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Photovoltaic (PV) arrays — Design requirements

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National foreword

This British Standard is the UK implementation of IEC 62548:2016. It supersedes PD IEC/TS 62548:2013 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/82, Photovoltaic Energy Systems.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Groupes photovoltaïques (PV) – Exigences de conception

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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PHOTOVOLTAIC (PV) ARRAYS – DESIGN REQUIREMENTS

FOREWORD

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International Standard IEC 62548 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This International Standard cancels and replaces the first edition of IEC TS 62548 published in 2013.

This International Standard includes the following significant technical changes with respect to IEC TS 62548:

a) provisions for systems including DC to DC conditioning units;
b) considerable revision of Clause 6 on safety issues which includes provisions for protection against electric shock including array insulation monitoring and earth fault detection.

The text of this document is based on the following documents:

FDIS	Report on voting
82/1149/FDIS	82/1166/RVD

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

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

Attention is drawn to the co-existence of IEC 60364-7-712 and IEC 62548. Both standards have been developed in close coordination by different technical committees.

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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.

PHOTOVOLTAIC (PV) ARRAYS – DESIGN REQUIREMENTS

1 Scope and object

This International Standard sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads. An exception is that provisions relating to power conversion equipment are covered only where DC safety issues are involved. The interconnection of small DC conditioning units intended for connection to PV modules are also included.

The object of this document is to address the design safety requirements arising from the particular characteristics of photovoltaic systems. Direct current systems, and PV arrays in particular, pose some hazards in addition to those derived from conventional AC power systems, including the ability to produce and sustain electrical arcs with currents that are not greater than normal operating currents.

In grid connected systems, the safety requirements of this document are however critically dependent on the inverters associated with PV arrays complying with the requirements of IEC 62109-1 and IEC 62109-2.

Installation requirements are also critically dependent on compliance with the IEC 60364 series (see Clause 4).

PV arrays of less than 100 W and less than 35 V DC open circuit voltage at STC are not covered by this document.

PV arrays in grid connected systems connected to medium or high voltage systems are not covered in this document. Variations and additional requirements for large-scale ground mounted PV power plants with restricted access to personnel will also be addressed in IEC TS 62738[1].

Additional requirements may be needed for more specialized installations, for example concentrating systems, tracking systems or building integrated PV.

The present international standard also includes extra protection requirements of PV arrays when they are directly connected with batteries at the DC level.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60228, *Conductors of insulated cables*

IEC 60269-6, *Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems*

[1] Under preparation. Stage at the time of publication: IEC 2CD 62738.

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

IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60364-4 (all parts), *Low-voltage electrical installations – Part 4: Protection for safety*

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-5 (all parts), *Electrical installations of buildings – Part 5: Selection and erection of electrical equipment*

IEC 60364-5-52, *Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems*

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

IEC 60364-6, *Low-voltage electrical installations – Part 6: Verification*

IEC 60445:2010, *Basic and safety principles for man-machine interface, marking and identification – Identification of equipment terminals, conductor terminations and conductors*

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

IEC 60898-2, *Circuit-breakers for overcurrent protection for household and similar installations – Part 2: Circuit-breakers for a.c. and d.c. operation*

IEC 60947 (all parts), *Low-voltage switchgear and controlgear*

IEC 60947-1, *Low-voltage switchgear and controlgear – Part 1: General rules*

IEC 60947-2, *Low-voltage switchgear and controlgear – Part 2: Circuit-breakers*

IEC 60947-3, *Low-voltage switchgear and controlgear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

IEC 61215 (all parts), *Terrestrial photovoltaic (PV) modules – Design qualification and type approval*

IEC 61557-2, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 2: Insulation resistance*

IEC 61557-8, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 8: Insulation monitoring devices for IT systems*

IEC 61643-21, *Low-voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods*

IEC 61643-22, *Low-voltage surge protective devices – Part 22: Surge protective devices connected to telecommunications and signalling networks – Selection and application principles*

IEC 61730-1, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC 61730-2, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

IEC 62109-1:2010, *Safety of power converters for use in photovoltaic power systems – Part 1: General requirements*

IEC 62109-2, *Safety of power converters for use in photovoltaic power systems – Part 2: Particular requirements for inverters*

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*

IEC 62446-1, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 1: Grid connected systems – Documentation, commissioning tests and inspection*

IEC 62852, *Connectors for DC-application in photovoltaic systems – Safety requirements and tests*

IEC 62930, *Electric cables for photovoltaic systems*

EN 50539-11, *Low-voltage surge protective devices – Surge protective devices for specific application including DC – Part 11: Requirements and tests for SPDs in photovoltaic applications*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms, definitions and symbols

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
blocking diode
diode connected in series with 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)

3.1.2
bonding conductor
conductor provided for functional or protective equipotential bonding

3.1.3
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

3.1.4
cable
assembly of one or more conductors and/or optical fibers, with a protective covering and possibly filling, insulating and protective material

[SOURCE: IEC 60050-151:2001,151-12-38]

3.1.5
charge controller
unit used between a battery and a PV array to regulate charge delivered to the battery

3.1.6
closed electrical operating area
room or location for electrical equipment to which access is restricted to skilled or instructed persons by the opening of a door or the removal of a barrier by the use of a key or tool and which is clearly marked by appropriate warning signs

3.1.7
competent person
person, who has acquired, through training, qualification or experience or a combination of these, the knowledge and skill enabling that person to perform the required task correctly

3.1.8
DC conditioning units
DCU
unit connected to individual PV modules or groups of PV modules to allow DC conditioning of the PV output

3.1.9
decisive voltage classification
DVC
highest voltage which occurs continuously between any two arbitrary live parts or between live parts and earth of the PV array during worst-case rated operating conditions when used as intended

Note 1 to entry: See decisive voltage class limits in Annex E.1.

[SOURCE: IEC 62109-1:2010, 3.12 modified — The word "classification" has been added to the term, a note has been added, and the definition has been modified to make applicable to PV array application.]

3.1.10
disconnector
mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements

Note 1 to entry: A disconnector is capable of opening and closing a circuit when either negligible current is broken or made, or when no significant change in the voltage across the terminals of each of the poles of the disconnector occurs. It is also capable of carrying currents under normal circuit conditions and carrying currents for a specified time under abnormal conditions such as those of short circuit.

[SOURCE: IEC 60050-441:2000, 441-14-05]

3.1.11
double insulation
insulation comprising both basic insulation and supplementary insulation

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

3.1.12
extraneous conductive part
conductive part not forming part of the electrical installation and liable to introduce an electric potential, generally the electric potential of a local earth

[SOURCE: IEC 60050-851:2008, 851-14-57, modified — The note has been deleted.]

3.1.13
functionally earthed PV array
PV array that has one conductor intentionally connected to earth for purposes other than safety

Note 1 to entry: Such a system is not considered to be an earthed array.

Note 2 to entry: Examples of functional array earthing include earthing one conductor through an impedance, or only temporarily earthing the array for functional or performance reasons.

Note 3 to entry: In PCE intended for an array not connected to a functional earth that uses a resistive measurement network to measure the array impedance to earth, that measurement network is not considered a form of functional earth.

3.1.14
independent manual operation
independent manual operation of a mechanical switching device
stored energy operation where the energy originates from manual power, stored and released in one continuous operation (e.g. spring release), such that the speed and force of the operation are independent of the action of the operator

[SOURCE: IEC 60050-441:2000, 441-16-16, modified — The brackets have been added to the definition.]

3.1.15
irradiance
G
electromagnetic radiated solar power per unit of area

Note 1 to entry: Expressed in W/m^2.

[SOURCE: IEC TS 61836:2007, 3.6.25, modified — The adjective "solar" has been added to the definition, and the note has been replaced.]

3.1.16
$I_{\text{MOD\_MAX\_OCPR}}$
PV module maximum overcurrent protection rating determined by IEC 61730-2

Note 1 to entry: This is often specified by module manufacturers as the maximum series fuse rating which refers to the fuse rated current in IEC 60269-1 and IEC 60269-6.

3.1.17
I_{n}
nominal rated current

3.1.18
$I_{\text{SC ARRAY}}$
short-circuit current of the PV array at standard test conditions (STC), and is equal to

$$I_{\text{SC ARRAY}} = I_{\text{SC MOD}} \times N_{\text{S}}$$

where

N_{S} is the total number of parallel-connected PV strings in the PV array

3.1.19
$I_{SC\ MOD}$
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 1 to entry: As PV strings are a group of PV modules connected in series, the short circuit current of a string is equal to $I_{SC\ MOD}$.

3.1.20
$I_{SC\ S\text{-}ARRAY}$
short circuit current of a PV sub-array at standard test conditions (STC), and equal to

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

where

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

3.1.21
separated PCE
PCE with at least simple separation between the AC output circuits and PV circuits

Note 1 to entry: The separation may be either integral to the PCE or provided externally by a transformer with at least simple separation.

3.1.22
junction box
closed or protected enclosure in which circuits are electrically connected

[SOURCE: IEC TS 61836: 2007, 3.2.16]

3.1.23
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 1 to entry: This concept does not necessarily imply a risk of electric shock.

