Proposed Interim Guideline for the wiring of LV grid-embedded PV installations not exceeding 1000kVA in South Africa

WARNING

This guideline should only be used until a national standard is in place.

1. Preamble

SANS 10142-1, The Wiring of Premises, does not approve of the installation of generators embedded in the installation where such generators may be operated in parallel with the grid. Standards for the installation of embedded generators do not exist in any of the regulatory standards at present, but are in the process of preparation.

This document establishes an interim approach as well as point out the way forward towards a mature state of the use of embedded generators.

By way of a note, the South African National Standard, SANS 0142-1, [Code of Practice for] The Wiring of Premises, specifically excludes embedded generators in the ambit of applicability, i.e. where such embedded generators will be operated in parallel with a utility distribution grid.

Electrical equipment installed in and around an embedded generator (e.g. grid-tie inverter with certain peripheral equipment), should comply to the wiring code, in order that a Certificate of Compliance (CoC) may be issued.

The Occupational Health and Safety Act, Act 85 of 1993 (OHS Act) places an onus on the users of a premises where electricity is consumed (and/or distributed and even arguably generated) to be in possession of a valid Certificate of Compliance.

Notwithstanding the particular embedded generator exclusion of SANS 10141-1, a photovoltaic (PV) installation should be approved and signed off by a competent person, insofar the OHS Act imposes the weight of the law.

Whereas, the proposed standard to cover embedded generation is not yet approved and published, reasonable opinion seems to be that certain categories of "competent persons", as defined in the Act under the General Machinery Regulations, would bear responsibility in the design and approval of PV embedded generation systems.

"Registered Persons" are understood to be categories of persons as described more comprehensively under the Electrical Installation Regulations (clauses 9 and 11) of the OHS Act. Only registered persons may issue a CoC.

It must be noted that inverters might be specifically excluded by a registered person issuing a conventional CoC for that part of an installation deemed to be embedded generation.

In the anticipation of an approved Code of Practice (proposed SANS 10142-3), some essential requirements should be imposed on an installation in the meantime, hence the proposed application of a draft version of SANS 10142-3 may need to be considered as an interim measure, even to guide installers towards sensible practice.

A draft version entitled “additional CoC” has been prepared in expectation of the next standard and the application thereof in the context of an interim practice document deserves serious consideration.

NORMATIVE References

SANS 10142-1, The wiring of premises Part 1: Low-voltage installations

NRS 097-2-1

IEC 30364

IEC 60364-7-712

IEC 62109-1

IEC 62109-2

Particular attention is drawn to Table 4.2 in SANS 10142-1

Once approved:

NRS 097-2 series…

Informative references

IEC/TS 62548

Regulatory requirements

Connection of embedded generators is only allowed with the written approval of the supply utility.

Embedded generation installations shall comply with the requirements of SANS 10142-1 to the full extent of applicability, the NRS 097 series, as well as the proposed SANS 10142 Parts 3 and 5, as and when approved.

Wherever provisions of this guideline may appear to contradict any provisions of the documents listed in the preceding paragraph, the provisions of the latter shall take precedence over this guideline.

Contents

PV System: 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 provoke tripping of the power supply's automatic disconnect. The most frequently used protective measures do not therefore apply to PV systems. PV modules are installed outdoors and are exposed to the elements. Moreover, since they can be installed on roof structures, critical attention should be paid to the risk of fire and the protection of fire fighters and emergency services personnel.

Protecting people against electric shock

According to paragraph 412.1.1 of IEC 60364-4-41: Double or reinforced insulation is a protective measure whereby, elementary protection is provided by basic insulation and fault protection is provided by supplementary insulation, whereas, 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.

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, reverse current in a PV module, or overloading cables or equipment.

Insulation fault detection

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

When an insulation fault is detected, whatever the solution is, the inverter is stopped and disconnected from AC side, but the fault is still present on DC side and moreover, the voltage between poles is the open circuit voltage of the PV generator as long as the 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 “Over-current protection”.

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:

1 It is **<u>not</u>** permitted to earth one pole.

2 AC protection measures can be used to detect insulation faults.

When the AC side and DC side are provided with galvanic separation:

1. An over-current protective device (which also detects insulation faults) should be used to trip the grounded conductor in the event of a fault, where the PV cell technology (e.g. thin films of amorphous silicon) requires one of the conductors to be directly grounded.

2. An insulation monitoring device should be used if the PV cell technology requires one of the conductors to be resistance-grounded.

3. An insulation monitoring device should also be used when PV cell technology does not require either conductor to be earthed.

Insulation monitoring devices shall be selected taking into consideration both $\mathbf{U_{OC\,MAX}}$ 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 500uF is suitable for a PV system.

IEC 60364-7-712 stipulates that PV systems whose maximum $\mathbf{U}_{OC\ MAX}$ is higher than 120V DC should use “double or reinforced insulation” as a protection against electric shock.

Switchgear devices, such as circuit-breakers or fuses on the DC side, do not afford protection against electric shock, as there is **<u>no automatic</u>** disconnection of the power supply.

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

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-circuit 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 PV modules. PV module withstand capability should therefore be tested in accordance with the IEC 61730-2 standard and the PV module manufacturer shall provide the maximum reverse current value (**I_{RM}**)

Reverse current into the faulty string = total current of the remaining strings

String over-current 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:

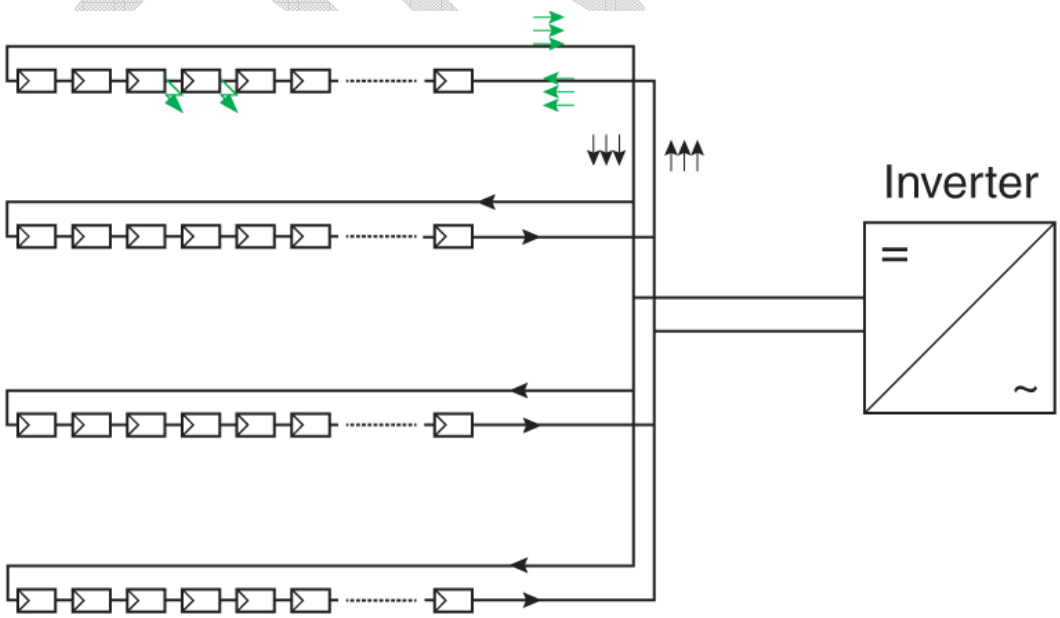
$1.35\ I_{RM} < (Ns - 1)\ I_{SC\ MAX}$,

where:

I_{RM} is the maximum reverse current characteristic of PV cells defined in IEC 61730

Ns is the total number of strings

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 lower than the maximum reverse current. Hence, when the PV generator is made up of only one or two strings, there is no mandatory requirement for reverse current protection.



Protection against over-current

As with any installation, there should be protection against thermal effects of over-current posing danger.

Short-circuit current depends on solar irradiance, but it may be lower than the trip threshold 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 $\mathbf{I_{STC\ MAX}}$.

IEC 60364-7-712, pertinent clauses:

712.433.1 Overload protection may be omitted to PV string and PV array cables when the continuous current-carrying capacity of the cable is equal to or greater than 1.25 times $\mathbf{I_{SC\ STC}}$ at any location.

712.433.2 Overload protection may be omitted to the PV main cable if the continuous current-carrying capacity is equal to or greater than 1.25 times $\mathbf{I_{SC\ STC}}$ of the PV generator.

