Safe and reliable photovoltaic energy generation

Selection of low voltage switchgears and circuit protection components per type of photovoltaic electrical architecture

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Contents

Introduction

Solar energy is growing at double-digit rates worldwide. And it will continue to do so in coming years across all its different applications – be it residential, in small and large buildings, or in power plants.

Driving the rise of solar power is the ever-improving performance of photovoltaic (PV) systems. They now guarantee the economic soundness and profitability of PV power generation technology. They have made it a prime source of clean, renewable energy that is making a major contribution to reducing the carbon footprint and building the environmental sustainability of power generation. Assembled in solar modules and arrays, PV cells are silent, combustion-free, and emit no pollution. Nor do they have moving parts and so require little maintenance over their long life spans. They also boast advantages over other renewable power sources like wind and water power which rely on turbines, are noisy, and prone to breakdowns.

Another compelling advantage of PV generation systems is how versatile and convenient they are. They can be used in standalone applications and installed in places that are difficult and uneconomical to supply with traditional power lines. In fact they can be installed pretty much anywhere: on the ground, on the sides of buildings, and on the roofs, regardless of whether they are flat or tilted. With solar cells, there is no danger of energy wastage. While large-scale systems over-generate in order to supply all users, solar cells can be installed in a distributed manner. And as demand grows in an economically vibrant area, for example, more cells can be added to supply new homes and business.

Even the main criticism leveled at solar energy – its initial cost – lacks credence, according to the experts from the Energy Efficiency and Renewable Energy Division of the U.S. Department of Energy. They argue that energy payback estimates for rooftop PV systems are between one and four years for life expectancies of 30 years. They also estimate that 87% to 97% of the energy that PV systems generate will not be plagued by pollution, greenhouse gases, and depletion of resources.

PV systems, it seems, can do no wrong. However – and at the risk of stating the obvious – they need to be safe, reliable and efficient. Only then is it possible to maximize their profitability, their operating and environmental benefits, and the energy they generate. PV system components need to be chosen in such a way that they ensure a solar cell or module functions perfectly and delivers optimized performance. In that sense, designing a PV installation is not a simple job.

The principles that usually flow from the classic configuration of a single centralized power source do not apply. Engineering a PV system requires thinking out of the box. Reasons include the use of variable DC output rather than one fixed AC supply and a weak short-circuit current. What's more, not all a PV power sources can be earthed or its power shut off completely. It is also important to understand that a photovoltaic architecture incorporates the following components:

- PV modules that convert sunlight into DC power
- DC protection, control, and disconnect devices
- Inverters for DC to AC conversion and grid connection
- AC protection, control, and disconnect devices
- AC power and energy metering

However selecting the right electrical architecture is just the beginning of engineering a PV system.

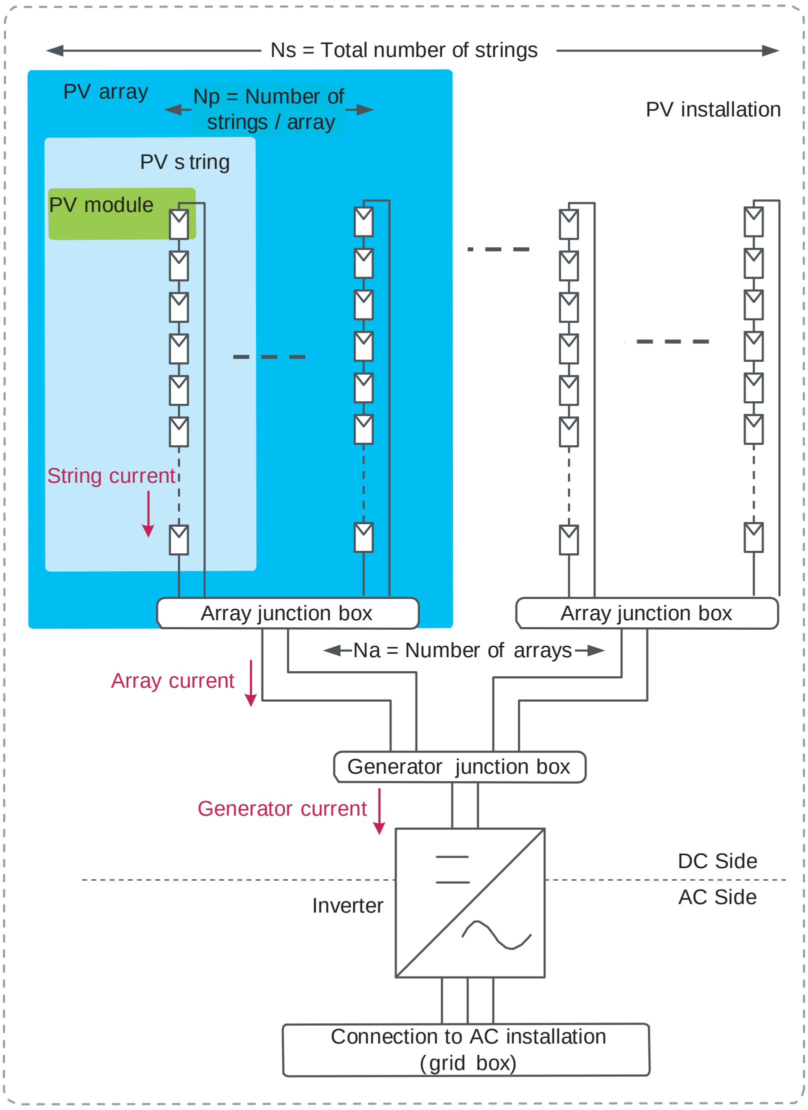
Scope and purpose of this paper

This application paper seeks to offer guidance in selecting the best protection and control components for a given PV system in residential premises, commercial buildings, and power plants.

It also sets out guidelines for optimizing system operation, maximizing the safety of people and property, and ensuring continuity of service.

The type of PV installation chosen to illustrate the selection of the right architecture and the installation of low-voltage switchgear is a grid-connected photovoltaic installation with an open-circuit maximum voltage ($U_{OC\ MAX}$) higher than 120 V DC (see figure below). The assumption is that the PV generator architecture and characteristics (voltage, current, PV modules, etc.) have been selected. The PV array's maximum voltage is considered equal to $U_{OC\ MAX}$ corrected to the lowest expected ambient temperature in accordance with the manufacturer's instructions or installation rules.

The figures below shows a typical PV architecture with the terms generally used in this document.



The switchgear for which guidance is provided encompasses:

- Switches
- Fuse carriers
- Circuit breakers
- Contactors
- Enclosures
- Surge protectors.

This paper also proposes answers to questions such as:

- Whether or not overcurrent protection is required and whether the best option is to use fuses or a circuit breaker.
- Where to use switches.
- Which enclosures are recommended.

IEC standard 60364 is applied throughout this document. Part 712 of the standard is of particular significance. It sets out rules for ensuring that solar photovoltaic power systems are safe and supplies a number of the definitions used in this paper (see "Definitions" at the end of the document).

1 PV system and installation rules

How to ensure safety during normal operation?

Two particular characteristics of PV generators are their DC voltage levels and the fact they cannot be shut off as long as PV modules are exposed to the sun. The short-circuit current produced by the PV module is too low to trigger the power supply's automatic disconnect. The most frequently used protective measures do not therefore apply to PV systems. However, as PV modules are installed outdoors they are exposed to the elements. And since they can be installed on roofs, critical attention should be paid to the risk of fire and the protection of fire fighters and emergency services staff.

Protecting people against electric shock

IEC 60364-712 stipulates that PV systems whose maximum $U_{OC\ MAX}$ is higher than 120 V DC should use « double or reinforced insulation » as a protection against electric shock.

Switchgear, such as fuses or circuit breakers on the DC side, do not afford protection against electric shock as there is no automatic disconnect of the power supply.

Over current protection, when used, protects PV cells against reverse current and cables against overload.

Earthing a pole on the DC side is functional and does not protect against electric shocks.

Risk of fire: protection against thermal effects

Generally speaking there are three situations that can lead to abnormally high temperatures and the risk of fire in a PV system: insulation fault, a reverse current in a PV module, and overloading cables or equipment.

Insulation fault detection

Double or reinforced insulation is a protective measure against electric shock but it does not exclude all risk of insulation fault. (The assumption here is that the likelihood of an insulation fault and of someone touching an energized part of the installation at the same is very low. Insulation faults in themselves do happen more frequently, however.) DC insulation fault could be more dangerous as arc has less chance to extinguish by itself as it does in AC.

The PV generator should be checked to ensure it is insulated from earth.

> When there is no galvanic insulation between the AC side and the DC side:
- It is impossible to earth one pole.
- AC protection can be used to detect insulation faults.

> When the AC side and DC side are galvanically separated:
- An over-current protective device (which also detects insulation faults) should be used to trip the grounded conductor in the event of a fault, if the PV cell technology (e.g. thin films of amorphous silicon) requires one of the conductors to be directly grounded.
- An insulation monitoring device should be used if the PV cell technology requires one of the conductors to be resistance-grounded.
- An insulation monitoring device should also be used when PV cell technology does not require either conductor to be earthed.

Insulation monitoring device shall be selected taking into consideration both $U_{OC\ MAX}$ and the capacitance between poles and earth causes leakage current. In addition cables and inverter capacitance should be also considered. An Insulation monitoring device able to handle capacitance up to 500 µF is suitable for PV system.

Paragraph 412.1.1 of IEC 60364 states:
Double or reinforced insulation is a protective measure in which
- basic protection is provided by basic insulation, and fault protection is provided by supplementary insulation, or
- basic and fault protection is provided by reinforced insulation between live parts and accessible parts.

NB: This protective measure is intended to prevent the appearance of dangerous voltage on the accessible parts of electrical equipment through a fault in the basic insulation.

Please note

When an insulation fault is detected whatever the solution is, inverter is stopped and disconnected from AC side, but the fault is still present on DC side and voltage between poles is open circuit voltage of PV generator as long as sun is shining. This situation cannot be tolerated over a long period and the fault has to be found and cleared. If not, a second fault may develop on the other pole, causing the current to circulate in the earthing conductors and metal parts of the PV installation with no guarantee that protective devices will operate properly. See "1.1.4 Protection against overcurrent".

Leakage capacitance in various PV systems

The literature provided by manufacturers of photovoltaic modules yield the following figures:

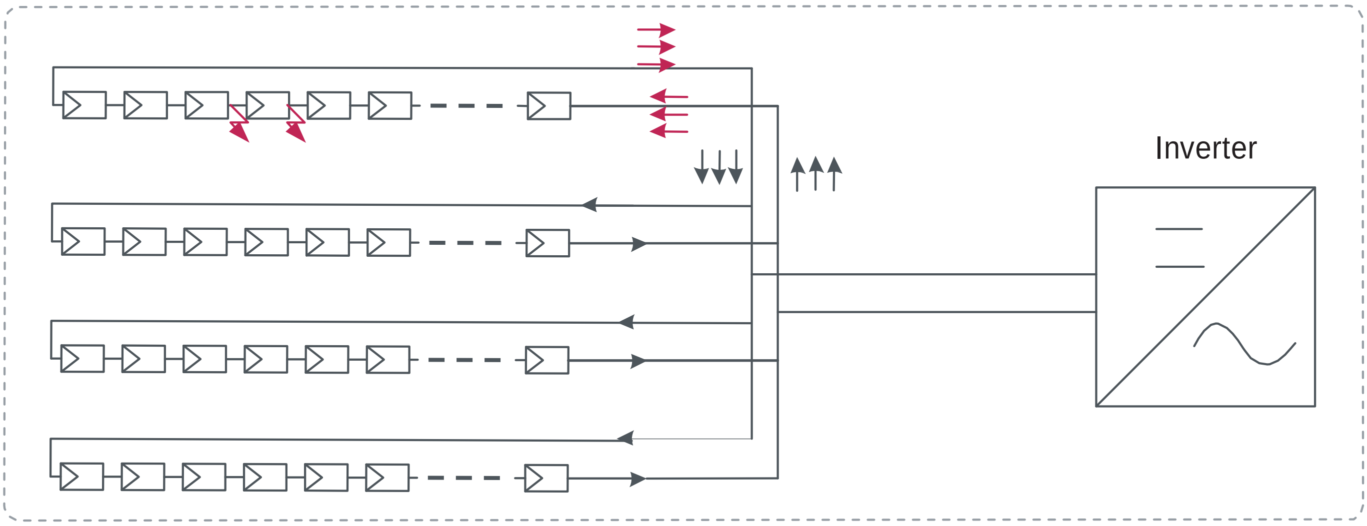
	Maximum power usually developed with a single inverter	Surface necessary to develop such a Power	Usual capacitance by m²	Usual capacitance between lines and earth for a single IT system
Frameless glass-glass module with aluminum frame on an assembly stand (open air)	1 MW	8000 m²	1 nF/m²	8 µF
In-roof glass-glass module with aluminum frame	100 kW	800 m²	5 nF/m²	4 µF
Thin-film PV module on flexible substrate	100 kW	800 m²	50 nF/m²	40 µF

