in certain types of modules and systems, namely amorphous (thin film) modules with metal frames or steel backing.

In such circumstances, appropriate and safe live working practices shall be adopted. An example of where such hazards may be encountered is the case where an installer is seated on earthed metal roof whilst wiring a large PV array. In such circumstances the installer could touch the PV cabling and might get an electric shock to earth. The electric shock voltage will increase with the number of series connected modules. The use of insulated tools and gloves, together with insulating matting to stand or sit on, can mitigate this hazard.

An electric shock may also be experienced due to the PV array developing a ground (earth) leakage path. Good wiring practice, double insulation, and modules of double or reinforced insulation (class II) construction can significantly reduce this problem, but in any installed systems, leakage paths may still occur. Any person working on a PV system must be aware of this and take the necessary precautions.

5. HYBRID INVERTER AND BATTERY SYSTEM INSTALLATION.

Two types of hybrid inverters are authorised to connect to the grid. Grid connected (Type 1) and Grid interactive (Type 2). The electrical circuit diagrams are given below.

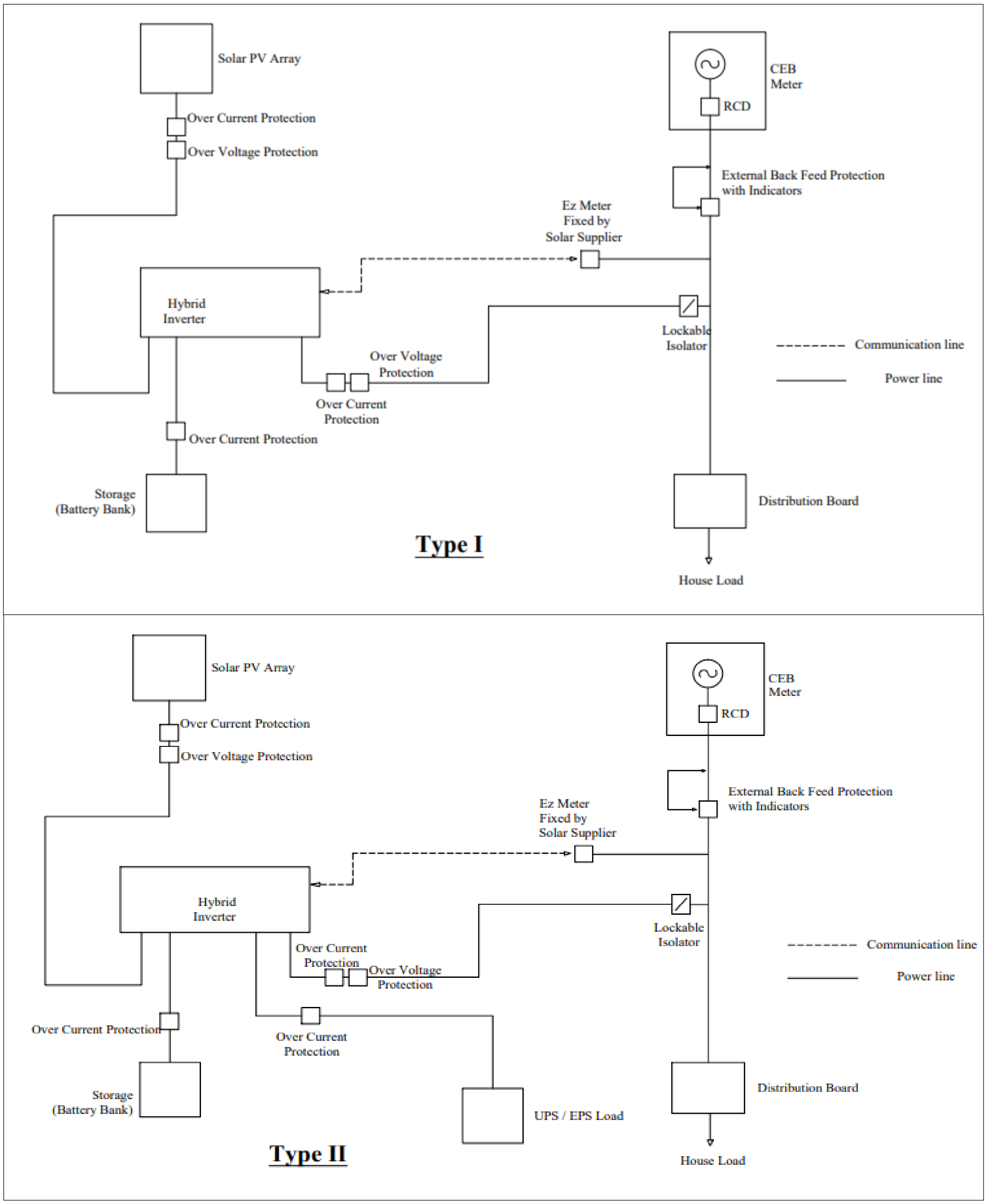


Figure 5.1: External Backup feed protection: Type 1 and 2

5.1 SAFETY FOR UTILITY SYSTEM

A Producer shall be solely responsible for providing adequate protection for its Generating Facility and interconnection facilities. The Producer's protective functions shall not affect the operation of other protective functions utilized in CEB's distribution system.

The generating facility shall cease to energize CEB distribution system for faults on CEB distribution system circuit to which it is connected. (IEEE1547 – 4.2.1). The generating facility shall cease to energize CEB distribution circuit prior to reclosure by CEB distribution system equipment. (IEEE 1547-4.2.2)7.2.6 The generating facility shall be automatically disconnected from the CEB distribution network within half a second (0.5 second) when the CEB supply is intentionally or automatically switched off. Testing of back feed protection in section 2.5.

5.2 HYBRID INVERTER AND BATTERY SYSTEM

The inverters used for interconnection shall be only those which complied with SLS 1680:2020. The ESS system should comply with IEC 61427-1 and IEC 61427-2. Batteries should be installed in outdoor with weatherproof enclosure. Enclosed system give protection to the batteries from dust and water. Also, it gives protection for direct touch of DC voltage. Also, it should allow access to electrical wiring and special consideration to flooding/splashing of the enclosure. It recommended to be out of direct sunlight and not be adjacent to heat or ignition sources. When installation ESS it should consider on ventilation of the system as it will help to reduce over heating of batteries.

The general hazards of batteries are related with electrical wiring and Chemicals. They can cause fire or explosion hazards. Customer should advise not to smoke around their battery storage system and service provider should ensure for not leaking of system vents gases. The minor upkeep and maintenance are important to keep battery running efficiently and safely. Service provider should ensure that the batteries have the correct safety and warning signs for the battery type and acknowledge the customer about the correct procedures in case of emergency.

Service provider should give warranty period for ESS and maintenance instructions as per manufacturer guidelines. And alternations should be done by qualified technical person. ESS should be capable of being reached quickly and conveniently 24 hours a day by CEB personnel for inspection, testing or reading, without obstacles.

5.3 BATTERY TYPES.

Lithium Batteries

The modern technology for solar power applications is the Lithium Iron Phosphate (LiFePO4) and Lithium-ion (Li-ion) technologies. They have the highest depth of discharge (about 80%). Also, they have low self-discharging rates (life time around 5 to 10 years), and have a high energy density. Lithium Batteries have superior efficiency (95-99% efficiency) and has very low internal resistance. They have more charging and discharging cycles than lead-acid batteries.

Lead Acid

Lead-acid batteries can be classified into two main groups: The two types are Flooded & Sealed. The first type is the flooded or ventilated lead-acid batteries (VLA). They have a small, ventilated access to their internal structure with removable plugs that allows verifying the specific gravity and the state of charge of the battery. The main disadvantage of this battery type is that they emit gases that are generated by the internal electrochemical reactions.

Sealed or Vented

These batteries are partially sealed to avoid the evaporation of electrolyte. VRLA batteries have a pressure-sensitive valve that automatically controls the emission of gas. The valves open to release these gases if there is high-pressure inside the battery.

Gel Cell

These batteries have a silicon compound. When added to the liquid electrolyte, the substance acquires a gel-type continuously.

