IEC/TS 62257-7-1

Edition 2.0 2010-09

TECHNICAL SPECIFICATION

colour inside

Recommendations for small renewable energy and hybrid systems for rural electrification –
Part 7-1: Generators – Photovoltaic generators

IEC/TS 62257-7-1:2010(E)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE XC

ICS 27.160

ISBN 978-2-88912-177-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RECOMMENDATIONS FOR SMALL RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 7-1: Generators – Photovoltaic generators

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62257-7-1, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This second edition cancels and replaces the first edition issued in 2006 and constitutes a technical revision.

The main technical changes with regard to the previous edition are the following:

– This new version is focused on small PV generators up to 100 kW_p.
– Case studies are provided.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
82/583/DTS	82/604/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62257 series, published under the general title*, Recommendations for small renewable energy and hybrid systems for rural electrification* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual edition of this document may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

The IEC 62257 series of publications intends to provide to different players involved in rural electrification projects (such as project implementers, project contractors, project supervisors, installers, etc.) documents for the setting-up of renewable energy and hybrid systems with a.c. voltage below 500 V, d.c. voltage below 750 V and power below 100 kVA.

These publications provide recommendations for

– choosing the right system for the right place;
– designing the system;
– operating and maintaining the system.

These publications are focused only on rural electrification concentrated in, but not specific to, developing countries. They must not be considered as all-inclusive of rural electrification. The publications try to promote the use of renewable energies in rural electrification. They do not deal with clean mechanism developments at this time (CO_2 emission, carbon credit, etc.). Further developments in this field could be introduced in future steps.

This consistent set of publications is best considered as a whole, with different parts corresponding to items for the safety and sustainability of systems at the lowest possible life-cycle cost. One of the main objectives of the series is to provide the minimum sufficient requirements relevant to the field of application, i.e. for small renewable energy and hybrid off-grid systems.

The purpose of IEC 62257-7-1 is to propose a technical specification for the design and building of small PV generators (e.g. up to 100 kW_p) used in rural electrification.

Numerous experts of TC 82 have expressed the opinion that the first edition of IEC/TS 62257-7-1 is far more general than just the PV array for rural electrification but can also be used for big PV arrays in big PV power stations.

Therefore it is now necessary to develop a second edition more dedicated and more specific to rural electrification. It is the purpose of this second edition to specify the general requirements for the design and the safety of PV generator used in decentralized rural electrification systems.

RECOMMENDATIONS FOR SMALL RENEWABLE ENERGY AND HYBRID SYSTEMS FOR RURAL ELECTRIFICATION –

Part 7-1: Generators – Photovoltaic generators

1 Scope

This part of IEC 62257 specifies the general requirements for the design and safety of generators used in decentralized rural electrification systems.

The earthing systems of the exposed conductive parts and neutral earthing systems which are considered in this technical specification are those specified in IEC 62257 series for IES (see IEC 62257-9-3 and IEC 62257-9-4) and CES (IEC 62257-9-2).

This technical specification contains requirements for ELV and LV PV arrays (see Table 1). Particular attention must be paid to voltage level, as this is important for safety reasons and has an influence on protective measures and on the skill and ability level of people operating the systems.

Table 1 – Voltage domains for PV arrays

Voltage domain	Voltage V	
	Alternating current	Smoothed direct current
ELV	$U_n \leq 50$ V	$U_{oc} \leq 120$ V
LV	50 V < $U_n \leq 1\,000$ V	120 V < $U_{oc} \leq 1\,500$ V
NOTE ELV limits are provided by IEC 61201.		

For the sake of completeness, this technical specification gives requirements for d.c. voltages below and above 120 V.

The aim is to provide safety and fire protection requirements for:

- uninformed persons, including owner(s)/occupier(s) and users of the premises where photovoltaic arrays are installed;
- informed workers (e.g. electricians) working on these systems; and
- emergency workers (for example fire fighters).

For installation of PV arrays see IEC 60364-7-712.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-811:1991, *International Electrotechnical Vocabulary (IEV) – Chapter 811: Electric traction*

IEC 60287 (all parts), *Electric cables – Calculation of the current rating*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-5-54, *Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors*

IEC 60364-7-712:2002, *Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 61140, *Protection against electric shock – Common aspects for installation and equipment*

IEC 61215, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61643-12, *Low voltage surge protective devices – Part 12: Surge protective devices connected to low voltage power distribution systems – Selection and application principles*

IEC 61646, *Thin–film terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61730 (all parts), *Photovoltaic (PV) module safety qualification*

IEC 62257-1, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 1: General introduction to rural electrification*

IEC 62257-5, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 5: Protection against electrical hazards*

IEC 62257-6, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 6: Acceptance, operation, maintenance and replacement*

IEC 62257-9-1, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-1: Micropower systems*

IEC 62257-9-2, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-2: Microgrids*

IEC 62257-9-3, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-3: Integrated system – User interface*

IEC 62257-9-4, *Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-4: Integrated system – User installation*

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62305-3, *Protection against lightning – Part 3: Physical damage to structures and life hazard*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
available, readily
capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like

3.2
blocking diode
diode connected in series to module(s), panel(s), sub-arrays and array(s) to block reverse current into such module(s), panel(s), sub-array(s) and array(s)

3.3
bypass diode
diode connected across one or more cells in the forward current direction to allow the module current to bypass shaded or broken cells to prevent hot spot or hot cell damage resulting from the reverse voltage biasing from the other cells in that module

3.4
cable
assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material

3.5
cable core
the conductor with its insulation but not including any mechanical protective covering

3.6
CES
Collective electrification system

3.7
shield (of a cable)
a surrounding earthed metallic layer to confine the electric field within the cable and/or to protect the cable from external electrical influence

NOTE Metallic sheaths, armour and earthed concentric conductors may also serve as shields.

[IEC 60050-461:1984, 461-03-04]

3.8
class I equipment
equipment in which protection against electric shock does not rely on basic insulation only, but which includes an additional safety precaution in that accessible conductive parts are connected to the protective earthing conductor in the fixed wiring of the electrical installation in such a way that accessible parts cannot become live in the event of a failure of the basic insulation

NOTE 1 Class I equipment may have parts with double insulation or parts operating at SELV.

NOTE 2 For equipment intended for use with a flexible cord or cable, this provision includes a protective earthing conductor as part of the flexible cord or cable.

3.9
class II equipment
equipment in which protection against electric shock does not rely on basic insulation only, but in which additional safety precautions such as double insulation or reinforced insulation

are provided, there being no provision for protective earthing or reliance upon installation conditions. Such equipment may be one of the following types:

– equipment having durable and substantially continuous enclosures of insulating material which envelops all metal parts, with the exception of small parts, such as nameplates, screws and rivets, which are isolated from live parts by insulation at least equivalent to reinforced insulation. Such equipment is called insulation-encased Class II equipment;

– equipment having a substantially continuous metal enclosure, in which double insulation is used throughout, except for those parts where reinforced insulation is used, because the application of double insulation is manifestly impracticable. Such equipment is called metal-encased Class II equipment;

– equipment that is a combination of the types described in items (a) and (b)

NOTE 1 The enclosure of insulation-encased Class II equipment may form part of the whole of the supplementary insulation or of the reinforced insulation.

NOTE 2 If the equipment with double insulation or reinforced insulation throughout has an earthing terminal or earthing contact, it is considered to be of Class I construction.

NOTE 3 Class II equipment may be provided with means for maintaining the continuity of protective circuits, insulated from accessible conductive parts by double insulation or reinforced insulation.

NOTE 4 Class II equipment may have parts operating at SELV.

3.10
class III equipment
equipment in which protection against electric shock relies on supply at SELV and in which voltages higher than those of SELV are not generated

NOTE Equipment intended to be operated at SELV and which have internal circuits that operate at a voltage other than SELV are not included in the classification and are subject to additional requirements.

3.11
double insulation
insulation comprising both basic insulation and supplementary insulation

[IEC 60050-195:1998, 195-06-08]

3.12
earthing
a protection against electric shocks

3.13
extra-low voltage
ELV
voltage not exceeding the relevant voltage limit of band I specified in IEC 60449

[IEC 60050-826:2004, 826-12-30]

NOTE 1 See also IEC 61201.

NOTE 2 Voltage not exceeding 50 V a.c. and 120 V d.c. ripple free are considered to be ELV.

3.14
HMPS
hybrid micropower system: micropower system including generators from different technologies

3.15
IES
Individual electrification system

3.16

$I_{MOD\_REVERSE}$

the current a module can withstand in the reverse direction to normal without damage to the module. This rating is obtained from the manufacturer at expected operating conditions

NOTE 1 This current rating does not relate to bypass diode rating. The module reverse current is the current flowing through the PV cells in the reverse direction to normal current.

NOTE 2 A typical figure for crystalline silicon modules is between 2 and 2,6 times the normal short circuit current rating ISC MOD.

3.17

$I_{SC\ MOD}$

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 $I_{SC\ MOD}$.

3.18

$I_{SC\ S\text{-}ARRAY}$

the short circuit current of a PV sub-array at Standard Test Conditions (STC), and equal to:

$$I_{SC\ S\text{-}ARRAY} = I_{SC\ STC\ MOD} \times S_{SA}$$

where S_{SA} is the number of parallel-connected PV strings in the PV sub-array

3.19

$I_{SC\ ARRAY}$

the short circuit current of the PV array at Standard Test Conditions, and is equal to:

$$I_{SC\ ARRAY} = I_{SC\ STC\ MOD} \times S_{A}$$

where S_A is the total number of parallel-connected PV strings in the PV array

3.20

junction box

closed or protected connecting device allowing making of one or several junctions

[IEC 60050-442:1998, 442-08-03]

3.21

live part

conductor or conductive part intended to be energized in normal operation, including a neutral conductor, but by convention not a PEN conductor or PEM conductor or PEL conductor

NOTE This concept does not necessarily imply a risk of electric shock.

[IEC 60050-195:1998, 195-02-19]

3.22

PEL conductor

conductor combining the functions of both a protective earthing conductor and a line conductor

[IEC 60050-195:1998, 195-02-14]

3.23
protected extra-low voltage
PELV
an extra-low voltage system which is not electrically separated from earth, but which otherwise satisfies all the requirements for SELV

3.24
PEM conductor
conductor combining the functions of both a protective earthing conductor and a midpoint conductor

[IEC 60050-195:1998, 195-02-13]

3.25
PEN conductor
conductor combining the functions of both a protective earthing conductor and a neutral conductor

[IEC 60050-195:1998, 195-02-12]

3.26
power conditioning unit
PCU
a system that converts the electrical power delivered by the PV array into the appropriate frequency and/or voltage values to be delivered to the load, or stored in a battery or injected into the electricity grid

3.27
power conditioning unit, isolated
a power conditioning unit where there is electrical separation between the input and output circuits (e.g. by means of an isolation transformer)

3.28
power conditioning unit, non-isolated
a power conditioning unit where there is no electrical separation between the input and output circuits

3.29
PV array
a) a mechanically integrated assembly of modules or panels and support structure that forms a d.c. electricity-producing unit. An array does not include foundation, tracking apparatus, thermal control, and other such components

[IEC 61836:2007, 3.3.45 a)]

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

[IEC 60364-7-712:2002, 712.3.4]

NOTE A PV array may consist of a single PV module, a single PV string, or several parallel-connected strings, or several parallel-connected PV sub-arrays and their associated electrical components. For the purposes of this standard the boundary of a PV array is the output side of the PV array disconnecting device. Two or more PV arrays, which are not interconnected in parallel on the generation side of the power conditioning unit, shall be considered as independent PV arrays.

3.30
PV array cable
the output cable of a PV array that connects the PV array junction box to the PV array disconnecting device

3.31
PV array, earthed
a PV array where one of the poles of the d.c. output circuit is electrically bonded to earth

3.32
PV array, unearthed
a PV array where none of the poles of the d.c. output circuit is electrically bonded to earth

3.33
PV array, floating
a PV array where none of the poles of the d.c. output circuit is electrically bonded to earth and connected to an application circuit which is either unearthed or double isolated

3.34
PV array, isolated
a PV array where there is at least a simple electrical separation between the PV array output circuit (d.c. side) and the a.c. system

NOTE A simple electrical separation of power circuits is usually achieved by means of a power transformer.

3.35
PV array junction box
a junction box where all strings of any array are connected

[IEC 60364-7-712:2002, 712.3.5, modified]

3.36
PV array voltage
the PV array voltage is considered to be equal to $V_{\mathrm{OC\ ARRAY}}$ under worst case conditions

NOTE The open circuit voltage is dependent on the cell temperature and technology.

3.37
PV cell
a) the basic unit of photovoltaic conversion, a semiconductor device that can convert light directly into electrical energy;
b) the basic photovoltaic device [see IEC 60904-3]

NOTE The preferred term is "solar photovoltaic cell" or "photovoltaic cell", colloquially referred to as a "solar cell".

3.38
PV module
the smallest complete environmentally protected assembly of interconnected cells

[IEC 60904-3]

NOTE Colloquially referred to as a "solar module".

3.39
PV module junction box
an enclosure affixed to a PV module, where the electrical connections to the PV module are made

3.40
PV string
a circuit of series-connected modules

3.41
PV string cable
a cable connecting the modules in a PV string, or connecting the string to a junction box or to the d.c. terminals of the power conditioning unit

3.42
PV sub-array
the portion of an array that can be considered as a unit

3.43
PV sub-array cable
the output cable of a PV sub-array that carries only the output current of its associated sub-array in normal operation, and that connects the PV sub-array with the other PV sub-arrays that constitute the PV array

NOTE PV sub-array cables are only relevant for PV arrays that are divided into sub-arrays (see Figure 7 for clarification).

3.44
PV sub-array junction box
an enclosure where all the PV strings of a PV sub-array are electrically connected in parallel and where protection devices may be located if necessary (see Figure 7)

NOTE PV sub-array junction boxes are only relevant for PV arrays that are divided into sub-arrays.

3.45
reinforced insulation
insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

NOTE Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

[IEC 60050-195:1998, 195-06-09]

3.46
supplementary insulation
independent insulation applied in addition to basic insulation, for fault protection

[IEC 60050-195:1998, 195-06-07]

3.47
simple separation
separation between electric circuits or between an electric on a local earth by means of basic insulation

[IEC 60050-826:2004, 826-12-28]

3.48
ripple-free d.c.
for sinusoidal ripple voltage, a ripple content not exceeding 10 % r.m.s.

NOTE Therefore the maximum peak value does not exceed 120 V for a nominal 108 V ripple-free d.c. system.

3.49
SELV
safety extra-low voltage
an extra-low voltage system which is electrically separated from earth and from other systems in such a way that a single fault cannot give rise to the risk of electric shock

3.50
STC
standard test conditions
a standard set of reference conditions used for the testing and rating of photovoltaic cells and modules. The standard test conditions are:

a) PV cell temperature of 25 ºC;

b) irradiance in the plane of the PV cell or module of 1 000 W/m^2;

c) light spectrum corresponding to an atmospheric air mass of 1,5

3.51
$V_{\mathbf{OC\ MOD}}$
the open circuit voltage of a PV module at the coldest expected operating condition

3.52
technical room / cabinet
room or cabinet where are located devices and apparatus dedicated to inter-connection of the different generators, protection of the different circuits, monitoring and control of the micropowersystem and interfacing with the application

3.53
trip current
current which activates the protection device

3.54
$V_{\mathbf{OC\ ARRAY}}$
the open circuit voltage at Standard Test Conditions of a PV array, and is equal to:

$V_{\text{OC ARRAY}} = V_{\text{OC MOD}} \times M$

where M is the number of series-connected PV modules in any PV string of the PV array.

NOTE This technical specification assumes that all strings within a PV array are connected in parallel; hence the open circuit voltage of PV sub-arrays and PV strings is equal to $V_{\text{OC ARRAY}}$.

3.55
voltage
differences of potential normally existing between conductors and between conductors and earth as follows:

a) extra-low voltage: not exceeding 50 V a.c. or 120 V ripple-free d.c.;

b) low voltage: exceeding extra-low voltage, but not exceeding 1 000 V a.c. or 1 500 V d.c.

c) high voltage: exceeding low voltage.

NOTE In consideration of ELV status, $V_{\text{OC ARRAY}}$ must be used.

4 Design

4.1 Electrical design

4.1.1 General

The cases of use of PV arrays which are considered in this document are the following:

PV array alone	For IES application circuit (IEC 62257-9-3 and IEC 62257-9-4) and CES application circuit (IEC 62257-9-2)
PV array coupled to another generator (see IEC 62257-9-1)	

Figure 1 illustrates the general functional configuration of a PV powered system with the localization of the functions described in Table 2.

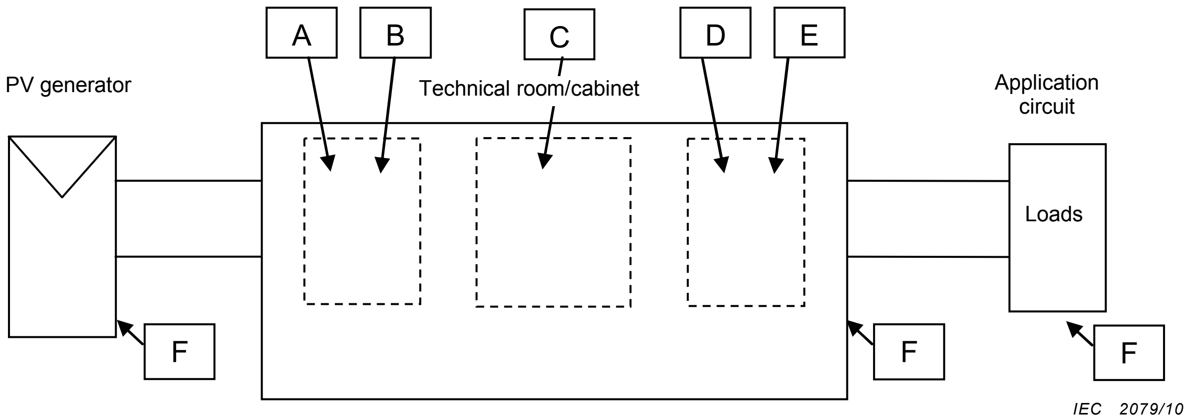


Figure 1 – General functional configuration of a PV system

Table 2 – Functions fulfilled by the technical room

Function	Description
A	Interface: connection between PV generator and technical room
B	Interface: isolation of the technical room from the PV generator
C	Other functions of the technical room + energy conversion, energy management, storage, if any
D	Interface: isolation of the application circuit from the technical room
E	Interface: connection between technical room and the application circuit
F	Earthing of exposed conductive part if required

For rural electrification projects it is strongly recommended to choose a voltage in the range of extra low voltage, taking into account the assumed skills of the operators, installers and users. Nevertheless, designers must be aware that decreasing the voltage means increasing the current and thus transferring voltage hazards to current risks (risk of fire, etc.).

Direct current systems, and photovoltaic systems in particular, pose various hazards in addition to those derived from conventional a.c. power systems, for example the ability to produce and sustain electrical arcs with currents that are not much greater than normal operating currents. This technical specification addresses those safety requirements arising from the particular characteristics of photovoltaic systems.

Except where the array is less than 200 W and the array voltage is ELV, all current-carrying conductors from the array shall be capable of being interrupted using a load-breaking switch.

NOTE In unearthed systems this is a general requirement of IEC 60364.

In earthed systems (where the application circuit is earthed), the switch is required to interrupt current caused by an earth fault within the array.

Because the array is current limited, overcurrent protection cannot provide interruption of this fault situation.

4.1.2 Earthing system of a IES or a CES including a PV array

4.1.2.1 General

To consider the PV array earthing it is necessary to consider the complete system earthing configuration. Two separate issues are addressed:

– earthing of the power cables (functional earthing) where required for operational or design reasons;
– earthing of exposed conductive parts for lightning protection and/or equipotential bonding (protective earthing).

NOTE To realize earthing on the field, see IEC 62305-3.

An earth conductor may perform one or more of these functions in an installation. The dimensions and location of the conductor are very dependent on its function.