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

3.1.24
low voltage
voltage exceeding DVC-A, but not exceeding 1 000 V AC or 1 500 V DC

3.1.25
main earthing terminal
terminal or bar provided for the connection of the main protective earthing conductor, bonding conductors and, if provided, the conductor for functional earthing

3.1.26
maximum power point tracking
MPPT
control strategy whereby PV array operation is always at or near the point on a PV device's current-voltage characteristic where the product of electric current and voltage yields the maximum electrical power under specified operating conditions

3.1.27
non-separated PCE
PCE without at least simple separation between the AC output and PV circuits

3.1.28
PEL conductor
conductor combining the functions of both a protective earthing conductor and a line conductor

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

3.1.29
PEM conductor
conductor combining the functions of both a protective earthing conductor and a mid-point conductor

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

3.1.30
PEN conductor
conductor combining the functions of both a protective earthing conductor and a neutral conductor

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

3.1.31
power conversion equipment
PCE
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

Note 1 to entry: See Figure 2 to Figure 4.

3.1.32
protective earthing
earthing of a point in an equipment or in a system for safety reasons

3.1.33
PV array
assembly of electrically interconnected PV modules, PV strings or PV sub-arrays

Note 1 to entry: For the purposes of this document a PV array is all components up to the DC input terminals of the inverter or other power conversion equipment or DC loads.

Note 2 to entry: A PV array does not include its foundation, tracking apparatus, thermal control, and other such components.

Note 3 to entry: 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 (see Figure 2 to Figure 4). For the purposes of this document the boundary of a PV array is the output side of the PV array disconnecting device.

3.1.34
PV array main cable
output cable of a PV array that carries the total output current of the array

3.1.35
PV cell
most elementary device that exhibits the photovoltaic effect, i.e the direct non-thermal conversion of radiant energy into electrical energy

Note 1 to entry: The preferred term is "solar photovoltaic cell" or "photovoltaic cell", colloquially referred to as a "solar cell".

Note 2 to entry: The original definition from IEC TS 61836:2007, 3.1.43 a), has been modified and expanded for clarity.

3.1.36
PV array combiner box
junction box where PV sub-arrays are connected and which may also contain overcurrent protection and/or switch-disconnection devices

Note 1 to entry: Small arrays generally do not contain sub-arrays but are simply made up of strings, whereas large arrays are generally made up of multiple sub-arrays.

3.1.37
PV array maximum voltage
$U_{OC\ ARRAY}$ corrected for the worst-case conditions of ambient temperature

Note 1 to entry: See 7.2.

3.1.38
PV module
complete and environmentally protected assembly of interconnected photovoltaic cells

[SOURCE: IEC TS 61836:2007, 3.1.43 f), modified — The adjective "photovoltaic" has been replaced by "PV" in the term.]

3.1.39
PV string
circuit of one or more series-connected modules

[SOURCE: IEC 61836:2007, 3.3.56, modified — The adjective "photovoltaic" has been replaced by "PV", and the words "one or more" have been added for clarity.]

3.1.40
PV string cable
cable interconnecting the modules in a PV string, or connecting the string to a combiner box, PCE or other DC loads

Note 1 to entry: See Figure 2 to Figure 4.

3.1.41
PV string combiner box
junction box where PV strings are connected which may also contain overcurrent protection devices and/or switch-disconnectors

Note 1 to entry: See Figure 4.

Note 2 to entry: PV string combiner boxes are only relevant for PV arrays that are divided into sub-arrays.

3.1.42
PV sub-array
electrical subset of a PV array formed of parallel connected PV strings

3.1.43
PV sub-array cable
output cable of a PV sub-array that carries the output current of its associated sub-array

Note 1 to entry: PV sub-array cables are only relevant for PV arrays that are divided into sub-arrays (see Figure 4 for clarification).

3.1.44
readily available
capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, parts of the PV array, cupboards, benches or the like

3.1.45
reinforced insulation
insulation of hazardous-live-parts which provides a degree of protection against electric shock equivalent to double insulation

Note 1 to entry: Reinforced insulation may comprise several layers which cannot be tested singly as basic insulation or supplementary insulation.

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

3.1.46
N_S
total number of parallel connected strings in a PV array

3.1.47
shield
<of a cable> surrounding earthed metallic layer to confine the electric field within the cable and/or to protect the cable from external electrical influence

Note 1 to entry: Metallic sheaths, armour and earthed concentric conductors may also serve as shields.

[SOURCE: IEC 60050-461:2008, 461-03-04, modified — The words "foils, braids" have been deleted from the note, as well as the second note.]

3.1.48
simple separation
separation between circuits or between a circuit and earth by means of basic insulation

[SOURCE: IEC 60050-826:2004, 826-12-28, modified — The definition has been rephrased.]

3.1.49
simultaneously accessible parts
conductors or conductive parts which can be touched simultaneously by a person or by an animal

Note 1 to entry: Simultaneously accessible parts may be: live parts, exposed conductive parts, extraneous conductive parts, protective conductors or earth electrodes.

[SOURCE: IEC 60050-826:2004, 826-12-12, modified — In the note, the words "soil or conductive floor" have been replaced by "earth electrodes".]

3.1.50
standard test conditions
STC
reference values of in-plane irradiance ($G_{I,ref}$ = 1 000 W·m^{-2}), PV cell junction temperature (25 °C), and air mass (AM = 1,5) to be used during the testing of any PV device

[SOURCE: IEC 61836:2007, 3.4.16 e)]

3.1.51
supplementary insulation
independent insulation applied in addition to basic insulation, for fault protection

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

3.1.52
switch-disconnector
mechanical switching device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions, and able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions

Note 1 to entry: A switch-disconnector complies with the requirements for a disconnector.

Note 2 to entry: Switch-disconnectors provide a load break isolation function. In this document these switches will be identified on warning signs and labels as “isolators” for simplicity in interpretation by the public.

3.1.53
$U_{\text{OC ARRAY}}$
open circuit voltage at standard test conditions of a PV array, and is equal to

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

where

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

Note 1 to entry: This document 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 $U_{\text{OC ARRAY}}$.

3.1.54
$\boldsymbol{U}_{\textbf{OC MOD}}$
open circuit voltage of a PV module at standard test conditions, as specified by the manufacturer in the product specification

3.2 Abbreviations

DVC-A decisive voltage classification, type A as defined in IEC 62109-1. See also Annex E.

DVC-B decisive voltage classification, type B as defined in IEC 62109-1

DVC-C decisive voltage classification, type C as defined in IEC 62109-1

4 Compliance with IEC 60364 (all parts)

The design, erection and verification of the PV system shall comply with the requirements of,

- IEC 60364-1,
- IEC 60364-4 (all parts),
- IEC 60364-5 (all parts), and
- IEC 60364-6.

5 PV array system configuration

5.1 General

5.1.1 Functional configuration of a PV system

PV arrays are used to supply power to an application circuit.

Figure 1 illustrates the general functional configuration of a PV powered system.

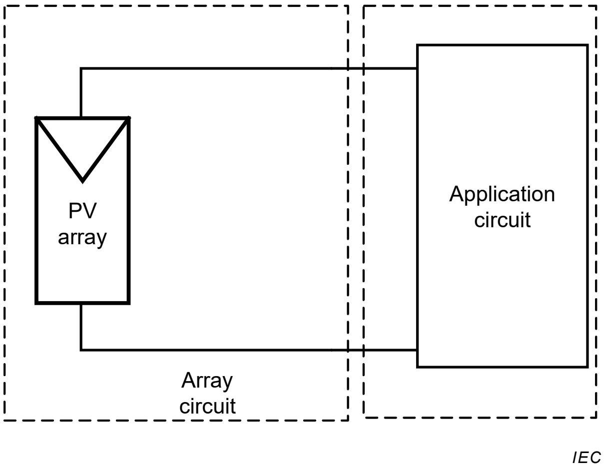


Figure 1 – General functional configuration of a PV powered system

Three kinds of application circuit are considered:

- PV array is connected to DC loads;
- PV array is connected to AC system via conversion equipment which includes at least simple separation;
- PV array is connected to AC system via conversion equipment which does not include simple separation.

5.1.2 PV system architectures

The relation of a PV array to earth is determined by whether any earthing of the array for functional reasons is in use, the impedance of that connection and also by the earth status of the application circuit (e.g. inverter or other equipment) to which it is connected. This and the location of the earth connection all affect safety for the PV array (refer to Annex B).