String protection

Where string over-current protection is required, each PV string shall be protected with an over-current protection device.

The nominal over-current protection (circuit breaker or fuse) rating of the string over-current protection device shall be greater than 1.25 times the string short circuit current $\mathbf{I_{SC\ STC}}$_string.

Array protection

The nominal rated trip current ($\mathbf{I_{TRIP}}$) of over-current protection devices for PV arrays (whether circuit breakers or fuses) shall be greater than 1.25 times the array short-circuit current $\mathbf{I_{SC\ STC}}$_array.

The selection of over-current protection rating shall be done in order to avoid unexpected tripping in normal operation, taking into account temperature. A protection rating higher than 1.4 times the protected string- or array- short-circuit current $\mathbf{I_{SC\ STC}}$ is usually recommended.

Circuit breakers or Fuses

Circuit breakers or fuses can be used to provide over-current 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 deployed, load-break switches should also be used to disconnect fuses from the inverter, in order to permit cartridge replacement. Therefore, an array box with fuses on fuse holders as string protection, for example, should also incorporate a main switch.

Circuit breakers offer better adjustment resolution and greater accuracy than fuses. Hence, circuit breakers would allow the use of cables (especially for sub-array cables), with ratings lower than would be adequately protected by fuses.

Double earth faults

PV systems are either insulated from the earth, or one pole is earthed through an over-current protection device. In both arrangements, there could 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 over-current protection in earthed systems shall detect a first fault and operations personnel shall attend to the first fault and clear it without 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 threshold of over-current protection (circuit breakers or fuses).

However, a DC arc fault does not self-extinguish, even when the current is low, which poses 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 currents associated with faults, with all poles at open-circuit maximum voltage ($\mathbf{U_{OC\ MAX}}$). To break the current when $\mathbf{U_{OC\ MAX}}$ is equal to 1000V, 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. Double pole switchgear is not designed for such 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 over-current protection in grounded systems should detect a so-called first fault. However, although the insulation fault monitoring system usually stops the inverter, the fault is still present. Personnel 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 whenever a first fault has been detected, but not cleared within the next few hours.

Switchgears and enclosure selection

Double insulation

Enclosures on the DC side shall provide double insulation.

Thermal issues

The thermal behaviour of switchgear and enclosures deserves 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 7-712 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 to guarantee that 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 $\mathbf{U_{OC\,MAX}}$ of 1000V, some equipment may show IEC 60947-1 Pollution Degree 2, rather than Pollution Degree 3.

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

Grid box

A utility-accessible, single-point-of-disconnection (SPOD), must be installed at the interface between the embedded generation sub-installation and the incoming utility supply, i.e. downstream of the utility meter. The enclosure containing the disconnection device, a disconnection device which must comply with SANS 10142-3 [once published], will for the purpose of this document be called a **grid box**.

PV System: protection against transient over-voltages

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

The distribution network as a result of lightning or any work carried out

Lightning bolts (nearby/on buildings and PV installations, or on lightning conductors)

Variations in the electrical field initiated by lightning strikes

Like all outdoor structures, photovoltaic installations are exposed to the risk of lightning, which varies from region to region. Preventative 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, so as to establish equal potential at all points in the installed system, as far as may be practicable.

Protection by surge protection devices (SPDs):

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

A Surge Protection Device is required where **L >= Lcrit**

Lcrit depends on the type of PV installation, and is calculated according to the following table:

Type of installation	Individual residential premises	Terrestrial production plant	Service/Industrial/Agricultural Buildings
Lcrit (in m)	115/Ng	200/Ng	450/Ng
L ≥ Lcrit	Surge protective device(s) compulsory on DC side		
L < Lcrit	Surge protective device(s) not compulsory on DC side		

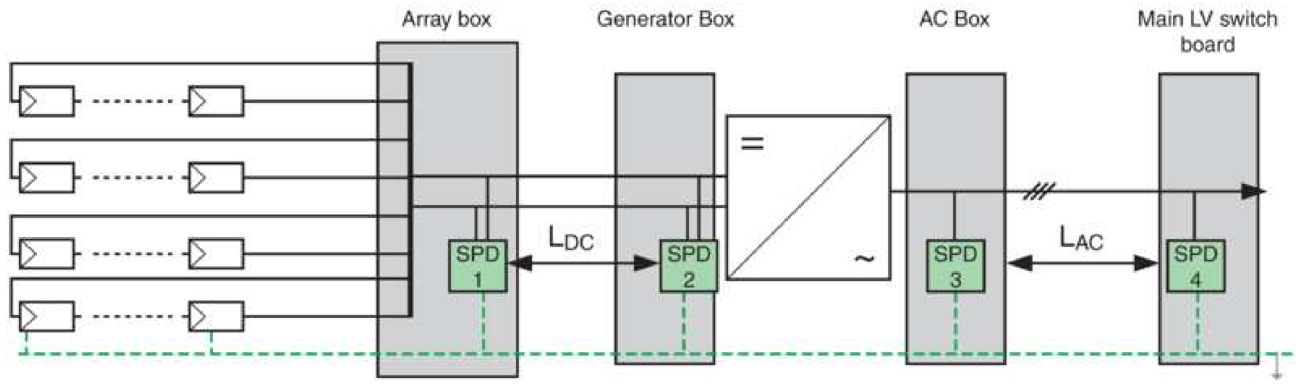
Critical length Lcrit calculation

L is the sum of :

- distances between the inverter(s) and the junction box(es), while observing that the lengths of cable located in the same conduit are counted only once, and

- distances between the junction box and the connection points of the photovoltaic modules forming the string, observing that the lengths of cable located in the same conduit are counted only once.

Ng: lightning strike density (number of strikes/km²/year)



Type of SPD according to location

SPD Protection							
Location	PV Modules or Array box		Inverter DC side	Inverter AC side		Main board	
	L_{DC}			L_{AC}		Lightning rod	
Criteria	<10m	>10m		<10m	>10m	Yes	No
Type of SPD	No need	SPD 1 Type 2[*]	SPD 2 Type 2[*]	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 kept

PV System: how to ensure safety during maintenance or emergency

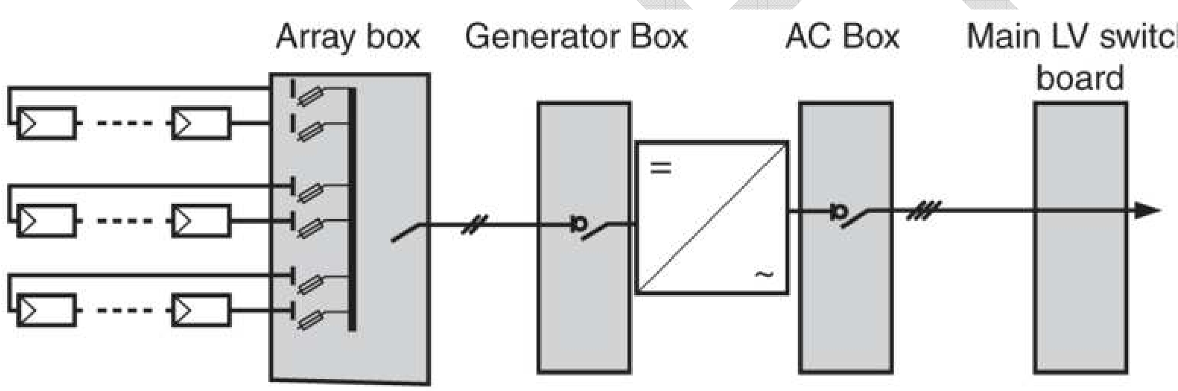
To ensure staff safety during maintenance and emergencies, disconnect devices should be appropriately located and enclosure installations should be failsafe.

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 at the point of entry of DC cables, to permit emergency disconnection.



Switch-disconnector location

Selecting and installing enclosures

Enclosures for different PV generator boxes and switch boards on the DC side must ensure double isolation, as well as, equipment protection against such outdoor hazards as temperatures, rain, vandalism and shock.

Enclosures and associated auxiliary equipment must ensure temperature and humidity control to allow equipment to operate smoothly. It is, however, difficult to propose a generic solution. Each installation needs to be analyzed in order to optimize the sizing of its enclosures and auxiliary equipment.

PV System: how to ensure safety during all the life cycle of the installation

IEC60364-6 requires initial and periodic verifications of electrical installations.

Particular aspects of photovoltaic installations (outdoor, high DC voltage, unsupervised sub-installations) make periodic checking very important.