Some measurements made in European plants are giving the following figures:

	Maximum power developed with a single inverter	Surface necessary to develop such a Power	Lowest capacitance measurement	Highest capacitance measurement	Maximum measured capacitance by m²
Frameless glass-glass module with aluminum frame on an assembly stand (open air)	Plant 1: 1 MW	8000 m²	Sunny afternoon: 5 µF	Rainy morning: 10 µF	1,25 nF / m²
	Plant 2: 750 kW	5000 m²	Sunny afternoon: 2 µF	Rainy morning: 4 µF	0,8 nF / m²
In-roof glass-glass module with aluminum frame	Plant 1: 100 kW	800 m²	Sunny afternoon: 2 µF	8 µF, 4 µF	5 nF / m²
	Plant 2: 50 kW	400 m²	Sunny afternoon: 0,5 µF	Rainy morning: 4 µF	2,5 nF / m²
Thin-film PV module on flexible substrate	Plant 1: 100 kW	800 m²	Sunny afternoon: 30 µF	Rainy morning: 50 µF	62,5 nF / m²
	Plant 2: 50 kW	400 m²	Sunny afternoon: 15 µF	Rainy morning: 25 µF	62,5 nF / m²

Protection of PV modules against reverse current

A short circuit in a PV module, faulty wiring, or a related fault may cause reverse current in PV strings. This occurs if the open-circuit voltage of one string is significantly different from the open voltage of parallel strings connected to the same inverter. The current flows from the healthy strings to the faulty one instead of flowing to the inverter and supplying power to the AC network. Reverse current can lead to dangerous temperature rises and fires in the PV module. PV module withstand capability should therefore be tested in accordance with IEC 61730-2 standard and the PV module manufacturer shall provide the maximum reverse current value (I_{RM}).



Reverse current in the faulty string = total current of the remaining strings String overcurrent protection is to be used if the total number of strings that could feed one faulty string is high enough to supply a dangerous reverse current: $1.35\ I_{RM} < (Ns - 1)\ I_{SC\ MAX}$
where:
- I_{RM} is the maximum reverse current characteristic of PV cells defined in IEC 61730
- Ns is the total number of strings
- $I_{SC\ MAX}$ is the maximum short-circuit current of PV string.

There is no risk of reverse current when there is only one string. When there are two strings with same number of PV modules connected in parallel, the reverse current will be always lower than the maximum reverse current. So, when the PV generator is made of one or two strings only there is no need for reverse current protection.

Protection against overcurrent

As in any installation, there should be protection against thermal effect of over current causing any danger.
Short-circuit current depends on solar irradiance, but it may be lower than the trip value of over current protection. Although this is not an issue for cables as the current is within current-carrying capacity, the inverter will detect a voltage drop and stop producing power. It is therefore recommended that the maximum trip current should be significantly lower than $I_{STC\ MAX}$.

String protection
Where string overcurrent protection is required, each PV string shall be protected with an overcurrent protection device.
The nominal overcurrent protection (Fuse or Circuit breaker) rating of the string overcurrent protection device shall be greater than 1,25 times the string short circuit current $I_{SC\ STC\_STRING}$

Array protection
The nominal rated trip current (ITRIP) of overcurrent protection devices for PV arrays (fuses or circuit breaker) shall be greater than 1,25 times the array short-circuit current $I_{SC\ STC\_ARRAy}$

The selection of overcurrent protection rating shall be done in order to avoid unexpected trip in normal operation taking into account temperature. A protection rating higher than 1.4 times the protected string or array short-circuit current I_{SC_STC} is usually recommended. Each fuses manufacturer provide rating selection recommendation. For Schneider Electric circuit breakers, see tables at the end of the document.

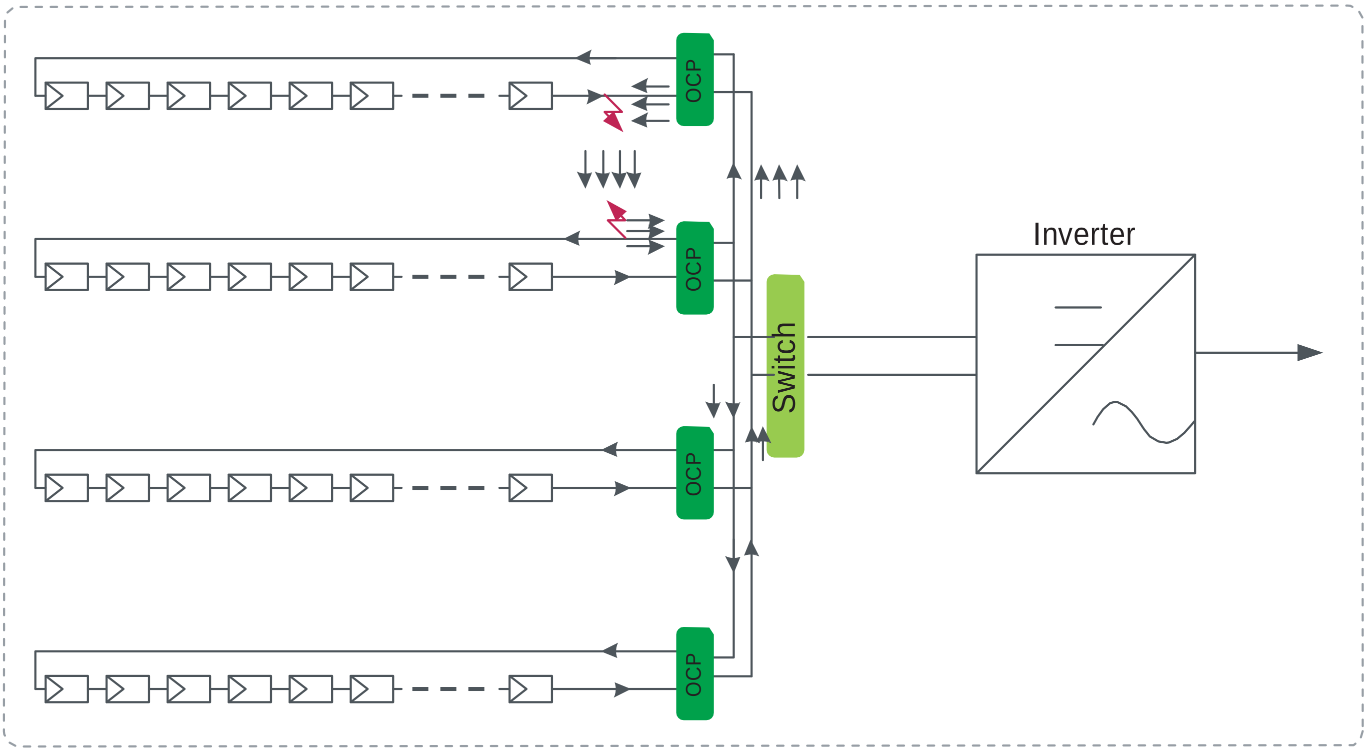
IEC 60364-712 on overload protection

712.433.1 Overload protection for the PV string and PV array cables may be omitted when the continuous current- carrying capacity of the cable is equal to or greater than 1.25 times I_{SC_STC} at any location.
712.433.2 Overload protection to the PV main cable may be omitted if the continuous current-carrying capacity is equal to or greater than 1.25 times I_{SC_STC} of the PV generator.

Circuit breakers or fuses

Circuit breakers or fuses can be used to provide overcurrent protection. Fuses, usually on the fuse holder or directly connected to bars or cables, do not provide a load-break switch function. So when fuses are used, load-break switches should also be used to disconnect fuses from the inverter in order to allow cartridge replacement. So an array box with fuses on fuse holders as string protection, for example, should also incorporate a main switch.
Circuit breakers offer finetuned adjustment and greater accuracy than fuses in order to allow the use of cables, especially for sub-array cables, that are smaller than fuses.

Double earth faults
PV systems are either insulated from the earth or one pole is earthed through an overcurrent protection. In both set-ups, therefore, there can be a ground fault in which current leaks to the ground. If this fault is not cleared, it may spread to the healthy pole and give rise to a hazardous situation where fire could break out. Even though double insulation makes such an eventuality unlikely, it deserves full attention.



For the two following reasons the double fault situation shall be absolutely avoided: Insulation monitoring devices or overcurrent protection in earthed system shall detect first fault and staff shall look after the first fault and clear it with no delay.

> The fault level could be low (e.g. two insulation faults or a low short-circuit capability of the generator in weak sunlight) and below the tripping value of overcurrent protection (circuit breaker or fuses). However, a DC arc fault does not spend itself, even when the current is low. It could be a serious hazard, particularly for PV modules on buildings.

> Circuit breakers and switches used in PV systems are designed to break the rated current or fault current with all poles at open-circuit maximum voltage ($U_{OC\ MAX}$). To break the current when $U_{OC\ MAX}$ is equal to 1000 V, for instance, four poles in series (two poles in series for each polarity) are required. In double ground fault situations, the circuit breaker or switches must break the current at full voltage with only two poles in series. Such switchgear is not designed for that purpose and could sustain irremediable damage if used to break the current in a double ground fault situation.

The ideal solution is to prevent double ground faults arising. Insulation monitoring devices or overcurrent protection in grounded systems detect the first fault. However, although the insulation fault monitoring system usually stops the inverter, the fault is still present. Staff must locate and clear it without delay. In large generators with sub-arrays protected by circuit breakers, it is highly advisable to disconnect each array when that first fault has been detected but not cleared within the next few hours.

Switchgear and enclosure selection

> Double insulation

The enclosures on the DC side shall provide double insulation.

> Thermal issues

The thermal behaviour of switchgear and enclosures warrants careful monitoring. PV generator boxes and array boxes are usually installed outdoors and exposed to the elements. In the event of high ambient temperatures, high IP levels could reduce air flow and thermal power dissipation.
In addition, the way switchgear devices achieve high voltage operation – i.e. through the use of poles in series – increases their temperature. Special attention should therefore be paid to the temperature of switchgear inside outdoor enclosures on the DC side.
Cable protection should comply with requirements of IEC 60364. Part 712 of the standard stipulates that all enclosures on the DC side should meet the requirements of IEC 61439. This standard covers low voltage switchgear and control gear assemblies and sets out requirements that guarantee the risk of temperature rises has been factored into the safe design of DC boxes (generator and array boxes).

> Pollution degree of switchgear and enclosure selection

In addition to the standard criteria for selecting enclosures in PV systems with $U_{OC\ MAX}$ of 1000 V, some equipment may show IEC 606947 - 1 Pollution Degree 2 rather than Pollution Degree 3.

If switchgear is Pollution Degree 2, the IP level of an enclosure according to IEC 60529 shall be at least IP5x.

The four degrees of pollution according to IEC60947-1 are set out in Chapter 6.1.3.2 of the standard

Pollution Degree 1:
No pollution or only dry, non-conductive pollution occurs.

Pollution Degree 2:
Normally, only non-conductive pollution occurs. Occasionally, however, a temporary conductivity caused by condensation may be expected.

Pollution Degree 3:
Conductive pollution occurs, or dry, non-conductive pollution occurs which becomes conductive due to condensation.

Pollution Degree 4:
The pollution generates persistent conductivity caused, for instance, by conductive dust or by rain or snow.

Protection against overvoltage: 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.