Absorbed Glass Mat (AGM)

The electrolyte is absorbed by a fiberglass that works as a sponge that immobilizes the sulfuric acid in AGM sealed batteries. They offer the same benefits as gel cell batteries. The AGM batteries withstand higher charging voltages than gel types. These batteries have a lower internal resistance due to their structure, which allow to deliver or absorb higher electrical currents during charging and discharging processes when compared to gel-type batteries. Because of the lower internal resistance, it helps to increases efficiency and discharge voltages.

Following table shows the comparison of different type of batteries.

Types of Solar Batteries				
	LITHIUM	**FLOODER LEAD ACID**	**SEALED AGM**	**SEALED GEL**
Upfront Cost	High	Low	Moderate	High
Cost per kWh cycle	Lowest	Low	Low to moderate	Moderate
Expected Lifespan	10+ years	3-5 years	4-5 years	5-6 years
Max recommended DoD	80%	50%	50%	50%
Regular Maintainance	None	Watering, equalizing, cleaning	None	None
Best Applications	All renewable energy systems	Full time residences with committed, hands-on owners willing to do regular maintainance and replacement	Part-time residences with intermittent use	Part-time residences without many high-surge loads
Worst Applications	Projects on a tight budget	Part-time residences with intermittent use	Systems requiring deep discharges	Systems requiring high amperage charging and discharging

5.4. BATTERY SIZING

Deep cycle battery is the recommended battery type for using in solar PV system. It is specifically designed for to be discharged to low energy level and rapid recharged or cycle charged and discharged day after day for years. The battery should be large enough to store sufficient energy to run the appliances at night and cloudy days. To find out the size of battery, following formula can be used.

Battery capacity = (Total Energy need * Days of Autonomy)/ (Voltage of the system * Depth of Discharge (DoD))

6. LABELLING

The PV system shall be labelled conforming to IEC 62446. Labelling of PV equipment is required owing to the high DC voltages as well non-familiarity of technicians and laymen with the PV system.

If the length of a DC cable is higher than 20m, a clear label shall be placed in each 5m intervals. The DC junction, if applicable box shall be clearly labelled with - ‘PV array DC junction box, Danger contains live parts during daylight’.

All circuits, protective devices, switches, and terminals shall be suitably labelled. A warning label shall be carried with all DC junction boxes indicating that the active parts inside the boxes are fed from a PV array. Main AC isolating switch shall be clearly labelled, and a dual supply warning label shall be fitted at point of interconnection. A single line wiring diagram, Inverter protection settings, installer details and emergency shutdown procedures shall be displayed on site.

6.1 DUAL SUPPLY LABEL

Dual supply labelling should be provided at the service termination, meter position and all points of isolation between the PV system and supplier terminals to indicate the presence of on-site generation and indicating the position of the main AC switch disconnector.

6.2 CIRCUIT DIAGRAM

the point of interconnection, the following information shall be displayed in the form of circuit diagram.

Circuit diagram showing the relationship between the inverter equipment and supply.
A summary of the protection settings incorporated within the equipment.
A contact telephone number for the supplier/installer/maintainer of the equipment.

It is also good practice for shutdown and start-up procedures to be detailed on this diagram.

7. TESTING AND COMMISSIONING

7.1 INSPECTION AND TESTING

The overall inspection activity of the rooftop PV system shall be divided into visual inspection and testing. Both the visual inspection and testing shall be carried out according to BS7671/ IEC 62446, 1st Ed. (2009-05). The check list for design and installation is given in Annex B and test procedure for certain tests are illustrated in the Annex C.

Visual inspection shall be carried out by the installer to verify the installation. A qualified personal shall visually verify the interconnection, workmanship, warranty compliance, ratings of equipment and labelling. The inspected shall further verify the safety of the system via over-current/voltage protection devices, residual current devices, surge and lightning protection, disconnectors, earthing and other contingencies.

Testing shall be carried out for performance and safety. Performance testing of PV modules, strings, inverter, and overall system output shall be carried out by a qualified personal. Continuity test, short circuit and open circuit tests, polarity test, earthing impedance, insulation test and anti- islanding test shall be carried out.

The inverter shall be certified by an accredited test laboratory for compliance of the grid code and the harmonics performance. Listed or previously certified inverter models are exempt from this test when appropriate documentation is available. Previous certificates of inverter models are valid only for 18 months.

Performance testing of the PV system shall be carried out at the site as per Annex C, when there are no valid certificates, customer or owner has to provide valid test certificates for inverter from an accredited test laboratory for compliance of the grid code and the harmonics performance.

The inspection and testing of AC circuits is comprehensively covered within BS 7671 and supporting technical guides, specifically Guidance Note 3.

Inspection and testing documentation for the AC side shall comprise 3 documents:

- Electrical installation certificate,
- Schedule of items inspected
- Schedule of test results

The inspection and testing of the DC side of the PV system shall be in accordance with the requirements of BS 7671 and also IEC 62446 Grid connected photovoltaic systems — Minimum requirements for system documentation, commissioning tests and inspection.

The verification sequence contained within BS EN 62446 includes.

- Inspection schedule
- Continuity test of protective earthing and/or equipotential bonding conductors (if fitted)
- Polarity test
- String open circuit voltage test
- String short circuit current test
- Functional tests
- Insulation resistance of the DC and ac circuits
- Measurement of earth electrode resistance

These tests shall be recorded on a PV array test report as per the guidance given in Annex D, which shall be appended to the AC documents listed above. Full details of the inspection schedule and guidance on test procedures is contained with BS EN 62446.

Testing for PV systems larger than 10 kW shall be carried by an independent third-party inspector/qualified engineer.

7.2 COMMISSIONING

Users of Solar PV systems should ensure that upon completion of the design, installation and commissioning of the system that adequate and proper documentation and handover is provided by the Solar PV System Integrator.

It is usually recognised that such goal can be achieved when the harmonic current emissions of a solar PV generating plant do not exceed the limits specified in the Grid Code. Harmonic distortion measurement shall be done as per the procedure in Annex C.

7.3 ROUTINE INSPECTION

The purpose of routine inspection is to ensure that the integrity of the installed Solar PV System remains intact throughout the intended life of the system.

Solar PV Systems typically requires little maintenance, and the majority of maintenance issues can be discovered by doing a proper visual inspection and understating the information provided by the remote monitoring and data logging systems provided by the majority of Inverter manufactures.

It is recommended that Solar PV Systems be inspected and maintained on regular basis, typically once a year. Refer to Annex C for recommended routine maintenance and remedial actions.

Refer the Guidance Note 1: Verification, Inspection and Testing for more information.

8. WARRANTY AND DOCUMENTATION

8.1 PERFORMANCE WARRANTY

The performance warranty of a PV module shall consist of two parts. The performance warranty shall commit less than 10 % performance degradation in power output during the first 10 years and less than 20% performance degradation during the subsequent 15 years. The typical workmanship warranty on a PV module shall be five years.

Warranty for the inverter shall be minimum 10 years and the installer shall provide overall system warranty of 10 years subjected to the conditions stipulated in the sales agreement between the installer and the consumer.

8.2 SYSTEM PERFORMANCE

The installer shall specify the expected annual energy generation from the system based on the irradiation data of the system. The installer shall use PVSyst or equivalent software for this purpose. The energy generation prediction report shall be included in the handing over document. The installer shall specify the performance of each subsystem.

8.2.1 GENERATION GUARANTEE

The installer shall provide a generation guarantee for the 90% of the annual expected energy generation specified in section 7.2 subjected to the terms and conditions specified by the installer.

8.3 PV SYSTEM MONITORING

The installer shall provide a performance monitoring system for the overall solar PV system. The monitoring system shall include the instantaneous power output from the inverter, cumulative energy generation, string voltages and any other parameters chosen by the manufacturer. The monitoring system shall be either proprietary software issued by the inverter manufacturer or a third-party software. The installer may provide remote monitoring system via internet or personal area network as well.