Exposed conductive parts of the PV array need not be earthed only:

– if the lightning risk is assessed to be low, and
– if the PV array installation complies with any of the following provisions (a, b or c):
  a) double insulation (applies only if the PV array complies with all 1), 2) and 3):
    1) general. PV modules complying with class A in accordance with IEC 61730;
    2) wiring outside junction boxes. Where cables may come into contact with accessible PV array conductive parts, the cables shall be of a type affording double insulation;
    3) wiring inside junction boxes. Conductors within junction boxes having double insulation shall be protected, secured or insulated so that, if any one conductor becomes detached from its termination, neither the conductor nor its functional insulation can come into contact with accessible metal. The attachment of one conductor to another by tying, lacing, clipping or the like, in such a manner as to prevent either conductor coming into contact with accessible conductive parts if it becomes detached from its termination, shall be deemed to comply with this requirement;
  b) protection by electrical separation in accordance with IEC 60364-4-41;
  c) protection by SELV or PELV in accordance with IEC 60364-4-41.

4.1.2.2 Earthing system of the power cables

DC power cables of the PV array shall be earthed when there is a risk of high frequency overvoltages due to lightning (see Figures 3, 5, 7).

In this case the one pole of the PV array shall be earthed.

NOTE It is preferable to earth the positive pole of the PV array to avoid possible corrosion problems.

If there is an equipotential bonding the earthing of the cables shall be made through the equipotential bonding system (see Figure 9).

4.1.2.3 Earthing of the technical room

The earthing of the exposed conductive parts of the technical room shall follow the requirements indicated in 4.1.2.4.

The earthing of the electrical components included in the technical room, like the power conditioner, shall follow the recommendations of the manufacturers.

4.1.2.4 Earthing system of exposed conductive parts

There are two possible reasons for earthing exposed conductive parts of a PV array:

a) to provide a path for fault currents to flow;
b) to provide a path for high frequency currents due to lighting overvoltages to flow. To determine if a protection against lightning is necessary see IEC 62257-9-1, 6.1.2.2.

Protection against lightning overvoltage is always required when the linear distance between the PV array and the technical room is more than 15 m.

The surge arresters should be placed as close as possible to the PV array and to the technical room.

4.1.2.5 Equipotential bonding

Equipotential bonding is required as soon as PV array is coupled to another a.c. generator.

Equipotential bonding is used to avoid uneven potentials due to overvoltages (including lightning overvoltages), across the system.

The cable of the equipotential bonding between the generators and the technical room shall be run as physically close as possible to the live conductors in order to avoid any wiring loops able to induce perturbations in the circuits.

The connections to earth shall be realized as close as possible to the equipment to be earthed.

4.1.2.6 Earthing conductor sizing

The sizing of the earthing cable shall be made according to IEC 60364-5-54. In case of protection against lightning, the cross-section of this cable shall be at least 16 mm². In all cases, the cross-section of this cable shall withstand at least the $1,25 \times I_{SC\ ARRAY}$ continuously. The conductor shall comply with the provisions for earthing conductors specified in national wiring standards or in absence of such standards, with the provisions set out in IEC 60364-5-54 with respect to material and type, insulation, identification, installation, connections and aluminium conductors.

4.1.2.7 Recommended PV system earthing configurations

The following Table 3 and Table 4 show the recommended PV system earthing configurations for the different cases of use of PV array considered in this Technical Specification.

To define the earthing configuration of a PV array, it is necessary to consider both the earthing status of the cables and the earthing status of the exposed conductive parts.

4.1.3 Extra low voltage segmentation

In low voltage PV arrays, means should be provided to sectionalise each PV string into segments whose open circuit voltage at STC is within ELV.

4.1.4 Earthing system

4.1.4.1 Earthing electrode

If a separate earthing electrode is provided for the PV array, this electrode shall be bonded to the installation earth.

See recommendations on the design of electrodes for lightning protection in 62257-5, 9.6.

4.1.4.2 Earthing conductors

All PV array earthing conductors shall comply with the material, type, insulation, identification, installation and connection requirements specified in IEC 60364-5-54.

4.1.4.2.1 Earthing terminal of PV system

When the PV array is earthed, the connection to earth shall be made at a single point and this point shall be bonded to the installation earth.

In systems without batteries, this connection point shall be between the PV array disconnection device and the power conditioning unit and as close as possible to the power-conditioning system.

In systems containing batteries, this connection point shall be between the charge controller and the battery protection device.

NOTE 1 This is to allow for interruption of any earth fault current.

NOTE 2 The earthing status of the various sections of the installation is determined at the design stage. Tables 1 and 2 are simply a guide to location of a suitable example wiring diagram for a variety of design options.

How to use Table 3 or 4:

- check the distance “d” between the PV array and the technical room and select the right table;
- identify the type of system you want to install in the left column;
- go through the table from the left to the right and find an example of earthing.

4.1.4.2.2 PV system earthing conductor

If the PV array is earthed, the PV system earthing conductor shall be sized to carry $1{,}25 \times I_{SC\ ARRAY}$ continuously, and comply with the provisions for earthing conductors specified in national wiring standards or in absence of such standards, with the provisions set out in IEC 60364-5-54 with respect to material and type, insulation, identification, installation, connections and aluminium conductors.

The 15 m limit designates the linear distance “d” between the output of the photovoltaic array and the input of the technical room. The cable length may be longer than 15 m. The Engineering consultant in charge of the system design shall try to reduce the cable length for two reasons:

- Reduce the cost
- Reduce the risk of overvoltages due to undesiderable loops (see IEC 62257-9-1)

Table 3 – PV system earthing configurations – distance “d” < 15 m

PV generator					Technical room	Application circuit				Figure
Type of micropower system and configuration			Status of the exposed conductive parts of the generator (s)	Status of the poles of the generator (s)	Status of the exposed conductive parts of the technical room	Type of loads	Type of application circuit	Status of the exposed conductive parts	Status of the poles	
PV alone IES P< 500 W	A	PV generator without inverter	PV array unearthed	unearthed	unearthed	d.c. only	indoor installation	unearthed	unearthed	Figure 2
	B	PV generator + inverter	PV array unearthed	unearthed	earthed	a.c. and d.c.		d.c. unearthed a.c. earthed	d.c. unearthed a.c. earthed	Figure 4
	C		PV array unearthed	unearthed	earthed	a.c. only		earthed	earthed	Figure 6
Hybrid IES	D	PV generator + inverter and other generators (ex: genset)	all generators earthed	unearthed	earthed	a.c. only		earthed	earthed	Figure 8
PV alone CES	E	PV generator +inverter + microgrid	pv array unearthed	unearthed	unearthed	a.c. only	micro grid	earthed	earthed	Figure 6
Hybrid CES	F	PV generator + inverter + microgrid	all generators earthed	unearthed	earthed	a.c. only		earthed	earthed	Figure 8

Table 4 – PV system earthing configurations – distance “d” > 15 m

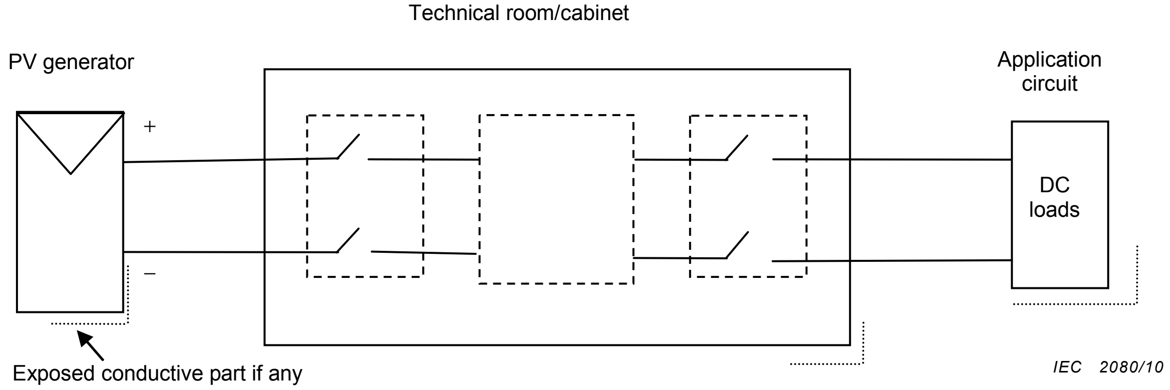
PV generator					Technical room	Application circuit				Figure
Type of micropower system			Status of the exposed conductive parts of the generator (s)	Status of the poles of the generator (s)	Status of the exposed conductive parts of the technical room	Type of loads	Type of application circuit	Status of the exposed conduc-tive parts	Status of the poles	
PV alone IES P< 500 W	G	PV generator without inverter	PV array unearthed	earthed	earthed + surge arrester if any	d.c. only	indoor installation	unearthed	unearthed	Figure 3
	H	PV generator + inverter	PV array unearthed	earthed	earthed + surge arrester if any	a.c. and d.c.		d.c. unearthed a.c. earthed	d.c. unearthed a.c. earthed	Figure 5
	I		PV array unearthed	earthed	earthed + surge arrester if any (see 62257-9-1 and 62257-9-4)	a.c. only		earthed	earthed	Figure 7
Hybrid IES	J	PV generator + inverter and other generators (ex: genset)	all generators earthed	earthed	earthed + surge arrester (see 62257-9-1 and 62257-9-4)-	a.c. only		earthed	earthed	Figure 9
PV alone CES	K	PV generator +inverter + microgrid	pv array unearthed	earthed	earthed + surge arrester (see 62257-9-1 and 62257-9-4)-	a.c. only	micro grid	earthed	earthed	Figure 7
Hybrid CES	L	PV generator + inverter + microgrid	all generators earthed	earthed	earthed + surge arrester (see 62257-9-1 and 62257-9-4)-	a.c. only		earthed	earthed	Figure 9

For ELV array supplying LV application circuit the inverter shall provide electrical separation between the PV array (and / or battery) and the application circuit. Annex G provides a test to determine if any inverter provides this separation.

The lightning stroke risk shall be assessed according to IEC 62257-1, Annex B and the results used to decide on the need for surge protection.

The only floating PV system is the one described in Figure 2.

The following Figures 2 to 9 illustrate the different system earthing arrangements.



NOTE Some components of such small photovoltaic IES may not have any exposed conductive part.

Figure 2 – Configuration A – PV alone IES P < 500 W – without inverter – d < 15 m

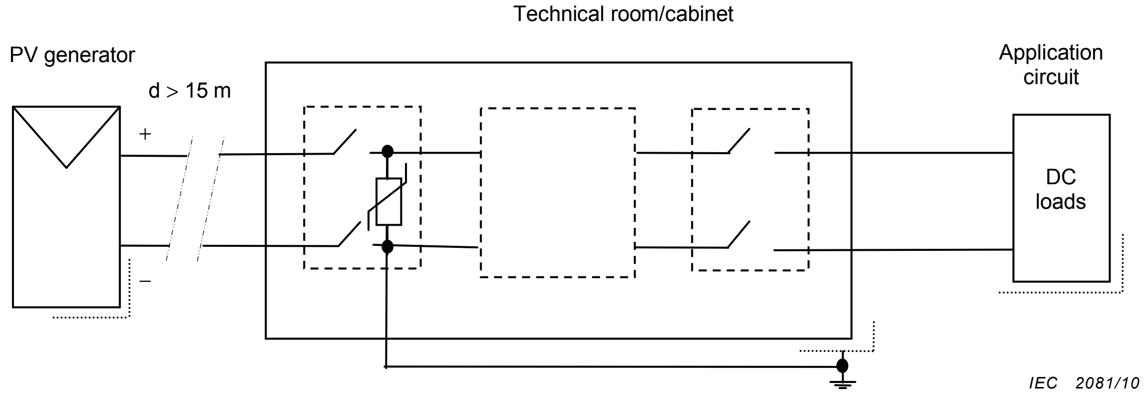


Figure 3 – Configuration G – PV alone IES P < 500 W – without inverter – d > 15 m

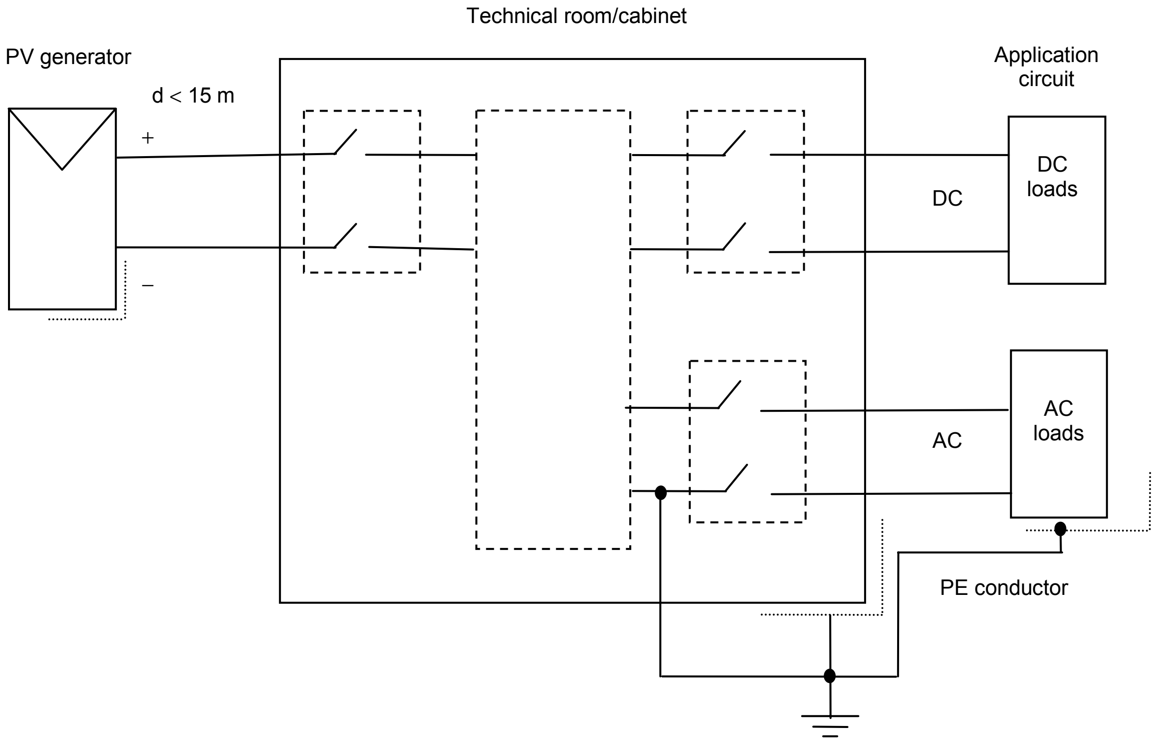


Figure 4 – Configuration B – PV alone IES P < 500 W – with inverter – d < 15 m

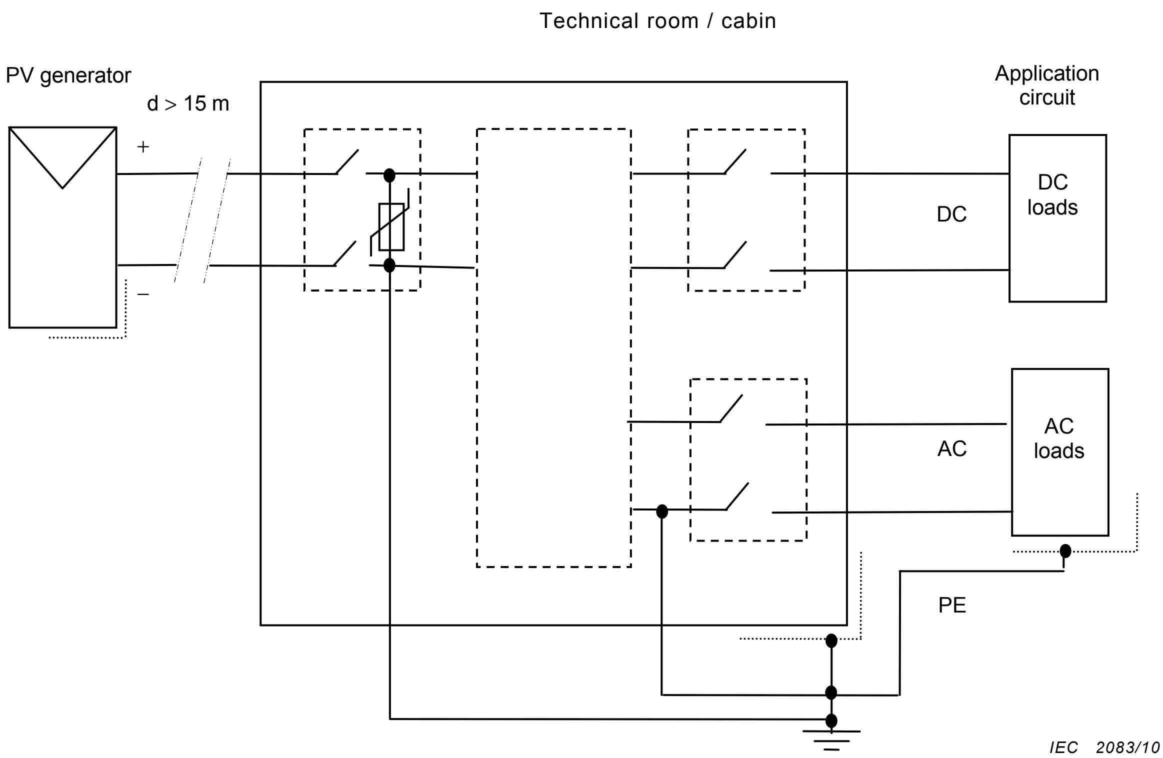


Figure 5 – Configuration H – PV alone IES P < 500 W – with inverter – d > 15 m

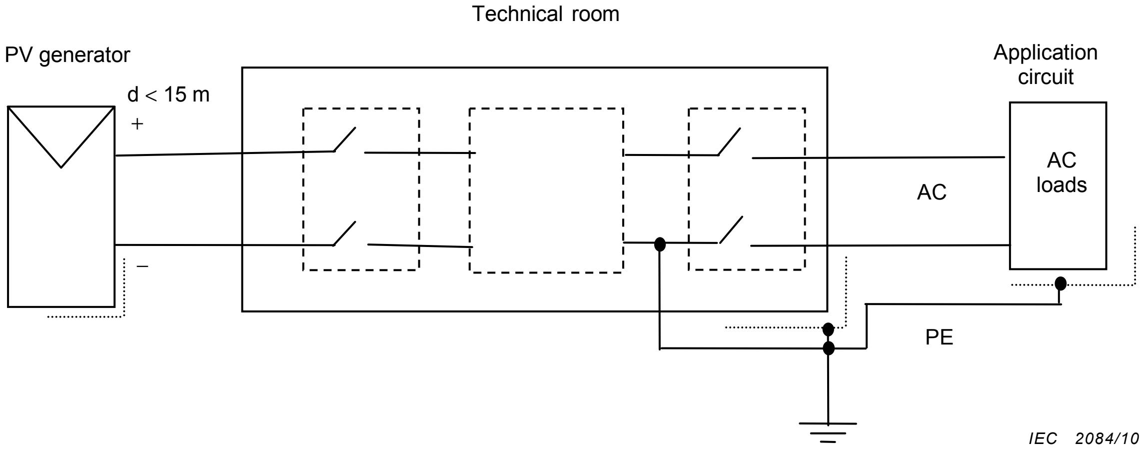


Figure 6 – Configuration C and E – PV alone IES or CES – P < 500 W – with inverter – d < 15 m

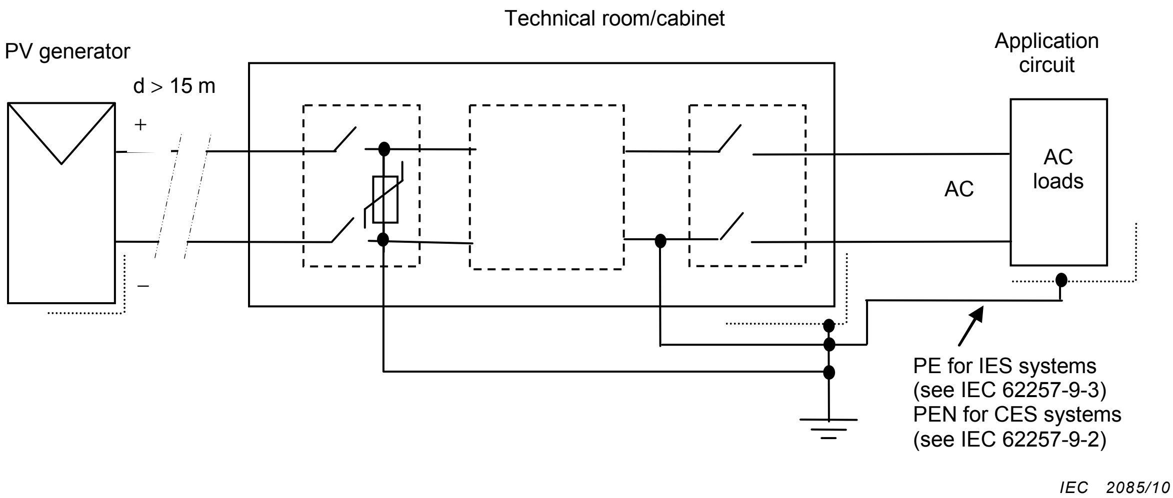


Figure 7 – Configuration I and K – PV alone IES or CES – P < 500 W – with inverter – d > 15 m