Protection by equipotential bonding

The first safeguard to put in place is a medium (conductor) that ensures equipotential bonding between all the 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.

Protection by surge protection devices (SPDs)

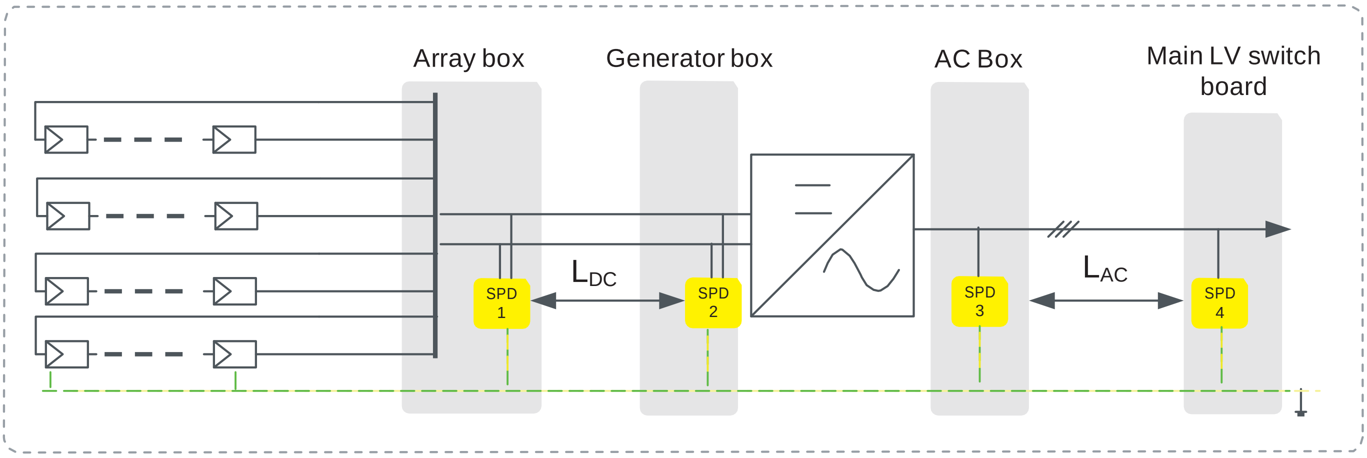
SPDs are particularly important to protect sensitive electrical equipments like AC/DC Inverter, monitoring devices and PV modules, but also other sensitive equipments powered by the 230 VAC electrical distribution network. The following method of risk assessment is based on the evaluation of the critical length L_{crit} and its comparison with L the cumulative length of the d.c. lines.

SPD protection is required if L ≥ Lcrit.
L_{crit} depends on the type of PV installation and is calculated as the following table sets out:

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

L is the sum of:
• the sum of distances between the inverter(s) and the junction box(es), taking into account 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.

Ng is arc lightning density (number of strikes/km²/year).

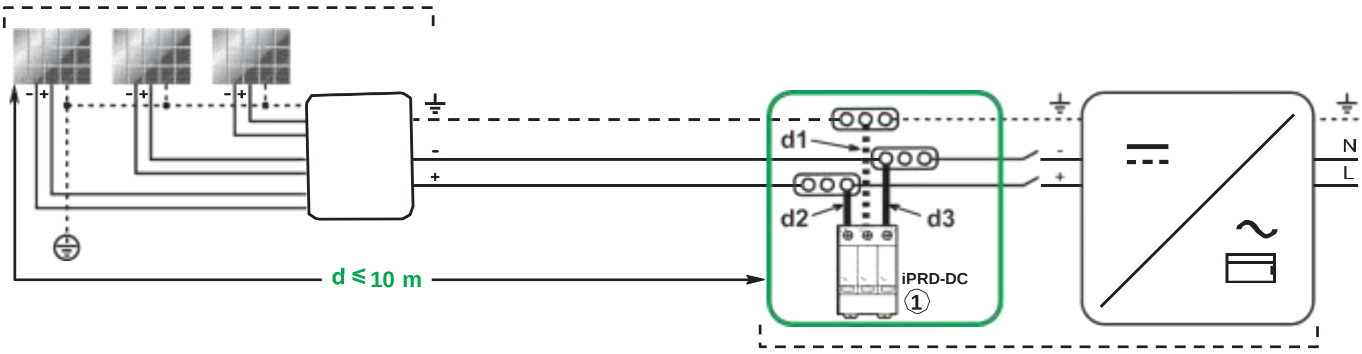


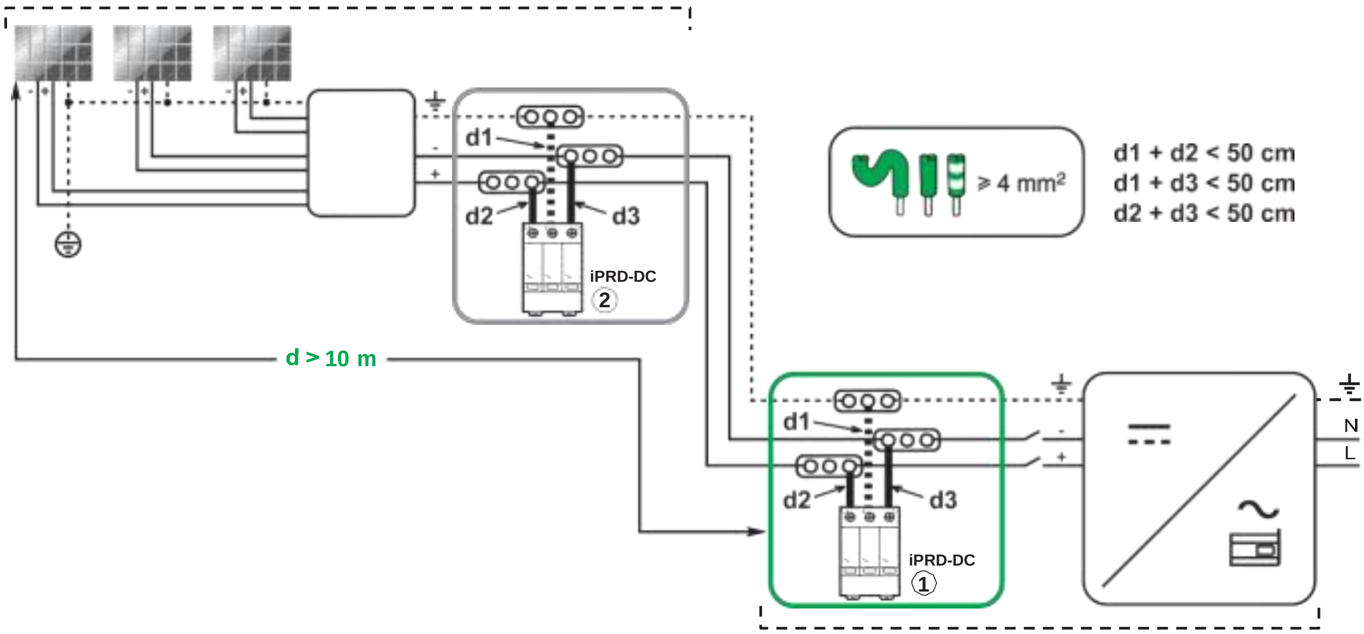
SPD Protection							
Location	PV modules or Array boxes		Inverter DC side	Inverter AC side		Main board	
	L_{DC}			L_{AC}		Ligthning rod	
Criteria	<10 m	>10 m		<10 m	>10 m	yes	No
Type of SPD	No need	"SPD 1" Type2*	"SPD 2" Type2*	No need	"SPD 3" Type 2	"SPD 4" Type 1	"SPD 4" Type 2 if Ng > 2,5 & overhead line

** Type 1 if separation distance according to EN 62305 is not observed.*

Installing an SPD
The number and location of SPDs on the DC side depend on the length of the cables between the solar panels 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 panel, the first one is located in the inverter area.
To be efficient, SPD connection cables to the L+ / L- network and between the SPD's earth terminal block and ground busbar must be as short as possible – less than 2.5 metres (d1+d2<50 cm).

Depending on the distance between the «generator» part and the «conversion» part, it may be necessary to install two surge arresters or more, to ensure protection of each of the two parts.



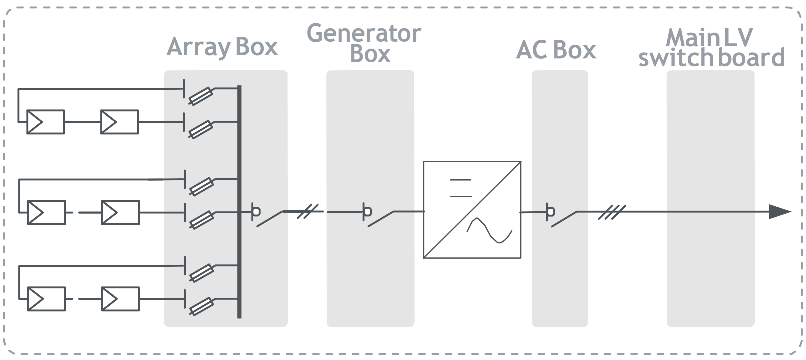


How to ensure safety during maintenance or emergency

To ensure staff safety during maintenance and emergencies disconnect devices should be appropriately located and enclosures installation should be failsafe.

Isolation switching and control

- The switch disconnectors on the AC side and DC side of the inverter shall be installed for inverter service and maintenance.

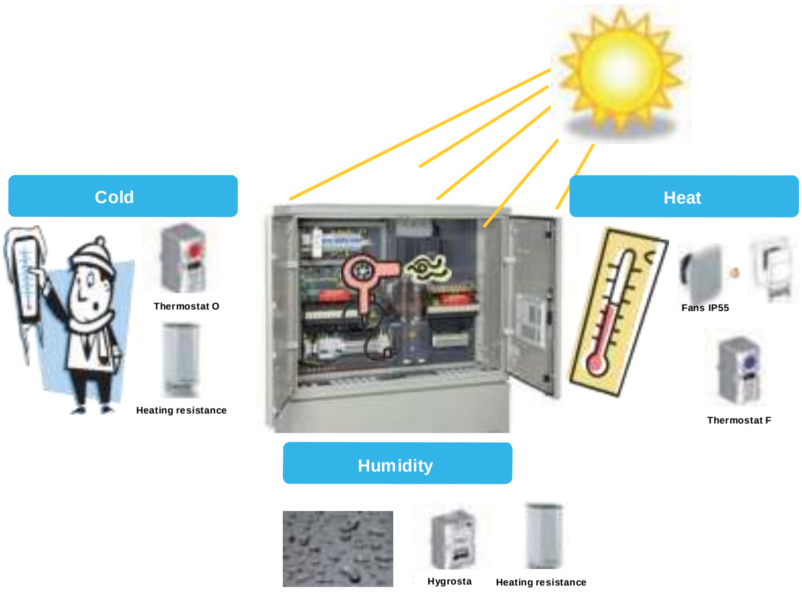


• As many switch disconnectors should be installed as are needed to allow operation on the PV generator, particularly to replace fuses in the array boxes and generator junction boxes.

• For PV systems inside buildings, a remotely-controlled switch disconnector should be mounted as closely as possible to the PV modules or to the point of entry of DC cables in the event of an emergency.

Selecting and installing enclosures

Enclosures for different PV generator boxes and switch boards on the DC side need to ensure double isolation, equipment protection against such outdoor hazards as temperatures, the rain, vandalism, and shock.
Enclosure and their ancillary equipment must ensure temperature and moisture control to allow equipment to operate smoothly. It is, however, difficult to propose a generic solution. Each installation needs to be analysed in order to optimize the sizing of its enclosures and ancillary equipment.
Schneider Electric provides customers with full support for selecting the enclosure and accessories that best fit their purpose.



Thermal risks and heating / cooling solution shall be studied

> Switches used in PV systems are designed to break the rated current of all poles at $U_{OC\ MAX}$. To break the current when $U_{OC\ MAX}$ is equal to 1000 V, for instance, four poles in series (two poles in series for each polarity) are required. In double ground fault situations, the circuit breaker or switch must break the current at full voltage with only two poles in series. Such switchgear is not designed for that purpose and could sustain irremediable damage if used to break the current in a double ground fault situation. For this reason double ground faults must be avoided at all costs.
> Insulation monitoring devices or overcurrent protection in grounded system detect the first fault. Staff shall locate it and clear it without delay.