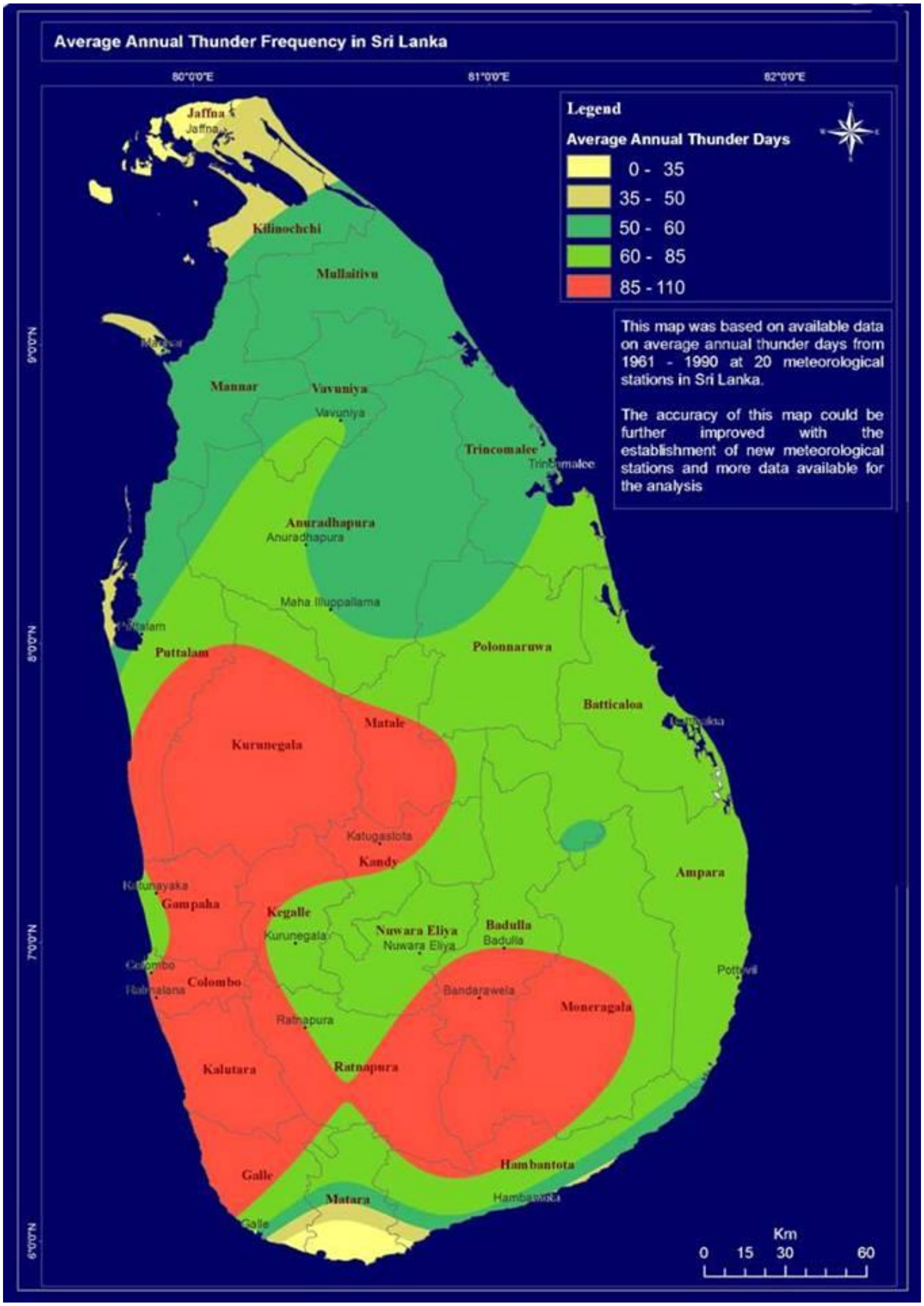
8.4 TECHNICAL DOCUMENTATION

The installer shall provide a complete hand over document to the client including following minimum documents and drawings as specified in IEC 62446, (2016+ABD1-2018 CSV).

- Contact information of various stakeholders such as PV system owner, project developer, EPC contractor, designer, lending agency, etc.
- Datasheets of key equipment and the overall PV system
- IEC certifications of the PV modules and inverters
- Warranty documents of key equipment by Original Equipment Manufacturer.
- Design document of the module mounting structure.

- Warranty document of the entire rooftop PV system as a whole by the installer.
- Generation estimation report based on realistic weather conditions.
- Operation and maintenance manual of the PV system.
- Test results and commissioning certificate.
- Purchase bills and contracting documents.
- Electrical Single Line Diagram
- Equipment layout diagram
- Wire and earthing layout diagram.

ANNEX A: AVERAGE ANNUAL THUNDER FREQUENCY IN SRI LANKA.



ANNEX B: DESIGN AND INSTALLATION CHECK LIST

No	Design & Installation Check list	Check
1	Select a location (e.g. Empty space on roof top)	
2	Check the premises electricity demand and determine the appropriate size of the Solar PV System.	
	Assess the installation site for space requirements, and access for maintenance.	
4	Select PV Module Type and rating Mounting method.	
5	Select inverter to match PV array Number of inverters needed Inverter type and rating Location of inverters (accessible for inspection and maintenance).	
6	Simulate the proposed system with PVSyst or equivalent and finalize the system design	
7	Select the most appropriate mounting system (mechanical structure) for the Solar PV system. Ensure there are fixing and mounting points available.	
8	Assess the proposed mounting structure: Additional load introduced by the Solar PV system on the roof must be checked. Additional wind load must be checked. Roof waterproofing must not be compromised during installation.	

9	Ensure solar system access: Ensure location to be mounted will get maximum exposure to sunlight (aim for South); Ensure location if away from any obstruction and shaded areas. Ensure adequate space is provided to perform routine module cleaning.	
10	Ensure all PV modules connected to the same inverter face the same direction or use multiple Maximum power point tracking (MPPT) tracking inverters.	
11	Ensure PV modules are mounted at the optimal tilt angle depending on installation conditions (typically a tilt angle of between 7° to 12° degrees is recommended).	
12	Ensure sufficient ventilation space is allocated behind the PV array for cooling purposes.	
13	Ensure: Cabling used meet sufficient current-carrying capacity and are suitably rated for usage in the environment. DC cables are single-core and double-insulated. Cable insulation on outdoor cables must withstand high temperature and UV exposure for an estimated period of more than 20 years. [Note: PVC and XLPE cables are inadequate on the DC side and must not be exposed to the weather elements.]	
14	Determine if a Lightning Protection System is needed. Consult a lightning specialist.	
15	Ensure that the installation is in full compliance with the requirements of the latest edition of the Electricity Wiring Regulations (i.e. General principles, Protection, Isolation and switching, Labelling, inspection and testing.	

16	During installation: PV system should be installed by qualified /experienced installers Safety rules must be observed Installer must wear safety protection equipment PPE; and Only proper certified safety equipment can be used e.g. scaffolding, stepladders, etc.	
17	Cables must be properly connected, secured, and routed.	
18	Ensure continuity and insulation tests are done.	
19	Ensure batteries are installed in safe location without loose connections.	
20	Completion of the required documentation, inspection and testing as outlined in Annex F	
21	Ensure the design meets local utility interconnection and approval requirements.	