Whereas, typically, the efficiency of all the system is checked in order to ensure the maximum production, it is recommended to perform periodic maintenance of equipment.

PV system operating conditions involve various environmental stresses: wide temperature variations, humidity, as well as, electrical stresses. In order to realize performance of equipment during the entire life cycle of an installation, particular attention shall be paid to the following:

Enclosure integrity (Double isolation IP level)

Switchgear operating condition and integrity

- to evaluate whether any overheating has occurred

- to examine switchgear for the presence of dust, moisture…

Visual check of electrical connections

Functional test of equipment and auxiliaries

Insulation monitoring device test

Insulation resistance test

Photovoltaic architectures - common characteristics

A PV array is made up of a number of modules in series or parallel, corresponding to the input characteristics of the inverter. However, since these modules are interconnected, the array is very sensitive to shade, or differences in terms of the direction/orientation.

By following a few simple cabling rules, supply can be optimized and operating problems may be avoided.

Position of the panels

If, when installing a PV array on a roof, panels face different directions owing to geometry, it is essential to assemble at least one string per direction and ensure that the modules (in one string) together face one direction, to ensure optimized supply. Each string must be connected to a specific inverter (or to inputs of a multi-MPPT inverter).

If this instruction is not observed, the array will not be damaged, but supply will be reduced, increasing the time to achieve a return on investment.

Shade

Besides the risk of destruction of shaded modules within a PV array, due to the “hot spot phenomenon” as described in Paragraph 2.2 (and for which manufacturers have devised solutions), research conducted by the “Institut National des Energies Solaires” (INES – France’s national institute for solar energy) suggests that shading of 10% of the surface area of a string may cause more than a 30% reduction in output!

It is therefore important to eliminate direct shading. However, in many cases, this is difficult (trees, chimneys, neighbouring walls, pylons, etc.).

If a PV array includes several strings:

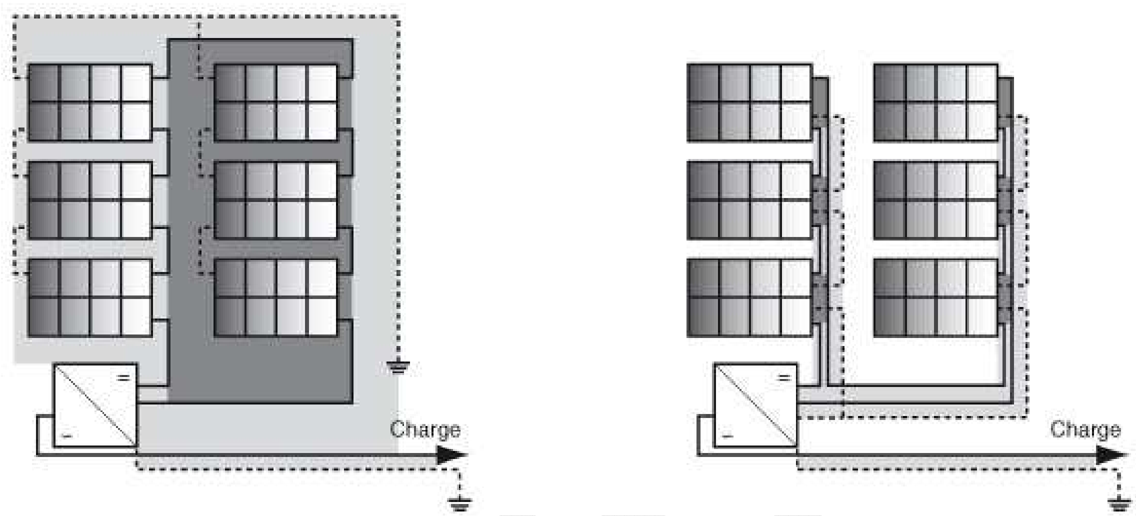
Where possible, shaded modules should be included in a single string

Otherwise, a technology should be chosen which responds better to diffuse light, than direct light.

Eliminating loops

When connecting components, the first precaution to take is to avoid loops in the cabling within strings.

Even though direct lightning strikes on arrays are relatively rare, currents induced by lightning are much more common and these currents are particularly destructive where there are large areas bounded by loops. The diagram below illustrates the principle of avoiding a large loop.



Avoiding loops when cabling strings

Photovoltaic architectures - installations connected to the grid

General Rules

Where photovoltaic installations are connected to the network and energy is sold, it is necessary to optimize efficiency and reduce installation costs. With this in mind, a relatively high DC operating voltage of between 200 and 500 V is often used for residential applications, with up to 1000 V being used for applications requiring a higher level of power.

All the modules in a PV array should be identical (same brand and same type) and selected to supply the same level of power. For example, the modules should all be 180 W, even though other power levels may exist in a particular PV module product range (e.g., 170 W, 180 W and 190 W).

In practice, the protection units (DC and AC units) should be positioned close to the inverters for ease of maintenance.

PV array with a single string of modules

This is the simplest configuration. It is used for small PV arrays with peak power of up to 3 kWp, depending on the modules deployed. In most cases, it is used for residential PV installations.

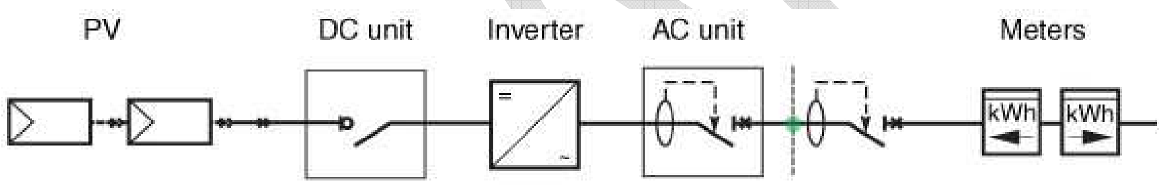


Diagram showing a single-string photovoltaic array

Modules are connected in series, supplying direct current of between 200 and 500 VDC, in this instance. Optimal efficiency is obtained from the inverter within this voltage range.

A single DC line is taken to the inverter. The PV array can be isolated from the inverter by means of a load break switch near the inverter.

PV array with several module strings in parallel

The configuration shown below, mainly deployed on buildings or in small PV power plants on the ground, is used for PV installations of, up to, thirty strings in parallel, with typically power output of around 100 kWp. This limit is imposed for technological and financial reasons. If exceeded, the required width of the main DC cable would be impractical.

Direct current (and DC voltage) can be determined based on the number of modules in series per string. In this instance, voltage is between 300 and 600 VDC. By paralleling identical strings, the power required for the installation can be attained. The strings are paralleled in a PV array box (or DC combiner box). This box includes the safety devices required for paralleling the strings and devices used to measure the strings current. A single DC cable connects these boxes to the inverter. The PV array can be isolated from the inverter by means a load break switch near the inverter.

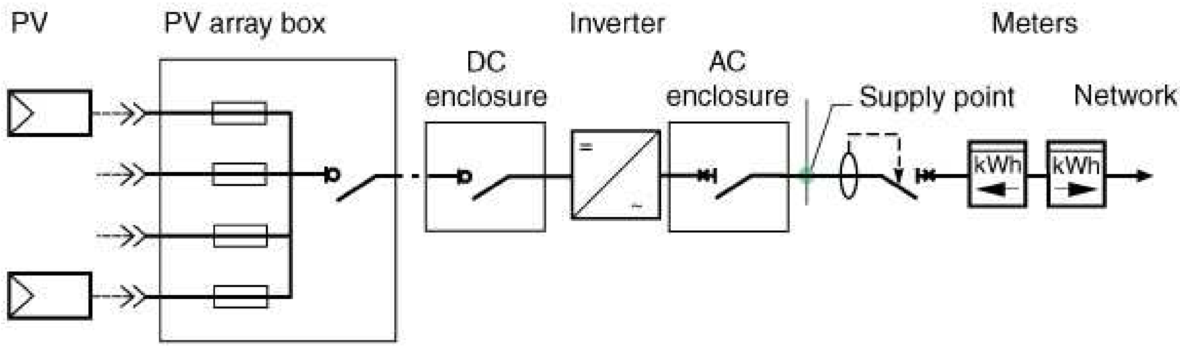


Diagram showing a multi-string photovoltaic array with one inverter

As a variation on this diagram, several single-phase inverters can be installed in a three-phase arrangement:

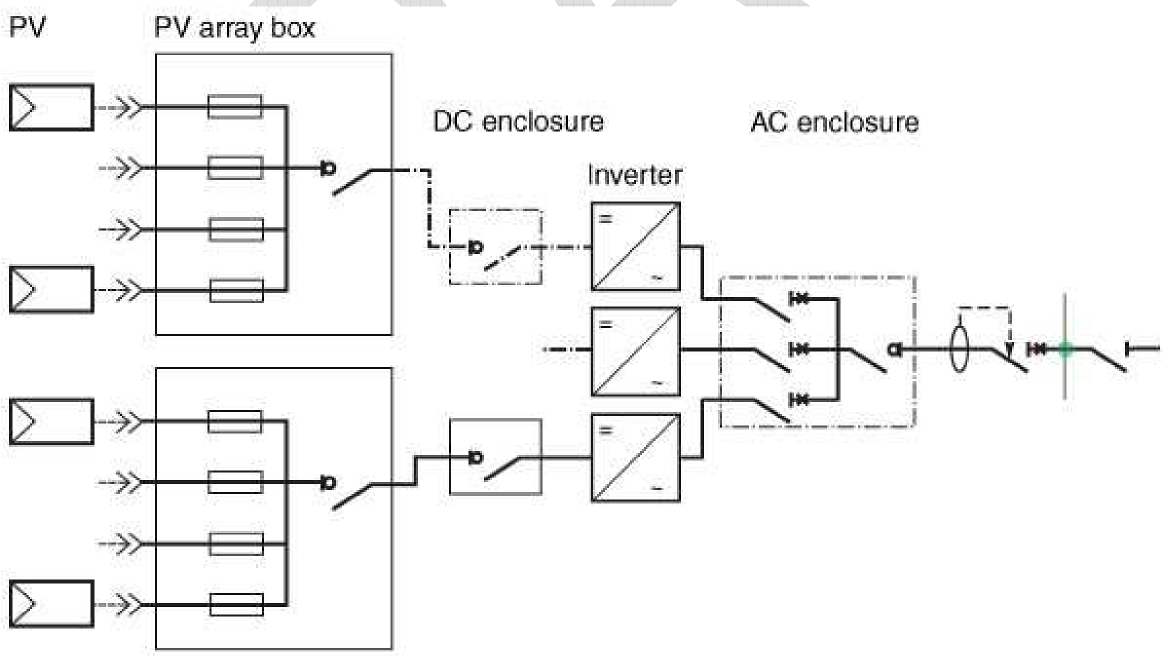


Diagram showing a multi-string photovoltaic array with several single-phase inverters connected in a three-phase arrangement

PV array with several strings divided into several groups

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

Strings in each subgroup are paralleled in subgroup PV array boxes (DC sub-combiner boxes). These boxes are fitted with safety devices, the necessary measuring equipment and monitoring devices.

The outputs of these boxes are paralleled in a PV array box (DC master-combiner box) near the inverter. This box is also fitted with the required safety devices as well as the measuring and monitoring equipment necessary for paralleling the subgroups.

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

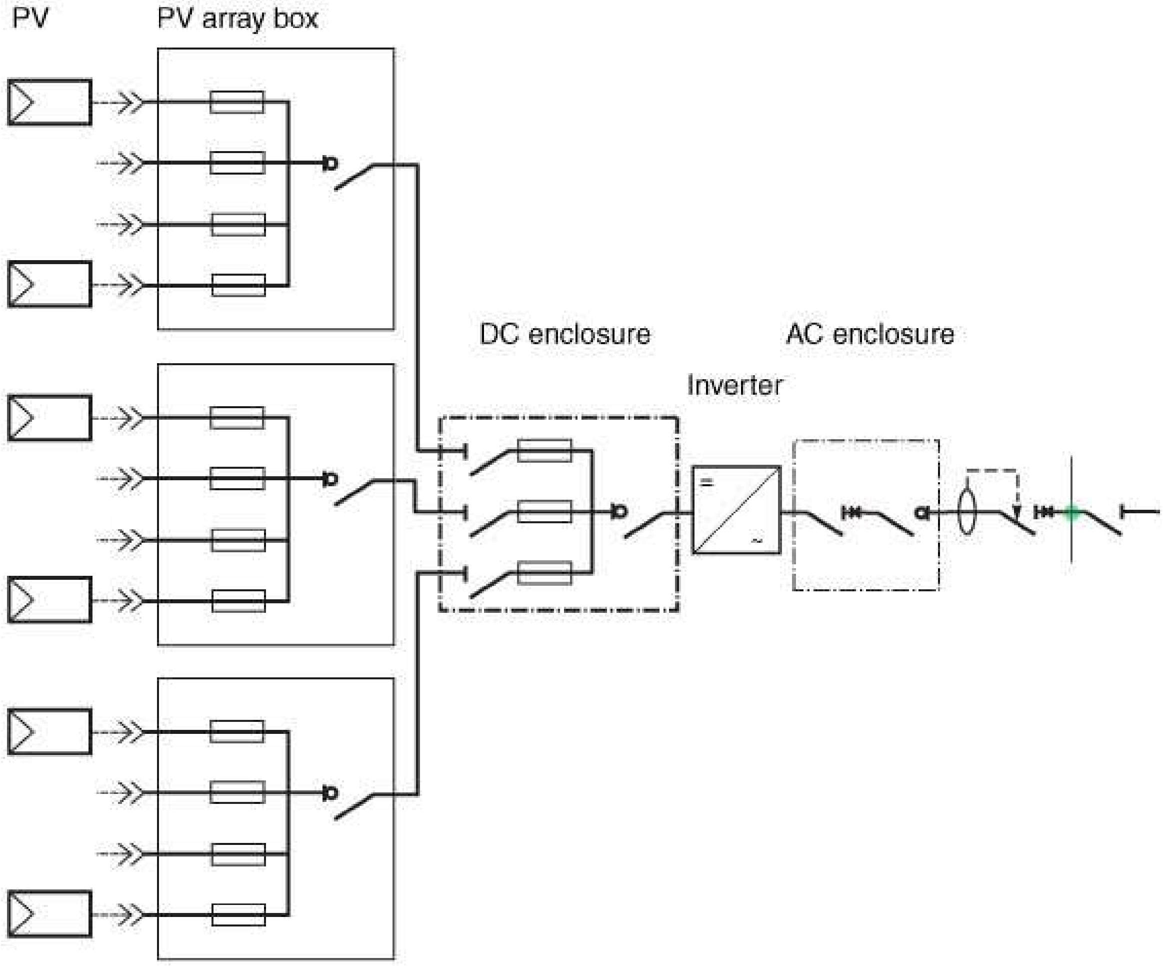


Diagram showing a photovoltaic array consisting of several groups

Photovoltaic system sizing

Calculating a photovoltaic array

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

Firstly, the approximate power output may be calculated based on the available surface area:

10 m^2 = 1 kWp

7140 m^2 (= football ground) = 700 kWp

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

String composition:

NB: Number of modules x Voc (at t° min) < inverter Vmax

The no load voltage of the string (Voc x number of modules in series) at the minimum temperature of the installation location must be lower than the inverter's maximum input voltage.

=> This must be strictly observed. Otherwise the inverter may be destroyed.

Apart from the aforementioned rule for preventing destruction of the inverter

Number of modules x Voc (at t° min) < inverter Vmax – two other limits must be observed:

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

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

- Isc strings < inverter I max

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

Inverter specifications

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

$0.8 < P_{inverter} / P_{array} < 1$

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

Single-phase or three-phase

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

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

Configuration software

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

Photovoltaic installation type

The installation type is a factor which should not be neglected since, in countries including France, the purchase price for power supplied is dependent on this. Along with shading, it should be taken into account when choosing a module.

There are three installation types – building integrated, partially integrated and ground-based:

Building Integrated PhotoVoltaic (BIPV)

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

Partially integrated

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

Ground-based

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

Photovoltaic system: electrical equipment selection

Grid connected PV system <= 10kW (Residential)

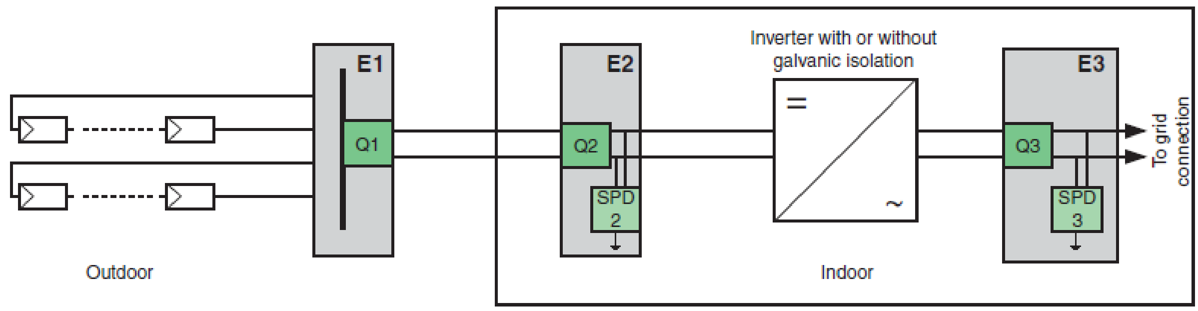
One single phase inverter

Typically, a 5kW grid-connected single-phase inverter. with UOC MAX ≤ 600V.