1.4. How to ensure safety during all the life cycle of the installation

IEC60364-6 requires initial and periodic verifications of electrical installations. Specificities of photovoltaic installation (outdoor, high DC voltage, unsupervised installation) make periodic checking very important.
If usually the efficiency of all the system is checked in order to ensure the maximum production, we recommend to perform periodic maintenance of equipment.
PV system operating conditions involve various environmental stresses: wide temperature variations, humidity, and electrical stresses. In order to ensure performances of equipment during all the life cycle of installation, particular attention shall be paid to the following:
• Enclosure integrity (double isolation IP level)
• Switchgears operating condition and integrity
  - to evaluate if any overheating has occurred
  - to examine switchgears for the presence of dust, moisture, etc.
• Visual check of electrical connections
• Functional test of equipment and auxiliaries
• Insulation monitoring device test
• Insulation resistance test

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2 Products & enclosure selection according to architectures

It is the responsibility of the designer to check electrical performances according to the actual installation (especially voltage and thermal current).

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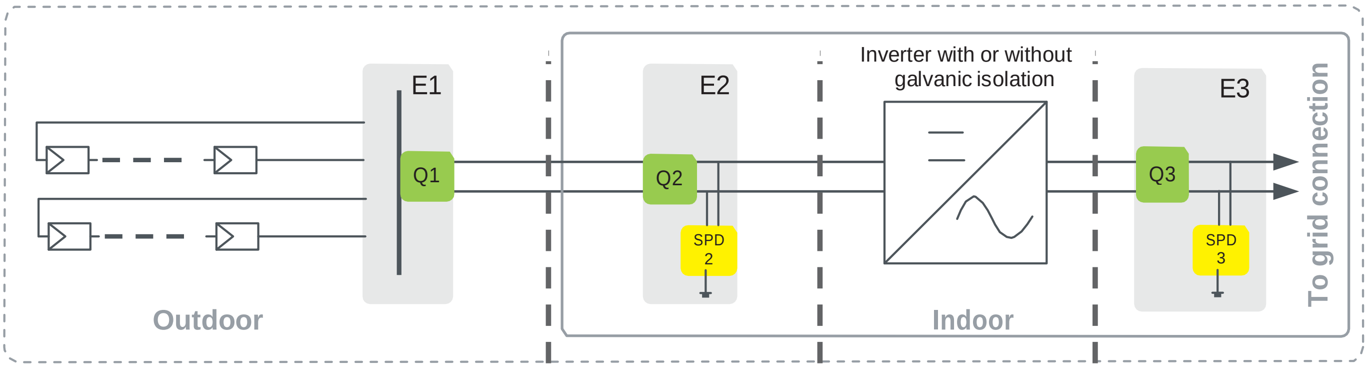
2.1. Grid-connected PV system ≤ 10 kW (residential)

2.2.1. One single phase inverter

Typically, a 5 kW grid-connected single-phase inverter, $U_{OC\ MAX} \leq 600$ V, one or two strings, $I_{sctc} < 25$ A, $I_{AC} < 32$ A. In this design there is no string protection. A PV main switch is necessary. When the inverter is indoors, an additional remote-controlled switch at the DC cable entry point is recommended for emergency services.



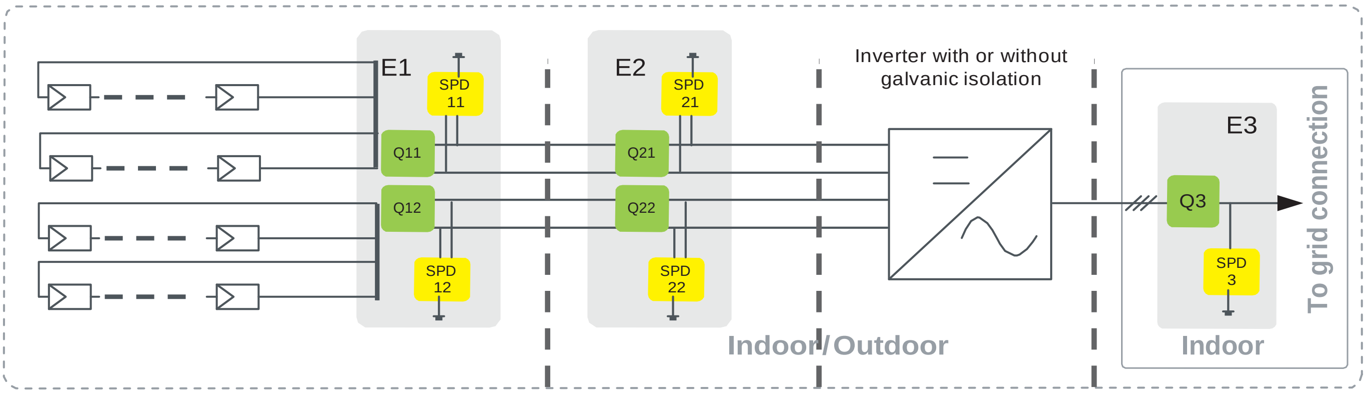
	String junction box	PV main switch	Inverter	AC box (230 V P/N)
Switchgears and control				
Needs				
Isolation	●	● (d)	(a)	● (d)
Switching (Making & breaking rated current)	● DC21B	● (d) DC21B	(a)	● (d)
Control	● (b)	● (d)	(e)	● (d)
Over-current	(c)			● (f)
Protection against Insulation fault			(h)	(h) RCD type B or A SI
Schneider Electric offer	"Q1" C60NA DC + MX / MN	"Q2" INS PV or C60NA DC		"Q3" DPN Si PV
Surge protection				
Needs		● type 2		● type 1 or 2
Schneider Electric offer		"SPD2" PRD 40r 600DC		"SPD3" Quick PF or Quick PRD 1P+N
Enclosure				
Needs	Outdoor Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Schneider Electric offer	"E1" Thalassa PLM	"E2" Thalassa PLM		"E3" Kaedra, Pragma, etc.
Measure				
Needs			Inverter relevant parameters	Energy
Schneider Electric offer				iEM2000

(a) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.
(b) Remote switching for emergency services located as closely as possible to the PV modules or to the point of entry of DC cables in the building.
(c) No protection is required when the number of strings does not exceed 2.
(d) Service and emergency switching
(e) The inverter shall include an islanding protection system (in accordance with standard VDE0126, for example)
(f) Overload and short-circuit protection B curve recommended.
(g) This SPD could be unnecessary if there is another SPD in the AC installation at a distance of less than 10 metres.
(h) If the inverter provides no galvanic separation a RCD protection is necessary on AC side. IEC 60364-712 specifies RCD type B Some local regulations require RCD type A SI.

10 kW-100 kW grid-connected PV system (small buildings)

Three-phase multi-input inverter without array box

Typically, 10 kW to 36 kW grid-connected inverters with $U_{OC\ MAX}$ probably higher than 600 V (i.e. 800 V or 1000 V) and I_{SCTC} < 125 A, I_{AC} < 63 A. In this range of power, inverters usually have between 2 and 4 maximum power point tracking (MPPT) inputs, so the number of strings in the same DC sub-network is equal to one or two. There is no need for string protection. A PV main switch for each MPPT input is necessary. When an inverter is indoors, additional remote-controlled switches at DC cable entry point are recommended for emergency services.

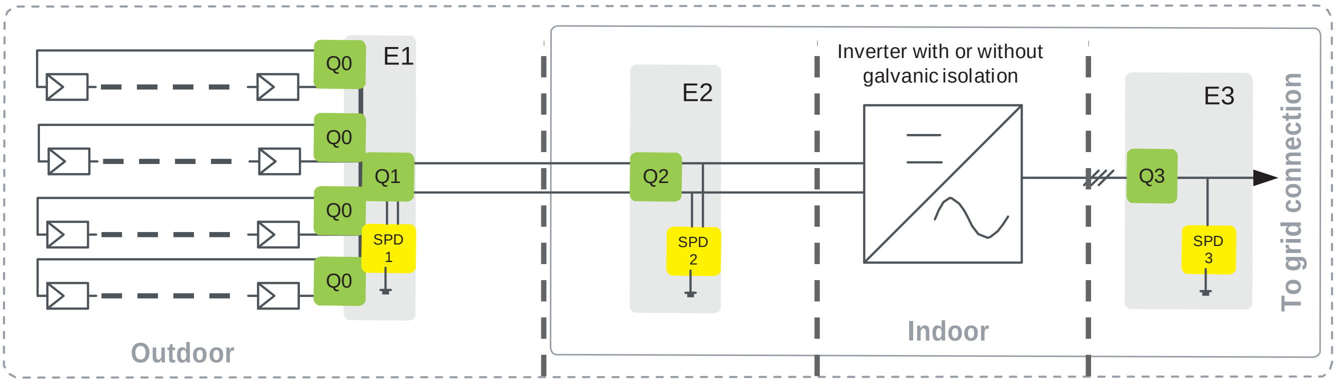


	String junction box	PV main switch	Inverter	AC box (400 V)
Switchgears and control				
Needs				
Isolation	●	● (d)	(a)	● (d)
Switching (Making & breaking rated current)	● DC21B	● (d) DC21B	(a)	● (d)
Control	● (b)	● (d)	(e)	● (d)
Over-current	(c)			● (f)
Protection against Insulation fault			(h)	(h) RCD type B or A SI
Schneider Electric offer	"Q1" 1-Q12 C60NA DC + MX / MN	"Q2" INS PV or C60NA DC		"Q3" iC60+RCCB-ID B type or Vigi SI
Surge protection				
Needs		● type 2		● type 1 or 2
Schneider Electric offer	"SPD1" 1-12 PRD 40r 600DC or 1000DC	"SPD2" 1-22 PRD 40r 600DC or 1000DC		"SPD3" Quick PF or Quick PRD 3P+N
Enclosure				
Needs	Outdoor Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Schneider Electric offer	"E1" Thalassa PLM	"E2" Thalassa PLM		"E3" Pragma or Thalassa
Measure				
Needs			Inverter relevant parameters	Energy
Schneider Electric offer				iEM3100 or iEM3110 MID compliant

(a) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.
(b) Remote switching for emergency services located as closely as possible to the PV modules or to the point of entry of DC cables in the building.
(c) No protection is required when the number of string does not exceed 2.
(d) Service and emergency switching
(e) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)
(f) Overload and short-circuit protection (B curve recommended).
(g) If there is no SPD in the inverter or if the distance between DC box and inverter exceeds 10m a SPD is necessary in this box.
(h) - If the inverter provides no galvanic separation a RCD protection is necessary on AC side. IEC 60364-712 specifies
RCD type B Some local regulations require RCD type A SI
- If the inverter provides at least simple separation
o Without functional earthing: insulation monitoring is necessary, it's usually done by the inverter in this range of power.
o With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

Three-phase inverter with one array box

Typically, 30 kW to 60 kW grid-connected inverters. $U_{OC\ max}$ is generally higher than 600 V (up to 1000 V), I_{SCTC} does not exceed 200 A, I_{AC} does not exceed 100 A. This design has more than 2 strings. Reverse current protection is therefore necessary. A main PV switch is required. When an inverter is inside, additional remote-controlled switches at DC cable entry point are recommended for emergencies.