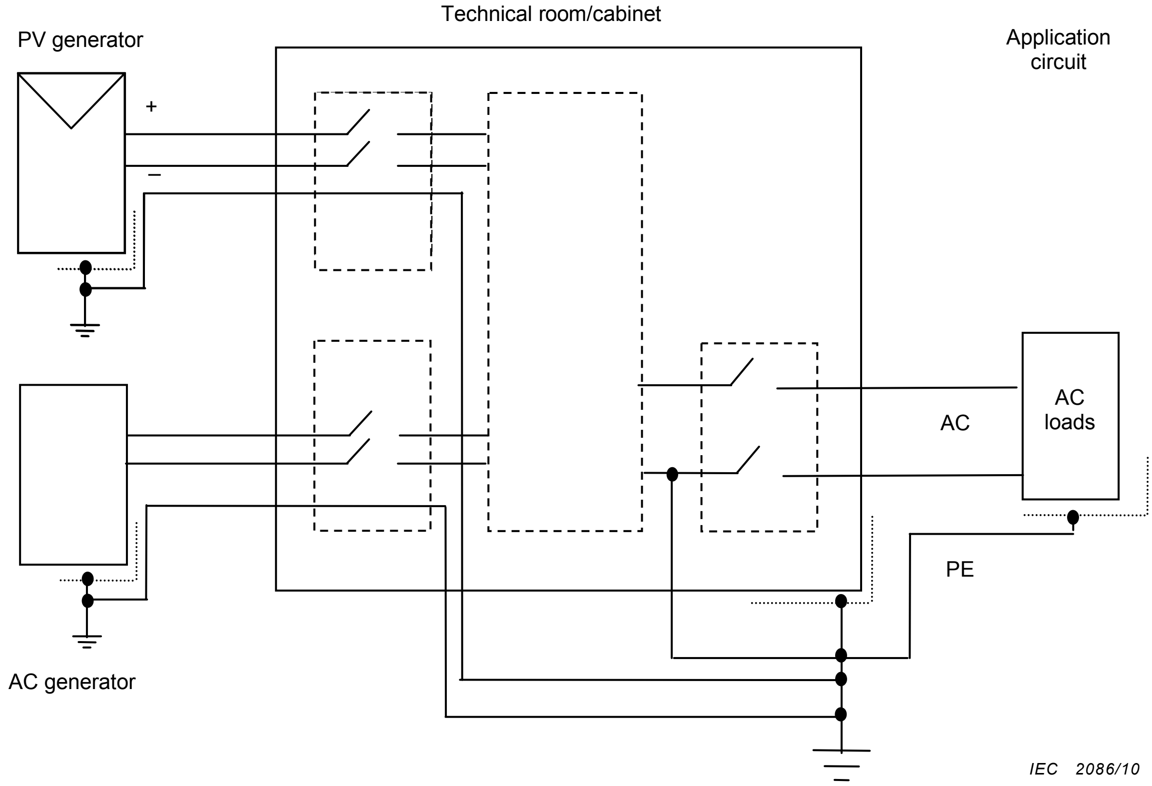


Figure 8 – Configuration D and F – Hybrid IES or CES –
PV generator + inverter and other generator – d < 15 m

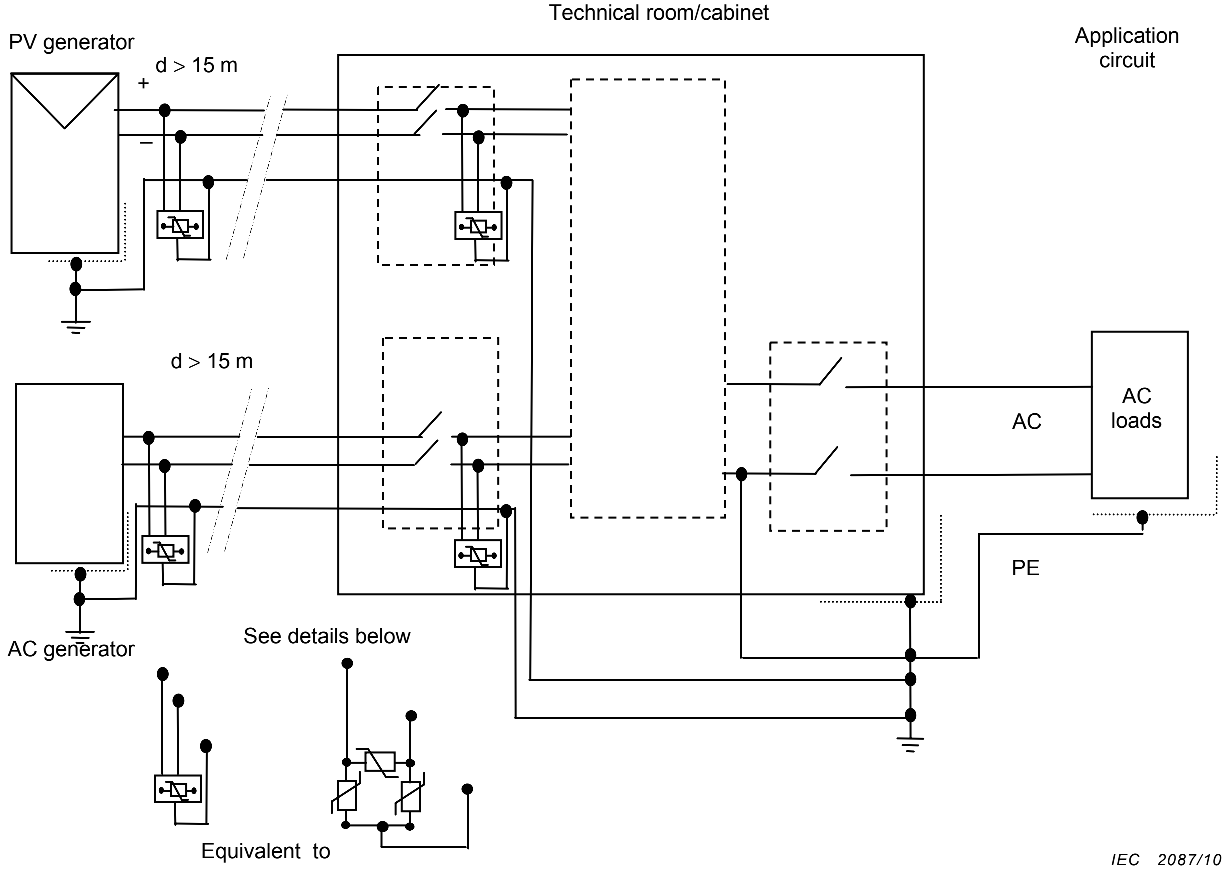


Figure 9 – Configuration J and L – Hybrid IES or CES – PV generator + inverter and other generator – d > 15 m

4.1.4.3 Particular case of a.c. application circuits

For all PV systems including a.c. application circuits, it is required that all a.c. application circuits be earthed.

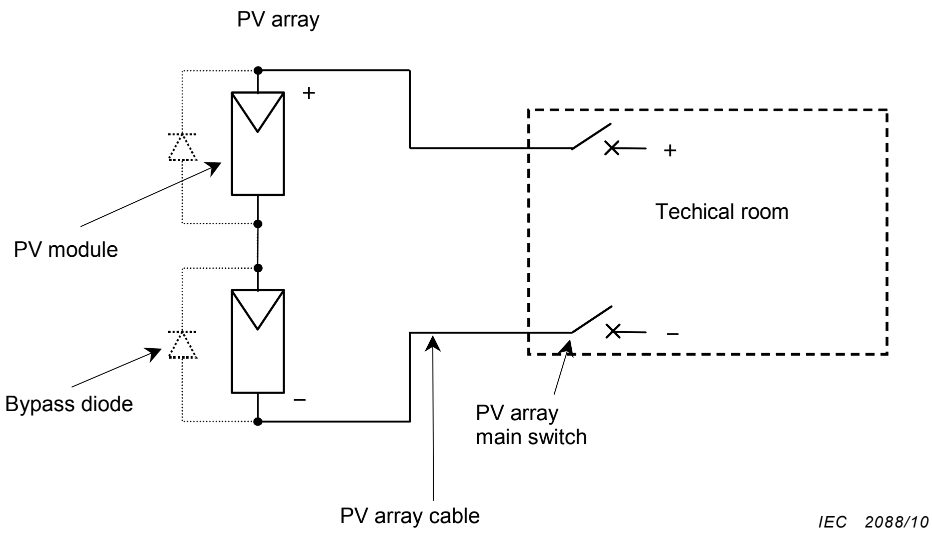
For small portable PV IES producing a.c. power through an inverter and for which it is impossible to earth the poles of the a.c. circuit, the inverter shall be double insulated.

4.1.5 Architectures

The diagrams in Figure 10 to Figure 12 show the basic electrical configurations of single-string, multi-string and multi-sub-array PV respectively.

The voltages to be used in rural electrification systems shall be chosen according to the skill of the local operators (see IEC 62257-9-1, Clause 9). The architecture of the PV array shall be chosen in order to comply with economic and operation constraints in order to provide the right power at the right voltage level.

The use of ELV can be made only for small systems where the value of the current remains low. As soon as the power of the system increases it is necessary to also increase the voltage in order to reduce both the current and the cross section of the power cables.



NOTE 1 If the array is designed with more than 2 modules, array voltage could be over ELV limits.

NOTE 2 Unless a battery is present a load-breaking isolator is sufficient as the PV array main switch. If a battery is present, overcurrent protection is required.

Figure 10 – PV array diagram – single string case

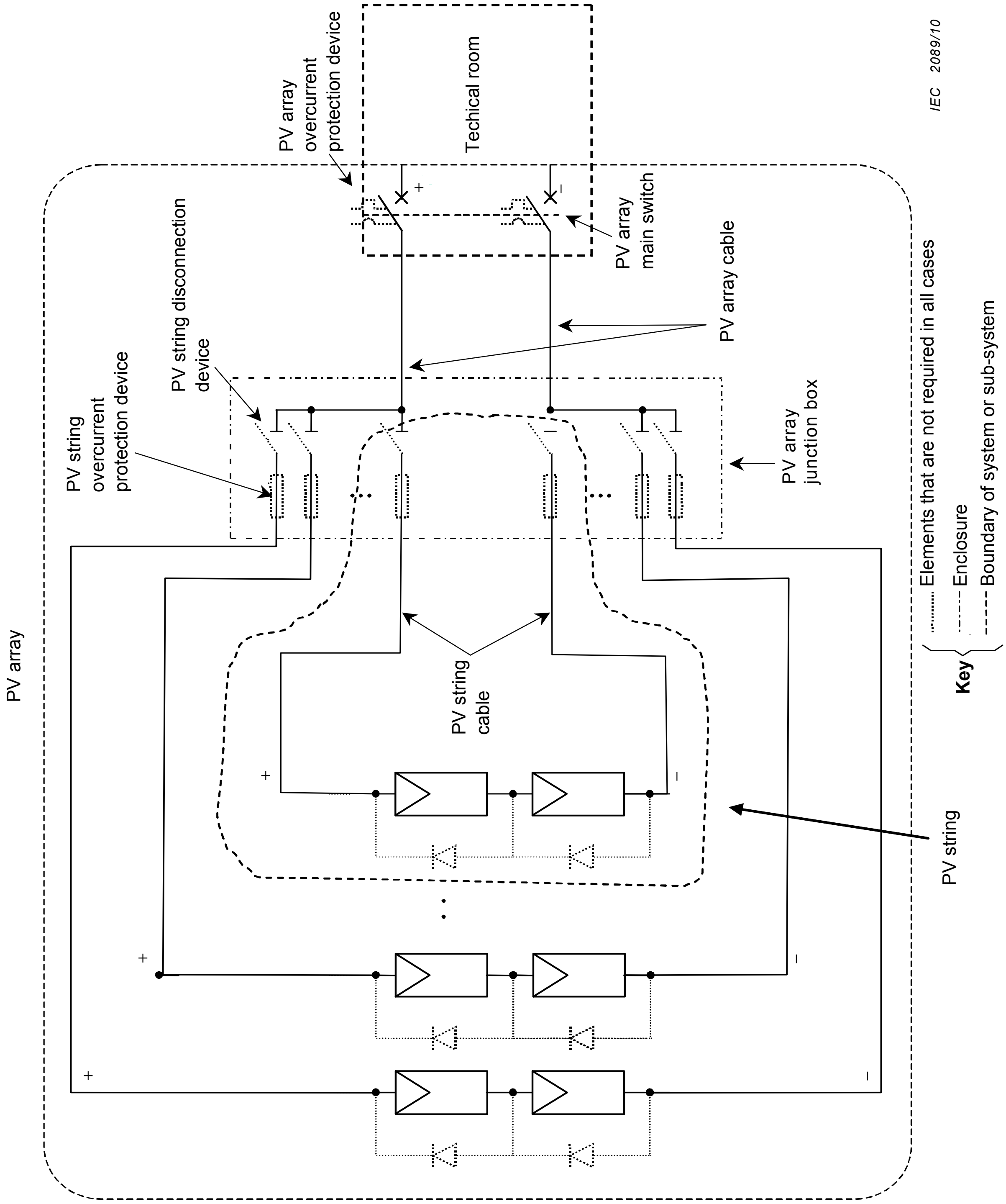


Figure 11 – PV array diagram – multi-string case

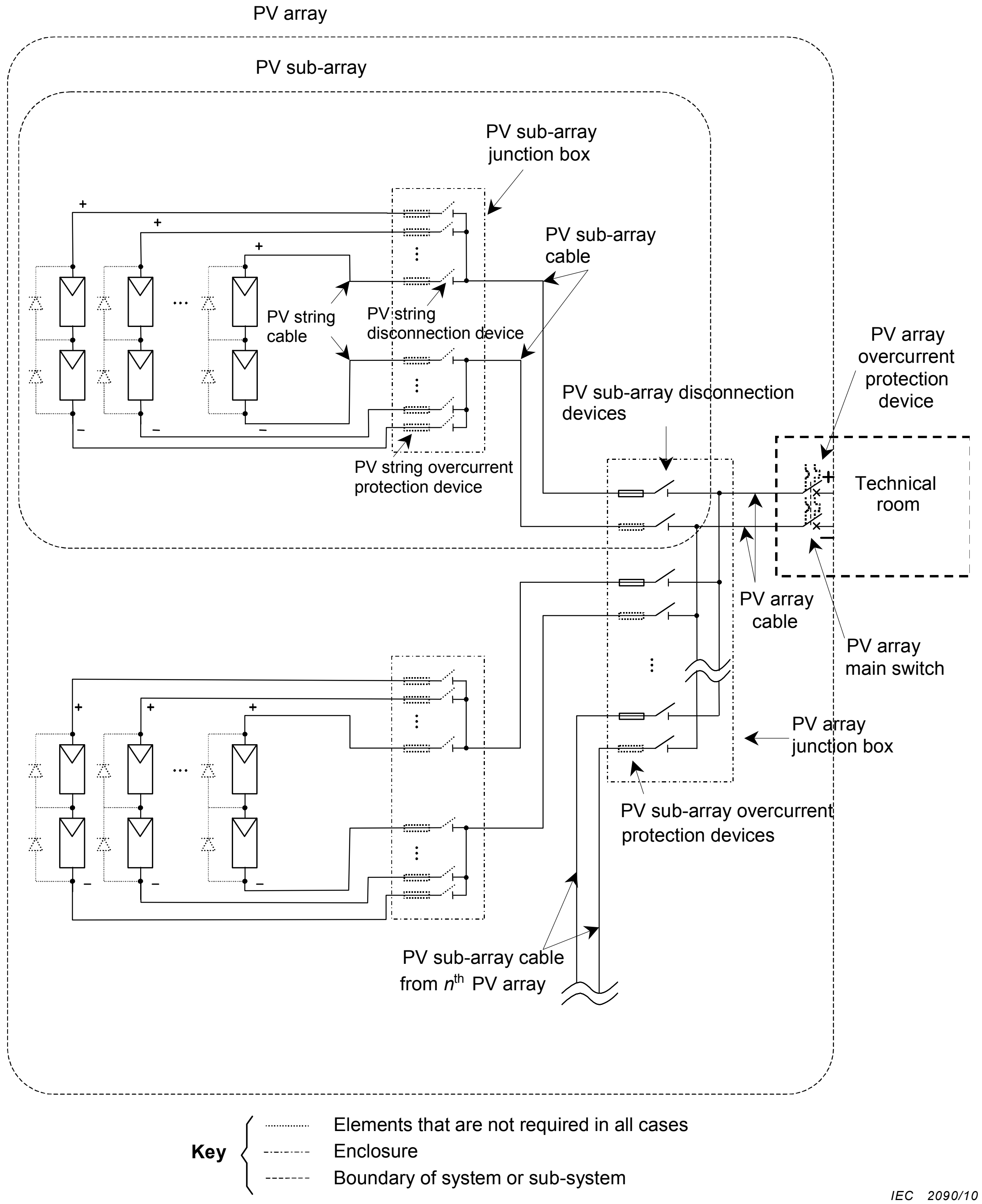


Figure 12 – PV array diagram – multi-string case with array divided into sub-arrays

NOTE In Figures 10 to 12, components drawn in dotted format are not required in all cases. The figures indicate the location in the circuit when they are required. See text for requirements (Tables 5, 6 and 7, and subclauses 6.1.7 and 6.1.8 are examples).

4.1.6 Series-parallel configuration

To reduce mismatch and improve PV array yield, all PV strings within a PV array should be of the same technology, have the same number of series connected PV modules. In addition, all PV modules within the PV array should have similar rated electrical characteristics including short circuit current, open circuit voltage, maximum power current, maximum power voltage and rated power (all at STC).

NOTE This is a design issue which needs to be considered by the project implementer, particularly when replacing modules or modifying an existing system.

4.1.7 Batteries in systems

Batteries in PV systems can be a source of high prospective fault currents. The location of fault current protection related to battery systems is generally between the battery and charge controller and as close as practical to the battery. This protection can be used to provide overcurrent protection for PV array cables (see 5.3.4.3) provided the PV array cable is rated to withstand the same current as the battery overcurrent protection device.

NOTE The current rating of string cables must be much higher in battery systems if no individual o/c protection is provided (see Table 6). In this case, the nearest downstream o/c protection may be the battery fuse.

4.1.8 Considerations due to prospective fault conditions within a PV array

In any installation, the source of prospective fault currents needs to be identified.

Systems containing batteries may have high prospective fault currents due to the battery characteristic (see 4.1.5).

In a PV system without batteries, as the PV cells (and consequently PV arrays) behave like current sources under low impedance faults, much greater than normal full load currents will not always flow even under short circuit conditions.

The fault current depends on the number of strings, the fault location and the irradiance level. This makes short circuit detection within a PV array very difficult. Electric arcs can be formed in a PV array with fault currents that would not trip an overcurrent device.

The implications for PV array design that arise from these PV array characteristics are as follows.

a) The possibility of line-to-line faults, earth faults and inadvertent wire disconnections in the PV array need to be minimized more than for conventional electrical installations. (Note that in conventional electrical installations the large inherent fault current capability of the system will generally blow a fuse, trip a circuit breaker or other protection system in the case where a fault occurs.)
b) Earth fault detection and disable could be required as part the system protection functions, depending on the array size and location, to eliminate the risk of fire.

4.1.9 Considerations due to operating temperature

PV modules ratings are stated at standard temperature conditions (25 °C).