One or two strings – Isctc < 25A, IAC < 32A.

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 emergencies services.



Requirements	**String junction box**	**PV array main switch**	**Inverter**	**AC box (400V)**
Switchgear and control (Q)				
- Isolation	•	• (4)	(1)	• (4)
- Switching (Making & breaking rated current	• DC21B	• (4) DC21B	(1)	• (4)
- Control	• (2)	• (4)	(5)	• (4)
- Over-current protection	(1)			
- Protection against Insulation fault			(8)	(8) RCD type B or A SI
Surge protection (SPD)		• type 2		• type 1 or 2
Enclosure (E)	Outdoor Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Metering			Inverter relevant parameters	Energy

Grid connected <= 10kW

(1) PV array main switch could be included in the inverter. This solution makes inverter service or replacement more difficult.

(2) 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.

(3) No protection is required when the number of string does not exceed 2.

(4) Service and emergency switching

(5) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)

(6) Overload and short-circuit protection B curve recommended.

(7) This SPD could be unnecessary if there is another SPD in the AC installation at a distance of less than 10 metres.

(8) 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 to 100kW grid connected PV system (Small building)

One three phase multi input inverter without array box

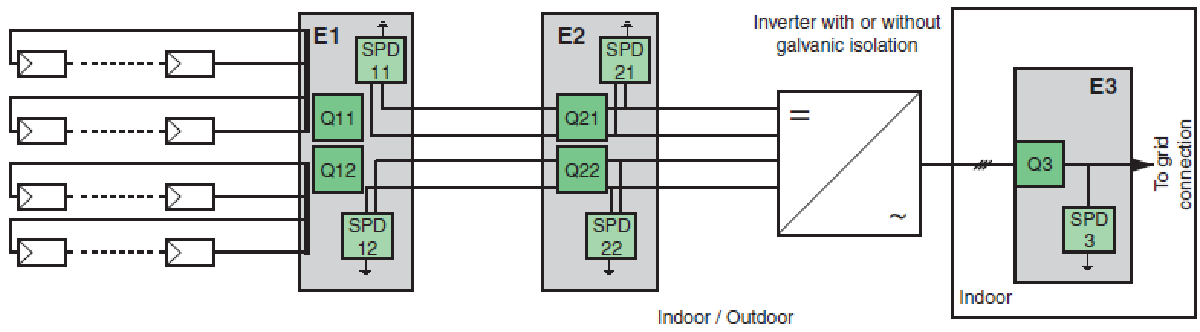
Typically, 10kW to 36kW grid-connected inverters, UOC MAX probably higher than 600V (i.e. 800V or 1000V), Isctc < 125A, Iac < 63A.

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 emergencies services.



Requirements	String junction box	PV array main switch	Inverter	AC box (400V)
Switchgear and control (Q)				
- Isolation	•	• (4)	(1)	• (4)
- Switching (Making & breaking rated current	• DC21B	• (4) DC21B	(1)	• (4)
- Control	• (2)	• (4)	(5)	• (4)
- Over-current protection	(3)			(6)
- Protection against Insulation fault			(8)	(8) RCD type B or A SI
Surge protection (SPD)		• type 2		• type 1 or 2
Enclosure (E)	Outdoor IP5x Double insulation	Indoor IP5x Double insulation		Standard AC requirement + grid code requirement
Metering				Energy

10-100kW single multi MPPT inverter

(1) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.

(2) 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.

(3) No protection is required when the number of string does not exceed 2.

(4) Service and emergency switching

(5) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)

(6) Overload and short-circuit protection (B curve recommended).

(7) 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.

(8) 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

Without functional earthing: insulation monitoring is necessary, it's usually done by the inverter in this range of power.

With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

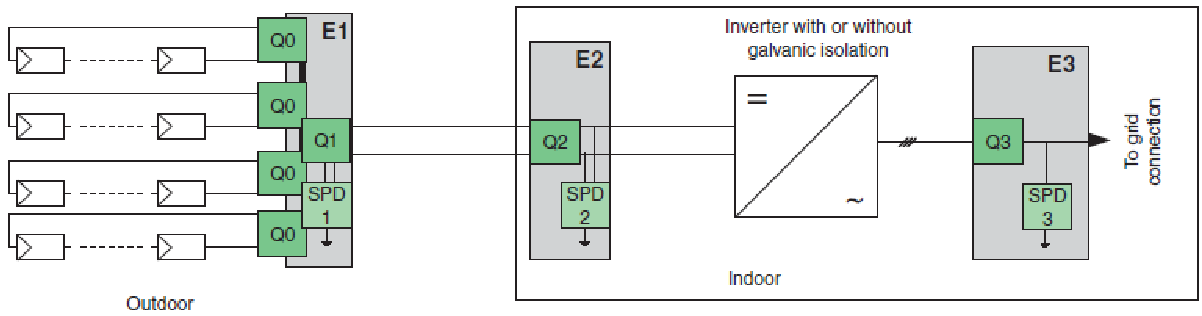
One three phase inverter with One Array box

Typically, 30kW to 60kW grid-connected inverters. UOC max is generally higher than 600V (up to 1000V), Isctc does not exceed 200A, Iac does not exceed 100A.

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 switch at DC cable entry point is recommended for emergencies.



Requirements	String junction box	PV array main switch	Inverter	AC box (400V)
Switchgear and control (Q)				
- Isolation	•	• (4)	(1)	• (4)
- Switching (Making & breaking rated current	• DC21B	• (4) DC21B	(1)	• (4)
- Control	• (2)	• (4)	(5)	• (4)
- Over-current protection	•	(3)		• (6)
- Protection against Insulation fault			(8)	(8) RCD type B or A SI
Surge protection (SPD)		• type 2		• type 1 or 2
Enclosure (E)	Outdoor IP5x Double insulation	Indoor IP5x Double insulation		Standard AC requirement + grid code requirement
Metering				P, Q, PF, Energy

10-100kW single MPPT inverter

(1) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.

(2) 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.

(4) Service and emergency switching

(5) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)

(6) Overload and short-circuit protection (B curve recommended).

(7) 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.

(8) 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

Without functional earthing: insulation monitoring is necessary

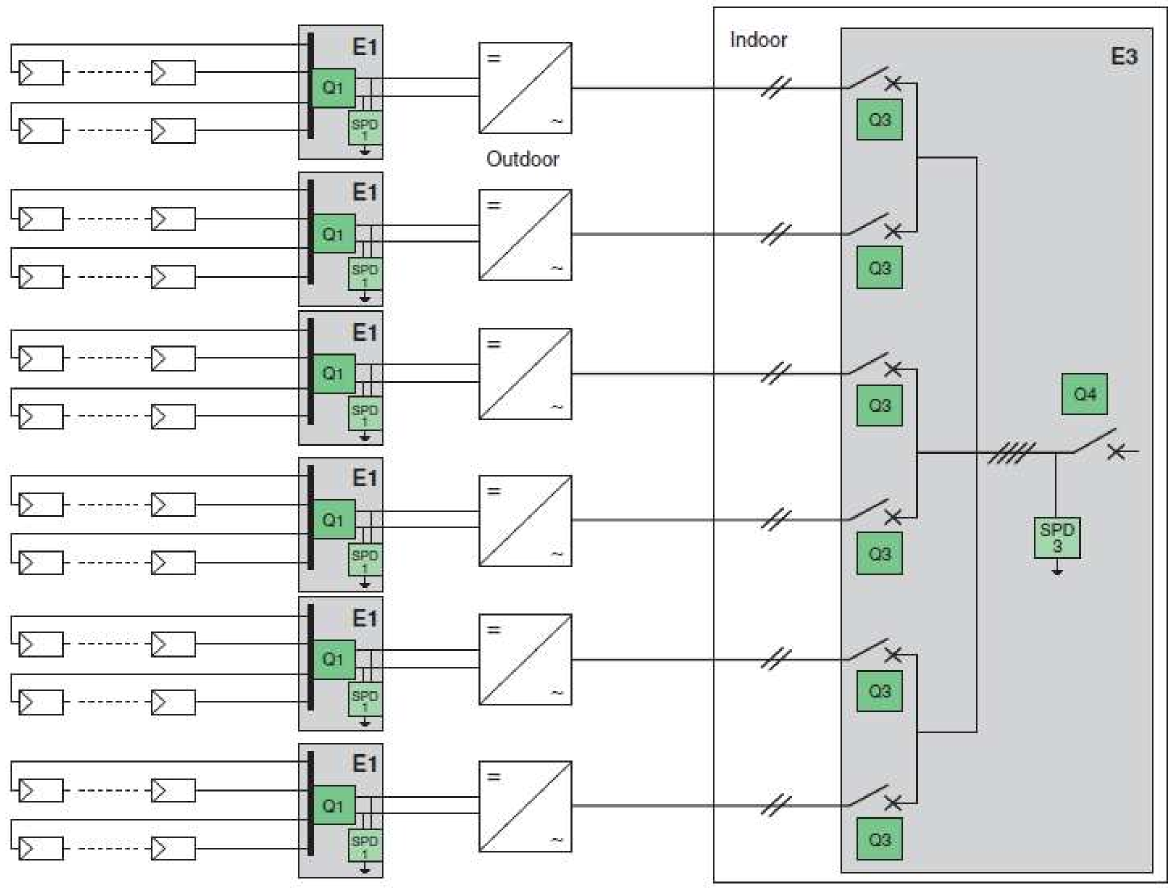
With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