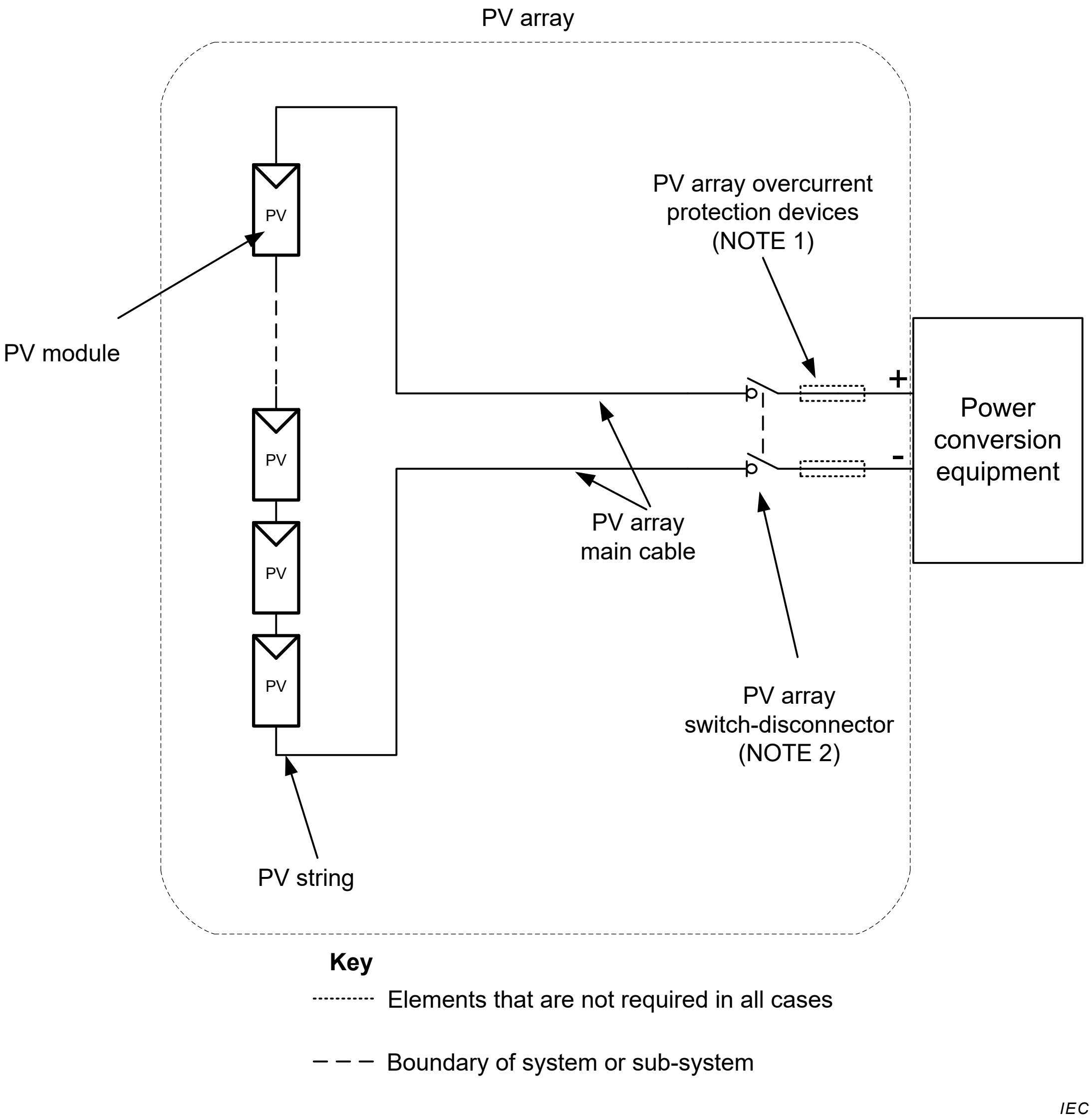
The requirements of manufacturers of PV modules and manufacturers of power conversion equipment to which the PV array is connected shall be taken into account in determining the most appropriate system earthing arrangement.

Protective earthing of any of the conductors of the PV array is not permitted. Earthing of one of the conductors of the PV array for functional reasons is not allowed unless there is at least simple separation between PV array DC power circuits and main AC power output circuits provided either internally in the PCE or externally via a separate transformer. Refer to 6.1.2.

A connection of one conductor to earth through internal connections inherent in the PCE via the neutral conductor is allowed in a system without at least simple separation.

5.1.3 Array electrical diagrams

The diagrams in Figure 2 to Figure 4 show examples of the basic electrical configurations of single string, multiple parallel string and multi-sub-array PV arrays respectively.

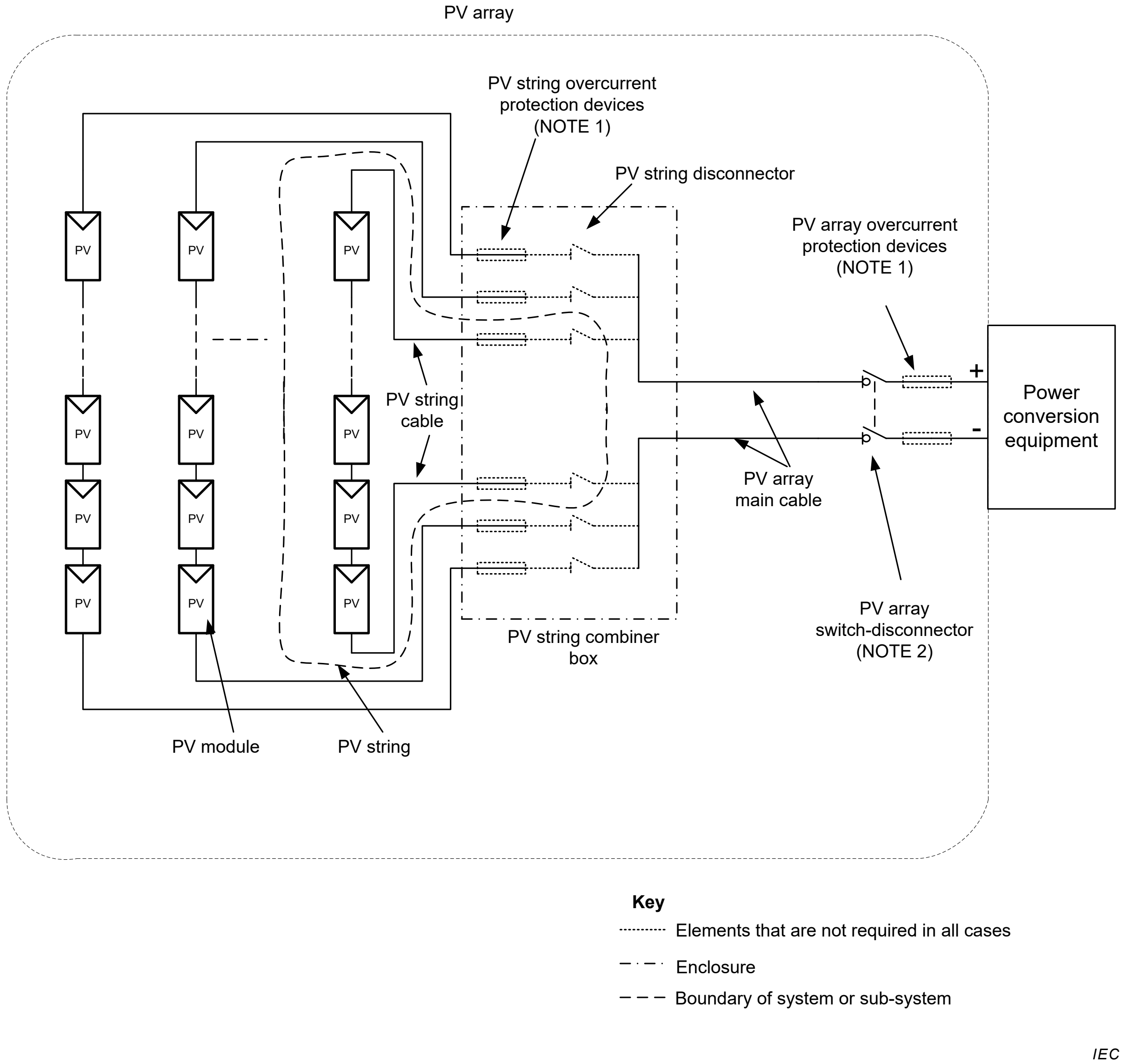


NOTE 1 Overcurrent protection devices where required (see 6.5).

NOTE 2 Refer to 7.3.6 and 7.4.1 for PV array isolator/switch-disconnector requirements.

NOTE 3 Overcurrent protection devices and switch disconnectors may be located inside power conversion equipment under certain conditions (see 7.4.1.2).