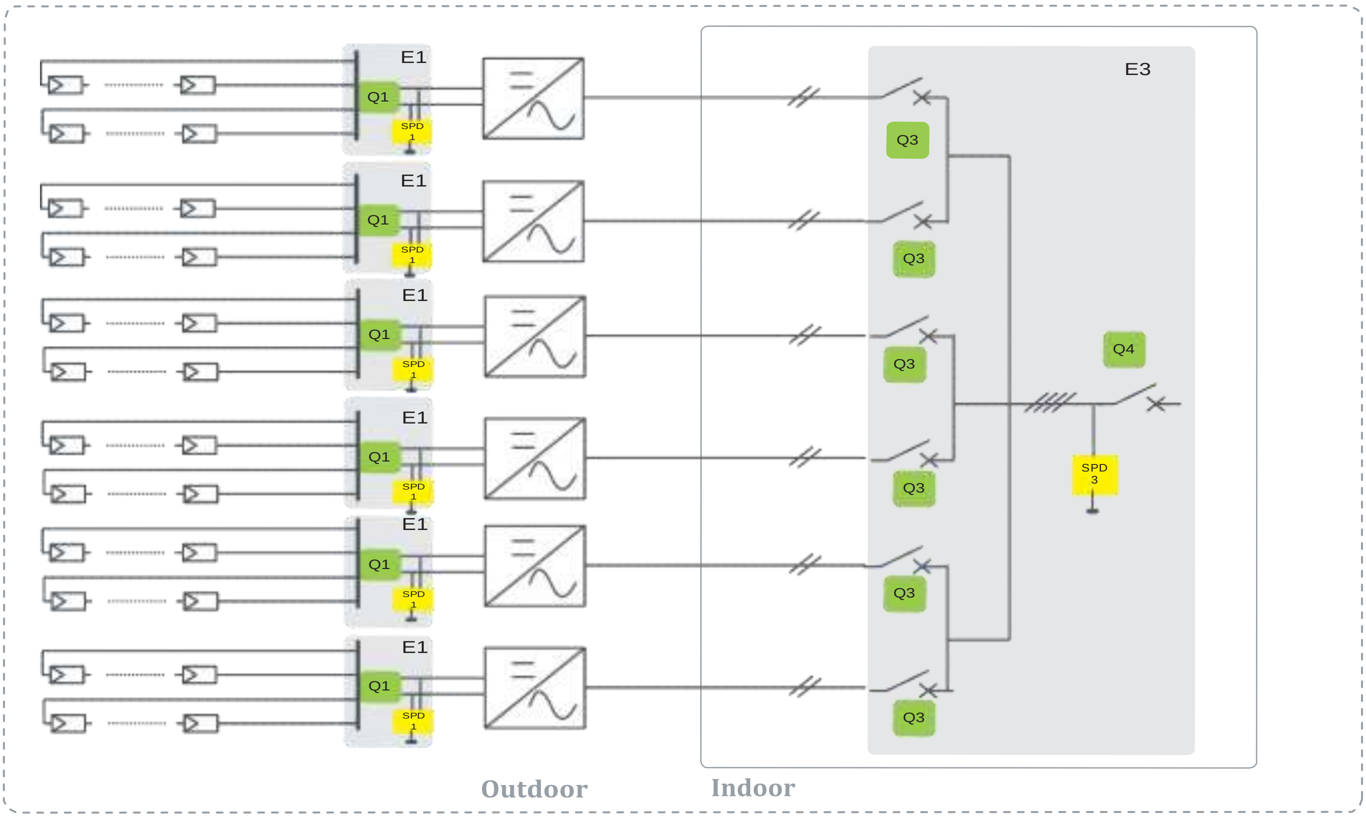


	String / Array junction box	PV array main switch	Inverter	AC box (400 V)
Switchgears and control				
Needs				
Isolation	●	● (d)	(a)	● (d)
Switching (Making & breaking rated current)	● DC21B	● (d) DC21B	(a)	● (d)
Control	● (b)	● (d)	(e)	● (d)
Over-current	●			● (f)
Protection against Insulation fault			(h)	(h) RCD type B or A SI
Schneider Electric offer	"Q0" TeSys DF "Q1" Compact NSX DC PV + MX / MN	"Q3" Compact NSX DC PV	(a)	"Q3" iC60 or Compact NSX
Surge protection				
Needs	(g)	● type 2		● type 1 or 2
Schneider Electric offer	"SPD1" PRD 40r 600DC or 1000DC	"SPD2" PRD 40r 600DC or 1000DC		"SPD3" Quick PF or Quick PRD 3P+N
Enclosure				
Needs	Outdoor IP5x Double insulation	Indoor IP5x Double insulation		Standard AC requirement + grid code requirement
Schneider Electric offer	"E1" Thalassa PLA	"E2" Thalassa PLM		"E3" Prisma
Measure				
Needs				P, Q, PF, Energy
Schneider Electric offer				Micrologic E on NSX circuit breaker or PM3250 (DIN), PM750 (flush mounting), iEM3255 MID compliant

(a) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.
(b) Remote switching for emergency services located as closely as possible to the PV modules or to the point of entry of DC cables in the building. The main switch in array box can be equipped with tripping coil and motor mechanism for remote reclosing for that purpose.
(d) Service and emergency switching
(e) The inverter shall include a protective device against islanding (in accordance with standard VDE 0126, for example).
(f) Overload and short-circuit protection (B curve recommended).
(g) If the inverter has no SPD or the distance between the DC box and inverter exceeds 10 m, the junction box requires an SPD.
(h) - If the inverter provides no galvanic separation a RCD protection is necessary on AC side. IEC 60364-712 specifies RCD type B Some local regulations require RCD type A SI
- If the inverter provides at least simple separation
o Without functional earthing: insulation monitoring is necessary
o With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

Multi single-phase inverter design

Typically, 6x5 to 20x5 kW grid-connected inverters. The design used for residential building can be duplicated as often as necessary. In that case, the DC system is very simple and the AC system is very similar to the usual AC systems.



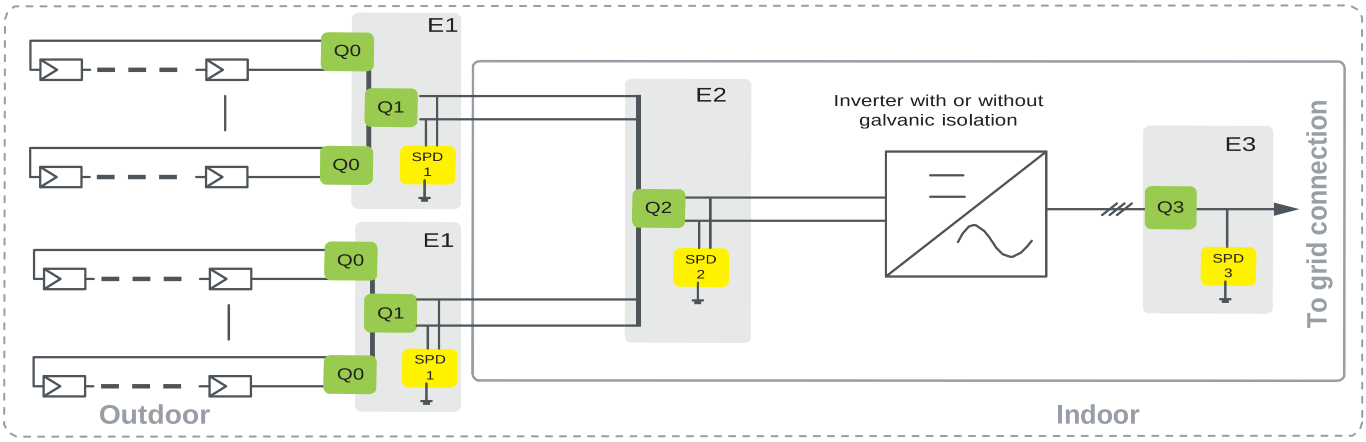
	PV main switch	Inverter		AC box (400 V)
Switchgears and control				
Needs	See 5 kW design			
Schneider Electric offer	"Q1" C60 NA DC-PV + MX / MN		"Q3" iC60N curve B + Vigi (h)	"Q4" Compact NSX
Surge protection				
Needs	type 2			type 1 or 2
Schneider Electric offer	"SPD1" PRD 40r 600DC			"SPD3" Quick PF or Quick PRD 3P+N
Enclosure				
Needs	Outdoor Double insulation			Standard AC requirement + grid code requirement
Schneider Electric offer	"E1" Thalassa PLM			"E3" Prisma
Measure				
Needs			Energy	P, Q, PF, Energy, unbalance
Schneider Electric offer			iEM2010 for each inverter	Micrologic E on NSX circuit breaker or PM3250 (DIN), PM750 (flush mounting) iEM3255 MID compliant

Compact NSX with Micrologic trip unit ensures full selectivity for iC60 up to 40 A and offers advanced measurement and communication capabilities.

(h) If the inverter provides no galvanic separation a RCD protection is necessary on AC side. IEC 60364-712 specifies RCD type B Some local regulations require RCD type A SI

Three-phase inverter with two array boxes (Na ≤ 2)

Typically, 60 kW to 100 kW grid-connected inverters with 2 arrays. Array cable protection is not necessary for 2 or 3 arrays. The I_{SCTC} array ≤ 200 A, I_{SCTC} ≤ 400 A, and I_{max} AC ≤ 200 A. A PV main switch is required close to the inverter. Remotely operated switches in array boxes allow disconnects to be located close to the PV modules in the event of emergencies.



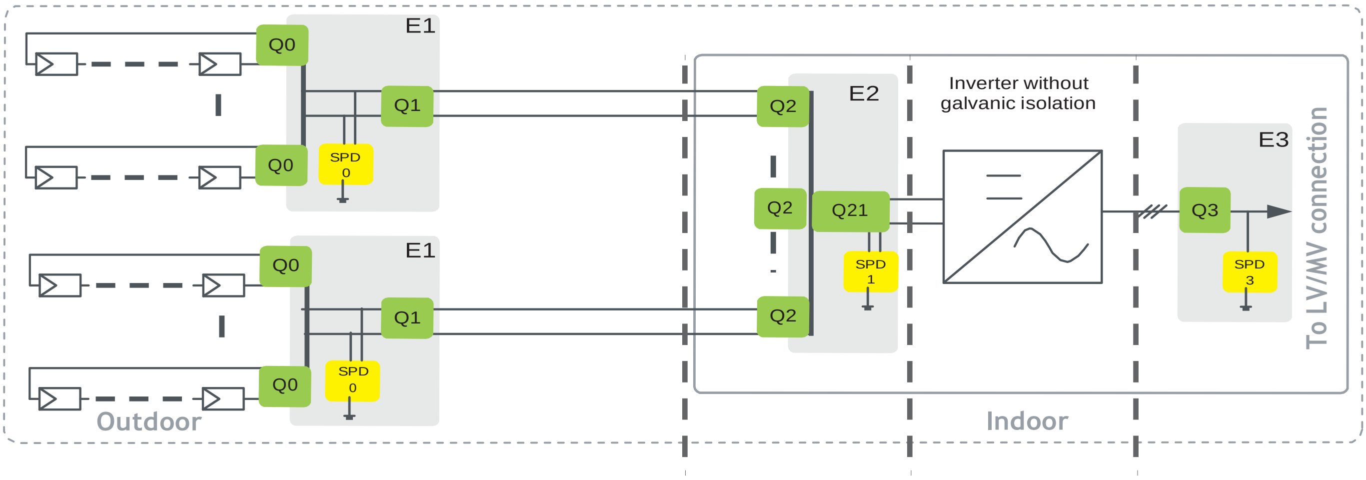
	String	Array junction box	PV generator main switch	Inverter	AC box 400 V or other voltage (Transfoless inverter)
Switchgears and control					
Needs					
Isolation	●	●	● (d)	(a)	● (d)
Switching (Making & breaking rated current)		● DC22A	● (d) DC22A	(a)	● (d)
Control		● (b)	● (d)	● (e)	● (d)
Over-current	●		(c)		● (f)
Protection against Insulation fault			(h)		(h) RCD type B or A SI
Schneider Electric offer	"Q0" TeSys DF	"Q1" Compact NSX NA DC PV	"Q3" Compact NSX NA DC PV	(a)	"Q5" Compact NSX
Surge protection					
Needs		(g)	● type 2		● type 1 or 2
Schneider Electric offer			"SPD1" PRD 40r 1000DC		Quick PF or Quick PRD 3P+N
Enclosure					
Needs		Outdoor IP5X Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Schneider Electric offer		"E1" Thalassa PLA	"E2" Thalassa PLM		"E3" Prisma
Measure					
Needs		Energy			P, Q, PF, Energy
Schneider Electric offer					Micrologic E on NSX circuit breaker or PM3250(DIN) PM750 (flush mounting), iEM3255 MID compliant

(a) PV array main switch could be included in the inverter. This solution makes inverter service or replacement more difficult.
(b) If emergency service switching is required, switches in array boxes can be equipped with tripping coils and motor mechanisms for remote reclosing.
(c) No protection is required when the number of arrays does not exceed 3, as there is no cable sizing benefit.
(d) Service and emergency switching.
(e) Disconnect for protection against islanding.
(f) Overload and short-circuit protection.
(g) If the inverter has no SPD or the distance between the DC box and inverter exceeds 10 m, the junction box requires an SPD.
(h) - If the inverter provides no galvanic separation a RCD protection is necessary on AC side. IEC 60364-712 specifies RCD type B Some local regulations require RCD type A SI
- If the inverter provides at least simple separation
o Without functional earthing: insulation monitoring is necessary
o With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

150 kW to 500 kW grid-connected PV system (large buildings and farms)

Three-phase inverter with more than two array boxes

Typically, 150 kW to 500 kW single inverter. This design is very similar to the previous one except that it has more arrays, which requires array cable protection. $I_{STC} \leq 400$ A, $I_{AC} \leq 1600$ A.