Documents Check List (based on the requirements of BS EN 62446):

No.	Documentations	☑ satisfactory ☒ not satisfactory ☐ not applicable ⊗ not provided
1	**System data**	
	Project Reference Number	
	Rated system power (kW DC or KVA AC)	
	PV modules and inverters – manufacture, model and quantity	
	Batteries- Manufacture/ Ratings/ model and quantity	
	Installation date	

	Commissioning date	
	Customer name	
	Site address	
2	**System designer information**	
	Company name	
	Contact person name	
	Company address, telephone number, postal address, and e-mail address	
3	**System installer information**	
	Company name	
	Contact person name	
	Company address, telephone number, postal address, and e-mail address	
4	**Wiring Diagram**	
	Module types	
	Total number of modules	
	Number of strings	
	Modules per string	
	String cable specifications – size and type	
	String over-current protective device specifications – type and voltage/current ratings	
	Blocking diode type	
	Array main cable specifications – size and type	

	Array junction box locations	
	DC isolator type, location and rating (voltage/current)	
	Array over-current protective device – type, location and voltage/current ratings	
	Details of earthing and bonding conductors – size and connection point, including details of array frame equipotential bonding cable where fitted	
	Details of connections to an existing lightning protection system	
	Details of any surge protection devices installed (both AC and DC) including location, type and rating	
	AC isolator, type and rating	
	AC overcurrent protective device location, type and rating	
	Residual current device locations, type and rating	
	Battery location, type and rating	
5	**Datasheets**	
	Modules datasheet	
	Inverter's datasheet	
	Battery's Data sheet	
6	**Mechanical design information**	
	Mounting system datasheet	
7	**Operation and maintenance information**	
	Procedures for verifying correct system operation	
	A checklist of what to do in case of a system failure	

	Emergency shutdown/isolation procedure	
	Maintenance and cleaning recommendation	
	Considerations for any future building works related to the PV array	
	Warranty documentation for PV modules and Inverters,batteries including the starting date of the warranty and period of warranty	
	Documentation on any applicable workmanship or weather-tightness warranties	
8	**Test results and commissioning date**	
	Copies of all test and commissioning data	

ANNEX C: INSPECTION AND TESTING PROCEDURE

Tests without interconnection:

The following tests shall be performed.

Insulation of LV connections dc and ac:

Test to be performed by applying a test voltage of maximum 1000 Vdc for 1 minute between live conductors and earth (structures). Limit value for acceptance of insulation resistance: 1 MΩ. Disconnect surge arresters prior to the test.

String Insulation

Test to be performed on each string with the poles (+) and (-) short-circuited and earth connected (other strings are open) by applying a test voltage of maximum 1000 Vdc for 1 minute. Disconnect surge arresters prior to the test.

Note: Testing string insulation to earth can be dangerous if not carried out properly and carefully. Particularly, connection and disconnection of (+) and (-) poles has to be performed by using a suitable DC switch-disconnector. alternatively, the test can be done in the dark or by covering the front of the PV modules.

Table C1 – Minimum values of insulation resistance

System Voltage ($V_{oc\ stc} \times 1.25$) V	Test Voltage V	Minimum Insulation resistance MΩ
< 120	250	0.5
120 - 500	500	1
>500	1 000	1
< 120	250	0.5
120 - 500	500	1

>500	1 000	1

Measurements on PV strings:

Note: Measuring string current I_{SC} can be dangerous if not carried out properly and carefully. Particularly, connection and disconnection of (+) and (-) poles has to be performed by using a suitable DC switch-disconnector.

Measure each single string voltage V_{OC} (inverter switched off, see Figure C1)

The open-circuit voltage should be measured to characterize overall, or segments of, array behaviour, especially when I-V curve measurements are not performed. The test will indicate whether the array is wired correctly with the proper polarity and whether there are breaks in the circuit. The test will also measure relative voltage values of each segment or string of the array before they are connected together.

The open-circuit voltage (V_{oc}) of the array or array segment may be measured at any time of the (reasonably bright or sunny) day with a voltmeter that has suitable voltage rating and a typical accuracy of at least 0.5%. The temperature of the back of a representative number of modules should be checked for consistency and the temperature(s) should be recorded with each measurement of voltage. This measurement may be done most conveniently by operating the array disconnect at each inverter. The system electrical diagram should be studied to determine a measurement point that will be adequately isolated from other array segments.

Measure each single string current I_{SC} (inverter switched off and dc side short circuited, see Figure C2)

The short circuit current (I_{sc}) of an array or test segment is measured by connecting a low resistance measurement device between the negative and positive legs of the test segment. For very small arrays, I_{sc} can be measured directly with a handheld multi-meter (typically up to 10 Amps). For larger arrays, a special shorting circuit consisting of a conductor, disconnect switch, and current sensor is needed. The current sensor may be a resistive current shunt, a hall-effect device, or other means.

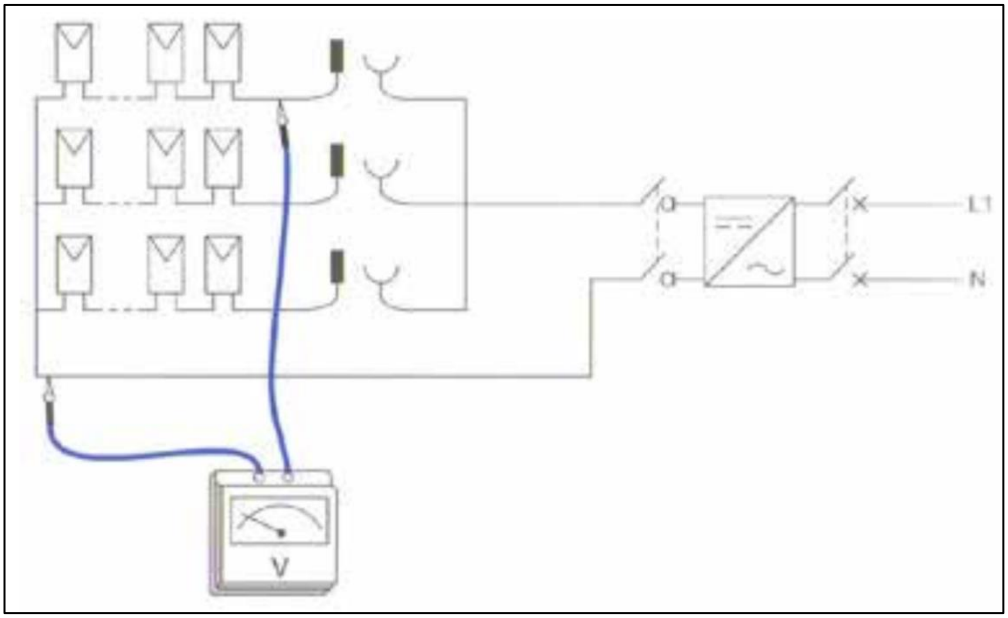


Figure C1: Measurement of String Open Circuit Voltage (VOC)

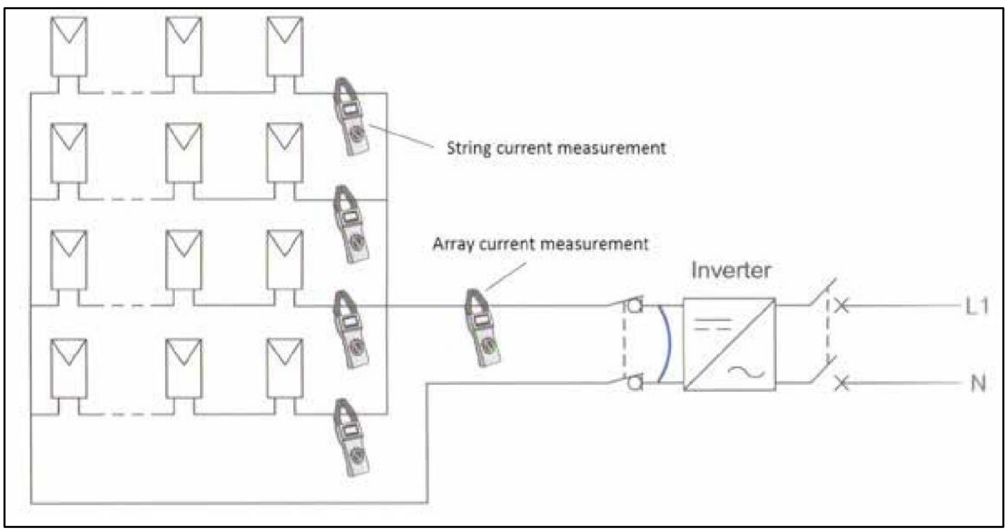


Figure C2: Measurement of String Short Circuit Current (ISC)

Measurement of Earth Resistance

It is necessary to maintain an earthed equipotential zone within the Solar PV installation where all the exposed conductive parts and extraneous conductive parts are maintained at substantially the same potential by bonding and earthing them, such as that, under fault conditions, the difference in potential between simultaneously accessible exposed and extraneous conductive parts will not cause electric shock.