Under normal operating conditions, 25 °C is a common steady state temperature rise with respect to the ambient temperature for crystalline silicon PV modules operating at the maximum power point under 1 000 W/m^2 solar irradiance and with adequate ventilation. This temperature rise can go up to 35 °C when modules are open circuited (i.e. the PV array has been disconnected due to a fully charged battery). The temperature rise can be even higher when irradiance levels are greater than 1 000 W/m^2 and when modules have poor ventilation.

The following two main requirements on the PV array design derive from this operating characteristic of PV modules.

a) For some PV technologies, the efficiency reduces as the operating temperature increases (for crystalline silicon solar cells the maximum power decreases between 0,4 and 0,5 % per each °C rise in operating temperature). Therefore adequate ventilation of the PV array should be a design goal, in order to ensure optimum performance for both modules and associated components.

b) All the components and equipment that may be in direct contact or near the PV array (conductors, inverters, connectors, etc.) need to be capable of withstanding the expected maximum operating temperature of the PV array.

c) Under cold conditions, for crystalline silicon technology based cells, the voltage increases (see 4.1.8 for further considerations).

4.1.10 Component voltage ratings

Open circuit voltage is one of the normal operating conditions of any PV array. Open circuit voltage can be as large as twice the nominal d.c. bus voltage. PV array components shall be rated for at least the open circuit voltage for a module temperature equal to the lowest ambient temperature of the site.

4.1.11 Performance issues

A PV array's performance may be affected by many factors, such as:

– shading;
– temperature rise;
– voltage drop in cables;
– pollution of the surface of the array.

Care shall be taken in selecting a site for the PV array. Nearby trees and buildings may cause shadows to fall on the PV array during some part of the day.

It is important that any shadowing be almost eliminated or at least reduced to a very small time period as even the smallest shadow on the array can severely limit its performance.

Issues of performance degradation due to temperature rise and the need for good ventilation are described in 4.2.2. Care should be taken to keep modules as cool as practicable.

In the design process the sizing of cables within the array and in cable connections from the array to the application circuit affect the voltage drop in those cables under load. This can be particularly significant in systems with low output voltage and high output current. It is recommended that under maximum load conditions the voltage drop from the most remote module in the array to the terminals of the application circuit should not exceed 5 % of the nominal system voltage.

Pollution of the surface of PV modules caused by dust, dirt, bird droppings, snow, etc. can significantly reduce the output of the array. Arrangements should be made to clean the modules regularly in situations where significant pollution may be a problem.

Suitable devices shall be fitted to the photovoltaic array in order to limit dirt building up as the result of bird droppings. Devices such as spikes or tubing-covered wires mounted on the apex of the array can be useful deterrents for birds.

Where such effects as sand winds or land animals may be present, the photovoltaic array shall be installed at suitable height above ground (typically 1,5 m to 2 m).

NOTE For cold climates, consider the maximum voltage rating of components for the maximum voltage expected increase at the lowest expected temperature of the PV modules.

4.2 Mechanical design

4.2.1 General

Support structures and module mounting arrangements should comply with applicable building codes (including earthquake requirements where relevant), regulations and standards.

4.2.2 Thermal aspects

Provisions should be taken in the mounting arrangement of PV modules to allow for the maximum expansion/contraction of the modules under expected operating temperatures, according to the manufacturer's recommendations.

NOTE Some types of PV modules degrade significantly in performance when inadequate ventilation allows the modules to operate at high temperature.

4.2.3 Mechanical loads on PV structures

The PV array support structures should comply with national standards and regulations with respect to loading characteristics. Particular attention should be given to wind loads on PV arrays.

NOTE Support structures are not usually a problem for small PV systems.

4.2.4 Wind

The indications provided under this heading are for quality guidance. Under no circumstances shall these instructions be used as a replacement for a case-by-case, detailed calculation.

Wind force applied to the PV array will generate a significant load for building structures. This extra load should be accounted for in assessing the capability of the building to withstand the resulting forces.

On assessing this component, the maximum wind speed observed (or known) on site shall be used, with due consideration for punctual wind events such as cyclones, tornadoes, hurricanes, etc. The PV array structure shall be secured in an appropriate manner or in accordance with local building standards.

4.2.5 Material accumulation on PV array

Snow, ice, or other material may build up on the photovoltaic generator and should be accounted for when calculating the supporting structure for the modules and likewise, when calculating the building capability to support the generator.

4.2.6 Corrosion

When possible all structures shall be made of corrosion resistant materials e.g. aluminium, galvanized steel, treated wood poles or structures, etc.

If the structure is metallic, aluminum or hot dipped galvanized steel are well suited to this type of use. If the array is installed in a marine or other highly corrosive environment, aluminum shall be anodized. Care should be taken to ensure that different metals are not in direct contact as this will encourage corrosion particularly in a salt environment.

The same applies to all bolts, nuts and fasteners.

5 Safety issues

5.1 General

Refer to the IEC 62257-5 technical specification.

5.2 Protection against electric shock and fire

For protection against electric shock the requirements of IEC 61140 shall apply.

Referring to the 62257-5 technical specification the following requirements shall be applied:

Protection by extra-low voltage systems (SELV and PELV systems) systems shall be classified as Class III or better.

For all other systems, protection by double or reinforced insulation between any live conductor and any earthed or exposed conductive part (i.e.Class II modules and double or reinforced insulation for the whole PV array) is required.

Earthing of one of the live conductors of the d.c. side is permitted, if there is at least simple separation between the d.c. side and the a.c. side.

5.3 Protection against overcurrent

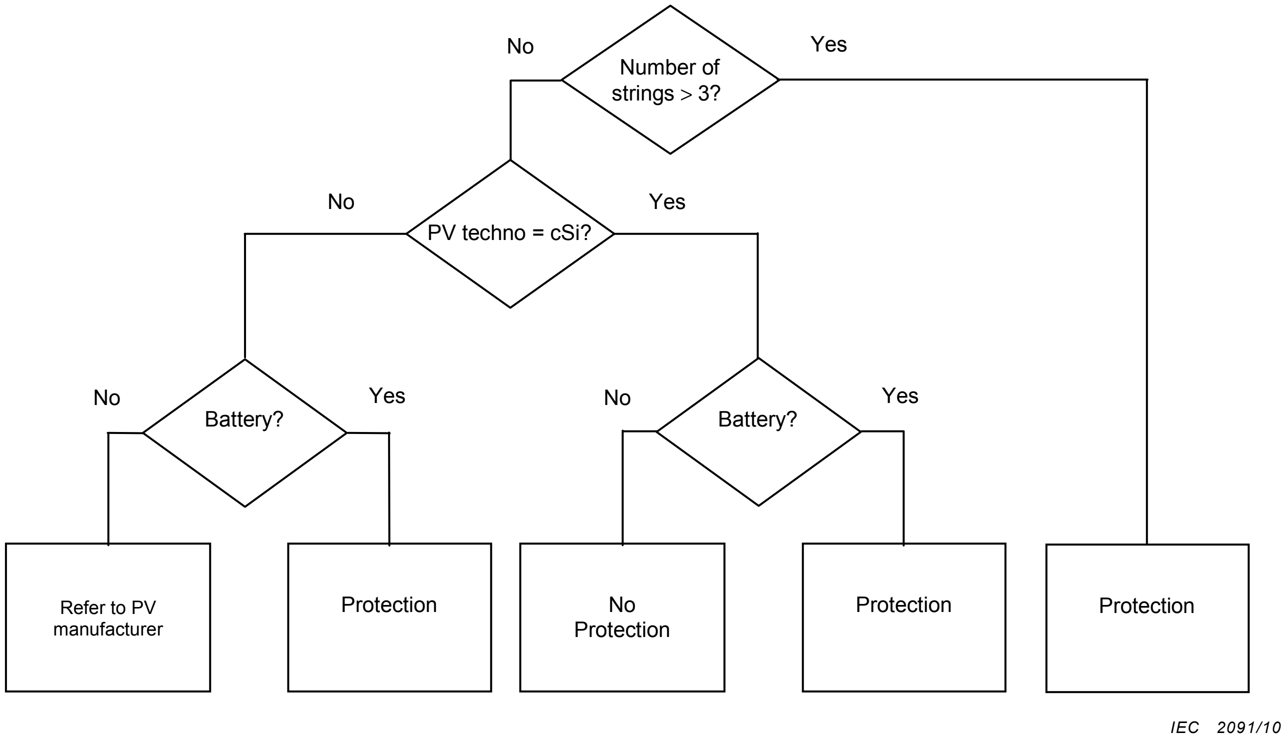
5.3.1 General

Fault currents due to short circuits in modules, in junction boxes or in module wiring or earth faults in array wiring can result in overcurrent in a PV array.

PV modules are current limited sources but because they can be connected in parallel and also connected to external sources (e.g. batteries), they can be subjected to overcurrents caused by either multiple parallel adjacent strings or from external sources or both.

5.3.2 Overcurrent protection requirements for PV strings

Situations where overcurrent protection is required in PV strings are introduced in Figure 13.



NOTE 1 For systems including batteries, see 5.3.4.3.

NOTE 2 For cable ratings, see 6.1.4.

NOTE 3 cSi refers to crystalline silicon, (either mono-crystalline or multi-crystalline).

Figure 13 – Needs for overcurrent protection in PV strings

5.3.3 Discrimination

Overcurrent protection within the PV array shall be graded in such a way that lower level protection trips first in the event of fault currents flowing from higher current sections to lower current sections of the PV array.

NOTE When circuit breakers with overcurrent protection elements are used, they also provide the disconnecting means required in clause 6.2.1.

5.3.4 Overcurrent protection sizing

5.3.4.1 PV string overcurrent protection

If there are more than two strings in parallel then the maximum fault current which can flow in any one string is equal to the (number of strings –1) times the short circuit rating of one of the strings.

Therefore if there are three or more parallel strings, the PV modules could be subjected to reverse currents of two or more times their nominal short circuit current. It is for this reason that the number of strings able to be connected in parallel without overcurrent protection in each string is linked to the reverse current rating of a module.

Fault current protection is irrelevant when there are only one to two strings in parallel, and there is no battery storage system, provided the PV modules are capable of withstanding a reverse current equal to their short circuit current.

For crystalline silicon modules, the number of strings in parallel without fusing shall not exceed 3.

For other technologies, refer to manufacturer's instructions if any. If no instructions are available, fuses shall be installed on every string.

The rated tripping current (I_{TRIP}) of overcurrent protection devices for PV strings shall be as specified by the PV module manufacturer. If the manufacturer does not give any recommendation, I_{TRIP} shall be determined with the following formula:

$$1,45 \times I_{SC\ MOD} \leq I_{TRIP\ STRING} \leq 2 \times I_{SC\ MOD}.$$

NOTE 1 The tripping current is the current which activates the protection device.

NOTE 2 In some PV module technologies $I_{SC\ MOD}$ is higher than the nominal rated value during the first weeks or months of operation. This should be taken into account when establishing overcurrent protection and cable ratings.

5.3.4.2 PV sub-array overcurrent protection

The rated trip current (I_{TRIP}) of overcurrent protection devices for PV sub-arrays shall be determined with the following formula:

$$1,45 \times I_{SC\ S\text{-}ARRAY} \leq I_{TRIP\ S\text{-}ARRAY} \leq 2 \times I_{SC\ S\text{-}ARRAY}.$$

NOTE 1 PV sub array protection is not compulsory but if it is not used then the size of the conductor for the sub array cable may be excessively large. Refer to Table 3. If PV sub array cables are used and protection provided then the protection and the cable size is related to $I_{TRIP\ S\text{-}ARRAY}$.

NOTE 2 It is thus better to compare two solutions the first one without fuse in the sub array cable and the second one with fuse. The physical size of the cables and the cost may be rather different from one solution to the other. It is the responsibility of the engineering consultant to choose the best techo-economic compromise. The greater the number of sub arrays, the higher the probability that fuses are usefull. See formula of sub array cables in Table 4 (sizing of PV array circuits).

5.3.4.3 PV array overcurrent protection

PV array cable overcurrent protection is only required for systems connected to batteries or where other sources of current may feed into the PV array under fault conditions. The trip current (I_{TRIP}) of PV array overcurrent protection devices shall be rated as follows:

$$1,45 \times I_{SC\ ARRAY} \leq I_{TRIP\ ARRAY} \leq 2 \times I_{SC\ ARRAY}$$

NOTE 1 The PV array overcurrent protection devices are commonly installed between the battery and the charge controller as close as possible to the battery. If these devices are appropriately rated, they provide protection to both, the charge controller and the PV array cable. In such cases, no further PV array cable overcurrent protection between the PV array and the charge controller is required.

NOTE 2 The current rating of string cables must be much higher in battery systems if no individual o/c protection is provided (see Table 6). In this case, the nearest downstream o/c protection may be the battery fuse.

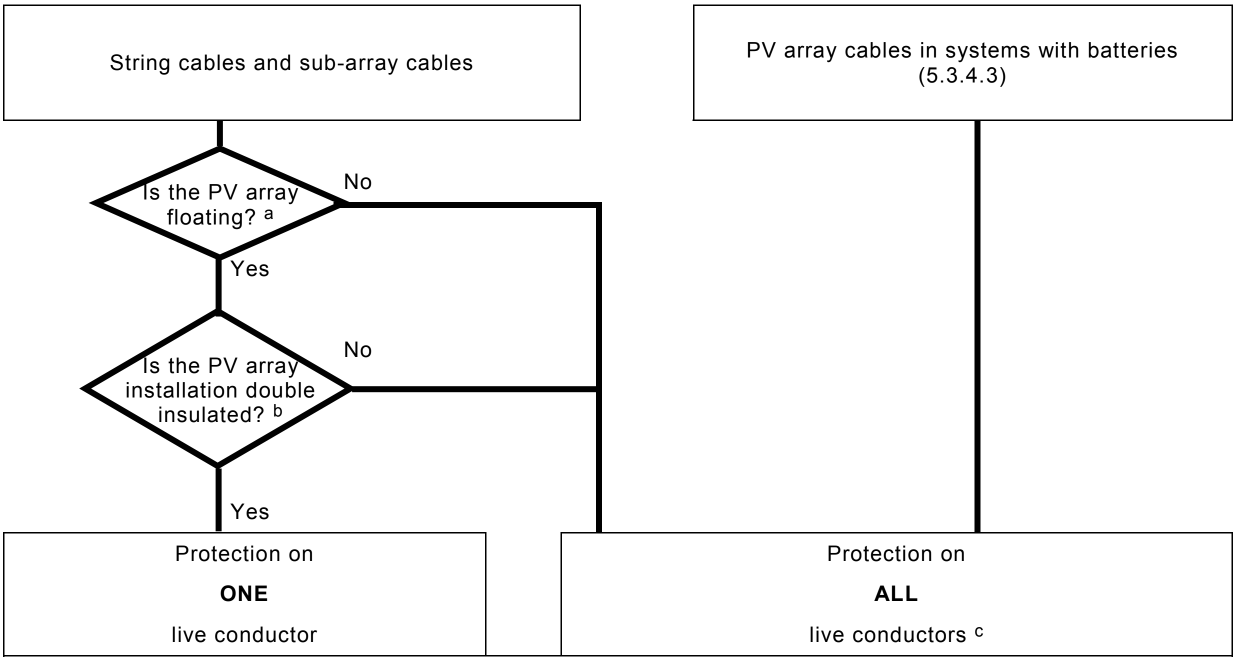
5.3.5 Overcurrent protection location

Overcurrent protection devices where required by the above clauses for PV array, PV sub-array, and PV strings shall be placed electrically at the load end of those cables.

NOTE The location of the overcurrent protection devices at the load end of the wiring is to protect the system and wiring from fault currents flowing from other sections of the PV array or from other sources such as batteries.

Overcurrent protective devices location requirements are introduced in Table 5.

Table 5 – Requirements for location of overcurrent protective devices according to the earth configuration



[a] Floating PV array: which is not directly connected to earth and connected to an application circuit which is either unearthed or isolated.

[b] If the PV array installation is double insulated with respect to earth, the risk of an earth fault is greatly reduced. It is only under conditions of a double earth fault on a floating PV array that overcurrent protection would be required in both live conductors. A single overcurrent protection will clear faults which develop within junction boxes and short circuits between live conductors. Reducing the number of overcurrent protection devices, reduces the number of joints in the wiring system thus reducing the risk of fire due to bad joints and also reduces cost and installation time.

[c] In an earthed PV array it is considered that there is only one live conductor (it is the one which is not connected to earth).

5.4 Protection against effects of lightning and over-voltage

5.4.1 General

For protection against over-voltages refer to IEC 61173 , IEC 62305-2 and IEC 62305-3.

5.4.2 Protection against direct stroke from lightning

A lightning protection system has the task of preventing severe damage caused by fire or mechanical destruction in case of a direct lightning strike in a building or structure. (For the assessment of the lightning stroke risk, see Annex B of IEC 62257-9-1.)

Lightning protection systems consist of three essential components:

a) an air termination system, consisting of metallic masts or rods of sufficient height to divert lightning currents through their structure;

b) a down conductor of sufficient cross-sectional area to conduct lightning currents to earth; and

c) an earth termination system.

The installation of a PV array on a building has a negligible effect on the probability of direct lightning strikes; therefore it does not necessarily imply that a lightning protection system should be installed if none is already present. However, if the physical characteristics or prominence of the building do change significantly due to the installation of the PV array, it is recommended that the need for a lightning protection system be assessed in accordance with IEC 62305-2 and, if required, it should be installed in compliance with IEC 62305-3. For practical assessment of lightning risk in the field see also IEC 62257-9-1 Annex B.

If a lightning protection system is already installed on the building, it should be verified that the PV array and associated equipment are within the protection zone of the system. If the PV array is not within the protection zone of the existing lightning protection system, additional air termination(s) in accordance with IEC 62305-3 should be provided.

When a PV array is protected by a lightning protection system, the metal structure of the PV array should be bonded to the lightning protection system, unless the minimum safety clearances as specified in IEC 62305-3 can be achieved.

5.4.3 Protection against over-voltage

5.4.3.1 Equipotential bonding

Damage caused by over-voltage is ultimately due to the failure of insulation between live parts or between live parts and earth. The intention of over-voltage protection is to equalize all exposed metallic sections of an installation to a common potential during the event of an over-voltage, to prevent insulation flashover. Equipotential bonding is therefore a most important over-voltage protection measure and shall be done in accordance with national standards or IEC 60364-5-54 (see also IEC 62257-5, IEC 61173).

To avoid the formation of wiring loops between earthed conductors and d.c. cabling, equipotential bonding conductors should run parallel and as close as possible to the d.c. cabling. It is also recommended to branch the bonding conductor to run parallel with all the d.c. cabling branches (see 6.2.4.3.).

5.4.3.2 Surge arresters

5.4.3.2.1 General guide

Surge arresters are a very common method of protecting electrical systems and equipment against over-voltages. When these devices are used the recommendations of IEC 61643-12 should be observed.

Over-voltage protection with surge arresters should be provided when the PV power system meets any of the following criteria:

a) the risk of overvoltages due to lightning has been assessed as high (see Annex B IEC 62257-9-1),
b) the system supplies critical loads (e.g. telecommunication repeater stations), or
c) the PV array has a rated capacity greater than 500 W, or
d) the PV array is protected with a lightning protection system.

Many commercial PV inverters and charge controllers are fitted with surge arresters on the PV input terminals, therefore this should be considered when specifying the over-voltage protection of the PV array.

5.4.3.2.2 Recommended specifications

The recommended specifications for surge arresters to protect PV arrays from over-voltages caused by indirect lightning strikes are as follows (refer to list of parameters for surge arrester selection in IEC 61643-12):

a) maximum continuous operating voltage (U_C): $U_C > 1,3 \times V_{OC\ STC\ GEN}$;
b) maximum discharge current (I_{max}): $I_{max} \geq 5$ kA;

c) voltage protection level (U_p): $U_C < U_p < 1{,}1$ kV.

6 Selection and erection of electrical equipment

6.1 Component requirements

6.1.1 PV modules

6.1.1.1 Operational conditions and external influences

Crystalline silicon PV modules shall comply with IEC 61215. Thin film PV modules shall comply with IEC 61646.

6.1.1.2 Equipment Class

PV modules should be Class II.

6.1.2 PV array and PV sub-array junction boxes

6.1.2.1 Environmental effects

PV Array and PV Sub-array junction boxes exposed to the environment shall be at least IP 54 compliant in accordance with IEC 60529, and shall be UV resistant.