Figure 2 – PV array diagram – single string example

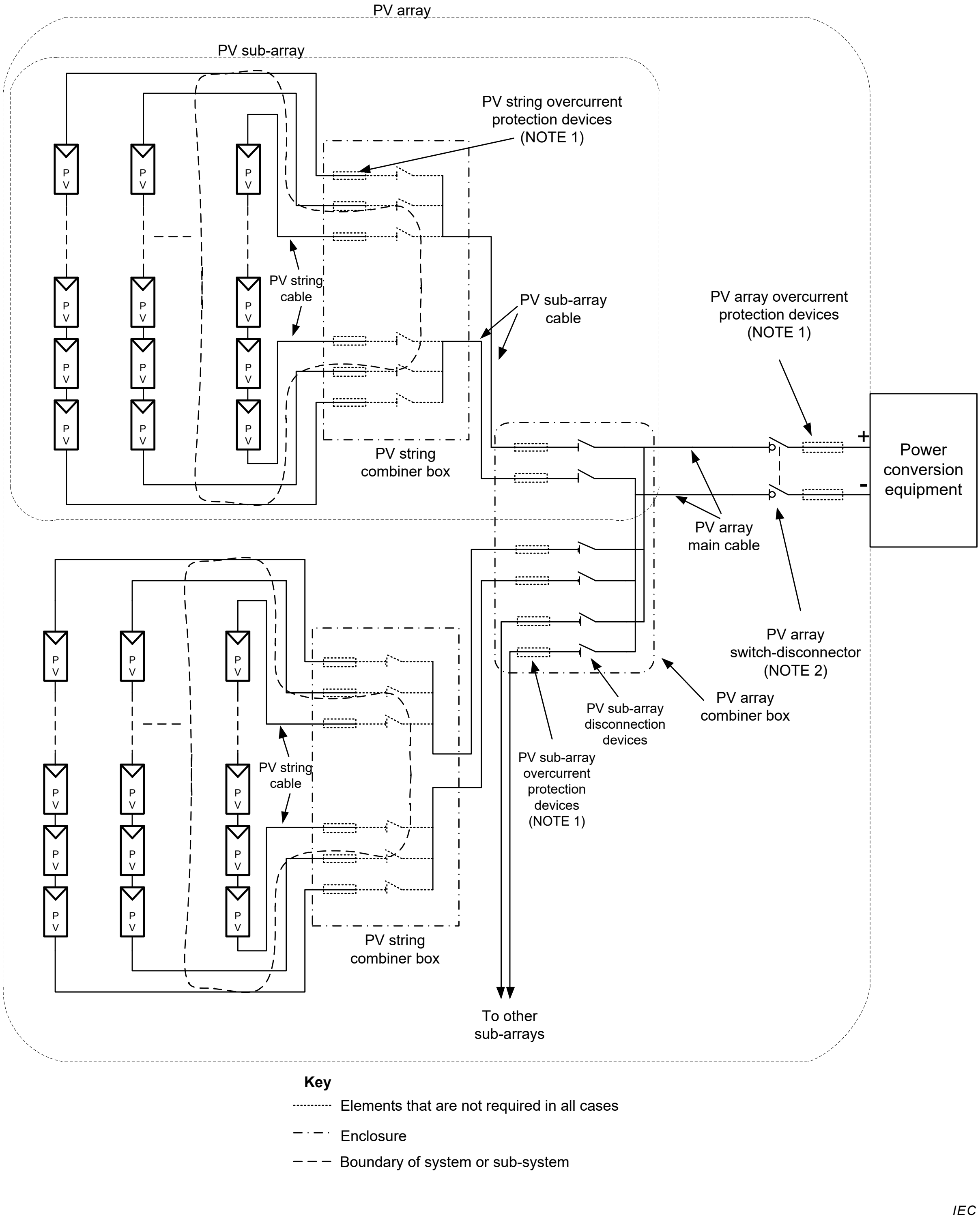


NOTE 1 Overcurrent protection devices where required (see 6.5).

NOTE 2 Refer to 7.3.6 and 7.4.1 for PV array isolator/switch-disconnector requirements.

NOTE 3 In some systems, the PV array main cable may not exist and all the PV strings or PV sub-arrays may be terminated in a combiner box immediately adjacent to or inside the power conversion equipment.

Figure 3 – PV array diagram – multiple parallel string example



NOTE 1 Overcurrent protection devices where required (see 6.5).

NOTE 2 Refer to 7.3.6 and 7.4.1 for PV array isolator/switch-disconnector requirements.

NOTE 3 In some systems, the PV array main cable may not exist and all the PV strings or PV sub-arrays may be terminated in a combiner box immediately adjacent to or inside the power conversion equipment.

Figure 4 – PV array diagram – multiple parallel string example with array divided into sub-arrays