Earth electrode resistance shall be measured by “Null Balance Earth Tester” or equivalent measure. The test should be performed when the soil is as dry as typically possible.

It is recommended to have combined earth electrode resistance below 10 Ω.

Some sites such as communication or substation sites or due to equipment manufacturer’s recommendation, it may require a substantially less ground resistance. In such case, it is recommended to reduce the electrode resistance below that recommended value. When resistance measurements are higher than the criteria stated above, additional ground rods, deeper ground rods, or other means may be used to reduce the resistance as necessary before the grid connection.

Testing with Interconnection

Harmonic Distortion Test shall be performed with the grid connection.

This test determines the current and voltage total harmonic distortion (THD) or individual harmonics contributed by the inverter. Power quality measurement device or a spectrum analyser has to be connected to the ac output of the inverter, ideally between the inverter and the utility interconnection point (Point of Common Coupling, PCC). Distortion criteria are applicable at 100% of inverter rating; thus, measurements are best done during clear sky conditions. When 100% of inverter rating is not possible, then data for the highest attainable power, which shall be more than 70% or rated power of the inverter, shall be taken. The power quality measuring equipment or a spectrum analyzer shall has a response of at least the 25^{th} harmonic. All test equipment shall be calibrated against nationally traceable standards. As many inverters operate with pulse-width-modulation circuits at high frequencies, it is advisable to use a measuring equipment with up to 50^{th} harmonic.

The emission limits are given below;

Parameter	Limit
Voltage Total harmonic distortion (VTHD)	5%
Total Demand Distortion (TDD)	5%

Individual harmonic order(h)	3≤h<11	11≤h<17	17≤h<23	23≤h<35	35≤h<50	TDD
Allowable Limit in % of I_L	4	2	1.5	0.6	0.3	5

Where,

$$VTHD = \frac{\sqrt{\sum_{h=2}^{h_{max}} V_h^2}}{V_1}, TDD = \frac{\sqrt{\sum_{h=2}^{h_{max}} I_h^2}}{I_L}$$

V_1 is the rms value of the fundamental voltage

I_L is the rms value of the maximum load current of the inverter under normal operating condition

Special Note: *Listed or previously certified* ***inverter models*** *are exempt from this test when appropriate documentation is available.* ***Previous certificates of inverter models are valid only for 18 months.***

ANNEX D-ROUTINE MAINTENANCE CHECK LIST

Solar PV Inspection Report ☐ **Routine Inspection**

Installation Address: Reference:

Date:

Circuits Inspected: Inspector:

Equipment/Circuits Inspected:

☑ Satisfactory	☒ not satisfactory (give details/comments)
☐ not applicable	⊗ urgent work required

a.c part of the electrical installation is tested in accordance with Regulations 8.1		
PV distribution boards room condition		
PV distribution boards condition		
Proper ventilation behind array		
Cable entry weatherproof		
Array frame correctly fixed and stable; roof fixings weatherproof		

Check for dust and dirt build up	It is recommended that modules are cleaned once every 4 weeks.	
Check for damaged modules	Replace damaged modules.	
Check for damaged cables	Replace damaged cables.	
Check for damaged connectors and loose connections	Replace damaged connectors and retighten connections	
Check array mounting frame for any damage or loose fixings	Repair or replace frame as required	
Check for proper ventilation behind PV array	Remove any obstructions that may affect ventilation from behind PV array	
PV Inverter		
Check Inverter mounting frame	Properly secure Inverter	
Check Inverter proper ventilation	Clean any dust build up that may affect ventilation of the inverter.	
Check Inverter cable connections	Tighten connection	

Check Inverter operating temperature	If temperature is abnormally high, replacement of inverter may be required.	
Check Inverter loss of grid functionality	If function does not work as intended, replacement of the inverter is required.	
Check Inverter installation location	Remove any obstructions that prevents access to the inverter	
Battery System		
Check Battery installed location	If the location is not clean and wet , necessary action to be taken.	
Check Battery connection	Tighten connection	
Check Battery operating temperature	If unwanted heating arise increment of ventilation or replacement is required.	
Cabling		
Check cables conditions (Module, String etc.)	Replace if damaged	
Check cables connections for signs of burn or discolouring	Replace if damaged	

Check cables supports and physical protection	Repair or protect cables are needed	
Switching and Isolation		
Check AC switch disconnector functionality	Replace if damaged or not working	
Check DC switch disconnector functionality	Replace if damaged or not working	
Bonding or exposed conductive parts to lightning protection system		
Check bonding connections	Tighten loose connection	
Check bonding cables conditions	Replace if damaged	
Check bonding cable continuity	Rectify if no continuity is found	
Labelling and identification		
Check all circuits, protective devices, switches and terminals are suitably labelled	Replace damaged labels	
All DC junction boxes (PV generator and PV array boxes) carry a warning label indicating that active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply.	Replace damaged labels	

The main AC and DC isolating switches are clearly labelled.	Replace damaged labels	
Dual supply warning labels are fitted at point of interconnection. –	Replace damaged labels	
A single line wiring diagram is displayed on site.	Replace or provide up to date wiring diagram	
Emergency shutdown procedures are displayed on site.	Provide up to date emergency shutdown procedures	
All signs and labels are suitably affixed and durable.	Replace damaged labels	

ANNEX E- SUPPORTING STANDARDS FOR THE PRODUCTS OF SOLAR PV SYSTEMS

CODE OF PRACTICE

SLS 1522: 2016 Sri Lanka Standard Code of Practice for Grid Connected Photovoltaic Power Systems - Requirements for System Documentation, Installation, Testing & Commissioning

POWER CONVERTERS

SLS 1543 Sri Lanka Standard Specification for Safety of Power Converters for use in Photovoltaic Power Systems –
Part 1:2016 General Requirements **(IEC 62109-1:2010)**
Part 2:2016 Particular Requirements for Inverters **(IEC 62109-2:2011)**

SLS 1547:2016 Sri Lanka Standard Specification for Photovoltaic (PV) Systems – Characteristics of the Utility Interface **(IEC 61727:2004)**.

HYBRID INVERTER

SLS 1680: 2020 Sri Lanka Standard Specification for Safety of Hybrid Inverter for Solar PV System.

SWITCHGEAR AND CONTROLGEAR

SLS 1554 - Sri Lanka Standard Specification for Low-Voltage Switchgear and Controlgear

Part 1: 2017 General Rules **(IEC 60947-1:2014)**

Part 2: 2017 Circuit-Breakers **(IEC 60947-2:2016)**

Part 3: 2017 Switches, Disconnectors, Switch-Disconnectors and Fuse-Combination Units **(IEC 60947-3:2015).**

DC CABLE

SLS 1542:2016 Sri Lanka Standard Specification for Electric Cable for Photovoltaic Systems **(EN 50618:2014)**

PHOTOVOLTAIC (PV) MODULES

SLS 1553 Sri Lanka Standard Specification for Photovoltaic(PV) Module Safety Qualification –

Part 1: 2017 Requirements for Construction **(IEC 61730-1:2016)**

Part 2: 2017 Requirements for Testing **(IEC 61730-2:2016)**

SLS 1544 Sri Lanka Standard Specification for Terrestrial Photovoltaic (PV) Modules – Design qualification and type approval –

Part 1:2016 Test Requirements **(IEC 61215-1:2016)**

Part 1-1:2016 Special Requirements for Testing of Crystalline Silicon Photovoltaic (PV) Modules **(IEC 61215-1-1:2016)**

Part 2:2016 Test Procedures **(IEC 61215-2:2016)**

SLS 1546:2016 Sri Lanka Standard Specification for Photovoltaic Systems – Power Conditioners – Procedure for Measuring Efficiency **(IEC 61683:1999)**

PERFORMANCE TESTING AND ENERGY RATING

SLS 1545 Sri Lanka Standard Specification for Photovoltaic (PV) Module Performance Testing and Energy Rating –