Multi single phase inverters design

Typically, 6x5 to 20x5kW 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 usual AC systems.



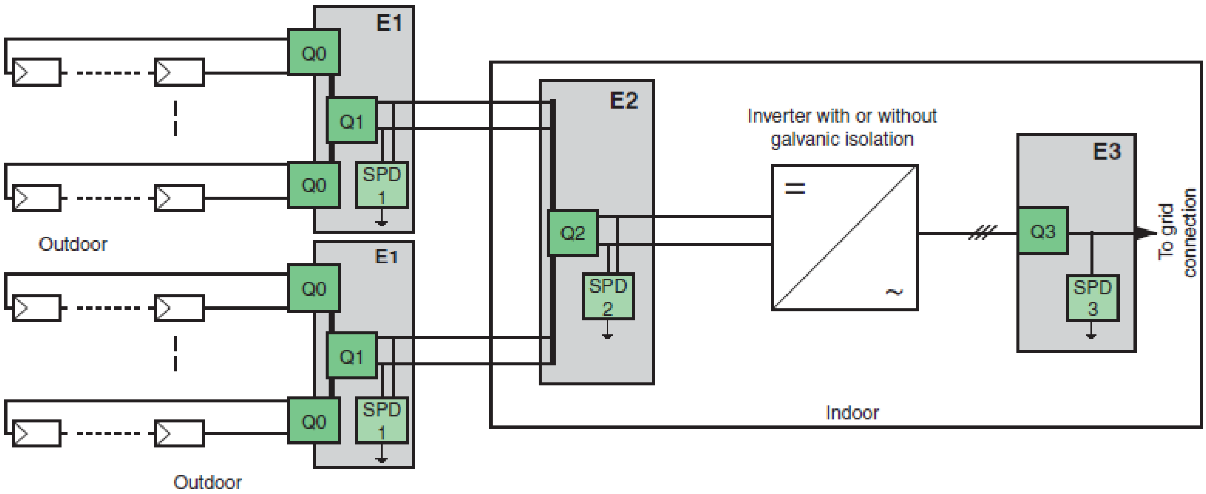
Requirements	PV array main switch	Inverter		AC box (400V)
Switchgears and control (Q)	See 5kW design		(8)	• (4)
Surge protection (SPD)	• type 2			• type 1 or 2
Enclosure (E)	Outdoor IP5x Double insulation			Standard AC requirement + grid code requirement
Metering			Energy	P,Q, PF, Energy, unbalance

10-100kW multi single MPPT

(8) 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 phases inverter with two Array boxes (Na <=2)

Typically, 60kW to 100kW grid-connected inverters with 2 arrays. Array cable protection is not necessary for 2 or 3 arrays. The Isctc array ≤ 200A, Isctc ≤ δ400A, and Imax AC ≤ 200A. 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.



Requirements	**String junction box**	**PV array main switch**	**Inverter**	**AC box (400V)**
Switchgear and control (Q)				
- Isolation	•	• (4)	(1)	• (4)
- Switching (Making & breaking rated current	• DC21B	• (4) DC21B	(1)	• (4)
- Control	• (2)	• (4)	(5)	• (4)
- Over-current protection	•	(3)		• (6)
- Protection against Insulation fault			(8)	(8) RCD type B or A SI
Surge protection (SPD)		• type 2		• type 1 or 2
Enclosure (E)	Outdoor IP5x Double insulation	Indoor IP5x Double insulation		Standard AC requirement + grid code requirement
Metering				P, Q, PF, Energy

10-100kW single MPPT inverter with 2 arrays

(1) PV array main switch could be included in the inverter. This solution makes inverter service or replacement difficult.

(2) 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.

(3) No protection is required when the number of arrays <= 3 (No cable sizing benefit)

(4) Service and emergency switching

(5) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)

(6) Overload and short-circuit protection.

7() 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.

(8) 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

Without functional earthing: insulation monitoring is necessary

With functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

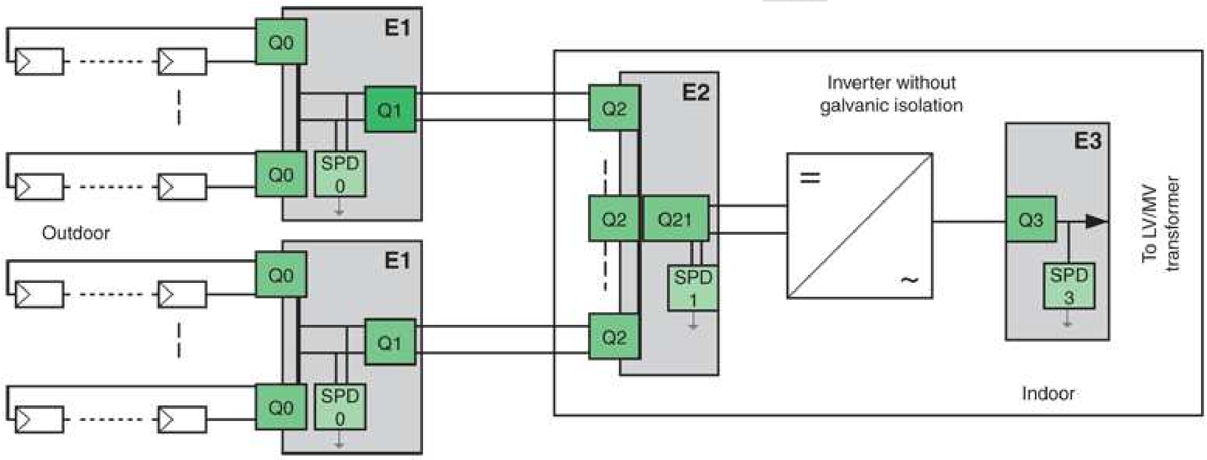
150kW to 500kW Grid connected PV system (Large building and farm)

Three phases inverter with more than two Array boxes

Typically, 150kW to 500kW single inverter.

This design is very similar to the previous one except that it has more arrays, which requires array cable protection.

Istc <= 400A, IAC <= 600A.



Requirements	String	Array junction box	Generator junction box	Inverter	AC box 400V or other voltage (Transformerless inverter)
Switchgear and control (Q)					
- Isolation	•	•	•	(1)	• (4)
- Switching (Making & breaking rated current		• DC22A	• DC22A	• (1)	• (4)
- Control		• (2)		• (1)	• (4)
- Over-current protection	•				•(6)
- Protection against Insulation fault				• (8)	• (8)
Surge protection (SPD)		(7)	• type 2		• type 1 or 2
Enclosure (E)		Outdoor IP5x Double insulation	Indoor Double insulation		Standard AC requirement + grid code requirement
Metering					P, Q, PF, Energy, Alarm, THD, individual harmonics

150-500kW single MPPT inverter with N arrays > 2

(1) PV array main switch could be included in the inverter. This solution makes inverter service or replacement more difficult.