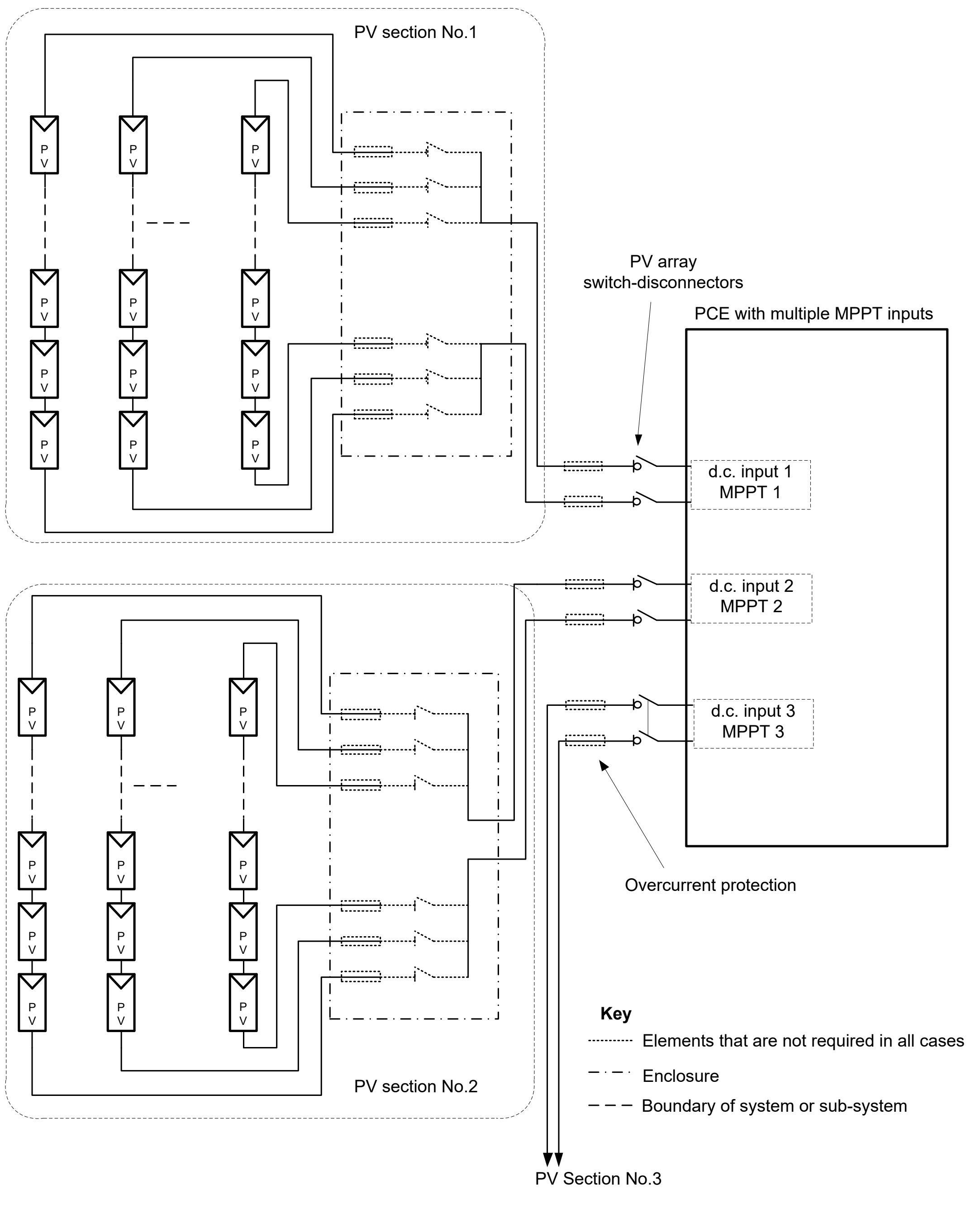


Figure 5 – PV array example using a PCE with multiple MPPT DC inputs

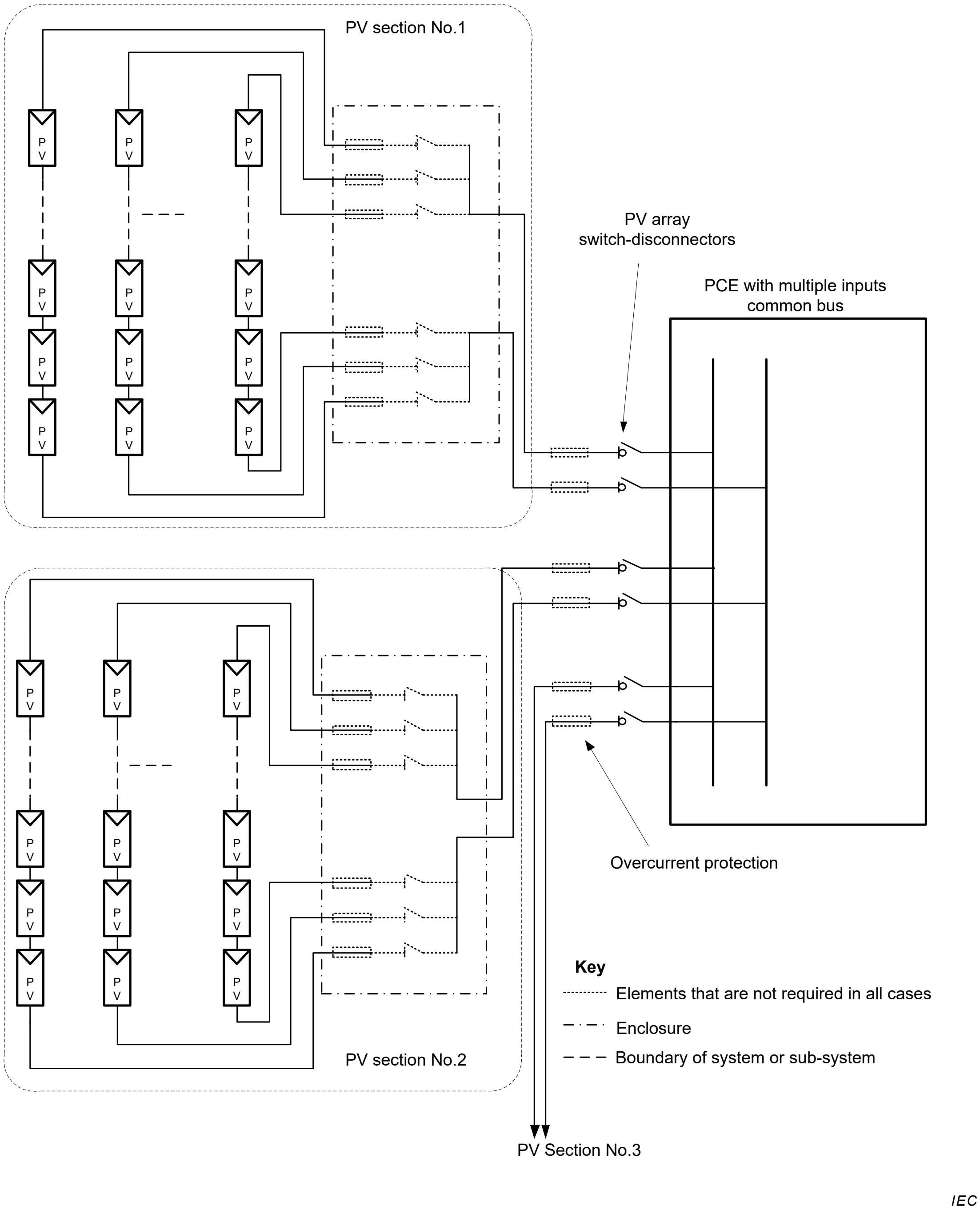


Figure 6 – PV array example using a PCE with multiple DC inputs internally connected to a common DC bus

5.1.4 Use of PCE with multiple DC inputs

5.1.4.1 General

PV arrays are often connected to PCEs with multiple DC inputs (refer to Figures 5 and 6). If multiple DC inputs are in use, overcurrent protection and cable sizing within the various sections of the PV array(s) are critically dependent on the limiting of any backfeed currents (i.e. currents from the PCE out into the array) provided by the input circuits of the PCE.

5.1.4.2 PCEs with separate maximum power point tracking (MPPT) inputs

Where PCE's provide separate maximum power point tracking inputs, the overcurrent protection of the section of the array connected to those inputs shall take into account any backfeed current as required to be specified by IEC 62109-1 and IEC 62109-2.

Each PV section connected to an input (refer to Figure 5) may be treated for the purposes of this document as a separate PV array. Each PV array shall have a switch-disconnector to provide isolation of the PCE. The provisions of multiple switch-disconnectors in 7.4.1 apply, and a warning sign as required in 10.5.2 shall be provided.

5.1.4.3 PCEs with multiple inputs internally connected together in the PCE

Where a PCE's multiple input circuits are internally paralleled onto a common DC bus, each PV section connected to one of those inputs (refer to Figure 6) shall be treated for the purposes of this document as a sub-array, and all the PV sections combined shall be classified as the complete PV array. Isolation of the PCE shall be provided, either by one array switch disconnector for the complete PV array or sub-array switch disconnectors for each sub-array. Where multiple switch disconnectors are used the provisions of multiple switch-disconnectors in 7.4.1.3 apply and a warning sign as required in 10.5.2 shall also be provided.

5.1.5 Strings constructed using DC conditioning units

5.1.5.1 General

In some array designs DC conditioning units (DCUs) may be connected to individual PV modules or small groups of PV modules to allow DC conditioning of the PV output or allow for automatic shutdown of the output under certain defined conditions. Figure 7 shows an example of this type of configuration.

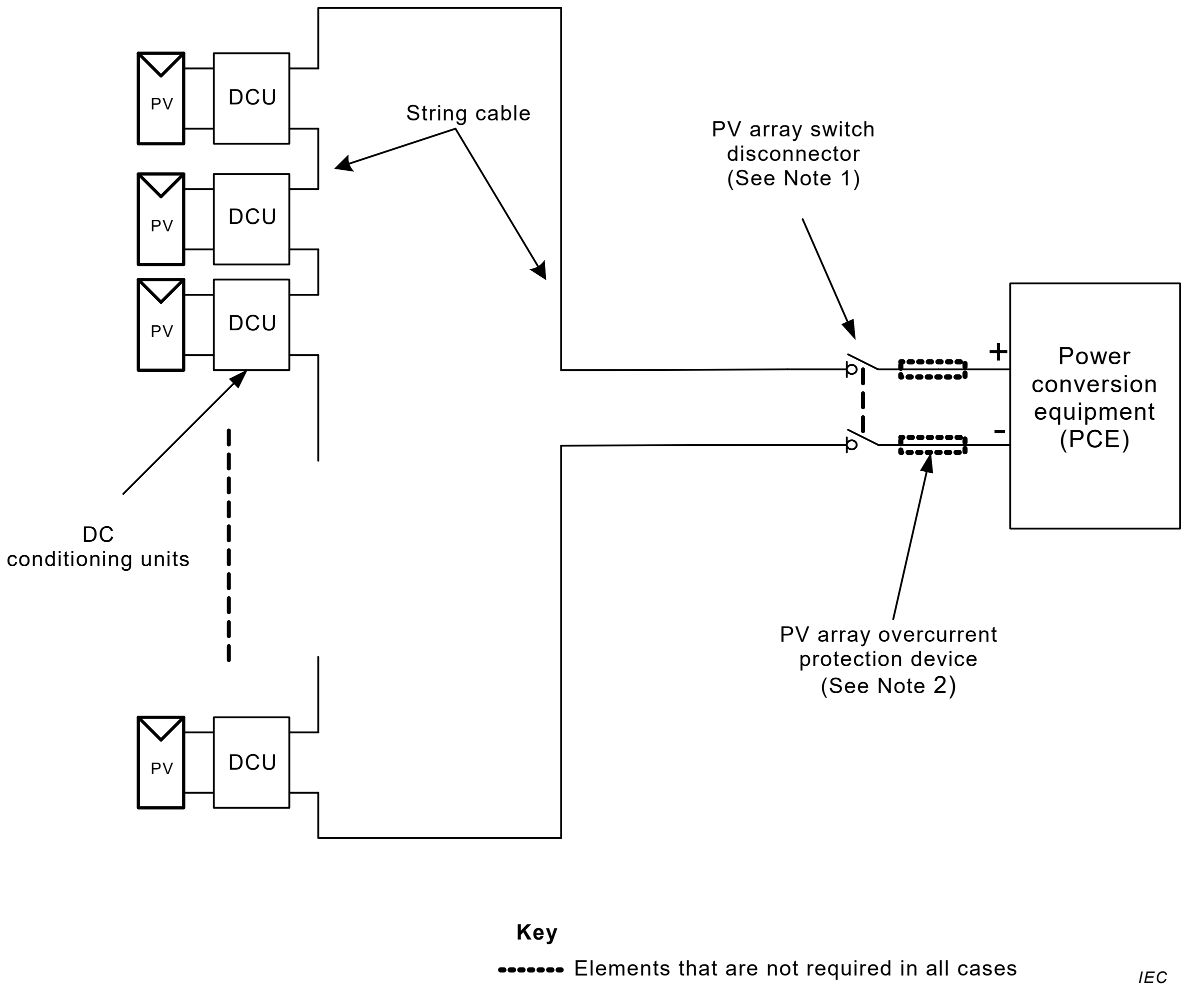
DCUs shall be qualified to IEC 62109-1.

NOTE A future part of the IEC 62109 series may specifically address DCUs.

5.1.5.2 Voltage and current ratings of downstream circuits

Where DCUs are connected to the PV modules:

- the current rating to be applied to downstream circuits shall be taken as either the maximum output of the DCU ($I_{\text{DCU-max}}$) *or* 1,25 × $I_{\text{SC\_MOD}}$ whichever is the greater;
- the voltage rating to be applied to downstream circuits shall be taken as either the maximum output of the DCU ($U_{\text{DCU-max}}$) times the number of DCUs in series or the value of PV array maximum voltage (i.e. as calculated without DCUs) whichever is the greater;
- an exception applies where an accredited testing laboratory can provide a written confirmation that for all possible operational and single fault scenarios for a combination of DCUs and inverter or control unit, the system (i.e. the combination of the DCUs and inverter or control unit) will limit the bus voltage (where the bus voltage is the voltage at the input to the inverter) to $U_{\text{BUS-MAX}}$, then systems shall be rated to the inverter maximum rated input voltage or $U_{\text{BUS-MAX}}$ whichever is greater.



NOTE 1 Refer to 7.3.6 and 7.4.1 for PV array switch-disconnector requirements.

NOTE 2 Overcurrent protection devices where required (see 6.5).

Figure 7 – PV string constructed using DC conditioning units

5.1.6 Series-parallel configuration

PV arrays shall be designed to prevent circulating currents within the array. PV strings connected in parallel shall have matched open circuit voltages within 5 % per string.