Part 1:2016 Irradiance and Temperature Performance Measurements and Power Rating **(IEC 61853-1:2011)**
Part 2: 2017 Spectral Responsivity, Incidence Angle and Module Operating Temperature Measurements **(IEC 61853-1:2017)**

SLS 1637: 2019 Sri Lanka Standards Specification for Connectors for DC-application in photovoltaic systems – Safety requirements and tests

SLS IEC 62548: 2018 - Sri Lanka Standard Specification for Photovoltaic (PV) Arrays – Design Requirements **(IEC 62548: 2016)**

SLS IEC 62446:2017 - Sri Lanka Standard Specification for Photovoltaic (PV) Systems – Requirements For Testing, Documentation And Maintenance – **Part 1: 2017** Grid Connected Systems – Documentation, Commissioning Tests And Inspection **(IEC 62446-1:2016).**
SLS IEC 60364: 2018 - Sri Lanka Standard Specification for Low Voltage Electrical Installation - **Part 6: 2018** verification **(IEC 60364-6: 2016)**

SLS 1472 SRI LANKA STANDARD FOR PROTECTION AGAINST LIGHTNING

PART 1: 2013 // IEC 62305 - 1: 2010 – GENERAL PRINCIPLES
This part of IEC 62305 provides general principles to be followed for protection of structures against lightning, including their installations and contents, as well as persons.

PART 2: 2013 // IEC 62305 - 4: 2010 – RISK MANAGEMENT
This part of IEC 62305 is applicable to risk assessment for a structure due to lightning flashes to earth. Its purpose is to provide a procedure for the evaluation of such a risk.

PART 3 // IEC 62305 - 4: 2010 – **PHYSICAL DAMAGE TO STRUCTURES AND LIFE HAZARD**
This part of IEC 62305 provides the requirements for protection of a structure against physical damage by means of a lightning protection system (LPS), and for protection against injury to living beings due to touch and step voltages in the vicinity of an LPS

PART 4 // IEC 62305 - 4: 2010 – ELECTRICAL AND ELECTRONIC SYSTEMS WITHIN STRUCTURES

This part of IEC 62305 provides information for the design, installation, inspection, maintenance and testing of electrical and electronic system protection (SPM) to reduce the risk of permanent failures due to lightning electromagnetic impulse (LEMP) within a structure. This standard does not cover protection against electromagnetic interference due to lightning, which may cause malfunctioning of internal systems.

SLS 1473 SRI LANKA STANDARD FOR LOW VOLTAGE SURGE PROTECTIVE DEVICES

PART 1: 2013// IEC 61643 - 11: 2011 – SURGE PROTECTIVE DEVICES CONNECTED TO LOW-VOLTAGE POWER SYSTEMS - REQUIREMENTS AND TEST METHODS

This part of IEC 61643 is applicable to devices for surge protection against indirect and direct effects of lightning or other transient overvoltages.

PART 2: 2015 // IEC 61643 - 12: 2008 – SURGE PROTECTIVE DEVICES CONNECTED TO LOW-VOLTAGE POWER DISTRIBUTION SYSTEMS - SELECTION AND APPLICATION PRINCIPLES

This part of IEC 61643 describes the principles for selection, operation, location and coordination of SPDs to be connected to 50 Hz to 60 Hz a.c. and to d.c. power circuits and equipment rated up to 1 000 V r.m.s. or 1 500 V d.c.

PART 3: 2015 // IEC 61643 - 21: 2009 – SURGE PROTECTIVE DEVICES CONNECTED TO TELECOMMUNICATIONS AND SIGNALLING NETWORKS – PERFORMANCE REQUIREMENTS AND TESTING METHODS

This International Standard is applicable to devices for surge protection of telecommunications and signalling networks against indirect and direct effects of lightning or other transient overvoltage.

PART 4: 2015 // IEC 61643 - 22: 2004 – SURGE PROTECTIVE DEVICES CONNECTED TO TELECOMMUNICATIONS AND SIGNALLING NETWORKS –SELECTION AND APPLICATION PRINCIPLES

This part of IEC 61643 describes the principles for the selection, operation, location and coordination of SPDs connected to telecommunication and signalling networks with nominal system voltages up to 1 000 V r.m.s. a.c. and 1 500 V d.c.

PART 5: 2019 // IEC 61643-31: 2018 REQUIREMENTS AND TEST METHODS FOR SPDS FOR PHOTOVOLTAIC INSTALLATIONS

This part of IEC 61643 is applicable to Surge Protective Devices (SPDs), intended for surge protection against indirect and direct effects of lightning or other transient over voltages. These devices are designed to be connected to the DC side of photovoltaic installations rated up to 1 500 V DC.

PART 6: 2019 // IEC 61643-32 SURGE PROTECTIVE DEVICES CONNECTED TO THE D.C. SIDE OF PHOTOVOLTAIC INSTALLATIONS – SELECTION AND APPLICATION PRINCIPLES.

This part of IEC 61643 describes the principles for selection, installation and coordination of SPDs intended for use in Photovoltaic (PV) systems up to 1 500 V DC and for the AC side of the PV system rated up to 1 000 V rms 50/60 Hz.

SLS 1496 SRI LANKA STANDARD FOR LIGHTNING PROTECTION SYSTEM COMPONENTS

PART 1: 2015 // IEC 62561 - 1: 2012 – REQUIREMENTS FOR CONNECTION COMPONENTS

PART 2: 2015 // IEC 62561 - 2: 2012 – REQUIREMENTS FOR CONDUCTORS AND EARTH ELECTRODES

PART 3: 2015 // IEC 62561 - 3: 2012 – REQUIREMENTS FOR ISOLATING SPARK GAPS (ISG)

PART 4: 2015 // IEC 62561 - 4: 2010 – REQUIREMENTS FOR CONDUCTOR FASTENERS

PART 5: 2015 // IEC 62561 - 5: 2011 – REQUIREMENTS FOR EARTH ELECTRODE INSPECTION HOUSINGS AND EARTH ELECTRODE SEALS

PART 6: 2015 // IEC 62561 - 6: 2011 – REQUIREMENTS FOR LIGHTNING STRIKE COUNTERS

PART 7: 2015 // IEC 62561 - 7: 2011 – REQUIREMENTS FOR EARTHING ENHANCING COMPOUNDS

GUIDANCE NOTE 1: MORE INFORMATION ON VERIFICATION, INSPECTION AND TESTING

1. VERIFICATION

1.1 GENERAL: GRID CONNECTED PV SYSTEM

Much of the verification of a grid connected PV system should be done with reference to IEC 60364-6, which provides the requirements for initial and periodic verification of any electrical installation.

This Clause provides the requirements for the initial and periodic verification of a grid connected PV electrical installation in particular. It references IEC 60364-6 where appropriate and details of additional requirements or considerations for the verification of a PV system. Initial verification takes place upon completion of a new installation or completion of additions or of alterations to existing installations. Periodic verification is to determine, as far as reasonably practicable, whether the installation and all its constituent equipment remain in a satisfactory condition for use.

NOTE

Typical verification test sheets are provided in the annexes to this standard.

1.2 GENERAL: INSTALLATION OF SUBSYSTEMS AND COMPONENTS

Every installation of subsystems and components shall be verified during erection, as far as reasonably practicable, and on completion, before being put into service by the user with reference to IEC 60364-6. Initial verification shall include comparison of the results with relevant criteria to confirm that the requirements of IEC 60364 have been met.

For an addition or alteration to an existing installation, it shall be verified that the addition or alteration complies with IEC 60364 and does not impair the safety of the existing installation.

Initial and periodic verifications shall be made by a skilled person, competent in verification.