6.1.2.2 Location of PV array and PV sub-array junction boxes

PV array and PV sub-array junction boxes, where installed, shall be readily available.

6.1.3 Switching devices

6.1.3.1 General

All switching devices, shall comply with the following requirements:

– be rated for d.c. use (especially when voltage is over 30 V due to the risk of arcs);
– have a voltage rating equal to or greater than $V_{OC\ ARRAY}$;
– not have exposed live metal parts in connected or disconnected state;
– interrupt all poles, except in the case of a pole connected either to earth or to a protective conductor.

6.1.3.2 Disconnectors

In addition to the requirements of 6.1.3.1, disconnectors (see IEC 60050-811:1991, 811-29-17) shall have a current rating equal to or greater than the associated overcurrent protection device, or in the absence of such device, have a current rating equal to or greater than the required current carrying capacity of the circuit to which they are fitted (refer to Table 6).

In addition, circuit breakers and any other load breaking disconnection devices used for protection and/or disconnecting means shall comply with the following requirements:

– not be polarity sensitive (fault currents in a PV array may flow in the opposite direction of normal operating currents);
– be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present;
– when overcurrent protection is incorporated, the trip current shall be rated according to 5.3.4.

Plug connections for interruption under load may also be used if equivalent level of safety can be assured.

NOTE Only specially constructed plugs and sockets are capable of interrupting load safely. All systems with an open circuit voltage greater than 30 V can experience d.c. arcs. Plugs and sockets which are not specially constructed for load interruption if disconnected under load represent a safety risk and generally incur damage to the connection which will compromise the quality of the electrical connection and could lead to overheating of the connection.

6.1.4 Cables

6.1.4.1 Sizing

6.1.4.1.1 General

Cable sizes for PV string cables, PV sub-array cables and PV array cable shall be determined with regard to both, the minimum current capacity and the maximum voltage drop requirements. The larger cable size obtained from these two criteria shall be applied.

6.1.4.1.2 Current carrying capacity (CCC)

The minimum cable sizes for PV array wiring, based on CCC, shall be based upon a current rating calculated from Table 6, and the current carrying capacity of cables as specified in IEC 60287 series.

NOTE In some PV module technologies $I_{SC\ MOD}$ is higher than the nominal rated value during the first weeks or months of operation. This should be taken into account when establishing cable ratings.

Table 6 – Current rating of PV array circuits

<table>
<tr><th>Type of cable</th><th colspan="2">Minimum current upon which cable cross sectional area should be chosen [a, b]</th></tr>
<tr><td rowspan="3">PV string cable</td><td colspan="2">$I_{\text{STRING CABLE}}$ = Trip current [c] of the nearest downstream overcurrent protection device + 1,45 × $I_{\text{SC MOD}} \times (S_{\text{PO}} - 1)$
Where:
S_{PO} is the number of parallel connected strings protected by the nearest overcurrent protection device.</td></tr>
<tr><td>PV string overcurrent protection not provided</td><td>The nearest downstream overcurrent protection is the sub-array overcurrent protection.
$I_{\text{STRING CABLE}} = I_{\text{TRIP S-ARRAY}} + 1{,}45 \times I_{\text{SC MOD}} \times (S_{\text{P0}} - 1)$
with :
$1{,}45 \times I_{\text{SC S-ARRAY}} \leq I_{\text{TRIP S-ARRAY}} \leq 2 \times I_{\text{SC S-ARRAY}}$.
NOTE When no sub array overcurrent protection is used S_{PO} is the total number of parallel connected strings in the PV array; and the trip current of the nearest overcurrent protection device is replaced by zero.</td></tr>
<tr><td>PV string overcurrent protection provided</td><td>The nearest downstream overcurrent protection is the string overcurrent protection.
$I_{\text{STRING CABLE}} = I_{\text{TRIP STRING}}$
with :
$1{,}45 \times I_{\text{SC MOD}} \leq I_{\text{TRIP STRING}} \leq 2 \times I_{\text{SC MOD}}$.</td></tr>
<tr><td rowspan="3">PV sub-array cable</td><td colspan="2">$I_{\text{S-ARRAY CABLE}}$ =Trip current [c] of the nearest downstream overcurrent protection device + 1,45 × $I_{\text{SC MOD}} \times (S_{\text{PO}} - 1)$
Where:
S_{PO} is the number of parallel connected strings protected by the nearest overcurrent protection device.</td></tr>
<tr><td>PV sub-array overcurrent protection not provided</td><td>The nearest downstream overcurrent protection is the array overcurrent protection.
$I_{\text{S-ARRAY CABLE}}$ = The greater of the following:
a) Trip current [c] of the PV array overcurrent protection device + 1,45 × Sum of short circuit current of all other sub-arrays
b) $1{,}45 \times I_{\text{SC S-ARRAY}}$ (of relevant array)
NOTE When PV array overcurrent protection is not used, the corresponding parameter is replaced by zero in equation (a).</td></tr>
<tr><td>PV sub-array overcurrent protection provided</td><td>$I_{\text{S-ARRAY CABLE}}$ = Trip current [c] of the PV sub-array overcurrent protection device</td></tr>
<tr><td rowspan="2">PV array cable</td><td>PV array overcurrent protection not provided</td><td>$I_{\text{ARRAY CABLE}} = 1{,}45 \times I_{\text{SC ARRAY}}$</td></tr>
<tr><td>PV array overcurrent protection provided</td><td>$I_{\text{ARRAY CABLE}}$ =Trip current [c] of the PV array overcurrent protection device</td></tr>
</table>

a	The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature of maximum expected ambient temperature + 40 °C should be considered for cables installed near or in contact with PV modules.
b	The location and method of installation (i.e. enclosed, clipped, buried etc) of cables also needs to be considered in establishing a cable rating. Cable manufacturers recommendations need to be taken into account in establishing the rating according to installation method.
c	Trip current is the nominal current at which the overcurrent protection device is calibrated to operate. The current at which the device trips will generally be greater than the nominal rated current.

6.1.4.2 Insulation

The insulation of cables used within the PV array shall:

– have a voltage rating of at least $V_{\mathrm{OC\ ARRAY}}$,

NOTE 1 The use of single core insulated and sheathed cable is recommended for wiring of LV PV arrays, to minimise the risk of faults within the wiring.

– have a temperature rating according to the application,

NOTE 2 PV modules frequently operate at temperatures of the order of 40 °C above ambient temperature. Cable insulation of wiring installed in contact or near PV modules need to be rated accordingly.

– if exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection, or the cables be installed in UV-resistant conduit;

– be fire resistant.

6.1.5 Protection devices and cables sizing process

Step 1: sizing of the overcurrent protection of the strings: see 5.3.4.1; location of the protection devices: see Table 5.

Step 2: sizing of the overcurrent protection devices of the sub-arrays: see 5.3.4.2; location of the protection devices: see Table 5.

Step 3: sizing of the overcurrent protection devices of the arrays: see 5.3.4.3; location of the protection devices: see Table 5.

Step 4: sizing of the cables of the arrays based on the rating of the overcurrent protection of the arrays in systems with batteries otherwise sizing based on 1,45 × current rating of the array.

Step 5: sizing of the cables of the sub-arrays based on the rating of the overcurrent protection of the sub-arrays.

Step 6: sizing of the cables of the strings based on the rating of the overcurrent protection of the strings.

Some case studies relevant with small PV power systems for rural electrification are proposed in Annex E to illustrate the sizing process:

Case 1: ELV PV array with number of parallel strings < 3, no battery

Case 2: ELV PV array with number of parallel strings < 3, with battery

Case 3: ELV PV array with number of parallel strings > 3, no battery

Case 4: ELV PV array with number of parallel strings ≥ 3, with battery

Case 5: ELV PV array with number of parallel strings ≥ 3, 2 sub-arrays with battery

6.1.6 Plugs, sockets and couplers

Plugs, sockets and couplers shall comply with the following requirements:

- be rated for d.c. use;
- have a voltage rating equal or greater than $V_{OC\ ARRAY}$;
- be protected from contact with live parts in connected and disconnected state (e.g. shrouded);
- have a current rating equal to or greater than the cable to which they are fitted;
- require a deliberate force to disconnect;
- have a temperature rating suitable for their installation location;
- if multipolar, be polarised;
- comply with Class II;
- if exposed to the environment, be rated for outdoor use, be UV-resistant and be at least IP 54 compliant;
- plugs and socket outlets normally used for the connection of household equipment to low voltage a.c. power shall not be used in PV arrays.

NOTE The purpose of this requirement is to prevent confusion between a.c. and d.c. circuits within an installation.

6.1.7 Fuses

6.1.7.1 General

Fuses used in PV arrays shall comply with the following requirements:

- be rated for d.c. use;
- have a voltage rating equal or greater than $V_{OC\ ARRAY}$;
- be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid, if present;
- be of an overcurrent and short current protective type suitable for PV – e.g. DC rated type gR fuse.

NOTE When fuses are provided for overcurrent protection, the use of fused switch-disconnectors (fuse-combination units) is recommended.

6.1.7.2 Fuse holders

Fuse holders shall comply with the following requirements:

- have a voltage rating equal or greater than $V_{OC\ ARRAY}$;
- have a current rating equal or greater than the corresponding fuse;
- provide a degree of protection not less than IP 2X.

6.1.8 By-pass diodes

By-pass diodes may be used to prevent PV modules from being reverse biased and consequent hot spot heating. If by-pass diodes are used, and they are not embedded in the PV module encapsulation, they shall comply with the following requirements:

- have a voltage rating at least $2 \times V_{OC\ MOD}$ of the protected module;
- have a current rating of at least $1{,}45 \times I_{SC\ MOD}$;
- be installed according to module manufacturer's recommendations;
- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

6.1.9 Blocking diodes

Blocking diodes may be used but they are not a substitute for overcurrent protection.

In systems containing batteries it is recommended that some device will be implemented to avoid reverse current leakage from the batteries into the array at night. A number of solutions exist to achieve this including blocking diodes.

If used, blocking diodes shall comply with the following requirements:

– have a voltage rating at least $2 \times V_{\text{OC ARRAY}}$;
– have a current rating of at least 1,45 times the short circuit current at STC of the circuit that they are intended to protect; that is:
  - $1{,}45 \times I_{\text{SC MOD}}$ for PV strings;
  - $1{,}45 \times I_{\text{SC S-ARRAY}}$ for PV sub-arrays;
  - $1{,}45 \times I_{\text{SC ARRAY}}$ for PV arrays;
– be installed so no live parts are exposed;
– be protected from degradation due to environmental factors.

If there is a special recommendation from the manufacturer or from local regulation to use blocking diodes in PV strings of the PV array, these diodes shall be installed as shown in the following Figure 14.

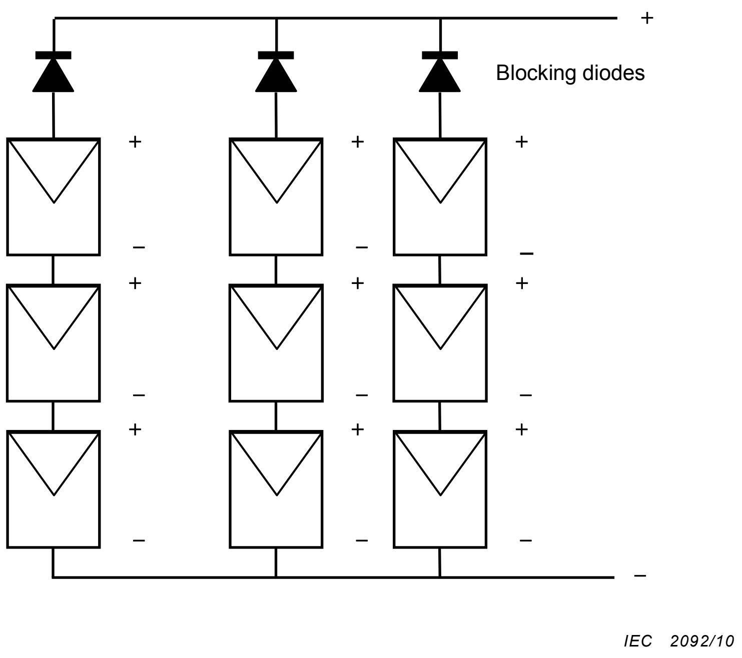


Figure 14 – Blocking diode implementation (example)

6.2 Location and installation requirements

6.2.1 Disconnecting means

6.2.1.1 General

Disconnecting means shall be provided in PV arrays according to Table 7 and Table 8 to isolate the PV array from the power conditioner and vice versa and to allow for maintenance and inspection tasks to be carried out safely.

NOTE This subclause does not apply to module inverters where the inverter is an integral part of the PV module.

6.2.1.2 Installation

Suitably rated circuit-breakers used for overcurrent protection may also provide load breaking disconnecting facilities.

Other disconnection and isolation devices having the characteristics described in 6.1.3.2 may be used as a disconnection means.

Fuse systems used for overcurrent protection are acceptable non-load breaking disconnecting means if they have removable fusing elements, preferably with a disconnection mechanism (fuse-combination unit).

For a reference to the location of disconnection devices see Table 8 which indicates with respect to the system configuration where the disconnecting mean should be installed (on one or both live conductors of the cable) and which type is this connecting mean.

Table 7 – Disconnecting means requirements in PV array installations

PV array Voltage	Circuit or sub-circuit	Type of disconnection device	Requirement
ELV	String cable	Disconnection device	Recommended
	Sub-array cable	Readily available disconnection device	Required
	Array cable	Readily available load-breaking disconnection device	Required
LV	String cable	Readily available disconnection device	Required
	Sub-array cable	Readily available load-breaking disconnection device	Required
	Array cable	Readily available lockable [a] load-breaking disconnection device	Required [b]

[a] "Lockable" disconnection device is a switch or circuit breaker that has provision for insertion of a mechanical device to prevent the switch being closed by an unauthorized person. A mechanical device in this context could constitute sealing with plastic cord, a pin, a wire or other device that prevents operation of the switch.

[b] A lockable disconnection device is not required if the whole circuit is visible from the location of the switch.

Table 8 – Location of disconnection devices according to system configuration, where required

System configuration	Location of disconnecting devices		
	PV string cables	PV sub-array cables	PV array cable
Unearthed PV array	On all live conductors [a]		On all live conductors
Earthed PV array			On all current carrying conductors [b, c]

[a] Live conductors are those not directly connected to earth.

[b] The disconnection device is required in this situation to interrupt the earth conductor so that earth fault currents may be interrupted.

[c] In earthed arrays the earthed conductor is a current carrying conductor and needs to be able to be disconnected to allow for interruption of any earth fault condition.

6.2.2 PV array production optimization

To optimize the PV array production it is necessary to fulfil the following requirements:

6.2.2.1 Orientation, tilt angle and flatness

In so far as possible, the orientation and tilt angle of the modules shall optimize the production of energy in relation to the needs. The north or south orientation of the modules is hemisphere dependent. However, the building may not necessarily allow ideal orientation of these two parameters (roof not orientated south or north, vertical front, etc.) and therefore they shall be clearly accounted for in the production calculation at the sizing design phase.

Whatever the array latitude, it is generally recommended that the slope keeps to a minimum value of ten degrees (10°) in relation to the horizontal, thus preventing stagnation and allowing rain water to carry away dust deposits. Moreover, periodical cleaning actions shall be performed, however, as need be.

The surface for fitting photovoltaic modules to structures shall be perfectly flat in order not to induce mechanical stresses on securing the modules in order to avoid risks of module rupture.

6.2.2.2 Location: accounting for shadow

6.2.2.2.1 Environmental

Shadowing of the PV array should be minimized or preferably eliminated over the whole day with consideration given to all seasons of the year.

A shadow blanking off a photovoltaic cell may cause loss of almost the whole production of this module, significantly reducing the performance of a string of modules.

6.2.2.2.2 One line of photovoltaic modules over the other

On flat roofs, photovoltaic modules are arranged in rows. The first row is fully exposed to sunshine and therefore, the shadow thus generated may affect the next row and so on.

As a basic rule, no shadow should be generated from one row to another.

It may occur that the available space will not allow the ready application of this rule: an energy production study versus the various structure configurations should be conducted (e.g., more or less high, hence more or less spaced structures, acceptance of shadow early in the morning and end of the afternoon, change of orientation and/or of slope, etc.).

A compromise should be retained allowing to best fulfillment of the site requirements for energy yield.

NOTE Where more than one row of adjacent modules are on a mounting rack and the lower row of modules may be subject to some form of shading then the wiring configuration should be arranged if possible to put all the shaded modules in the same string so that if shading occurs then only one string is affected. This will make it possible for upper modules to continue producing energy even though lower modules are in the shadow.

6.2.2.3 Location: other recommendations

Prior to implementing a solar generator, it is important to know the behavior and habits of the users and neighborhood. Some locations shall be avoided, especially those exposed to damage that could occur to modules.

Due consideration for environmental risks provides for system durability and is directly linked to the project designers' knowledge of the local social canvas.

6.2.2.4 Maintaining the integrity of the covering

The attachment of structures to the building shall keep to the sealing efficiency of the covering and mechanical integrity of the building.

Special care shall be exercised with terrace fitted units where the quality of the covering and related structure is often very poor. It is advisable to have structures laid onto the building instead of attached to it.

6.2.2.5 Theft prevention devices

Where building maintenance does not oblige to remove the modules and if the latter are accessible, theft prevention bolt and nuts shall be adopted. In the opposite case, standard bolting will be used. Where small structures (a few modules per structure) are used, a theft prevention device shall also be used for securing structures to the building.

6.2.3 Array voltage

6.2.3.1 General

$V_{\mathrm{OC\ ARRAY}}$ shall not exceed the maximum allowed operating voltage of the PV modules (as specified by the manufacturer).

6.2.4 Wiring system

6.2.4.1 General

Wiring of PV arrays shall be laid in such a way that the possibility of line to line and line to earth faults occurring is minimised.

All connections shall be verified for tightness and polarity during installation to reduce the risk of faults and possible arcs during commissioning and operation.

6.2.4.2 Compliance with wiring standards

The PV array wiring shall comply with the wiring requirements mandated by local standards and regulations. In absence of national standards and or regulations, wiring systems used in PV arrays shall comply with the IEC 60364 series.

NOTE Particular attention should be given to the protection of wiring systems against external influences.

6.2.4.3 Wiring loops

To reduce the magnitude of lightning-induced over-voltages, the PV array wiring should be laid in such a way that the area of conductive loops is minimum, e.g. by laying cables in parallel as shown in Figure 15.

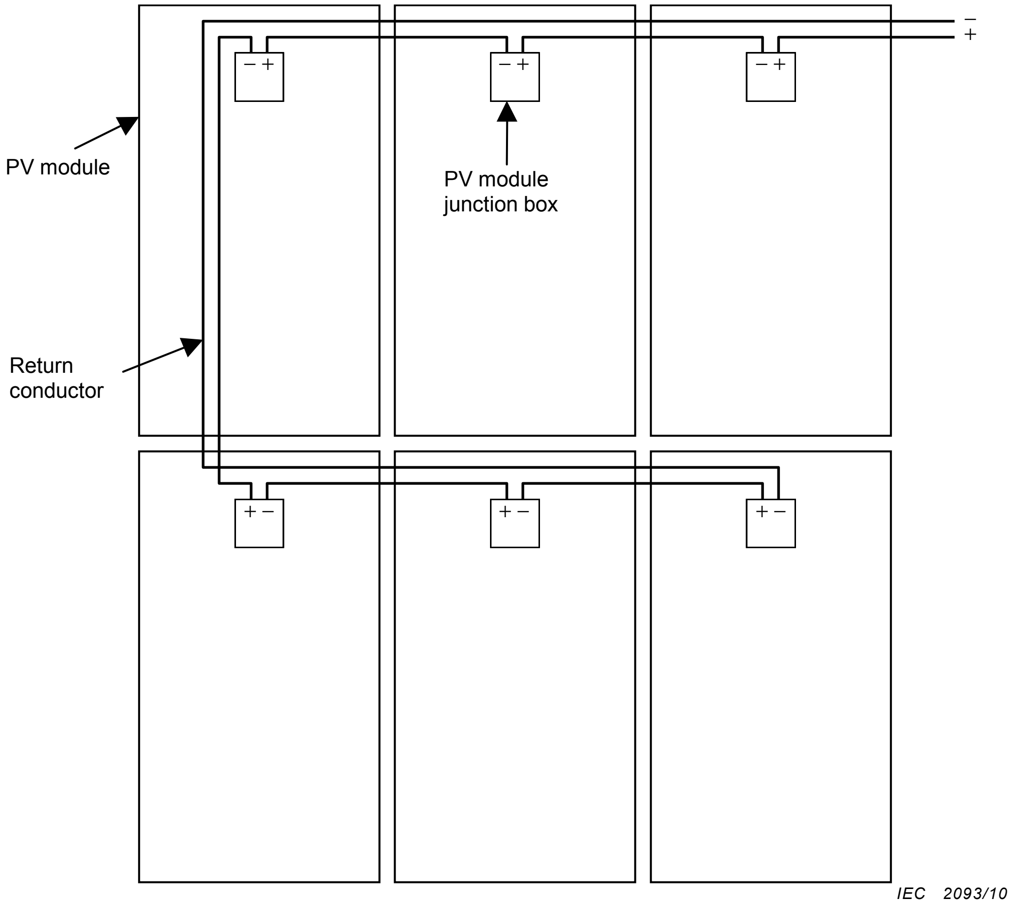


Figure 15 – PV string wiring with minimum loop area

6.2.4.4 String wiring

Wiring of PV strings between modules may be done without laying cables in conduit, provided that the following requirements are met:

- insulated and sheathed cables are used, and
- cables are protected from mechanical damage, and
- the cable is clamped to relieve tension in order to prevent the conductor from coming free from the connection.