(2) 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.

(3) Array cable protection is recommended to prevent cable overszing. To ensure fast trip of protections 6 to 8 arrays are recommended.

(5) Inverter shall include a protection for anti-islanding (in accordance with VDE 0126 for example)

(6) Overload and short-circuit protection.

(7) 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.

(8) Galvanic insulation is provided by LV/MV transformer,

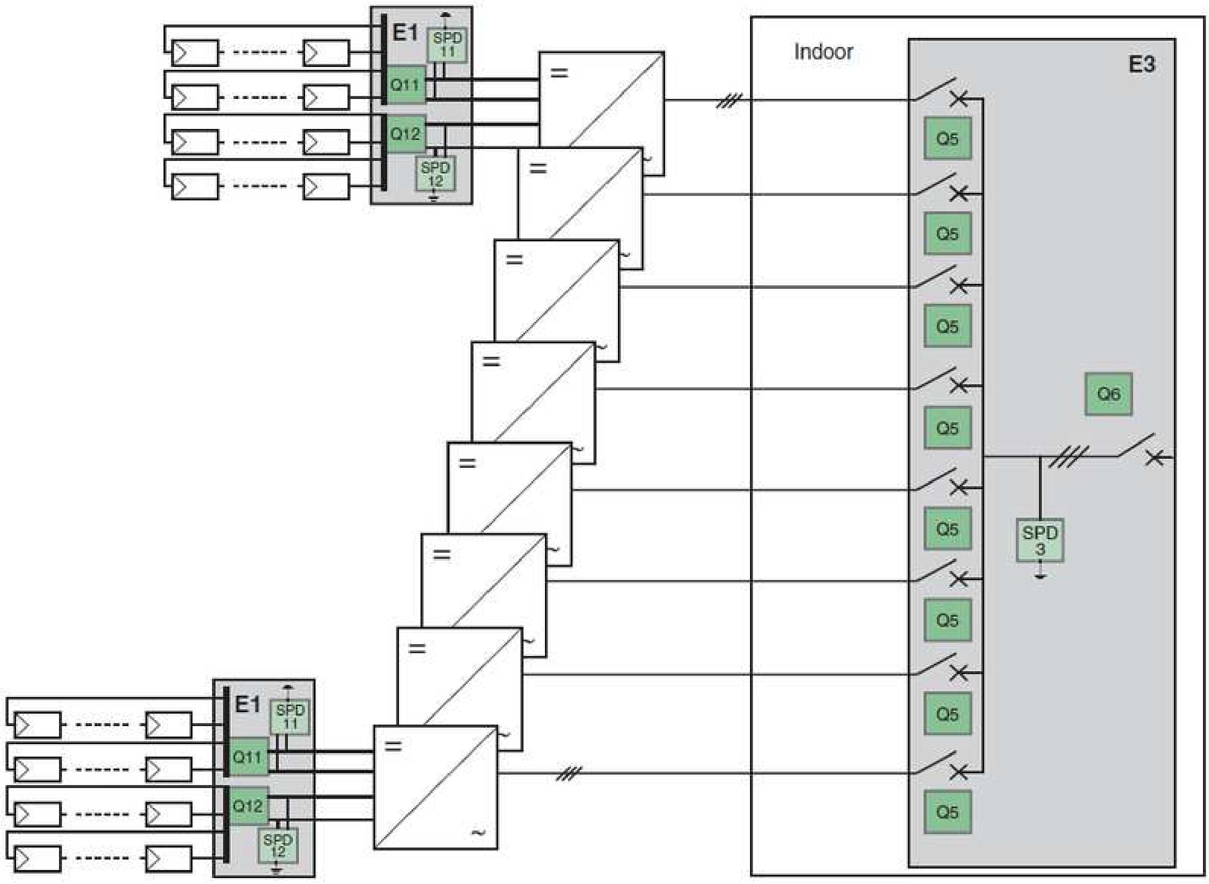
PV system without functional earthing: insulation monitoring is necessary: IMD - IM20 and accessory IMD-IM20-1700

PV system with functional earthing: the earthing shall be done with a DC MCB breaker (C60PV 4P series 2 – 10A) or a fuse.

Multi single-phase inverters design

Typically 10x20 to 20x30kW grid connected inverters

Uoc max ≤ 1000V one or two string per inverter. IAC max 50A for one inverter.

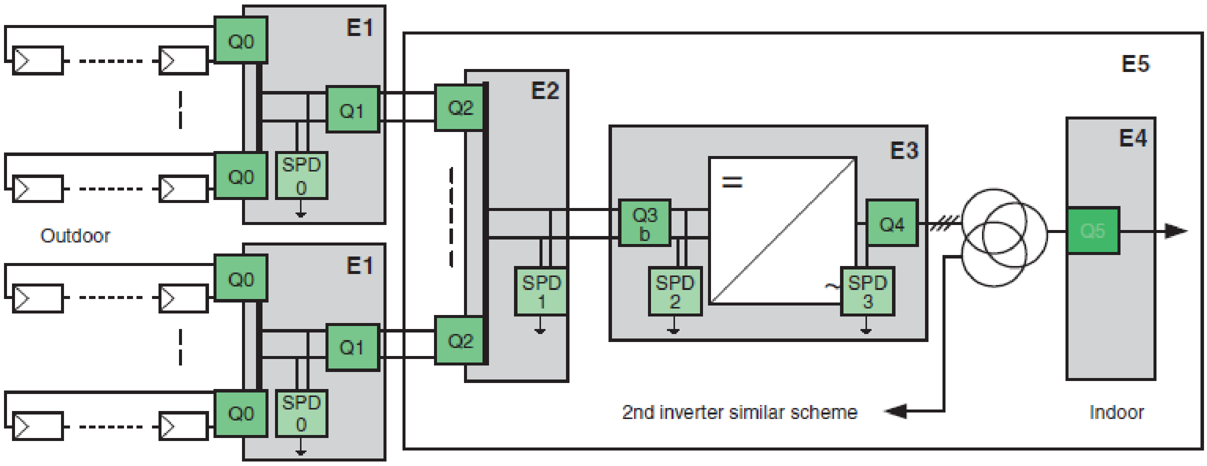


Requirements	String junction box			AC Combiner box
Switchgears and control (Q)	See 10 to 36kW design			
Surge protection (SPD)	• type 2			• type 1 or 2
Enclosure (E)	Outdoor IP5x Double insulation			Standard AC requirement + grid code requirement
Metering			Energy	P, Q, PF, Energy, Alarm

150-500kW multi 3-phases inverters

Multi MW Grid connected PV system (Large building and farm)

Typically 500kW-630kW inverters with LV/MV transformers and MV substation



Requirements	String	Array junction box	Generator junction box	Inverter	AC box 400V or other voltage (Transformerless inverter)
Switchgear and control (Q)					
- Isolation	•	•	•(1)	See PV monitoring	•
- Switching (Making & breaking rated current		• DC22A	•(1)		•
- Control		•(2)			•
- Over-current protection	•		• (3)		•(6)
- Protection against Insulation fault			• (8)		• (8)
Surge protection (SPD)		(7)	• type 2	(7)	• type 1 or 2
Enclosure (E)		Outdoor IP5x Double insulation	Indoor Double insulation		
Metering		Energy			P, Q, PF, Energy, Alarm, Power quality

500-630kW inverters with LV/MV transformers

(1) PV array main switch is usually included in the inverter panel.

(2) 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.

(3) Array cable protection is recommended to prevent cable overszing. To ensure fast trip of protections 6 to 8 arrays are recommended.

(6) Overload and short-circuit protection.

(7) If there is no SPD in the inverter or if the between DC box and inverter >10m a SPD is necessary in this box.

(8) 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.

PV monitoring

Since the profitability of photovoltaic installations depends mainly on operational uptime, it is essential to ensure that they are permanently up and running. The best way of ensuring this is to install a monitoring system covering key equipments of the installation. This system should notify all faults immediately, be capable of detecting drifts in output, and possibly control equipment remotely.

Types of monitoring systems

Several types of monitoring systems are available for installations, depending mainly of the size of the installation.

Systems for Residential up to commercial, 1 to 1000 kWp, are able to monitor the inverters – status, measurements and alarms - and key electrical values related to the output of the installation.

These systems are based on a data -logger, mostly equipped with a RS232/485 serial port to communicate with the inverters, using Modbus or a proprietary protocol. Data acquisition is based on low speed polling rate, every 10 minutes in average. Data may be stored locally in the data-logger, for free, but for a short period of time, or pushed to an external server which store the data over the years and deliver a front end, providing an annual service fee. In that case, the communication with the distant server can be or via GPRS, or via Ethernet.