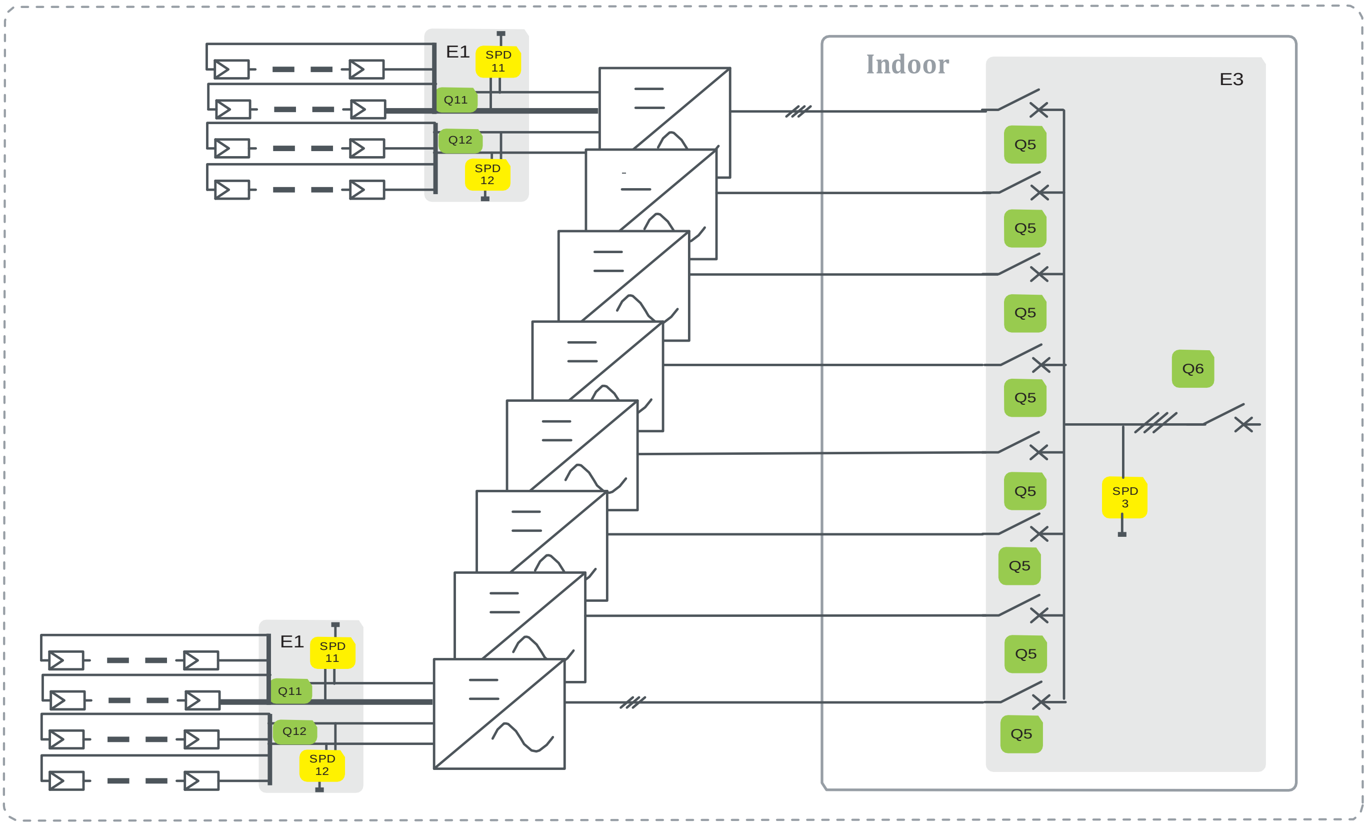


	String	Array junction box	Generator junction box	Inverter	AC box 400 V or other voltage (Transfoless inverter)
Switchgears and control					
Needs					
Isolation	●	●	●	●	● (d)
Switching (Making & breaking rated current)		● DC22A	● DC22A	● (a)	● (d)
Control		● (b)		● (a)	● (d)
Over-current	●		(c)		● (f)
Protection against Insulation fault			● (h)	● (h)	● (h)
Schneider Electric offer	"Q0" TeSys DF	"Q1" Compact NSX NA DC PV	"Q2" Compact NSX DC PV		"Q5" Masterpact or Compact NS
Surge protection					
Needs		(g)	● type 2		● type 1 or 2
Schneider Electric offer			"SPD1" PRD 40r 1000DC		Quick PF or Quick PRD 3P+N
Enclosure					
Needs		Outdoor IP5X Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Schneider Electric offer		"E1" Thalassa PLA	"E2" Thalassa PLM		"E3" Prisma
Measure					
Needs		Energy			P, Q, PF, Energy, Alarm, THD, individual harmonics
Schneider Electric offer					Micrologic E/H on Masterpact or PM820

(a) PV array main switch could be included in the inverter. This solution makes inverter service or replacement more difficult.
(b) If switching for emergency services is required, the main switch in array box can be equipped with tripping coil and motor mechanism for remote reclosing.
(c) Array cable protection is recommended to prevent cable oversizing. To ensure protection is tripped fast, 6 to 8 arrays are recommended.
(d) Protection against islanding, e.g. VDE 0126.
(e) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)
(f) Overload and short-circuit protection.
(g) If the inverter has no SPD or the distance between the DC box and inverter exceeds 10 m, the junction box requires an SPD.
(h) If the inverter is not galvanically insulated, RCD protection is necessary on the AC side. IEC 60364 712 requires a B-type trip curve. If inverter provides at least simple separation
- PV system without functional earthing: insulation monitoring is necessary: IMD - IM20 and accessory IMD-IM20-1700
- PV system With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

Multi three-phase inverter design without array box

Typically, 10x20 to 20x30 kW grid-connected inverters. $U_{OC\,MAX} \leq 1000$ V. One or two string per inverter. $I_{AC\,MAX}$ 50 A for one inverter.

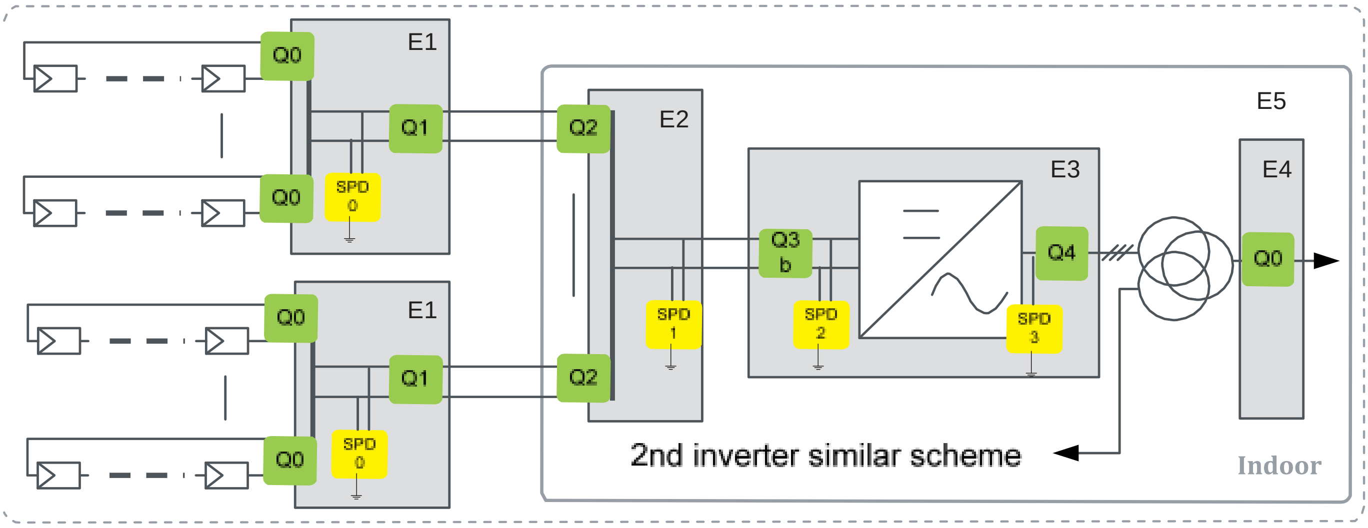


String / Array junction box			AC Combiner Box	
Switchgears and control				
Needs	See 10 to 36 kW design			
Schneider Electric offer SW60DC	C60NA DC		"Q5" iC60 + RCD type B or A SI	"Q6" Compact NSX 100-630A
Surge protection				
Needs	type 2			type 1 or 2
Schneider Electric offer	"SPD21-22" PRD 40r 600DC or 1000DC			"SPD3" Quick PF or Quick PRD 3P+N
Enclosure				
Needs	Outdoor IP5x Double insulation			Standard AC requirement + grid code requirement
Schneider Electric offer	"E1" Thalassa PLA			"E3" Pragma, Prisma
Measure				
Needs			P, Q, Energy	P, Q, PF, Energy, Alarm
Schneider Electric offer			P, Q, Energy	Micrologic E on Compact NSX or Masterpact or PM810 / 820

Compact NSX with Micrologic trip unit ensures full selectivity with iC60 up to 40 A and offer advanced measurement and communication capabilities.

2.4. Multi MW grid-connected PV system (large buildings and farms)

Typically, 500 kW to 630 kW inverters with LV/MV transformers and MV substation.



	String	Array junction box	Generator junction box	Inverter	AC box 400 V or other voltage (Transfoless inveter)
Switchgears and control					
Needs					
Isolation	●	●	● (a)	See page 24	●
Switching (Making & breaking rated current)		● DC22A	● (a)	See page 24	●
Control		● (b)		See page 24	●
Over-current	●		● (c)	See page 24	● (f)
Protection against Insulation fault				See page 24	
Schneider Electric offer	“Q0 ” TeSys DF	“Q1” Compact NSX NA DC PV	“Q2” Compact NSX DC PV	See page 24	“Q5” Medium Voltage equipment
Surge protection					
Needs		(g)	● type 2	(g)	● type 1 or 2
Schneider Electric offer			“SPD1/2” PRD 40r 1000DC	“SPD3”PRD40r 1000DC Quick PRD 3P+N	
Enclosure					
Needs		Outdoor IP5X Double insulation	Indoor Double insulation (i)		
Schneider Electric offer		“E1” Thalassa PLA	“E2” Thalassa PLA	“E3” Spacial SF&SM	“E5” Prefabricated substation
Measure					
Needs		Energy			P, Q, PF, Energy, Alarm, Power, quality
Schneider Electric offer					ION7650/PM870

(a) PV array main switch is usually included in the inverter panel.
(b) If switching for emergency services is required, the main switch in array box can be equipped with tripping coil and motor mechanism for remote reclosing.
(c) Array cable protection is recommended to prevent cable overszing. To ensure fast trip of protections 6 to 8 arrays are recommended.
(f) Overload and short-circuit protection.
(g) If there is no SPD in the inverter or if the between DC box and inverter >10m a SPD is necessary in this box.
(h) Galvanic insulation is provided by LV/MV transformer,
- PV system without functional earthing: insulation monitoring is necessary: IMD - IM20 and accessory IMD-IM20-1700
- PV system With functional earthing: the earthing shall be done with a DC MCB breaker

(C60PV 4P series 2 – 10A) or a fuse.