1.3 INSPECTION

Inspection shall precede testing and shall normally be done prior to energizing the installation. The inspection shall be done to the requirements of IEC 60364-6. It is to be ensured that the following items, specific to grid connected PV systems, are included in the inspection

1.3.1 DC SYSTEM INSPECTION

Inspection of the DC installation shall include, at least verification that:

- The DC system has been designed, specified, and installed to the requirements of IEC 60364 in general and IEC 60364-7-712 in particular.
- All DC components are rated for continuous operation at DC and at the maximum possible DC system voltage and maximum possible DC fault current ($V_{oc\ stc}$ corrected for local temperature range and based on module type; and current at 1.25 × $I_{sc\ stc}$ according to IEC 60364-7-712.433:2002).
- Protection by use of class II or equivalent insulation adopted on the DC side – yes / no (class II preferred - IEC 60364-7-712.413.2:2002).
- PV string cables, PV array cables and PV DC main cables have been selected and erected so as to minimize the risk of earth faults and short-circuits (IEC 60364-7-712.522.8.1:2002). Typically achieved by the use of cables with protective and reinforced insulation (often termed “double insulated”).
- Wiring systems have been selected and erected to withstand the expected external influences such as wind, temperature, and solar radiation (IEC 60364-7-712.522.8.3:2002).

- For systems without string over-current protective device: verify that the module reverse current rating (I_r) is greater than the possible reverse current; also, verify that the string cables are sized to accommodate the maximum combined fault current from parallel strings (IEC 60364-7-712.433:2002).

- For systems with string over-current protective device: verify that the string over-current protective devices are fitted and correctly specified to local codes or to the manufacturer’s instructions for protection of PV modules according to the NOTE of IEC 60364-7- 712.433.2:2002.

- Verify that a DC switch disconnector is fitted to the DC side of the inverter (IEC 60364-7- 712.536.2.2.5:2002).

- If blocking diodes are fitted, verify that their reverse voltage rating is at least 2 × $V_{oc\ stc}$ of the PV string in which they are fitted (IEC 60364-7-712.512.1.1:2002).

- If one of the DC conductors is connected to earth, verify that there is at least simple separation between the AC and DC sides and that earth connections have been constructed so as to avoid corrosion (IEC 60364-7-712.312.2:2002) according to the 5.10.12.

NOTE

Inspection of the DC system requires knowledge of the maximum system voltage and current.The maximum system voltage is a function of the string / array design, the open circuit voltage (V_{oc}) of the modules and a multiplier to account for temperature and irradiance variations.

The maximum possible fault current is a function of the string / array design, the short circuit current (I_{sc}) of the modules and a multiplier to account for temperature and irradiance variations (IEC 60364-7-712.433:2002). Where a module reverse current rating (I_r) is not provided by the manufacturer it should be taken to be 1,35 × the modules over-current protection rating.

Module over-current protection rating should be taken as the value provided by the manufacturer as per the requirements of IEC 61730-1.

1.3.2 PROTECTION AGAINST OVERVOLTAGE / ELECTRIC SHOCK

Inspection of the PV system shall include, at least verification that:

- Verification of type B RCD where: an RCD is installed and the PV inverter is without at least simple separation between the AC side and the DC side, - according to IEC 60755 (IEC 60364-7-712.413.1.1.1.2:2002 and Figure 712.1).
- To minimize voltages induced by lightning, verify that the area of all wiring loops has been kept as small as possible (IEC 60364-7-712.444.4:2002).
- Where required by local codes, verify that array frame and/or module frame protective earthing conductors have been correctly installed and are connected to earth. Where protective earthing and /or equipotential bonding conductors are installed, verify that they are parallel to, and bundled with, the DC cables (IEC 60364-7-712.54:2002).

1.3.3 AC SYSTEM

Inspection of the PV system shall include, at least verification that:

- A means of isolating the inverter has been provided on the AC side;
- All isolation and switching devices have been connected such that PV installation is wired to the “load” side and the public supply (IEC 60364-7-712.536.2.2.1:2002);
- The inverter operational parameters have been programmed to local regulations.

1.3.4 LABELLING AND IDENTIFICATION

Inspection of the PV system shall include at least verification that:

- All circuits, protective devices, switches, and terminals are suitably labelled.
- All DC junction boxes (PV generator and PV array boxes) carry a warning label indicating that active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply.
- The main AC isolating switch is clearly labelled.
- Dual supply warning labels are fitted at point of interconnection.
- A single line wiring diagram is displayed on site.
- Inverter protection settings and installer details are displayed on site.
- Emergency shutdown procedures are displayed on site.
- All signs and labels are suitably affixed and durable.

2. TESTING

2.1 GENERAL

Testing of the electrical installation shall be done to the requirements of IEC 60364-6. Measuring instruments and monitoring equipment and methods shall be chosen in accordance with the relevant parts of IEC 61557. If other measuring equipment is used, it shall provide an equivalent degree of performance and safety. The test methods described in this Clause are given as reference methods; other methods are not precluded, provided they give no less valid results.

In the event of a test indicating a fault: once that fault has been rectified, all previous tests shall be repeated in case the fault influenced the result of these tests.

The following tests shall be carried out where relevant and should preferably be made in the following sequence:

- Tests to all AC circuit(s) to the requirements of IEC 60364-6. Once tests to the AC circuit(s) are complete, the following tests shall be carried out on the DC circuit(s) forming the PV array.
- continuity of protective earthing and/or equipotential bonding conductors, where fitted (see **7.4.2**);
- polarity test (see **7.4.3**);
- string open circuit voltage test (see **7.4.4**)
- string short circuit current test (see **7.4.5**)
- functional tests (see **7.4.6**);
- insulation resistance of the DC circuits (see **7.4.7**).

In the event of any test indicating failure to comply with the requirements, that test and any preceding test that may have been influenced by the fault shall be repeated.

2.1.1 CONTINUITY OF PROTECTIVE EARTHING AND/OR EQUIPOTENTIAL BONDING CONDUCTORS

Where protective or bonding conductors are fitted on the DC side, such as bonding of the array frame, an electrical continuity test shall be made on all such conductors. The connection to the main earthing terminal should also be verified.

2.1.2 POLARITY TEST

The polarity of all DC cables shall be verified using suitable test apparatus. Once polarity is confirmed, cables shall be checked to ensure they are correctly identified and correctly connected into system devices such as switching devices or inverters.

NOTE

For reasons of safety and for the prevention of damage to connected equipment, it is extremely important to perform the polarity check before other tests and before switches are closed or string over-current protective devices inserted. If a check is made on a previously connected system and reverse polarity of one string is found, it is then important to check modules and bypass diodes for any damage cause by this error.

2.1.3 PV STRING - OPEN CIRCUIT VOLTAGE MEASUREMENT

The open circuit voltage of each PV string should be measured using suitable measuring apparatus. This should be done before closing any switches or installing string over-current protective devices (where fitted). Measured values should be compared with the expected value. Comparison to expected values is intended as a check for correct installation, not as a measure of module or array performance. Verification of module / array performance is outside the scope of this standard.

For systems with multiple identical strings and where there is stable irradiance conditions, voltages between strings shall be compared. These values should be the same (typically within 5 % for stable irradiance conditions). For non stable irradiance conditions, the following methods can be adopted:

Testing may be delayed
Tests can be done using multiple meters, with one meter on a reference string
An irradiance meter reading may be used to adjust the current readings.

NOTE

Voltages less than the expected value may indicate one or more modules connected with the wrong polarity, or faults due to poor insulation, subsequent damage and/or water accumulation in conduits or junction boxes. High voltage readings are usually the result of wiring errors

2.2 PV STRING - CURRENT MEASUREMENT

2.2.1 GENERAL

Like the open circuit voltage measurements, the purpose of a PV string current measurement test is to verify that there are no major faults within the PV array wiring. These tests are not to be taken as a measure of module / array performance.

Two tests methods are possible and both will provide information on string performance. Where possible the short circuit test is preferred as it will exclude any influence from the inverters.

2.2.2 PV STRING – SHORT CIRCUIT TEST

The short circuit current of each PV string should be measured using suitable test apparatus. The making / interruption of string short circuit currents is potentially hazardous and a suitable test procedure, such as that described below, should be followed. Measured values should be compared with the expected value. For systems with multiple identical strings and where there are stable irradiance conditions, measurements of currents in individual strings shall be compared. These values should be the same (typically within 5 % for stable irradiance conditions).

For non-stable irradiance conditions, the following methods can be adopted:

- Testing may be delayed
- Tests can be done using multiple meters, with one meter on a reference string
- An irradiance meter reading may be used to adjust the current readings.