The data-logger can also be equipped with auxiliary inputs, such as analogue inputs to monitor temperature or irradiance sensors, digital input to monitor the status of an equipment and/or pulse input to connect with an energy meter equipped with digital output.

Systems for large commercial up to Utility scale power plant, from 500 kWp upwards, are able to monitor the complete installation, from the string input to the point of connection to the grid.

These systems are based on a SCADA (Supervision Control And Data Acquisition) system, which enable multi site monitoring, DC & AC measurements, remote control of motorized equipments, smart alarming, generation of reports, performance indication and other capabilities such as in-depth analysis.

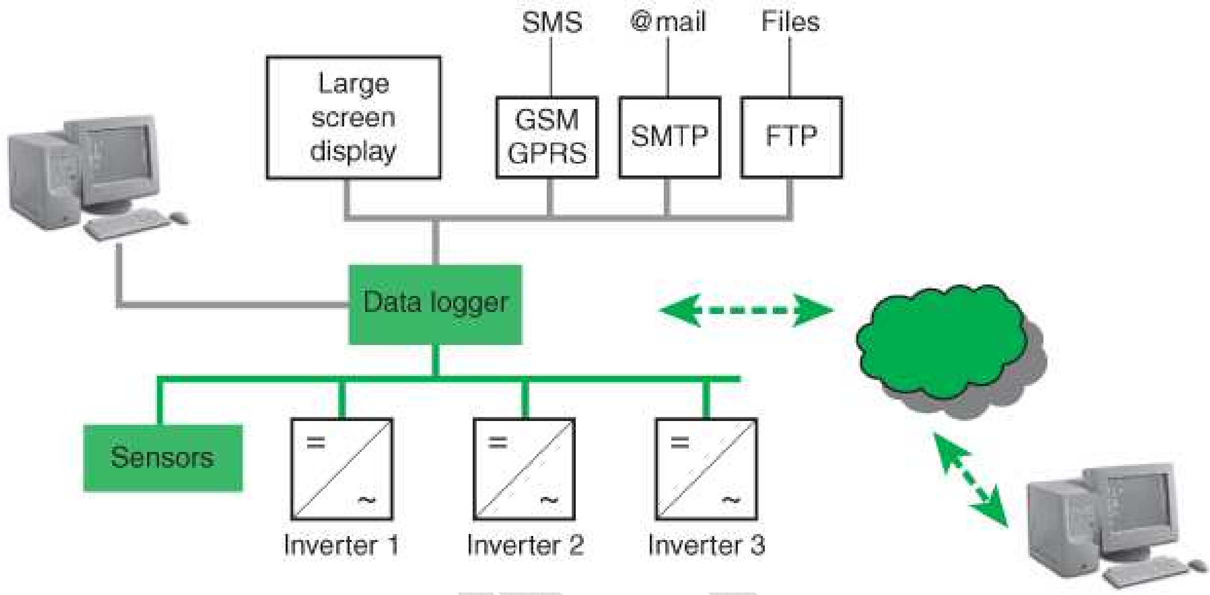
These systems also include other equipment to run the site more efficiently, such as weather station (temperatures, wind rain gauge), irradiance sensors, a plant controller - device which communicate with the grid operator, to adapt the production of the site to the grid variation (Voltage, Power Factor) – and specific meters such as revenue grade meters, close the point of connection

These SCADA systems can be local and/or remote, with redundancy capabilities and high performance for data processing.

This type of installation is mostly served by a Service contract for Operations & Maintenance and in many cases, with performance objectives which can be production, performance ratio or availability.

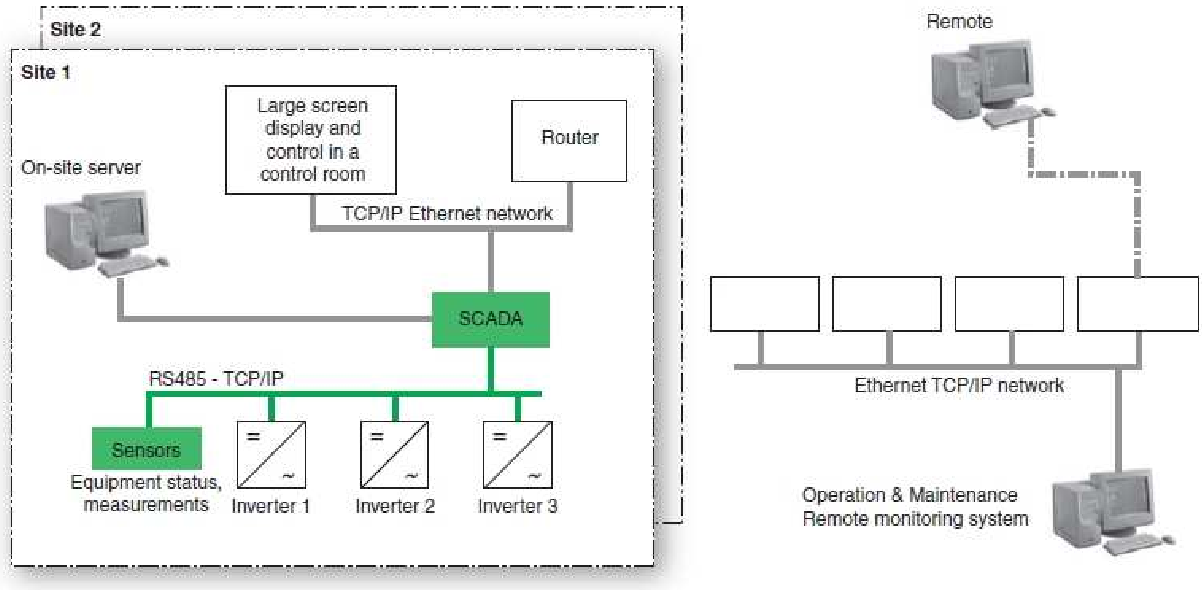
Monitoring systems

These systems may be autonomous or include remote monitoring, such as "cloud-based" systems.



Example of an autonomous monitoring system mostly used in residential to commercial PV installations

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



Example of a system for remote monitoring mostly used in utility scale power plants

Sensors

Sensors provide data to the monitoring systems and include:

A sensor for measuring instantaneous luminous flux such as a pyranometer (heat flow sensor used to measure the quantity of solar energy in natural light (W/m2), see Fig. P32). This is the standard reference for the installation. It may be used to identify shifts over time and is recommended to all suppliers wishing to conduct comparative analyses and compile statistics for their installations. At least one sensor is needed at the location, however, it is not uncommon for at least two to be installed: one in the global horizontal (GHoz.) position and one in the plan of the array (POA) assuming the system is installed at some angle other than horizontal.

A temperature sensor – this is an important factor for photovoltaic power supply. This sensor either serves as an external probe, is attached to the back of a module or both.

A kilowatt hour meter – typically, this meter is of a "revenue grade", i.e. <+/-2% tolerance. This is especially important for companies that may be engaged in power purchase agreements (PPA) which rely on accurate data for billing purposes.

In the United States of America, the owner of the photovoltaic system may often install their own revenue grade meter to bill the purchaser. At times, the purchaser may also install a meter to verify the output or demand the seller's meter to be calibrated regularly. In other markets it may be the case when selling power, only the kilowatt hour meter operated by the energy distributor purchasing the electricity may be used as a reference.

The other meters fitted within an installation (in the inverter or next to the official meter) are only indicators with their own specific levels of accuracy. Variations of more than 10% may occur between the values given by an installation's devices and that given by the official meter. However, these variations are not only due to different levels of accuracy. They are also caused by energy lost in the cables and safety devices downstream from the inverter.

It is therefore important to use cables of minimal length and clearly identify:

The location where the installation will be connected to the network

The locations where the energy distributor's meters will be connected

Security of the installation

Since modules are expensive and in some cases openly accessible, sites need to be monitored by security such as:

Cameras (*)

Microwave

Motion Sensors

Active Personnel

Other electronic means

(*) NB – although this type of surveillance may be authorized for private sites, certain prohibitions may apply at public highways, installations, or other state-owned premises.

Bibliography

[1] Schneider Electric publication: Electrical installation guide 2015, According to IEC international standards, Chapter P: Photovoltaic Installations

See also:

http://www.electrical-installation.org/enwiki/PhotoVoltaic_(PV)_installation