6.2.4.5 Wiring installation in junction boxes

The following provisions apply to the installation of wiring systems in junction boxes:

Where conductors enter a junction box without conduit, a tension relief system shall be used to avoid cable disconnections inside the junction box (for example by using a gland connector).

All cable entries when installed shall maintain the IP rating of the enclosure.

NOTE Water condensation inside junction boxes may be a problem in some locations; provision may need to be provided to drain water build-up.

For LV PV arrays, where any return conductor is routed through module junction boxes, such return conductor(s) shall be a single-core double-insulated cable, and the cable and its insulation shall maintain double insulation status over its entire length, particularly through junction boxes (i.e. these provisions also apply to any joints).

6.2.4.6 Wiring identification

Appropriate identification shall be provided for PV array cabling where it can be confused with other wiring systems.

6.2.4.7 Over-voltage protection

6.2.4.7.1 Surge arresters

6.2.4.7.1.1 Selection

The preferred type of surge arresters for over-voltage protection of PV arrays is metal-oxide varistors (MOVs). These devices are voltage dependent resistors that have a high resistance at normal circuit operating voltage, but their resistance reduces continuously with increased surge voltage and current. Spark gap devices are not suitable for use in d.c. circuits as once conducting, they will not stop conducting until the voltage across their terminals is typically less than 30 V.

Because the performance of MOVs deteriorates with repeated operation (their resistance decreases), it is usual to allow a high safety margin in the selection of the device rating in lightning prone areas. Alternatively, facilities should be provided to give an indication of device failure. The use of thermally monitored MOVs is recommended to avoid excessive system losses and troubleshooting time caused by device failure.

6.2.4.7.1.2 Usage and installation

The following recommendations should be observed for the utilization and connection of surge arresters to protect PV arrays:

A surge arrester should be connected between each pole of the PV array cable and earth. Differential mode protection is not required unless the voltage protection level (VP) of the surge arresters is greater than 1 100 V.

In sub-divided PV arrays, the provision of surge arresters in both poles of each PV sub-array cable is recommended.

The cable distance between the surge arresters and the PV modules should not exceed 15 m.

When the PV array cable exceeds 20 m, surge arresters should be connected at each end of the cable, one set next to the PV array, and the other one next to the power conditioning device. For this purpose, it should be verified if the power conditioning equipment is already fitted with surge arresters.

Junction boxes are a good place to install the surge arresters. Care should be taken to connect them on the PV module side of any disconnecting devices.

The common terminal of surge arresters should be connected to both, conductive PV array frames and structures, and to the equipotential bonding system.

Cables for connecting surge arresters should be as short as possible and have a cross-sectional area not less than 6 mm^2.

6.2.4.7.2 Shielding

When the PV array frame is bonded to a lightning protection system, the PV array cable should be shielded by one of the following methods, and the shielding conductor should be connected to earth at both ends:

– with a metallic cable armour or shield with an equivalent cross sectional area of 6 mm^2 Cu; or
– with a metallic conduit suitable as a bonding conductor; or
– with an equipotential bonding conductor with a cross-sectional area of 6 mm^2.

6.2.4.8 Automatic disconnection devices

Earth fault detection installed on the d.c. side shall cause disconnection of the PV array from the application circuit. The disconnecting device shall be located between the PV array and the earthing point of the PV array as shown in Figures 5 and 7.

6.2.5 Surge protective devices

Refer to 5.4.3.2.

6.2.6 Earthing arrangement, protective conductors

Refer to 4.1.2.

7 Acceptance

7.1 General

PV array acceptance procedure will refer to the IEC 62257-6 technical specification.

Commissioning tests are specified in 7.3 to 7.4 to ensure that the PV array complies with the requirements of this standard. The tests specified in 7.5 to 7.6 are additional recommended tests for commissioning of PV arrays larger than 10 kW.

7.2 Conformance with system general specification

The PV array shall be inspected for conformity with the general ratings and technical specifications stated in the contract.

7.3 Wiring and installation integrity

7.3.1 Compliance with wiring standards

The PV array wiring shall be inspected for compliance with wiring standards and regulations in accordance with 6.2.4.

7.3.2 Compliance with this standard

The PV array installation shall be inspected for compliance with the requirements set out in this standard and corrected if necessary.

7.4 Open circuit voltage

This subclause discusses open circuit voltage for

a) systems with less than 20 strings;
b) systems with more (see 7.5).

7.4.1 General

This test is intended to ensure that wiring polarity and continuity of the PV array are correct.

7.4.2 Procedure

The open circuit voltage of every string shall be measured before connecting to other strings. All PV string open circuit voltages shall be within 5 % variation; otherwise the connections shall be verified for polarity, continuity and possible faults and repaired. Once the verification is complete and satisfactory, the PV strings can be connected in parallel.

The same procedure shall be carried out to verify PV sub-array open circuit voltages (if relevant) and PV array open circuit voltage before connecting to the PV array to the power conditioning unit.

NOTE All measurements should be made when practicable under stable irradiance conditions. Conditions close to solar noon are preferable.

7.5 Open circuit voltage measurements for PV arrays with a large number of strings

7.5.1 General

This procedure is a guide on open circuit voltage measurements for PV arrays with a large number of PV strings (20 or more) where the environmental conditions and PV array operating conditions are likely to change significantly during the measurements due to the time required for each measurement.

7.5.2 Procedure

Before closing any switches and installing fuses, the open circuit voltage of each PV string shall be measured. The measured values shall be compared with the expected value. Temperature corrections shall be applied where required according to manufacturers' specification. Module temperature shall be measured in the back of one of the central modules of each string. Voltage measurements should be made with an accuracy of 2 %; temperature measurements shall have an accuracy of 1 ºC.

NOTE 1 Voltages less than the expected value may indicate one or more modules connected with the wrong polarity, or a partial line-to-line or line-to-ground fault due to insulation damage and/or water accumulation inside conduits.

NOTE 2 High voltage readings are usually the result of wiring errors.

The measured open circuit voltage of each PV string shall be within 3 % of the expected value. If there are larger differences, the PV string should be verified for any of the conditions in Note 1 above and the wiring corrected. Once every string has been verified and if necessary corrected, they should be parallel connected via switching devices and/or by installing fuse elements.

7.5.3 PV arrays and sub-arrays measurement

Once the PV strings have been verified and connected in parallel, the open circuit voltage of each PV sub array (if relevant) and of the PV array shall be measured using the same procedure as with PV strings.

The measured values shall be within 3 % of the expected value; otherwise the wiring shall be verified and corrected if necessary. In addition to wrong polarity and insulation faults, defective surge protection devices could be the cause of lower than expected voltage readings in the case of PV arrays and sub-arrays.

NOTE Line-to-ground voltages in bipolar arrays should be relatively balanced around zero with one line above zero (positive) and one line below zero (negative).

7.6 Short circuit current measurements

7.6.1 General

PV array short circuit measurements shall be included in the acceptance of large PV arrays to further verify that there are no faults within the PV array wiring and that the PV modules and other components are in good condition.

It is very difficult to obtain accurate results under variable irradiance conditions. It is recommended to use this method only under stable irradiance conditions. Under these stable conditions, it is possible to compare current measurements in different strings to check for major wiring faults.

It can be dangerous to interrupt short circuit currents in PV arrays. The recommended procedure should be carried out in order to prevent injuries.

7.6.2 Procedure

- **Procedure 1: Current measurement under normal application circuit load using clip-on ampere meter**

The first recommended procedure is to connect the array to the application circuit and use a clip-on ampere meter to compare current measurements in each string.

- **Procedure 2: Short circuit current measurement using clip-on ampere meter**

a) If there is any current source (e.g. batteries) in the application circuit, these sources should be isolated and any precaution taken to prevent any switch-on of theses sources (the same person shall switch off the sources and switch them on again after measurement).
b) Ensure PV array load-breaking disconnecting device or load-breaking switch is open.
c) Connect a short circuit between positive and negative terminals on the application side of the disconnecting device.
d) Ensure the conductor used for this short circuit is rated equal to or greater than the current rating of the PV array cable and that it is securely connected (e.g. screwed connections).
e) Close all arrays disconnection devices.
f) Close the load-breaking disconnecting device or switch.
g) Use a clip-on ampere meter to compare current measurements in each string.
h) After measurement completed, open the load breaking disconnection switch.
i) Remove short circuit.

- **Procedure 3: Short circuit current measurement when a clip on ampere meter is not available**

a) If there is any current source (e.g. batteries) in the application circuit these sources should be isolated and any precaution taken to prevent any switch on of these sources. (the same person shall switch off the sources and switch them on again after measurement).
b) Ensure PV array load breaking disconnecting device or load breaking switch is open.
c) Connect an ampere meter between positive and negative terminals on the application side of the disconnecting device.
d) Ensure the conductor and the ampere meter is rated equal to or greater than the current rating of the PV array cable and that it is securely connected (e.g. screwed connections).
e) Open all arrays disconnection devices.

f) Switch on one string.

g) Close the load-breaking disconnecting device or switch.

h) Measure the short circuit current.

i) Open the load-breaking disconnecting device.

j) Switch off the string.

k) Repeat steps f) to j) for each string.

l) After measurement completed, open the load breaking disconnection switch.

m) Remove ampere meter.

Where large discrepancies are found between string currents under stable irradiance conditions, the strings with low measured current should be investigated for faults.

It is very difficult to carry out these procedures for very large arrays due to the main difficulty to have stable irradiance conditions over the period of measurement.

For larger arrays a possible procedure is to use procedure 1 and compare the current supplied to the application circuit with *N* times the current in a single string.

Where a significant discrepancy is observed, the currents have to be compared at the sub-array level and so on.

NOTE 1 The expected short circuit current of an array may be estimated more accurately if a measurement of in plane irradiance is available, e.g. using a pyrometer or reference cell.

Use the formula below to estimate the short circuit current:

$$I_{\text{SC EXPECTED}} = n \times I_{\text{SC MOD}} \times G_{\text{I}} \times 0{,}95$$

where:

$I_{\text{SC EXPECTED}}$	= expected short circuit current of the segment under test (A);
n	= number of parallel connected strings in the segment under test;
G_{I}	= plane of array irradiance (kW/m^2);
0,95	= factor to account for mismatch.

NOTE 2 I_{SC} of the PV array or array segment should be measured with the array not shaded under clear sky, and as close as possible to noontime conditions.

NOTE 3 The short circuit current of crystalline silicon-based PV devices is relatively insensitive to variations in ambient temperature over a wide operating range (–10 °C to 40 °C), increasing slightly with increasing temperature.

NOTE 4 Other PV cell technologies may be more sensitive to temperature or to other conditions such as spectral content. Additional constraints may have to be observed or modifications made to the above equation.

NOTE 5 Some PV module technologies have a settling time period when the output electrical parameters are significantly higher than the nominal values. This fact should be taken into account to modify the above equation accordingly.

NOTE 6 Low I_{SC} measurements can indicate the presence of circulating ground fault currents in the array due to multiple ground faults or shading.

Higher than expected measurements can indicate an array configuration other than expected or increased irradiance on the array not being sensed by the pyranometer.

7.7 Commissioning records

The inspecting personnel shall prepare a commissioning report that includes the applicable records from the list of items a) to e) below:

a) a report that states whether the PV array complies with the general ratings and technical specifications established in the contract;

b) a certificate stating if the work done on the installation meets the requirements of this standard and either those of local wiring codes or the IEC 60364 series according to 6.2.4.2;

c) a table with the final open circuit voltage measurements for each string, sub array and array; and a statement with the condition of the PV array wiring after the test, including any repairs and corrections carried out as a result of the inspections. When temperature measurements were carried out, these values should also be tabulated along with the actual voltage readings and the expected voltage values;

d) when relevant, a report with the measured trip values of current and/or resistance of the earth fault protection system before and after any adjustments to the calibration;

e) when short circuit current measurements are made as part of the acceptance process, a report that includes the test procedures used and the current measurements, stating the condition of the PV array wiring after the test, including any repairs and corrections carried out as a result of the inspections;

   1) this report shall be given to the owner, and if necessary to the relevant authorities. Examples of commissioning records are given in Annex A.

8 Operation/maintenance

8.1 General

This clause gives general guidance for the preparation of operation and maintenance procedures for PV arrays. Examples of such procedures are given in Annex C.

8.2 Safety

Attention should be given in the operation and maintenance procedures to the following safety requirements:

a) emergency shutdown procedure;

b) obey all warning signs;

c) shut system down and interrupt PV array currents according to the manual shutdown procedure;

d) split strings into extra low voltage sections (if relevant);

e) warn of the live parts that cannot be de-energised during daylight.

8.3 Operation and maintenance procedures

PV arrays do not generally require control actions in normal operation. The most important operation procedures for PV arrays are those related to switching and shutdown for emergency and maintenance purposes.

Operation and maintenance procedures should include the following:

a) a short description of the function and operation of all installed equipment. More detailed information should be available from the manufacturer's documentation (see item d);

b) emergency and maintenance shutdown procedures;

c) periodic maintenance requirements including procedures and schedule. Annex B gives an example of a maintenance schedule;

d) equipment manufacturer's documentation (data sheets, handbooks, etc.) for all equipment supplied.

9 Replacement

For each project the project implementer will have to list the replacement criteria.

Some guidance for criteria can be found in the maintenance schedule (see Annex B). Particular attention is drawn to the measurement of short circuit current of the array, which may give an indication of deterioration in performance for which replacement criteria thresholds could be specified, provided measurements of irradiance are available.

10 Marking and documentation

10.1 Equipment marking

All electrical equipment shall be marked according to the requirements for marking in IEC or to local standards and regulations when applicable. Markings should be in the local language or use appropriate local warning symbols. English examples of sign texts are included here.

10.2 Requirements for signs

All signs required in this clause shall:

a) comply with IEC;
b) be indelible;
c) be legible from at least 0,8 m unless otherwise specified in the relevant clauses (or see examples of signs in Annex D);
d) be constructed and affixed to remain legible for the life of the equipment it is attached or related to;
e) be understandable by the operators.

Examples of signs are given in Annex D.

10.3 Labelling of PV array and PV sub-array junction boxes

A sign containing the text 'SOLAR d.c.' shall be attached to PV array and PV sub-array junction boxes as well as labels indicating “live during daylight” to d.c.junction boxes and switches.

10.4 Labelling of disconnection devices

10.4.1 General

Disconnection devices shall be marked with an identification name or number according to the PV array wiring diagram.

All switches shall have the ON and OFF positions clearly indicated.

10.4.2 PV array disconnecting device

The PV array main switch shall be provided with a sign affixed in a prominent location with the following text: 'PV ARRAY MAIN SWITCH'.

10.5 Fire emergency information signs

10.5.1 General

For PV arrays installed on buildings that have a PV array voltage greater than 120 V, a sign shall be displayed next to the main building switchboard. This sign shall state 'Warning:

Electric Solar Array' and give an indication of its location. This sign shall be legible from at least 1,5 m.

The sign shall also include the following PV array information:

a) open circuit voltage;
b) short circuit current.

NOTE In small installations the indication of location may be simple, e.g. "On Roof". In larger installations more detail should be provided.

10.6 Documentation

The PV system designer shall prepare the following documents and a copy shall be handed to the PV system owner:

a) A basic circuit diagram that includes the electrical ratings of the PV array, including the information required by 10.5.
b) PV system or parts certification as required by relevant authorities and provided by manufacturer.
c) A copy of the emergency shutdown procedure including the location of relevant switching devices.
d) A copy of the operation and maintenance procedures in accordance with Clause 8.

Annex A
(informative)

Examples of commissioning records

Table A.1 – Verification of PV array general ratings and technical specifications

	Characteristic	Reference value	Conform Yes/No	Remarks
PV modules	Nominal power			
	Technology			
	Quantity			
	Manufacturer			
	Model			
	Standards	IEC 61215 / IEC 61646		
	Equipment class			
	Reverse current withstand	$2{,}6 \times I_{\mathrm{SC\ STC\ MOD}}$		
	Cell appearance	No defects		
	Sealing	No defects		
	Frames	No corrosion or defects		
	By-pass diodes			
PV array	Total rated power			
	Nominal voltage			
	Nominal current			
	$V_{\mathrm{OC\ ARRAY}}$	7.4 and 7.5		
	$I_{\mathrm{SC\ ARRAY}}$			
	No. of series modules			
	No. of parallel strings			
	Inclination			
	Azimuth			
	Total area			

Table A.2 – Verification of compliance with the requirements of IEC 62257-7-1

	Characteristic	Reference value	Conform Yes/No	Remarks
Protection against electric shock and fire	Insulation system	5.2		
Protection against overcurrent	Strings	5.3.2 and 5.3.4		
	Sub arrays	5.3.2 and 5.3.4 (if relevant)		
	Array	5.3.2 and 5.3.4		
	Discrimination	5.3.3		
	Location	5.3.5		
Lightning and over-voltage protection	Lightning protection	IEC 62305-2 and IEC 62305-3 recommended		
	Equipotential bonding	4.1.2 and 5.4.3.1		
	Wiring loops	5.4.3.1 and 6.2.6.3 recommended		
	Surge arresters	5.4.3.2 and 6.2.6.7.1 recommended		
	Shielding	6.2.6.7.2 recommended		
Selection and erection of equipment	Components requirements			
	PV modules	6.1.1		
	Junction boxes	6.1.2 (if relevant)		
	Switching devices	6.1.3 (if relevant)		
	Plugs, sockets and couplers	6.1.5 (if relevant)		
	Fuses	6.1.6 (if relevant)		
	By-pass diodes	6.1.7 (if relevant)		
	Blocking diodes	6.1.8 (if relevant)		
	Wiring installation			
	String wiring	6.2.6.4		
	Junction boxes wiring	6.2.6.5		
	Junction boxes location	6.1.2.2		
	Wiring identification	6.2.6.6		
	Cable selection			
	Cable size	6.1.4.1		
	Insulation	6.1.4.2		
	Disconnecting means	6.1.3.2 and 6.2.1.2		
	ELV segmentation	6.2.2 (if relevant)		
	Earthing			
	Electrode	6.2.3.1		
	Equipment earthing	6.2.3.2		
	System earthing	6.2.3.3		
Operation and maintenance	Safety and procedures	8.2 recommended		

	Characteristic	Reference Value	Conform Yes/No	Remarks
Marking and documentation	Marking			
	Equipment	10.1		
	Signs requirements	10.2		
	Junction boxes	10.3		
	Disconnection devices	10.4		
	PV array main switch	10.4.2		
	Fire emergency information	10.5		
	Documentation	10.6		
Mechanical	Ventilation	Recommended		
	Wind loading	Recommended		

Annex B
(informative)

Example of maintenance schedule

Sub-system or component	Maintenance action	Freq.	Remarks
Array field	Verify cleanliness (accumulation of dust or other shading materials)	Quarterly	The array field should be cleaned if necessary
PV modules	Check for visual defects • Fractures • Browning • Moisture penetration • Seal integrity • Frame corrosion	1 year	Modules with visual defects should be further inspected for performance and safety to determine the need for replacement
	Inspect junction boxes • Tightness of connections • Water accumulation/buildup • Integrity of lid seals • Integrity of cable entrance and/or conduit sealing • Integrity of clamping devices • Verify by-pass diodes	1 year	Any defective seals, clamps and by-pass diodes should be replaced
Wiring installation	Mechanical integrity of conduits	5 years	Any damaged conduit should be replaced
	Insulation integrity of cables installed without conduit	5 years	Any damaged cable should be replaced
	Junction boxes • Tightness of connections • Water accumulation/buildup • Integrity of lid seals • Integrity of cable entrance and/or conduit sealing • Integrity of clamping devices • Verify blocking diodes • Verify surge arresters for degradation	1 year	Any defective seals, clamps blocking diodes and surge arresters should be replaced
	Earthing connections • Tightness of connections • Corrosion	1 year	
Electrical characteristics	Measurement of open circuit voltages	1 year	According to 7.4 and 7.7
	Measurement of short circuit currents	1 year	According to 7.6
	Measurement of insulation resistance in dry and wet conditions	1 year	If the recorded values of insulation resistance drop significantly (20 % to 30 % or more), special attention shall be paid to the variation of the values. If the value of the resistance continues to decrease, check the wiring and installation.
	Measurement of earth resistance	1 year	
	Measurement of I-V characteristics	5 years	Refer to IEC 61829

Sub-system or component	**Maintenance action**	**Freq.**	**Remarks**
Protective devices	Verification of fuses	1 year	
	Verification of CBs and RCDs	1 year	
	Verification of earth fault protection system	1 year	According to 7.7
Mounting structures	Verify tightness and integrity of bolts and other fastening devices	5 years	
	Verify if there is significant corrosion	5 years	

Annex C
(informative)

Replacement

PV module(s) and structures should be replaced if considered unsafe. This may occur due to extreme climatic conditions or through age and corrosion of structural materials.