3 Additional information for large centralized inverter (100 – 630 kW)

Usually large inverters are embedding protection and control switchgear on DC side and AC side.

DC side:

For service and protection a switchgear providing isolation, switching and control is necessary on DC side.
Several options could be used: motor operated switch-disconnector or contactor + switch disconnector.
Switchgear shall be design to withstand $I_{TH} \geq 1,25\ I_{SCTC}$ total.
The number of operation is usually low (≤ 1 open/close per day)

Schneider Electric can provide TeSys B bar contactor or Masterpact NW20HA DC-D PV with motor mechanism for remote operation.

Insulation monitoring device IMD - IM20 and accessory IMD-IM20-1700 for 1000 V has been tested and show reliable performance in PV system.

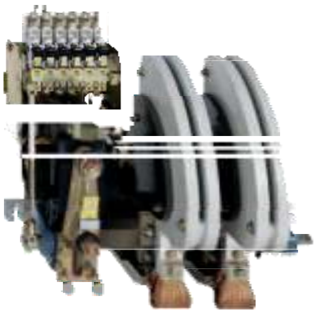
AC side:

For service and protection a switchgear providing isolation, switching and control is necessary on AC side.
Several options could be used: Contactor + fuse - switch or contactor + circuit breaker.
Overcurrent protection could be located outside of the inverter but in that case it shall be coordinated with switch disconnector and/or contactor inside the inverter.
Schneider Electric can provide TeSys F range up to 2100 A AC1 contactor and AC range of Compact or Masterpact protection.

Enclosure:

Schneider Electric propose steel floor-standing solution (Spacial SF & SM).
In order to go to the reference level we have a product selector software (Digital Rules) that helps to define the enclosure and all the accessories.

Masterpact NW DC air circuit breaker



TeSys B bar contactor

TeSys F AC1 contactor

IDM-IM20 insulation monitoring device

4 Detailed characteristics of DC-PV switchgear

DC-PV switch disconnectors

$U_{oc\ max}$	I_F	$I_{SCTC\ MAX}$ (Tmin = -25°)	kWc (Indicative)	Range	Product	Required Series connection	Prefabricated series connection	IP
400 V	32	25,6	4	Interpact	INS PV1	2x2p	No	IP0/IP2X opt.
500 V	25	20	4	Interpact	INS PV1	2x2p	No	IP0/IP2X opt.
600 V	10	8	2	Interpact	INS PV1	2x2p	No	IP0/IP2X opt.
700 V	50	40	12 Acti 9		C60NA-DC	2x2p	included	IP0/IP2X opt.
800 V	32	25,6	9 Acti 9		C60NA-DC	2x2p	included	IP0/IP2X opt.
1000 V	20	16	7 Acti 9		C60NA-DC	2x2p	included	IP0/IP2X opt.
1000 V	50	40	18 Acti 9		SW60	2x2p	included	IP0/IP2X opt.
1000 V	100	80	36	Compact	NSX100NA DC PV	2x2p	0	IP0/IP2X opt.
1000 V	160	128	60	Compact	NSX100NA DC PV	2x2p	0	IP0/IP2X opt.
1000 V	200	160	75	Compact	NSX100NA DC PV	2x2p	0	IP0/IP2X opt.
1000 V	400	320	150	Compact	NSX100NA DC PV	2x2p	0	IP0/IP2X opt.
1000 V	500	400	180	Compact	NSX100NA DC PV	2x2p	0	IP0/IP2X opt.
1000 V	2000	1600	700	Masterpact	NW20 HA DCD-PV 3P	2+1P	included	IP0
1000 V	4000	3200	1400	Masterpact	NW20 HA DCD-PV 3P	2+1P	included	IP0


C60 NA-DC


SW 60


Interpact INS PV1

U_{IMP}	Degree of pollution	Utilization category	Mechanical durability	Electrical durability	$I_{E MAX}$	I_{TH} 25°	I_{TH} 40°	Polarised	Suitability for isolation
8 kV	III	DC21B	1 700	300	32	32	32	NO	yES
8 kV	III	DC21B	1 700	300	25	32	32	NO	yES
8 kV	III	DC21B	1 700	300	10	32	32	NO	yES
6 kV	II	DC21B	20 000	300		50	40	NO	yES
6 kV	II	DC21B	20 000	300		50	40	NO	yES
6 kV	II	DC21A	20 000	1 500		50	40	NO	yES
6 kV	II	DC21A	20 000	1 500		50	50	yES	yES
8 kV	III	DC22A	50 000	1 500			100	NO	yES
8 kV	III	DC22A	50 000	1 000			160	NO	yES
8 kV	III	DC22A	40 000	1 000			200	NO	yES
8 kV	III	DC22A	15 000	1 000			400	NO	yES
8 kV	III	DC22A	15 000	1 000			500	NO	yES
12 kV	IV	DC23A	10 000	2 000			2000	NO	yES
12 kV	IV	DC23A	10 000	2 000			4000	NO	yES

Compact NSX 200 NA DC PV

Masterpact NW 20 HA DCD-PV

DC-PV switch disconnectors - accessories

Range	Product	Reference (without accesories)	Serial connection for poles	Top terminal shields	Bottom terminal shields
Interpact	INS PV1	28907		●	●
Acti 9	C60NA-DC	A9N61690	Included	●	●
Acti 9	SW60	A9N61690	Included	●	●
Compact	NSX100NA DC PV	LV438100	Mandatory 2x LV438328	LV438327 or Interphase barrier 1x LV429329	LV429518 or Interphase barriers 3x LV429329
Compact	NSX160NA DC PV	LV438160	Mandatory 2x LV438328	LV438327 or Interphase barrier 1x LV429329	LV429518 or Interphase barriers 3x LV429329
Compact	NSX200NA DC PV	LV438250	Mandatory 2x LV438328 or 2X LV438339	LV438327 or Interphase barrier 1x LV429329	LV429518 or Interphase barriers 3x LV429329
Compact	NSX400NA DC PV	LV438300	Mandatory 2x LV438338	LV438337 or Interphase barrier 1x LV432570	LV432594 or Interphase barriers 3x LV432570
Compact	NSX500NA DC PV	LV438500	Mandatory 2x LV438338	LV438337 or Interphase barrier 1x LV432570	LV432594 or Interphase barriers 3x LV432570
Masterpact	NW20 HA DCD-PV 3P	Consult us			
Masterpact	NW20 HA DCD-PV 3P	Consult us			

MN/MX remote opening accessory for Acti 9 range

MCH remote O/C accessory for Masterpact range

Direct rotary handle accessory for Compact NSX range

Level /Togle	Direct front rotaryhandle	Extended front rotary handle	Remote opening	Remote open / close	Aux.contacts
	●	●			●
●			●		●
●			●		●
●	●	●	●	●	●
●	●	●	●	●	●
●	●	●	●	●	●
●	●	●	●	●	●
●	●	●	●	●	●
		●	●	●	OF
			●	●	OF

Extended rotary handle accessory for Compact NSX range

DC-PV switch disconnectors – temperature de-rating

Range	Product	IP	Bottom interphase barrier	Bottom terminal shield	Top interphase barrier	Top terminal shield
Interpact	INS PV1					
Acti 9	C60NA-DC					
Compact	NSX100NA DC PV 4P	IP0	3 (LV429329)	No	1 (LV429329)	No
Compact	NSX100NA DC PV 4P	IP4X	No	LV429518	No	LV438327
Compact	NSX160NA DC PV 4P	IP0	3 (LV429329)	No	1 (LV429329)	No
Compact	NSX160NA DC PV 4P	IP0	3 (LV429329)	No	1 (LV429329)	No
Compact	NSX160NA DC PV 4P	IP4X	No	LV429518	No	LV438327
Compact	NSX200NA DC PV 4P	IP0	3 (LV429329)	No	1 (LV429329)	No
Compact	NSX200NA DC PV 4P	IP0	3 (LV429329)	No	1 (LV429329)	No
Compact	NSX200NA DC PV 4P	IP4X	No	LV429518	No	LV438327
Compact	NSX400NA DC PV 4P	IP2X	No	LV438327	No	LV438327
Compact	NSX400NA DC PV 4P	IP0	3 (LV432570)	No	1 (LV432570)	No
Compact	NSX500NA DC PV 4P	IP2X	No	LV438327	No	LV438327
Compact	NSX500NA DC PV 4P	IP0	3 (LV432570)	No	1 (LV432570)	No
Masterpact	NW20 HA DCD-PV 3P					
Masterpact	NW20 HA DCD-PV 3P					

(1) T° rise have been checked with four cables on bottom connections with section and length according to IEC60947-1 Table 9
a. When used in array boxes, with short connection to string protections the cross section of the bars or cables shall have a higher cross section.
b. When cables have a cross section lower than the value indicated an additional 0,9 derating coefficient shall be applied.

Values in the tables are provided for vertical mounting only. In case of horizontal mounting consult us.

Compact NSX100NA DC PV with short heat sinks and interphase barriers

Compact NSX200 NA DC PV with long heat sinks and interphase barriers

Top series connection	40°	45°	50°	55°	60°	65°	70°	Cooper cable cross section[(1)]
	Maximum current (A): I_{TH}							
	32	32	32	32	32	32	32	Cu 6 mm²
	50	48	46	43	41	37	35	Cu 10 mm²
Short 2X LV438328	100	100	100	100	100	100	100	Cu 35 mm²
Short 2X LV438328	100	100	100	100	100	100	100	Cu 35 mm²
Short 2X LV438328	160	160	160	160	160	155	145	Cu 70 mm²
Long 2X LV438339	160	160	160	160	160	160	160	Cu 70 mm²
Short 2X LV438328	160	160	160	160	150	145	135	Cu 70 mm²
Short 2X LV438328	200	195	190	180	170	160	150	Cu 95 mm²
Long 2X LV438339	200	200	200	200	195	185	170	Cu 95 mm²
Short 2X LV438328	190	180	175	165	155	150	140	Cu 95 mm²
LV438338	400	400	400	400	400	390	380	Cu 240 mm²
LV438338	400	400	400	400	400	400	400	Cu 240 mm²
LV438338	500	500	490	470	450	435	420	Cu 2x150 mm²
LV438338	500	500	500	500	500	500	480	Cu 2x150 mm²
	1400	1400	1400	1400	1400	1400	1400	
	3600	3600	3600	3600	3600	3200	3200	

DC-PV overcurrent protection

In A	$I_{SCTC\ MAX}$ (Tmin = -25°)	kW (Indicative)	Range	Product	Prefabricated Series connection	IP
≤ 25			TeSys	DF101PV (10x38)	NA	IIP20
1	0,8	0,25	Acti 9	C60DC-PV	included	IP0/IP2X opt.
2	1,6	0,5	Acti 9	C60DC-PV	included	IP0/IP2X opt.
3	2,4	0,8	Acti 9	C60DC-PV	included	IP0/IP2X opt.
5	4	1,3	Acti 9	C60DC-PV	included	IP0/IP2X opt.
8	6,4	2	Acti 9	C60DC-PV	included	IP0/IP2X opt.
10	88	2,6	Acti 9	C60DC-PV	included	IP0/IP2X opt.
13	10	3,5	Acti 9	C60DC-PV	included	IP0/IP2X opt.
15	12	4	Acti 9	C60DC-PV	included	IP0/IP2X opt.
16	12,8	4,3	Acti 9	C60DC-PV	included	IP0/IP2X opt.
20	16	5	Acti 9	C60DC-PV	included	IP0/IP2X opt.
25	20	8	Acti 9	C60DC-PV	included	IP0/IP2X opt.
80	63	33	Compact	NSX80 TM DC PV	Mandatory	IP4X
125	100	45	Compact	NSX80 TM DC PV	Mandatory	IP4X
160	125	53	Compact	NSX125 TM DC PV	Mandatory	IP4X
200	160	67	Compact	NSX200 TM DC PV	Mandatory	IP4X