NOTE 1 This is an important safety issue. If strings which are connected in parallel have different voltages, then circulating currents will result, and when the array DC disconnector is in the open position, those circulating currents can still flow representing a hazard if series connections are broken.

All PV strings within a PV array connected in parallel should be of compatible technology with similar module/string characteristics per manufacturer recommendations. All PV strings within a PV array connected in parallel shall have similar rated electrical characteristics of open circuit voltage and maximum power voltage at STC, and temperature coefficients.

Deviations may be permitted under engineering supervision and approval by the applicable manufacturers and local approving authorities with engineering justification.

This is a design issue which needs to be considered by designer/installer, particularly when replacing PV modules or modifying an existing system.

PV modules that are electrically in the same string should be all in the same orientation within ±5° (azimuth and tilt angle).

Where each PV module (or small groups of PV modules) is connected to individual MPPT devices and the outputs of those devices are then connected to an inverter or other PCE, each of those PV modules or groups may be oriented differently provided the overall design is within the manufacturer's recommended design parameters.

NOTE 2 DCUs can contain MPPT units and so enable the connection of modules in different orientations as per 5.1.6.

5.1.7 Batteries in systems

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

Battery overcurrent protection should be placed in all active (non-earthed) conductors.

5.1.8 Considerations due to prospective fault conditions within a PV array

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

Systems containing batteries may have high prospective fault currents due to the battery characteristic (see 5.1.7).

In a PV system without batteries, the PV cells (and consequently PV arrays) behave like current sources under low impedance faults. Consequently, fault currents may not be much greater than normal full load currents, 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 operate an overcurrent device.

The implications for PV array design that arise from these PV array characteristics are that 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 In conventional electrical installations, the large inherent fault current capability of the system will generally blow a fuse, operate a circuit breaker or other protection system in case a fault occurs.

Refer to 6.5 for overcurrent protection requirements and to 6.4 for insulation fault protection requirements.

5.1.9 Considerations due to operating temperature

The installation shall not result in the maximum rated operating temperature of any component being exceeded.

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

Under normal operating conditions, cell temperatures rise significantly above ambient. A typical temperature rise of 25 °C is common with respect to the ambient temperature for crystalline silicon PV modules under 1 000 W/m^2 solar irradiance and with adequate ventilation. The temperature rise can be considerably higher when irradiance levels are greater than 1 000 W/m^2 and when modules have poor ventilation.

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

a) For PV technologies, the efficiency reduces as the operating temperature increases. 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 7.2 for further considerations).

NOTE For crystalline silicon solar cells, the maximum power decreases between 0,4 % and 0,5 % per each °C rise in operating temperature.

5.1.10 Performance issues

A PV array's performance may be affected by many factors, including but not limited to the following:

- shading or partial shading;
- temperature rise;
- voltage drop in cables;
- soiling of the surface of the array caused by dust, dirt, bird droppings, snow, industrial pollution, etc.;
- orientation;
- module mismatch;
- PV module degradation.

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 shadowing be reduced as much as is practical. Designs should be optimized to consider the impact of module shading using suitable engineering analysis. Module manufacturer guidance should be consulted for acceptable and unacceptable shading scenarios.

Issues of performance degradation due to temperature rise and the need for good ventilation are important for some module technologies. 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. 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. The cleaning instructions of the module manufacturer, if any, should be considered.

5.2 Mechanical design

5.2.1 General

Support structures and module mounting arrangements shall comply with applicable building codes regulations and standards and module manufacturer's mounting requirements.

Variations to these requirements for large-scale ground mounted PV power plant are addressed in the future publication IEC TS 62738.

5.2.2 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. Similar provisions should be taken for other applicable metallic components, including mounting structures, conduits and cable trays.

When multiple spans are mechanically connected, the connection mechanism shall be designed to tolerate thermal contraction/expansion especially when it's also part of the bonding path.

5.2.3 Mechanical loads on PV structures

5.2.3.1 General

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

Consideration should be given to site drainage and, in areas where the ground freezes, the freeze-thaw characteristics of the soil shall also be taken into account.

5.2.3.2 Wind

PV modules, module mounting frames, and the methods used for attaching frames to buildings or to the ground shall be verified to meet or exceed the maximum expected wind speeds at the location according to local codes.

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

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

5.2.3.3 Material accumulation on PV array

Snow, ice, or other material may build up on the PV array and should be accounted for when selecting suitably rated modules, calculating the supporting structure for the modules and likewise, when calculating the building capability to support the array.

NOTE 1 Immediately after snow falls, these loads are often evenly distributed. After some time, they can be very unevenly distributed as the snow starts to slide down. This can lead to significant damage to the module and support structure.

NOTE 2 In some areas, sudden release of snow could create an impulse force on obstructions, in addition to the static load.

5.2.4 Corrosion

Module mounting frames, and the methods used for attaching modules to frames and frames to buildings or to the ground, shall be made from corrosion resistant materials suitable for the lifetime and duty of the system. for example aluminium, galvanized steel, treated timber, etc.

If aluminium is installed in a marine or other highly corrosive environment, it shall be anodized to a thickness and specification suitable for the location and duty of the system. Corrosive gases such as ammonia, in farming environments also need to be considered.

Care shall be taken to prevent electrochemical corrosion between dissimilar metals. This may occur between structures and the building and also between structures, fasteners and PV modules.

Stand-off materials shall be used to reduce electrochemical corrosion between galvanically dissimilar metal surfaces; for example nylon washers, rubber insulators, etc.

Manufacturer’s instructions and local codes should be consulted regarding the design of mounting systems and any other connections such as earthing systems.

6 Safety issues

6.1 General

6.1.1 Overview

PV arrays for installation on buildings shall not have maximum voltages greater than 1 000 V DC Where the maximum PV array voltage exceeds 1 000 V DC, the entire PV array and associated wiring and protection, shall have access restricted to competent persons only.

The future publication IEC TS 62738 documents requirement variations and additional considerations for several parts of Article 6 as they apply to large-scale PV power plants. These include requirements related to:

- site and component access to unqualified personnel;
- protection against overcurrent;
- fault detection and alarm;
- lightning and overvoltage protection.

6.1.2 Separation of PV array from main AC power output circuits

Separation of PV array DC power circuits from main AC power output circuits is an important issue for safety in some array designs (refer to 5.1.2.). The separation of the PV array DC power circuits from the main AC power output circuits may be either integral to the PCE or provided externally by a transformer with at least simple separation. If the simple separation is provided externally, then in order for the combination to be treated as a separated PCE, the following shall be complied with:

a) there shall be no other equipment connected to the same winding of the external transformer as the PCE, or
b) where the system is rated only for use in closed electrical operating areas, other equipment is allowed to be connected to the same winding as the PCE output, as follows:
   - other PCEs, if specifically rated for connecting to a common winding; and/or
   - associated loads connected through additional transformer(s) providing at least simple separation.

NOTE In a PCE with more than two external circuits, there can be separation between some pairs of circuits and no separation between others. For example, an inverter with PV, battery, and mains circuits can provide separation between the mains circuit and the PV circuit, but no separation between the PV and battery circuits.

Where more than one PCE output is connected to the same transformer winding, circulating currents shall be limited by selection of system topology (for example using unearthed arrays or high impedance functionally earthed arrays), design techniques in the PCE, and/or by protective means such as residual current monitoring with disconnection.

6.2 Protection against electric shock

6.2.1 General

For protection against electric shock, the requirements of IEC 60364-4-41 shall apply:

One of the following protective measures shall be used:

- double or reinforced insulation (see 6.2.2);
- extra-low voltage (SELV or PELV) (see 6.2.3).

6.2.2 Protective measure: double or reinforced insulation

The requirements of IEC 60364-4-41:2005, Clause 412, shall apply with the following additions.

The equipment, for example PV modules, junction boxes or cabinets, cables, used on the DC side (up to the DC terminals of the PV inverter) shall be class II or equivalent insulation.

6.2.3 Protective measure: extra-low-voltage provided by SELV or PELV

The requirements of IEC 60364-4-41:2005, Clause 414, shall apply with the following additions.

Basic protection is not required if the nominal voltage does not exceed 35 V DC as given by DVC-A (see IEC 62109-1).

6.3 Protection against thermal effects

Protection against thermal affects is provided in this document by:

- protection against the effects of insulation faults (refer to 6.4),
- overcurrent protection (refer to 6.5),
- appropriate rating of components (refer to Clause 7), and
- signage to alert emergency services workers (refer to Clause 10).

In DC systems, overheating of connections and consequent arc faults may occur when high resistance connections are present or develop due to temperature cycling in an installation. It is important that care be taken to ensure:

- all connections are correctly tightened to avoid points of failure over time,
- all connectors are properly locked into place, and
- all crimp connections are performed according to manufacturer's instructions. Special care should be taken in the site assembly of DC connectors.

NOTE Failure of connectors (due to poor assembly or crimping) has been identified as a statistically significant failure mode.

6.4 Protection against the effects of insulation faults

6.4.1 General

The protective measures to be applied, depend on how the PV system's DC circuits are earth referenced.