2.2.3 SHORT CIRCUIT TEST PROCEDURE

Ensure that all PV strings are isolated from each other and that all switching devices and disconnecting means are open.

A temporary short circuit shall be introduced into the string under test. This can be achieved by either:

- A short circuit cable temporarily connected into a load break switching device already present in the string circuit.
- The use of a “short circuit switch test box” – a load break rated device that can be temporarily introduced into the circuit to create a switched short circuit.

In either case the switching device and short circuit conductor shall be rated greater than the potential short circuit current and open circuit voltage.

The short circuit current can then be measured using either a clip-on ammeter or by an in-line ammeter.

NOTE

*A “short circuit switch box” is an item of test apparatus that can be used for both short circuit tests and also array insulation tests (see **7.4.7**).*

2.2.4 PV STRING – OPERATIONAL TEST

With the system switched on and in normal operation mode (inverters maximum power point tracking) the current from each PV string should be measured using a suitable clip on ammeter placed around the string cable.

Measured values should be compared with the expected value. For systems with multiple identical strings and where there are stable irradiance conditions, measurements of currents in individual strings shall be compared. These values should be the same (typically within 5 % for stable irradiance conditions).

For non-stable irradiance conditions, the following methods can be adopted:

- Testing may be delayed
- Tests can be done using multiple meters, with one meter on a reference string
- An irradiance meter reading may be used to adjust the current readings.

2.3 FUNCTIONAL TESTS

The following functional tests shall be performed:

- Switchgear and other control apparatus shall be tested to ensure correct operation and that they are properly mounted and connected.
- All inverters forming part of the PV system shall be tested to ensure correct operation. The test procedure should be the procedure defined by the inverter manufacturer.
- A loss of mains test shall be performed: With the system operating, the main AC isolator shall be opened – it should be observed (e.g. on a display meter) that the PV system immediately ceases to generate. Following this, the AC isolator should be re-closed, and it should be observed that the system reverts to normal operation.

NOTE

The loss of mains test can be amended during stable irradiance conditions. In such cases, before opening the main AC isolator, loads within the building can be selected so as to match, as close as is practical, the power being generated by the PV system.

2.4 PV ARRAY INSULATION RESISTANCE TEST

2.4.1 GENERAL

PV array DC circuits are live during daylight and, unlike a conventional AC circuit, cannot be isolated before performing this test.

Performing this test presents a potential electric shock hazard, it is important to fully understand the procedure before starting any work. It is recommended that the following basic safety measures are followed:

Limit the access to the working area.
Do not touch and take measures to prevent any other persons to touch any metallic surface with any part of your body when performing the insulation test.
Do not touch and take measures to prevent any other persons from touching the back of the module/laminate or the module/laminate terminals with any part of your body when performing the insulation test.
Whenever the insulation test device is energised there is voltage on the testing area. The equipment is to have automatic auto-discharge capability.
Appropriate personal protective clothing / equipment should be worn for the duration of the test.

NOTE

For some installations, for example larger systems or where insulation faults due to installation or manufacturing defects are suspected, or where the results of the dry test are questionable, a wet array insulation test may be appropriate. Wet array insulation test procedures can be found in ASTM Std E 2047, Test Method for Wet Insulation Integrity Testing of PV Arrays.

2.4.2 PV ARRAY INSULATION RESISTANCE TEST – TEST METHOD

The test should be repeated for each PV array as a minimum. It is also possible to test individual strings if required. Two test methods are possible:

- Test method 1 -Test between array negative and earth followed by a test between array Positive and Earth.
- Test method 2 - Test between earth and short-circuited array positive and negative.

Where the structure/frame is bonded to earth, the earth connection may be to any suitable earth connection or to the array frame (where the array frame is utilised, ensure a good contact and that there is continuity over the whole metallic frame).

For systems where the array frame is not bonded to earth (e.g. where there is a class II installation) a commissioning engineer may choose to do two tests: a) between array cables and earth and an additional test b) between array cables and frame.

For arrays that have no accessible conductive parts (e.g. PV roof tiles) the test shall be between array cables and the building earth.

NOTES

Where test method 2 is adopted, to minimise the risk from electrical arcs, the array positive and negative cables should be short-circuited in a safe manner. Typically, this would be achieved by an appropriate short-circuit switch box. Such a device incorporates a load break rated DC switch that can safely make and break the short circuit connection - after array cables have been safely connected into the device

The test procedure should be designed to ensure peak voltage does not exceed module or cable ratings.

2.4.2 PV ARRAY INSULATION RESISTANCE - TEST PROCEDURE

Before commencing with the test: limit access to non-authorized personnel; isolate the PV array from the inverter (typically at the array switch disconnector); and disconnect any piece of equipment that could have an impact on the insulation measurement (i.e. overvoltage protection) in the junction or combiner boxes.

Where a short circuit switch box is being used to test to method 2, the array cables should be securely connected into the short circuit device before the short circuit switch is activated.

The insulation resistance test device shall be connected between earth and the array cable(s) as appropriate to the test method adopted. Test leads should be made secure before carrying out the test.

Follow the insulation resistance test device instructions to ensure the test voltage is according to Table 1 and readings in MΩ. The insulation resistance, measured with the test voltage indicated in Table 1, is satisfactory if each circuit has an insulation resistance not less than the appropriate value given in Table.

Ensure the system is de-energised before removing test cables or touching any conductive parts.

Minimum values of insulation resistance

Test Method	System Voltage ($V_{oc\ stc}$ × 1.25) V	Test Voltage V	Minimum Insulation resistance MΩ
Test method 1 Separate test to array positive and array negative	< 120	250	0.5
	120 - 500	500	1
	>500	1 000	1
Test method 2 Array positive and negative shorted together	< 120	250	0.5
	120 - 500	500	1
	>500	1 000	1

2.5 EXTERNAL BACK FEED PROTECTION SYSTEM - TEST PROCEDURE

An external back feed protection isolation device is provided externally as a backup protection to the inbuilt back feed protection. The operation of the device shall be done automatically. Compliance shall be determined by relevant circuit diagram inspection and carrying out following tests/inspection based on IEC 62040-1 Clause 5.1.4.

- Phase Failure Relay manufacturing standard conformity IEC standard or equivalent acceptable standard.
- Automatic reset capability of Phase Failure Relay.
- Functionality test during disconnection of CEB supply (from the breaker/fuse cut-outs at the meter). Isolation device shall operate (Close to Open) within 0.5 seconds after the disconnection.

- Functionality test during reconnection of CEB supply (from the breaker/fuse cut-outs at the meter). Isolation device shall operate (Open to Close) 1 second after the reconnection.
- Functionality test of Indication lamps of the Isolation device status and CEB supply status.

3. VERIFICATION REPORTS

3.1 GENERAL

Upon completion of the verification process, a report shall be provided. This report shall include the following information:

- Summary information describing the system (name, address, etc.).
- A list of the circuits that have been inspected and tested.
- A record of the inspection.
- A record of the test results for each circuit tested.
- Recommended interval until next verification.
- Signature of the person(s) undertaking the verification.

Model verification reports are shown in the annexes to this standard.

3.2 INITIAL VERIFICATION

Verification of a new installation shall be performed to the requirements of 8 of this standards. The initial verification report shall include additional information regarding the person(s) responsible for the design, construction, and verification of the system – and the extent of their respective responsibilities. The initial verification report shall make a recommendation for the interval between periodic inspections. This shall be determined having regard to the type of installation and equipment, its use and operation, the frequency and quality of maintenance and the external influences to which it may be subjected.

NOTE

In some countries the interval between verifications is stipulated by national regulations.

3.3 PERIODIC VERIFICATION

Periodic verification of an existing installation shall be performed to the requirements of 8 of this standard. Where appropriate, the results and recommendations of previous periodic verifications shall be considered.

A periodic verification report shall be provided and include a list of any faults and recommendations for repairs or improvements (such as upgrading a system to meet current standards).

4. APPLICATIONS & SYSTEM DOCUMENTS

This section includes latest applications, verifications and commissioning documents required for Solar PV system as per the SLS1522.