PV modules should be considered for replacement when they are no longer capable of supplying useful service. This can occur:

- after normal expected lifespan,
- deterioration of a module(s) under warrantee, or
- deterioration of a module(s) due to fault conditions within the array.

PV field junction boxes may be prone to failure due to corrosion and should be replaced as needed.

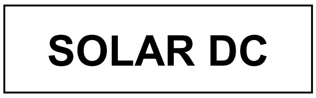
When replacing a module(s) or the whole array it is important that:

- the array be shut down according to proper procedure;
- any LV strings within the array be sectionalized into ELV sections;
- the replacement be carried out by suitably qualified personnel;
- the module(s) or the whole array should be replaced by mechanically and electrically compatible parts.

Annex D
(informative)

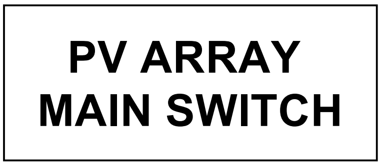
Examples of signs

This annex provides examples (see Figures D.1 to D.3) of appropriate signs as specified in Clause 10.



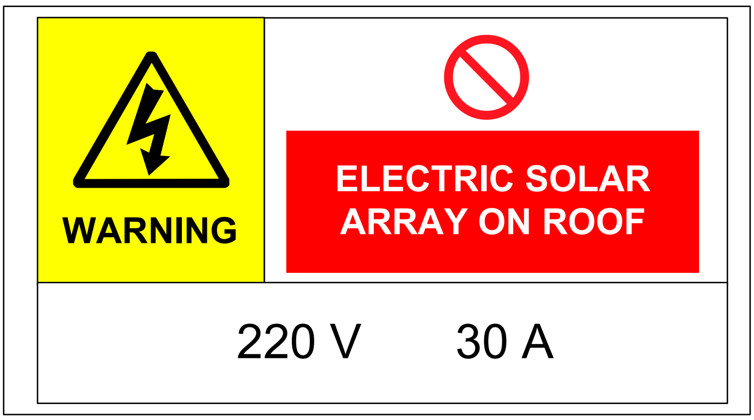
IEC 2094/10

Figure D.1 – Example of sign required on PV array junction box (10.3)



IEC 2095/10

Figure D.2 – Example of sign required adjacent to PV array main switch (10.4.2)



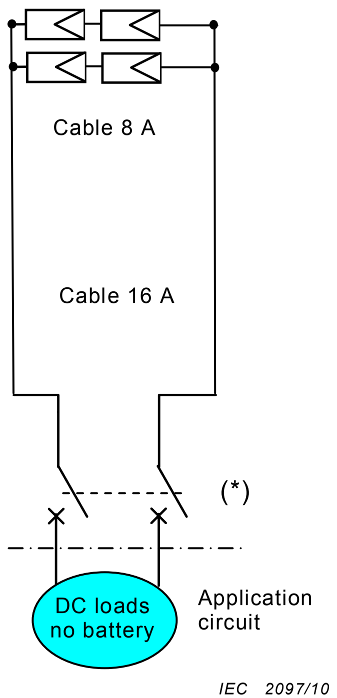
IEC 2096/10

Figure D.3 – Example of fire emergency information sign required in main building switchboard (10.5.1)

Annex E
(informative)

Case studies

Case 1: ELV PV array with number of parallel strings < 3 – No battery

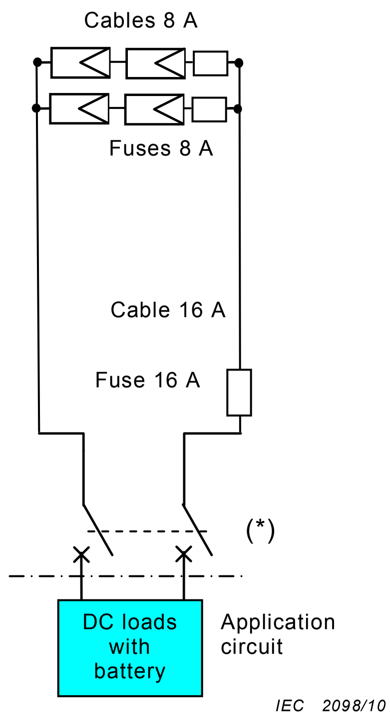


System earthing configuration			
PV generator	**Technical room**	**Application circuit**	
Unearthed	Unearthed	Unearthed DC loads	
Technical description			
PV array voltage	**Number of strings**	**Battery**	**Example of application**
ELV 24 V nominal 44 V_{oc}	2 (S_{P0} = 2)	No	pumping system
Array data			
$I_{SC\ MOD}$ = 5 A	$V_{OC\ MOD}$ = 22 V	P_{MOD} = 85 W_p	
$I_{SC\ S\text{-}ARRAY}$ = NA	$I_{SC\ ARRAY}$ = 10 A	$V_{OC\ ARRAY}$ = 44 V	P_{ARRAY} = 340 W_p

Protection devices and cables rating				
Sizing process step		**Sizing**		**Final value (*)**
Step 1	string protection 5.3.4.1	nb of strings in parallel ≤ 3 PV technology: Pc Si Battery : no (see Figure 13)	no overcurrent protection	NA
Step 2	sub array protection 5.3.4.2	NA	NA	NA
Step 3	array protection 5.3.4.3	No battery	no overcurrent protection	NA
Step 4	array cable 6.1.4.1.2 – Table 6	$I_{\text{ARRAY CABLE}} = 1{,}45 \times I_{\text{SC ARRAY}}$ $I_{\text{ARRAY CABLE}} = 1{,}45 \times 10 = 14{,}5$ A		16 A(*)
Step 5	sub array cable 6.1.4.1.2 – Table 6	NA		NA
Step 6	string cable 6.1.4.1.2 – Table 6	$I_{\text{STRING CABLE}} = I_{\text{TRIP S-ARRAY}} + 1{,}45 \times I_{\text{SC MOD}} \times (S_{P0} - 1)$ $I_{\text{STRING CABLE}} = 0 + 1{,}45 \times 5 \times (2\text{-}1) = 7{,}25$ A		8 A(*)
Disconnection device choice				
Comment Ref		Value		Clause ref.
(1)		necessary to have double pole switching ? see Annex F		Annex F

(*) Rounded-off value according to the standard values available on the market.

Case 2: ELV PV array with number of parallel strings < 3 – With battery

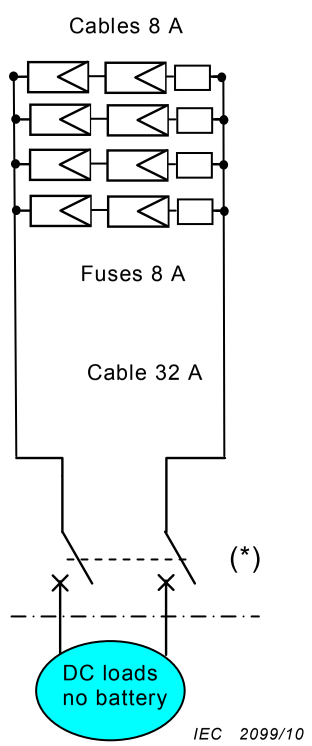


System earthing configuration			
PV generator	**Technical room**	**Application circuit**	
Unearthed	Unearthed	Unearthed DC loads	
Technical description			
PV array voltage	**Number of strings**	**Battery**	**Example of application**
ELV 24 V nominal 44 V_{oc}	2 $S_{P0} = 2$	yes	Small IES
Array data			
$I_{SC\ MOD} = 5$ A	$V_{OC\ MOD} = 22$ V	$P_{MOD} = 85\ W_p$	
$I_{SC\ S\text{-}ARRAY}$ = NA	$I_{SC\ ARRAY} = 10$ A	$V_{OC\ ARRAY} = 44$ V	$P_{ARRAY} = 340\ W_p$

Protection devices and cables rating				
Sizing process step		**Sizing**		**Final value (*)**
Step 1	string protection 5.3.4.1	nb of strings in parallel ≤ 3 PV technology: Pc Si Battery : yes (see Figure 13)	$1,45 \times I_{SC\ MOD} \le I_{TRIP\ STRING} \le 2 \times I_{SC\ MOD}$ $1,45 \times 5 \le I_{TRIP\ STRING} \le 2 \times 5$ $7,25 \le I_{TRIP\ STRING} \le 10$	8 A (*)
Step 2	sub array protection 5.3.4.2	NA	NA	NA
Step 3	array protection 5.3.4.3	Battery	$1,45 \times I_{SC\ ARRAY} \le I_{TRIP\ ARRAY} \le 2 \times I_{SC\ ARRAY}$ $1,45 \times 10 \le I_{TRIP\ ARRAY} \le 2 \times 10$ $14,5 \le I_{TRIP\ ARRAY} \le 20$	16 A
Step 4	array cable 6.1.4.1.2 – Table 6	$I_{ARRAY\ CABLE} = 1,45 \times I_{SC\ ARRAY}$ $I_{ARRAY\ CABLE} = 1,45 \times 10 = 14,5$ A		16 A (*)
Step 5	sub array cable 6.1.4.1.2 – Table 6	NA		NA
Step 6	string cable 6.1.4.1.2 – Table 6	$I_{STRING\ CABLE} = I_{TRIP\ S\text{-}ARRAY} + 1,45 \times I_{SC\ MOD} \times (S_{P0} - 1)$ $I_{STRING\ CABLE} = 0 + 1,45 \times 5 \times (2\text{-}1) = 7,25$ A		8 A (*)
Disconnection device choice				
Comment Ref		Value		Clause ref.
(1)		necessary to have double pole switching ? see Annex F		Annex F

(*) Rounded-off value according to the standard values available on the market.

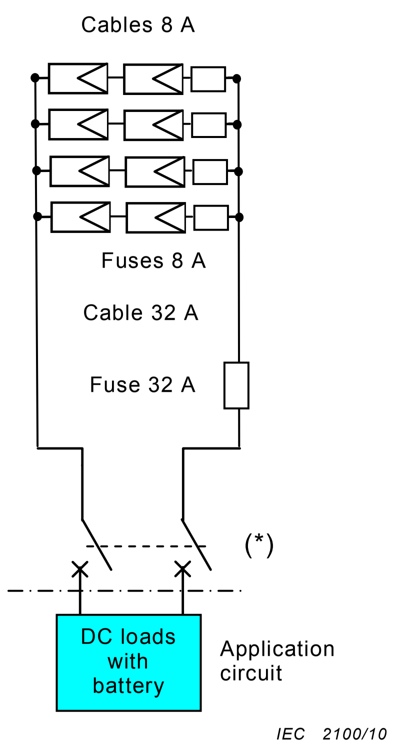
Case 3: ELV array with number of parallel strings > 3 – No battery



System earthing configuration			
PV generator	**Technical room**	**Application circuit**	
Unearthed	Unearthed	Unearthed DC loads	
Technical description			
PV array voltage	**Number of strings**	**Battery**	**Example of application**
ELV 24 V nominal 44 V_{oc}	4	No	pumping system
Array data			
$I_{SC\ MOD}$ = 5 A	$V_{OC\ MOD}$ = 22 V	P_{MOD} = 85 W_p	
$I_{SC\ S\text{-}ARRAY}$ = NA	$I_{SC\ ARRAY}$ = 20 A	$V_{OC\ ARRAY}$ = 44 V	P_{ARRAY} = 680 W_p

Protection devices and cables rating				
Sizing process step		Sizing		Final value
Step 1	string protection 5.3.4.1	nb of strings in parallel > 3 PV technology: Pc Si Battery : no (see Figure 13)	$1,45 \times I_{SC\ MOD} \leq I_{TRIP\ STRING} \leq 2 \times I_{SC\ MOD}$ $1,45 \times 5 \leq I_{TRIP\ STRING} \leq 2 \times 5$ $7,25 \leq I_{TRIP\ STRING} \leq 10$	8 A (*)
Step 2	sub array protection 5.3.4.2	NA	NA	NA
Step 3	array protection 5.3.4.3	No battery	No overcurrent protection	NA
Step 4	array cable 6.1.4.1.2 – Table 6	$I_{ARRAY\ CABLE} = 1,45 \times I_{SC\ ARRAY}$ $I_{ARRAY\ CABLE} = 1,45 \times 20 = 29$ A		32 A (*)
Step 5	sub array cable 6.1.4.1.2 – Table 6	NA		NA
Step 6	string cable 6.1.4.1.2 – Table 6	$I_{STRING\ CABLE} = I_{TRIP\ STRING}$ $1,45 \times I_{SC\ MOD} \leq I_{TRIP\ STRING} \leq 2 \times I_{SC\ MOD}$ $1,45 \times 5 \leq I_{TRIP\ STRING} \leq 2 \times 5$ $7,25 \leq I_{TRIP\ STRING} \leq 10$		8 A (*)
Disconnection device choice				
Comment Ref		Value		Clause ref.
(1)		necessary to have double pole switching ? see Annex F		Annex F

Case 4: ELV array with number of parallel strings ≥ 3 – With battery

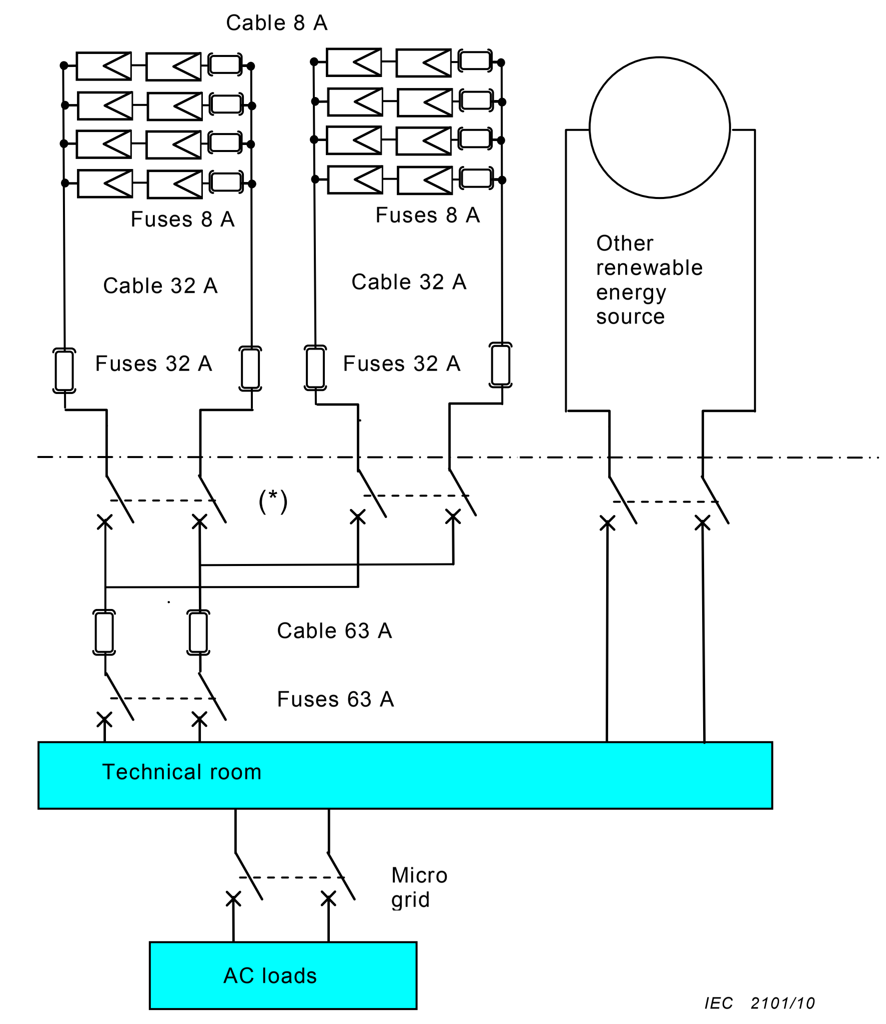


System earthing configuration			
PV generator	**Technical room**	**Application circuit**	
Earthed	Earthed	Earthed	
Technical description			
PV array voltage	**Number of strings**	**Battery**	**Example of application**
ELV 24 V nominal 44 V_{oc}	4	yes	Small IES
Array data			
$I_{SC\ MOD}$ = 5 A	$V_{OC\ MOD}$ = 22 V	P_{MOD} = 85 W_p	
$I_{SC\ S\text{-}ARRAY}$ = NA	$I_{SC\ ARRAY}$ = 20 A	$V_{OC\ ARRAY}$ = 44 V	P_{ARRAY} = 680 W_p

Protection devices and cables rating				
Sizing process step		**Sizing**		**Final value**
Step 1	string protection 5.3.4.1	nb of strings in parallel > 3 PV technology: Pc Si Battery : yes (see Figure 13)	$1{,}45 \times I_{SC\ MOD} \le I_{TRIP\ STRING} \le 2 \times I_{SC\ MOD}$ $1{,}45 \times 5 \le I_{TRIP\ STRING} \le 2 \times 5$ $7{,}25 \le I_{TRIP\ STRING} \le 10$	8 A (*)
Step 2	sub array protection 5.3.4.2	NA	NA	NA
Step 3	array protection 5.3.4.3	Battery	$1{,}45 \times I_{SC\ ARRAY} \le I_{TRIP\ ARRAY} \le 2 \times I_{SC\ ARRAY}$ $1{,}45 \times 20 \le I_{TRIP\ ARRAY} \le 2 \times 20$ $29 \le I_{TRIP\ ARRAY} \le 40$	32 A (*)
Step 4	array cable 6.1.4.1.2 – Table 6	$I_{ARRAY\ CABLE}$ =Trip current **c** of the PV array overcurrent protection device		32 A (*)
Step 5	sub array cable 6.1.4.1.2 – Table 6	NA		NA
Step 6	string cable 6.1.4.1.2 – Table 6	$I_{STRING\ CABLE} = I_{TRIP\ STRING}$ $1{,}45 \times I_{SC\ MOD} \le I_{TRIP\ STRING} \le 2 \times I_{SC\ MOD}$ $1{,}45 \times 5 \le I_{TRIP\ STRING} \le 2 \times 5$ $7{,}25 \le I_{TRIP\ STRING} \le 10$		8 A (*)
Disconnection device choice				
Comment Ref		Value		Clause ref.
(1)		necessary to have double pole switching ? see Annex F		Annex F

(*) Rounded-off value according to the standard values available on the market.