PV arrays may be categorised as

- non separated PV arrays, i.e. PV arrays where PV DC circuits are connected to an earth referenced system through a non-separated PCE,

- functionally earthed PV arrays, i.e. an array with one of the main DC conductors connected to a functional earth, and
- non earth referenced PV arrays, i.e. a PV array that has none of its main DC conductors referenced to earth either directly or through the PCE.

NOTE Functionally earthed systems include PV arrays connected via a protection/isolation means to the system earth or connected via a resistance to the system earth.

Some module technologies require a functional earth on either the positive or negative main conductor to bleed charge away from the PV cells. This is a functional/operational requirement or it may be required to prevent degradation of the cells. It is recommended that manufacturer's instructions be followed.

6.4.2 Detection and fault indication requirements

6.4.2.1 General

Table 1 shows the requirements for measurements of PV array earth insulation resistance and PV array residual currents as well as the actions and indications required if a fault is detected according to system type.

NOTE The system types are categorised by the type of earth referencing of the main DC PV array circuits in 6.4.1. This is independent of any frame earthing requirements.

Table 1 – Requirements for different system types based on PCE isolation and PV array functional earthing

		System type		
		Non separated PV arrays	**Functionally earthed PV arrays**	**Non earth referenced PV arrays**
Insulation resistance to earth of a PV array	**Measurement**	According to 6.4.2.2		
	Action on fault	Shut down PCE and disconnect all conductors of the AC circuit or all poles of the PV array from the PCE **or** disconnect all poles of the faulty portion of the array from the PCE (operation is allowed)	Shut down PCE and disconnect all poles of the PV array from earth[1] **or** disconnect all poles of the faulty portion of the PV array from earth[1] (operation is allowed)	Connection to the AC circuit is allowed (PCE is allowed to operate)
	Indication on fault	Indicate a fault in accordance with 6.4.2.5 If the insulation resistance of the PV array to earth has recovered to a value higher than the limit shown in Table 2, the circuit is allowed to reconnect.		
PV earth fault detection by means of Current monitoring	**Detection/ protection**	According to 6.4.2.3	Residual current monitoring according to 6.4.2.3 **or** a device or association of devices, in accordance with 6.4.2.4	Not required
	Action on fault	Shut down PCE and disconnect all conductors of the AC circuit or all poles of PV array from the PCE **or** disconnect all poles of the faulty portion of the PV array from the PCE (operation is allowed)	Disconnect all poles of the faulty portion of the PV array from the PCE; or functional earth connection shall be disconnected. Connection to the AC circuit is allowed. (PCE is allowed to operate)	
	Indication on fault	Indicate a fault in accordance with 6.4.2.5	Indicate a fault in accordance with 6.4.2.5	
For functional earthing requirements, refer to 7.4.2. Systems using non-isolated PCEs where the AC circuit is referenced to earth are not allowed to use functional earthing on the PV side of the PCE (refer to 5.1.2). [1] Disconnection from earth can be direct, by opening a device in the functional earthing path, or indirect by disconnecting all poles of the PV array or faulty portion of the PV array from the PCE, where the functional earthing circuit is in the PCE.				

6.4.2.2 Array insulation resistance detection

The requirements in 6.4.2.2 regarding detection and response to abnormal values of insulation resistance of the PV array main DC circuit to earth are intended to reduce hazards due to degradation of insulation.

A means shall be provided to measure the insulation resistance from the PV array to earth immediately before starting operation and at least once every 24 h. This can be done by an insulation measuring device according IEC 61557-2, or by an insulation monitoring device (IMD) according to IEC 61557-8 that is able to detect insulation faults to prevent a possible high risk of fire.

The functionality for insulation resistance monitoring or measurement may be provided within the PCE according to IEC 62109-2.

Minimum threshold values for detection shall be according to Table 2.

Table 2 – Minimum insulation resistance thresholds for detection of failure of insulation to earth

PV array rating kW	**R limit** kΩ
≤ 20	30
> 20 and ≤ 30	20
> 30 and ≤ 50	15
> 50 and ≤ 100	10
> 100 and ≤ 200	7
> 200 and ≤ 400	4
> 400 and ≤ 500	2
> 500	1

It is recommended that the threshold of detection for insulation resistance should be set at values greater than the minimum values specified in Table 2. A higher value will increase the safety of the PV installation by detecting potential faults earlier.

It is necessary to disconnect the PV array functional earth connection during the measurement.

The action on fault required is dependent on the type of system in use, and shall be according to Table 1.

In all cases of insulation fault, the insulation resistance detection measurements may continue, the fault indication may stop and the system may resume normal operation if the insulation resistance of the PV array to earth has recovered to a value higher than the limit above.

6.4.2.3 Protection by a residual current monitoring system

Where required by 6.4.2 Table 1 and where an earth fault interrupting means according to 6.4.2.4 is not provided, residual current monitoring shall be provided that functions whenever the PV array is connected to an earth reference with the automatic disconnection means closed. The residual current monitoring means shall measure the total (both AC and DC components) RMS residual current.

Detection shall be provided to monitor for excessive continuous residual current according to the limits shown below.

The residual current monitoring system shall cause disconnection within 0,3 s and indicate a fault in accordance with 6.4.2.5 if the continuous residual current exceeds:

- maximum 300 mA for PCEs with continuous output power rating ≤ 30 kVA;
- the lesser of 5 A or (10 mA per kVA) of rated continuous output power for PCEs with continuous output power rating > 30 kVA.

If the PV array is functionally earthed via a resistor of high enough value such that the maximum residual current that can occur on a single fault is less than the limits above, or where an earth fault interrupting device according to 6.4.2.4 is provided, then no residual current monitoring is required.

NOTE 1 It is possible to implement distributed residual current monitoring system for example at sub-array level or in smaller subsections of the array. This can be beneficial especially in large arrays as it enables smaller thresholds of detection to be implemented. This can lead to more rapid identification of potential faults and can assist in identifying the section of the array that can be affected.

If the limits of the residual current monitoring system are exceeded, one of the following measures for disconnection shall be applied:

- disconnection of the output circuit from any earthed output circuit; or
- disconnection of the PV array; or
- disconnection of all poles of the faulty part of the PV array from the PCE.

The residual current monitoring system may attempt to re-connect if the array insulation resistance meets the limit in 6.4.2.2.

NOTE 2 This residual current functionality can be provided by PCEs according to IEC 62109-2.

6.4.2.4 Functionally earthed PV arrays earth fault interrupting means

Where required by 6.4.2.1 Table 1, and where residual current monitoring according to 6.4.2.3 is not provided, a functionally earthed PV array shall be provided with a means of interupting an earth fault.

If the PV array is functionally earthed via a resistor of high enough value such that the maximum current through the array functional earthing path due to a single fault is less than the limits in Table 3 below, then a means of interupting an earth fault is not required.

The device or association of devices shall automatically interrupt the current in the functional earthing conductor in the event of an earth fault on the DC side, and shall

- be rated for the maximum voltage of the PV array $U_{\text{OC ARRAY}}$, and
- have a rated breaking capacity not less than the maximum short circuit current of the PV array $I_{\text{SC ARRAY}}$, and
- have a rated current not exceeding that given in Table 3.

Table 3 – Rated current of automatic earth fault interrupting means

Total PV array power rating at STC kW	Rated current I_n A
0 to 25	1
> 25 to 50	2
> 50 to 100	3
> 100 to 250	4
> 250	5

The rated current "I_n" refers to fuses and circuit breakers, for which tripping is ensured at a fault current of typically 130 % to 140 % of I_n, and will occur within max times of 60 min at

135 % and 2 minutes at 200 %. Where the earth fault interruption function is provided by current sensing and an automatic disconnection means such as a relay, the setting may be different than the relevant I_n value in Table 3 provided the system causes disconnection within 60 min at 135 % and 2 min at 200 % of the relevant I_n value.

6.4.2.5 Earth fault indication

As required by 6.4.2 Table 1, an earth fault indication system shall be installed. If a fault in a system recovers, the indication may be reset automatically provided a record of the fault is maintained either by a log of faults or by an indication of previous faults. If a record of the fault is not able to be maintained, the original indication of a fault shall be maintained even if the fault (e.g. the insulation resistance) has recovered to an acceptable value.

The indication shall be of a form that ensures that the system operator or owner of the system becomes aware of the fault. For example, the indication system may be a visible or audible signal placed in an area where operational staff or system owners will be aware of the signal or another form of fault communication like RS485, e-mail, SMS or similar.

A set of operational instructions shall be provided to the system owner which explains the need for immediate action to investigate and to correct the fault.

Many inverters have earth fault detection and indication in the form of indicator lights. However, typical inverter mounting locations mean that this indication may not be noticed. IEC 62109-2 requires that inverters have a local indication and also a means of signalling an earth fault remotely.

6.5 Protection against overcurrent

6.5.1 General

Overcurrent within a PV array can result from earth faults in array wiring or from fault currents due to short circuits in modules, in junction boxes, combiner boxes or in module wiring.

PV modules are current limited sources but can be subjected to overcurrents because they can be connected in parallel and also connected to external sources (e.g. batteries). The overcurrents can be caused by the sum of currents from

- multiple parallel adjacent strings,
- some types of inverters to which they are connected, and/or
- external sources.

6.5.2 Requirement for overcurrent protection

Overcurrent protection shall be provided in accordance with 6.5.3 to 6.5.7 and with PV module manufacturer's requirements.