TeSys DF101PV fuse carrier

C60 PV-DC modular circuit breaker

Compact NSX200 TM DC PV with terminal shields

$U_{oc\ max}$	U_{IMP}	Degree of Pollution	I_{TH} 25 °	I_{TH} 40 °	I_{CU}	Required Series connection	Polarised	Suitability for isolation
1 000 V	6 kV	II	32			1 DF101 /polarity	NO	yES
800 V	6 kV	II	1		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	2		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	3		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	5		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	8		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	10		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	13		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	15		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	16		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	20		1.5 kA	2x2p	NO	yES
800 V	6 kV	II	25		1.5 kA	2x2p	NO	yES
1 000 V	8 kV	III		80	10 kA	2x2p	NO	yES
1 000 V	8 kV	III		100	10 kA	2x2p	NO	yES
1 000 V	8 kV	III		160	10 kA	2x2p	NO	yES
1 000 V	8 kV	III		200	10 kA	2x2p	NO	yES

DC-PV overcurrent protection - accessories

Range	Product	Réf (without accessories)	Serial connection for pole	Top terminal
TeSys	DF101PV (10x38)	DF101PV		
Acti 9	C60PV-DC 1A	A9N61653	Included	●
Acti 9	C60PV-DC 2A	A9N61654	Included	●
Acti 9	C60PV-DC 3A	A9N61655	Included	●
Acti 9	C60PV-DC 5A	A9N61656	Included	●
Acti 9	C60PV-DC 8A	A9N61657	Included	●
Acti 9	C60PV-DC 10A	A9N61650	Included	●
Acti 9	C60PV-DC 13A	A9N61658	Included	●
Acti 9	C60PV-DC 15A	A9N61659	Included	●
Acti 9	C60PV-DC 16A	A9N61651	Included	●
Acti 9	C60PV-DC 20A	A9N61652	Included	●
Acti 9	C60PV-DC 25A	A9N61660	Included	●
Compact	NSX80 TM DC PV	LV438081	Mandatory 2x LV438328	Mandatory 2x LV438327
Compact	NSX125 TM DC PV	LV438126	Mandatory 2x LV438328	Mandatory 2x LV438327
Compact	NSX160 TM DC PV	LV438161	Mandatory 2x LV438328	Mandatory 2x LV438327
Compact	NSX200 TM DC PV	LV438201	Mandatory 2x LV438328	Mandatory 2x LV438327

Insulation of live parts

Terminal shields

Terminal shields are sealable insulating accessories that protect against direct contact with power circuits. They deliver protection levels IP40 and IK07. Terminal shields are mandatory for Compact NSX DC PV circuit breakers, and for voltages where UDC = 500 V.

C60 DC-PV with interphase barriers

Compact NSX200 TM DC PV with terminal shields

Zoom on heat sinks and terminal shields for Compact NSX DC PV

Bottom terminal shields	Level / Toggle	Direct front rotaryhandle	Extended front rotaryhandle	Remote opening	Remote open/close	Aux.contacts
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
●	●			●		●
Mandatory 2x LV429518	●	●	●	●	●	●
Mandatory 2x LV429518	●	●	●	●	●	●
Mandatory 2x LV429518	●	●	●	●	●	●
Mandatory 2x LV429518	●	●	●	●	●	●

DC-PV overcurrent protection – temperature de-rating

For Compact NSX the overload protection is calibrated at 40 °C and for C60 DC-PV at 20 °C. This means that when the ambient temperature is less or greater than these temperatures, the Ir protection pickup is slightly modified.

- T° rise for Compact range have been checked with terminal shields (mandatory) heat sink on top, four cables on bottom connections with section and length according to IEC60947-1 Table 9,

- Values in the tables are provided for vertical mounting only. In case of horizontal mounting consult us. To obtain the tripping time for a given temperature:
- see the tripping curves for 20 or 40 °C
- determine tripping times corresponding to the Ir value (thermal setting on the device), corrected for the breaker ambient temperature as indicated in the tables below.

Range	Product	20 °	25 °	30 °	35 °	40 °
TeSys	DF101PV(10x38)	32	31	30	29	28
Acti 9	C60 DC-PV 1A	1,02	1	0,98	0,96	0,94
Acti 9	C60 DC-PV 2A	2,06	2	1,94	1,88	1,82
Acti 9	C60 DC-PV 3A	3,08	3	2,92	2,84	2,75
Acti 9	C60 DC-PV 5A	5,1	5	4,9	4,8	4,69
Acti 9	C60 DC-PV 8A	8,16	8	7,83	7,67	7,49
Acti 9	C60 DC-PV 10A	10,3	10	9,7	9,4	9,2
Acti 9	C60 DC-PV 13A	13,2	13	12,7	12,5	12,2
Acti 9	C60 DC-PV 15A	15,4	15	14,6	14,3	13,9
Acti 9	C60 DC-PV 16A	16,3	16	15,7	15,3	14,9
Acti 9	C60 DC-PV 20A	20,4	20	19,6	19,2	18,7
Acti 9	C60 DC-PV 25A	25,5	25	24,5	23,9	23,3
Compact	NSX80 TM DC PV	88	86	84	82	80
Compact	NSX125 TM DC PV	137,5	135	131	128	125
Compact	NSX160 TM DC PV	176	172	168	164	160
Compact	NSX200 TM DC PV					

- T° rise for Compact range have been checked with t erminal shields (mandatory) heat sink on top, four cables on bottom connections with section and length according to IEC60947-1 Table 9,
- Values in the tables are provided for vertical mounting only, in case of horizontal mounting consult us.

45°	50°	55°	60°	65°	70°	
27 25		23	22	21	20	
0,92 0,9		0,88	0,86	0,84	0,82	
1,76 1,7		1,63	1,56	1,48	1,41	
2,66 2,57		2,48	2,38	2,27	2,17	
4,58 4,47		4,36	4,24	4,12	4	
7,31 7,13		6,95	6,76	6,56	6,36	
8,9 8,6		8,2	7,9	7,6	7,2	
12 11,7		11,4	11,1	10,8	10,5	
13,5 13		12,6	12,2	11,7	11,2	
14,6 14,2		13,8	13,4	13	12,5	
18,3 17,9		17,4	16,9	16,4	15,9	
22,7 22,1		20,9	20,2	19,6	15,9	
77 75		72	69	66	63	Cu 25 mm²
121 116		112	108	103	98	Cu 50 mm²
153 147		142	136	130	118	Cu 70 mm²
Consult us						

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Conclusion

Solar photovoltaic (PV) solar power has asserted itself as a clean, convenient alternative power source that is versatile and cheap to run. It is nevertheless a relative newcomer in the field of power generation – both for grid-connected and stand-alone applications. As such its operating technology is still evolving, as are the installation and safety standards governing it.

Of paramount importance to the industry are the hazards for fire fighters and emergency service workers posed by building-mounted projects – thought to account for 55% of the European PV market. The DC voltage levels of PV generators, allied to fact that they cannot be interrupted as long as the sun is shining and that their short-circuit current is too weak to trip the disconnect switch, are issues like the safety of firefighters that shall be addressed. New standards are being developed, as are recommendations for good installation practices. In other words, standards are evolving. In the meantime, however, the best way to ensure normal operating safety is to select, install, and secure systems in accordance with manufacturer's instructions and IEC 60364 standard including part 60364-712.

Insulation monitoring solution and overcurrent protection, shall be selected to ensure safety taking into account the high level of voltage and the particular risk of double earth fault

Safety is not exclusively about protecting the PV system itself. It must be built into systems as the precondition for servicing and maintenance operations. Enclosures and switch disconnectors are indispensable for maintenance work on inverters and generators. In inverters there should be disconnectors on the AC and DC sides, while generators should have as many disconnectors as are required by servicing operations –particularly fuse replacements in the array and generator junction boxes. Their location, too, is critical – as near to the PV modules as possible or close to the DC cables' point of entry into the building.

Enclosures not only house and protect equipment, they protect service personnel. They should be double-insulated, well ventilated, and feature temperature and moisture control. They should be rugged to withstand the elements, vandalism, and impacts. Unlike other switchgear, however, enclosures do not afford generic solutions. They need to be tailored to the needs of a particular installation. That is why Schneider Electric provides customers with tools for selecting and configuring the enclosures that meet their needs.

Schneider Electric offers a full range of preventive and protective switchgear for different PV system architectures. To illustrate safety needs this application paper has used a standard grid-connected PV installation architecture operating above 120 V DC. In practice, however, Schneider Electric proposes switchgear and control equipment, surge protection devices, and enclosures across a wide range of grid-connected ground- and building-mounted PV architectures– from systems delivering 10 kW for residential applications and 10 kW-100 kW PV systems for small buildings to multi MW architectures for large buildings and farms and 150 kW to 500 kW systems for large buildings and farms.

Schneider Electric is a one-stop shop for protection devices and systems products that are available worldwide when customers need them. Fast turnaround times and an ever-reliable supply chain ensure customers can rely on Schneider Electric power protection for safely operating, safely serviced photovoltaics.

Definition (Ref IEC 60364-7-712)

PV module
Smallest completely environmentally protected assembly of interconnected PV cells

PV string
Circuit in which PV modules are connected in series, in order for a PV array to generate the required output voltage

PV array
Mechanically and electrically integrated assembly of PV modules, and other necessary components, to form a d.c. power supply unit

PV array junction box
Enclosure where all PV strings of any PV array are electrically connected and where protective devices can be located if necessary

PV generator
Assembly of PV arrays connected in parallel to one input of the inverter where one MPPT function is associated with

PV generator junction box
Enclosure where all PV arrays are electrically connected and where protection devices can be located if necessary

PV string cable
Additional cable, not provided with the PV modules, for interconnecting a PV string until a PV junction box

PV array cable
Output cable of a PV array

PV d.c. main cable
Cable connecting the PV generator junction box to the d.c. terminals of the PV inverter

PV inverter
Device which converts d.c. voltage and d.c. current of the PV generator into a.c. voltage and a.c. current

PV a.c. supply circuit
Circuit connecting the a.c. terminals of the PV inverter to the designated distribution board of the electrical installation

PV a.c. module
Integrated module/inverter assembly where the electrical interface terminals are a.c. only. No access is provided to the d.c. side

PV installation
Erected equipment of a PV power supply system

PV electrical installation
The electrical installation of a PV system starts from a PV module or a set of PV modules connected in series with their own cables (provided by the PV module manufacturer), up to a distribution network or to a customer installation

Standard test conditions (STC)
Test conditions specified in IEC 60904-3 for PV cells and PV modules

Open-circuit voltage under standard test conditions $U_{OC\ STC}$

Voltage under standard test conditions across an unloaded (open) PV module, PV string, PV array, PV generator or on the d.c. side of the PV inverter

Open-circuit maximum voltage $U_{OC\ MAX}$

Maximum voltage across an unloaded (open) PV module, PV string, PV array, PV generator or on the d.c. side of the PV inverter

Short-circuit current under standard test conditions $I_{SC\ STC}$

Short-circuit current of a PV module, PV string, PV array or PV generator under standard test conditions

$I_{SC\ MOD}$

The short circuit current of a PV module or PV string at Standard Test Conditions (STC), as specified by the manufacturer in the product specification plate

> **NOTE**
> As PV strings are a group of PV modules connected in series, the short circuit current of a string is equal to $I_{SC\ MOD}$.

$I_{SC\ ARRAY}$

The short circuit current of the PV array at Standard Test Conditions, and is equal to: $I_{SC\ ARRAy} = I_{SC\ MOD} \times SA$ where SA is the total number of parallel-connected PV strings in the PV array

I_{TRIP}

The nominal rating of an overcurrent protection device.

Short-circuit maximum current $I_{SC\ MAX}$

Maximum short-circuit current of a PV module, PV string, PV array or PV generator

Maximum reverse current I_{RM}

Defines the thermal PV module withstand capability under the test reverse current value $I_{TEST} = 1{,}35\ I_{RM}$ during 2 hours, as defined in standard IEC 61730-2 to determine the acceptability of the risk of fire

> **NOTE**
> I_{RM} value is given by the PV module manufacturer

d.c. side

Part of a PV installation from the PV modules to the d.c. terminals of the PV inverter

a.c. side

Part of a PV installation from the a.c. terminals of the PV inverter to the point of connection of the PV supply cable to the electrical installation

Maximum power point tracking (MPPT)

Internal control method of an inverter ensuring a search for operation at maximum power