Case 5: ELV array with number of parallel strings ≥ 3 – 2 sub arrays – With battery



System earthing configuration		
PV generator	**Technical room**	**Application circuit**
Unearthed	Unearthed	Unearthed DC loads

Technical description			
PV array voltage	**Number of strings**	**Battery**	**Example of application**
ELV 24 V nominal 44 V_{oc}	2 × 4	Yes	Hybrid CES

Array data			
$I_{SC\ MOD}$ = 5 A	$V_{OC\ MOD}$ = 22 V	P_{MOD} = 85 W_c	
$I_{SC\ S\text{-}ARRAY}$ = 20 A	$I_{SC\ ARRAY}$ = 40 A	$V_{OC\ ARRAY}$ = 44 V	P_{ARRAY} = 1360 W_c

Protection devices and cables rating				
Sizing process step		**Sizing**		**Final value**
Step 1	string protection 5.3.4.1	nb of strings in parallel > 3 PV technology: Pc Si Battery : yes	$1{,}45 \times I_{SC\ MOD} \leq I_{TRIP\ STRING} \leq 2 \times I_{SC\ MOD}$ $1{,}45 \times 5 \leq I_{TRIP\ STRING} \leq 2 \times 5$ $7{,}25 \leq I_{TRIP\ STRING} \leq 10$	8 A (*)
Step 2	sub array protection 5.4.3.2	NA	$1{,}45 \times I_{SC\ S\text{-}ARRAY} \leq I_{TRIP\ S\text{-}ARRAY} \leq 2 \times I_{SC\ S\text{-}ARRAY}$ $1{,}45 \times 20 \leq I_{TRIP\ S\text{-}ARRAY} \leq 2 \times 20$ $29 \leq I_{TRIP\ S\text{-}ARRAY} \leq 40$	32 A (*)
Step 3	array protection 5.4.3.3	Battery	$1{,}45 \times I_{SC\ ARRAY} \leq I_{TRIP\ ARRAY} \leq 2 \times I_{SC\ ARRAY}$ $1425 \times 40\ A \leq I_{TRIP\ ARRAY} \leq 2 \times 40\ A$ $58\ A \leq I_{TRIP\ ARRAY} \leq 80\ A$	63 A (*)
Step 4	array cable 6.1.4.1.2 – Table 6	Protection provided: $I_{ARRAY\ CABLE}$ =Trip current of the PV array overcurrent protection device		63 A (*)
Step 5	sub array cable 6.1.4.1.2 – Table 6	$I_{S\text{-}ARRAY\ CABLE}$ = Trip current of the PV sub-array overcurrent protection device		32 A (*)
Step 6	string cable 6.1.4.1.2 – Table 6	$I_{STRING\ CABLE} = I_{TRIP\ STRING}$ $1{,}45 \times I_{SC\ MOD} \leq I_{TRIP\ STRING} \leq 2 \times I_{SC\ MOD}$ $1{,}4 \times 5 \leq I_{TRIP\ STRING} \leq 2 \times 5$ $7{,}25 \leq I_{TRIP\ STRING} \leq 10$		8 A (*)
Disconnection device choice				
Comment Ref		Value		Clause ref.
(1)		necessary to have double pole switching ? see Annex F		Annex F

(*) Rounded-off value according to the standard values available on the market.

Annex F
(informative)

Double switching in PV array

F.1 Introductory remarks

F.1.1 General

The reasons for requiring double pole switching on a PV array are dependent on the type of system. Two types of systems have to be considered: unearthed systems and earthed systems.

F.1.2 Unearthed systems

For unearthed systems the requirement for switching in all active conductors comes from 536.2 Isolation, of IEC 60364-5-53.

Subclause 536.2.1 states that "Every circuit shall be capable of being isolated from each of the live supply conductors."

Subclause 536.2.2.1 states that devices for isolation "shall effectively isolate all live supply conductors from the circuit concerned subject to the provisions of 536.1.2" (where this 536.1.2 does not apply to floating systems.)

IEC 60364 states in the scope that it applies to all systems up to 1 000 V a.c. and 1 500 V d.c. This includes ELV and LV systems.

F.1.3 Earthed systems

In the case of earthed systems a double pole switch has been mandated in the PV array standard and the earthing point for the system is shown on the system side of the PV array main switch. If an earth fault develops in the PV array, this switch is the only safe means of interrupting the flow of this fault current.

F.2 Earth fault analysis

F.2.1 General

In this annex, the worst case PV array fault conditions are analysed for both earthed and floating PV arrays. The implications for overcurrent protection derived from the worst case fault current analysis are also discussed.

The analysis is made for the case of PV strings with four series modules, however they are valid for any number of series connected PV modules. Also, the earth faults are considered to be zero impedance faults which is the case when the fault currents are the highest.

F.2.2 Floating PV arrays

In floating PV arrays, there is no reference to earth; therefore a single earth fault does not produce any fault currents (see Figures F.1 and F.2). What a single fault does produce is an earth reference for the PV array circuit, and a path for earth fault current in the event of a second earth fault or a person touching the live conductors and earth simultaneously.

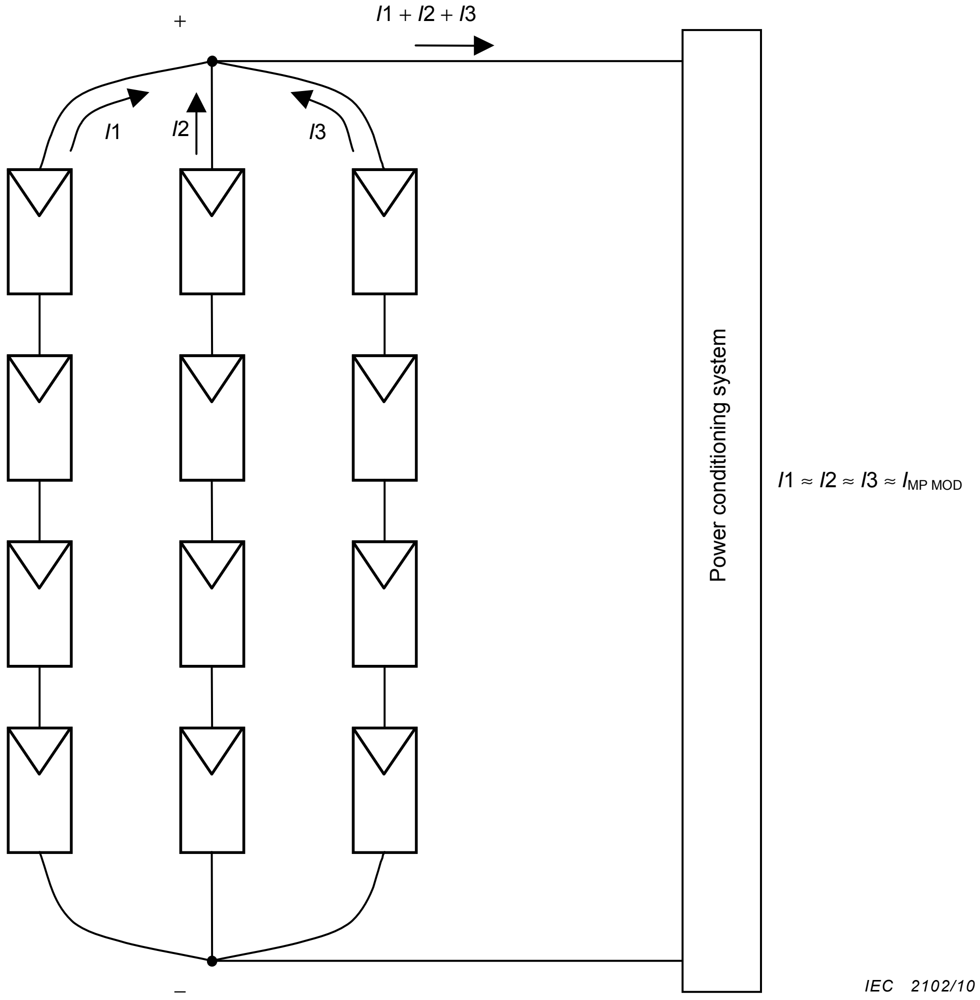


Figure F.1 – Floating PV array operating at maximum power point

When a single earth fault develops, the PV array currents remain the same if the system is not shut down, provided that the power conditioning system does not allow fault currents to pass through its power circuits from the load side to the PV array side. If there is electrical isolation between PV array and a.c. loads, the system can continue operating in most cases but it becomes unsafe as the PV array is no longer floating, increasing the risk of electric shock and earth fault currents due to a second earth fault.

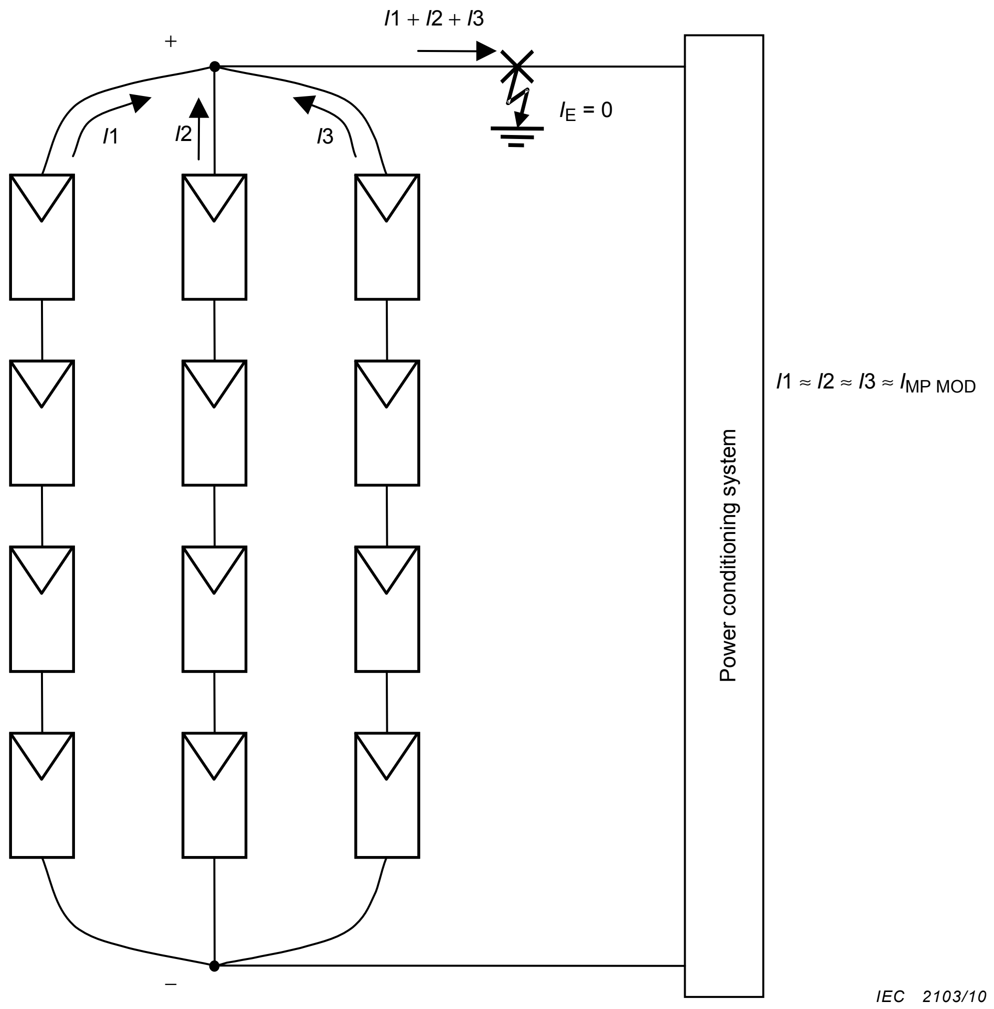


Figure F.2 – Floating PV array with single earth fault

If a second fault develops in the PV array, the earth loop is closed allowing fault currents to flow in the PV array wiring (see Figure D.3).

Under the fault conditions of Figure F.3, a three-module segment of string number 3 is short-circuited, and the remaining PV module in string number 3 is connected in parallel with strings 1 and 2. This would cause the PV array voltage to drop significantly, most likely causing the power conditioning system to disconnect itself from the PV array, thus leaving the PV array open circuited.

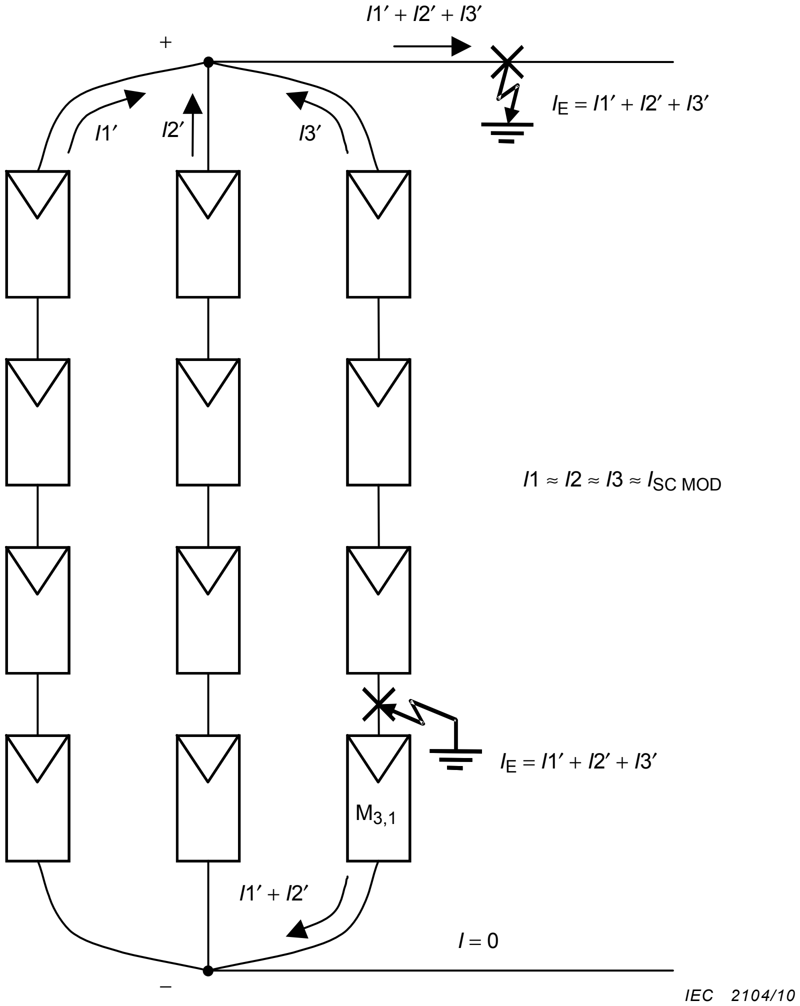


Figure F.3 – Floating PV array with double earth fault

The most important observations from the node analysis of this fault case are the following:

PV module $M_{3,1}$ is forward biased with a voltage that is larger than its open circuit voltage. Thus the module is operating in the second quadrant of its I-V characteristic (i.e. the current through it is negative and it is forced to dissipate the power delivered by PV strings 1 and 2).

As the voltage of strings 1 and 2 drops, their output current increases to approximately their short circuit value. If Standard Test Conditions are assumed, the reverse current through module $M_{3,1}$ is approximately twice $I_{SC\ MOD}$.

The current of the section of the string cable that connects module $M_{3,1}$ with the negative bus bar is also twice $I_{SC\ MOD}$.

The reverse current through PV module $M_{3,1}$ and through the segment of the string cable that connects it to the negative bus bar would increase by approximately $I_{SC\ MOD}$ for each additional parallel PV string in the circuit.

If the faults occurred in opposite locations of the PV array (see Figure F.4), then PV module $M_{3,4}$ would be forced to dissipate the power delivered by strings 1 and 2 and the segment that connects it to the positive bus bar would be overloaded. This implies that overcurrent protection in unearthed PV arrays, when required, has to be installed in both positive and negative cables of the corresponding circuit.

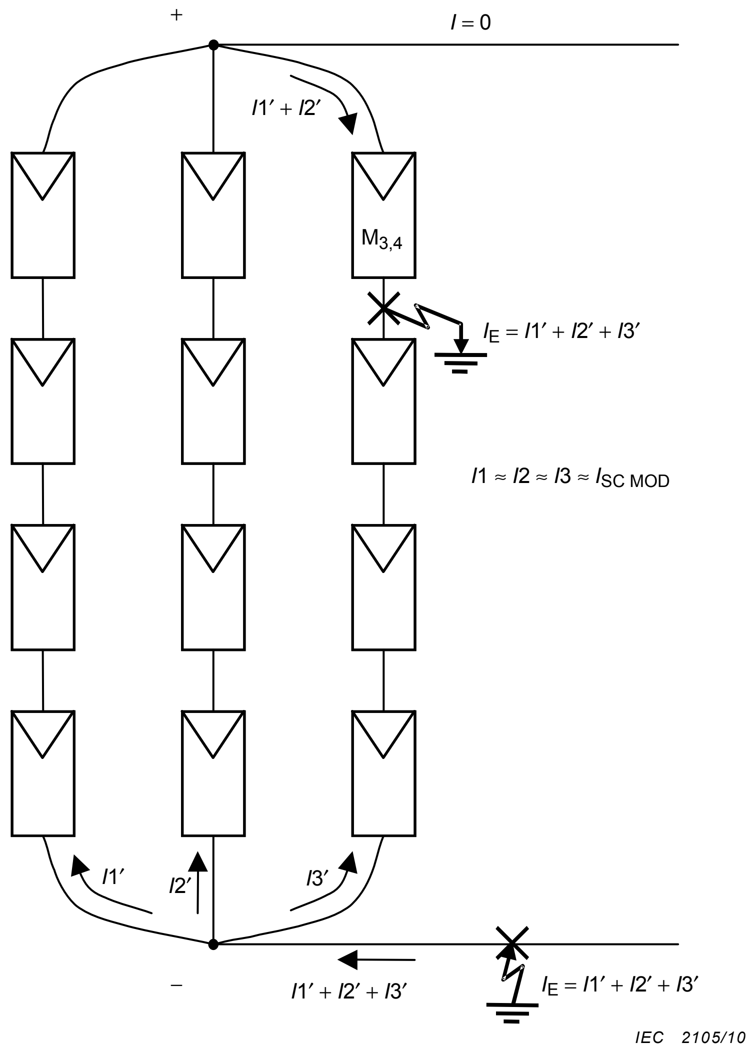


Figure F.4 – Floating PV array with double earth fault

F.3 Earthed PV arrays

In earthed PV arrays, there is already a reference to earth and a path for earth fault currents; therefore a single earth fault, or a person touching an unearthed conductor and earth simultaneously will produce earth fault currents to flow in the PV array.

Note that the worst-case earth fault scenario for earthed PV arrays is identical as that presented in Figure F.4, the only difference is that the connection to earth of the negative conductor of the PV array cable is not a fault, but an intentional connection.

The node analysis and most of the observations made for the floating case hold true, except for the last one. In the earthed case, the PV string cable segments that connect to the negative busbar cannot be overloaded with one or multiple earth faults.

F.4 Implications for overcurrent protection

F.4.1 General

The above discussion clearly shows that overcurrent protection for PV arrays is required in some cases to ensure a safe system in case of earth faults.

F.4.2 Number of strings

If the earth fault characteristics are taken into account, it can be seen that overcurrent protection is irrelevant when there are less than three parallel strings in the circuit, and there is no battery storage system, provided that the PV modules are capabe of withstanding a reverse current equal to their short circuit current.

Furthermore, when three parallel strings are connected and overcurrent protection devices are installed in each string, they will not trip if I_{TRIP} is 2 times $I_{SC\ MOD}$, unless there are increased irradiance conditions. Therefore, under this situation and the worst case earth fault situations presented above, PV modules would be subjected to reverse currents about twice their nominal short circuit current.

F.4.3 Battery storage

When battery storage is present, the battery is capable of overloading the PV array wiring and components regardless of the location of the fault or the number of parallel-connected strings.

F.4.4 Diodes

Blocking diodes are not a reliable protection against reverse current because they often fail in short circuit mode. The use of blocking diodes is currently restricted to prevent discharging the battery to an unenergised PV array at night. Their use should be avoided otherwise because they are sources of failures and power loss.

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