6.5.3 Requirement for string overcurrent protection

String overcurrent protection shall be used if:

$$((\mathrm{N}_S - 1) \times I_{\mathrm{SC\_MOD}}) > I_{\mathrm{MOD\_MAX\_OCPR}}$$

The overcurrent protective devices of the DC side shall be either gPV fuses in accordance with the IEC 60269-6 standard or another devices in accordance with IEC 60947 (all parts) or IEC 60898-2, selected such that the cable current carrying capacity, module maximum reverse current rating and the maximum current of other equipment are not exceeded.

NOTE The thermal withstand capability of a PV module under reverse current is qualified during a 2 h test specified in the module safety test from IEC 61730 and is specified on the module as the "maximum overcurrent protection" value.

When circuit breakers with overcurrent protection elements are used, they may also provide the disconnecting means required in 7.4.1.

6.5.4 Requirement for sub-array overcurrent protection

Sub-array overcurrent protection shall be provided if more than two sub-arrays are connected to a single PCE.

6.5.5 Overcurrent protection sizing

6.5.5.1 PV string overcurrent protection

Where string overcurrent protection is required, either

a) each PV string shall be protected with an overcurrent protection device (see Figures 3 to 6), where the overcurrent protection current rating of the string overcurrent protection device shall be I_n where:

   $I_n > 1{,}5 \times I_{SC\_MOD}$; and

   $I_n < 2{,}4 \times I_{SC\_MOD}$; and

   $I_n \leq I_{MOD\_MAX\_OCPR}$;

or

b) strings may be grouped in parallel (see Figure 8) under the protection of one overcurrent device provided:

$$I_{ng} > 1{,}5 \times N_G \times I_{SC\_MOD}; \textit{ and}$$

$$I_{ng} < I_{MOD\_MAX\_OCPR} - ((N_G - 1) \times I_{SC\_MOD})$$

   where

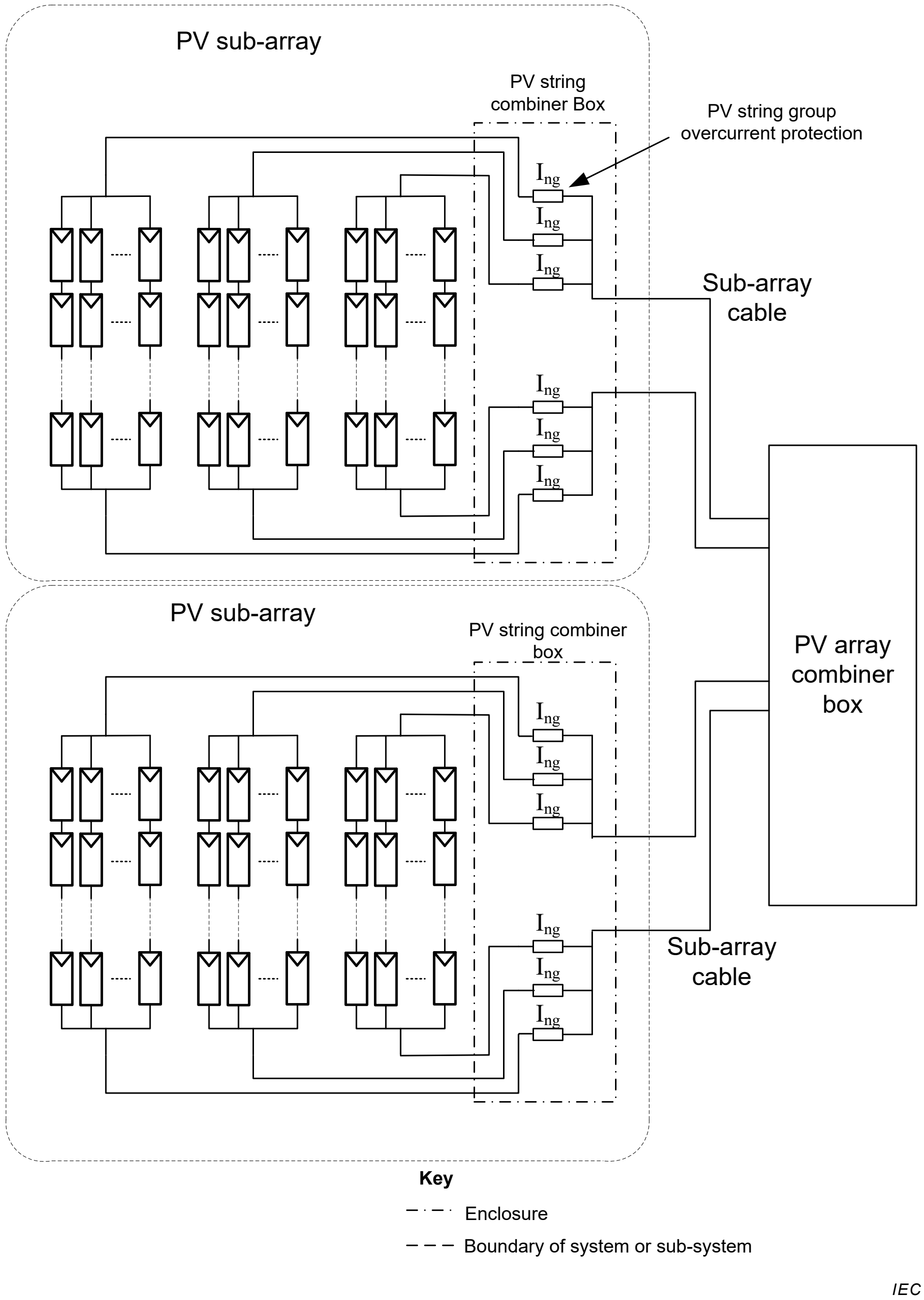
   N_G is the number of strings in a group under the protection of the one overcurrent device;

   I_{ng} is the overcurrent protection current rating of the group overcurrent protection device.

The factor of 1,5 considers a design allowance for high irradiance conditions. Individual designs should take into account local ambient irradiance and temperature conditions. Cycling load, grouping of fuses and unequal current flow through the parallel strings may lead to factors higher than 1,5.

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.

NOTE With the provisions under the formulae above, strings can generally only be grouped under one overcurrent protection device if $I_{MOD\_MAX\_OCPR}$ is greater than $4 \times I_{SC\_MOD}$.



NOTE 1 This is a special case and the design is only possible where the overcurrent protection rating of a PV module is much larger than its normal operating current.

NOTE 2 This is only an example and other switching, disconnecting and/or overcurrent protection devices can be required in individual cases, but for simplicity are not shown in this figure.

Figure 8 – Example of a PV array diagram where strings are grouped under one overcurrent protection device per group

6.5.5.2 PV sub-array overcurrent protection

The nominal rated current (I_n) of overcurrent protection devices for PV sub-arrays shall be determined with the following formula:

$$I_n > 1{,}25 \times I_{SC\ S\text{-}ARRAY}; \text{ and}$$

$$I_n \leq 2{,}4 \times I_{SC\ S\text{-}ARRAY}.$$

The 1,25 multiplier used here instead of the 1,5 multiplier used for strings is to allow designer flexibility. Care has to be taken in using a lower multiplier in areas where heightened irradiance occurs frequently as this would be likely to cause nuisance overcurrent operation.

6.5.5.3 PV array overcurrent protection

PV array 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 rated current (I_n) of PV array overcurrent protection devices shall be rated as follows:

$$I_n > 1{,}25 \times I_{SC\ ARRAY}; \text{ and}$$

$$I_n \leq 2{,}4 \times I_{SC\ ARRAY}$$

6.5.6 Overcurrent protection in PV systems connected to batteries

Overcurrent protection shall be provided in all PV systems connected to batteries. The PV array main cable protection may be built into the system immediately adjacent to the battery. If this is not the case, overcurrent protection shall be provided on the PV array main cable to protect this cable from fault currents originating from the battery system. See 6.5.5 for overcurrent protection sizing. All overcurrent protection used shall be capable of interrupting the maximum prospective fault current from the battery.

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

6.5.7 Overcurrent protection location

Overcurrent protection devices where required by 6.5 for PV array, PV sub-array, and PV strings shall be placed:

- for string overcurrent protection devices, they shall be where the string cables are combined or connected to the sub-array or array main cables (refer to Figures 3 and 4);
- for sub-array overcurrent protection devices, they shall be where the sub-array cables are combined (refer to Figure 4);
- for array overcurrent protection devices, they shall be where the array main cables join the application circuit or the PCE (refer to Figures 2 to 4).

NOTE 1 The location of the overcurrent protection devices at the end of those cables which are furthest away from the PV, sub-array or string 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 protection devices shall be in readily available locations.

An overcurrent protective device required for a string cable or sub-array cable shall be placed in each live conductor (i.e. each live conductor not connected to the functional earth).

An exception applies for systems that are not functionally earthed (i.e. do not have any PV array DC live conductors connected to earth) and that have only two active conductors if

- there is segregation by a physical barrier between string cables and sub-array cables, or
- there are no sub-arrays and therefore no sub-array cables i.e. in small systems,

  an overcurrent protective device need only be placed in one unearthed live conductor of the string cable or sub-array cable. The polarity of this conductor shall be the same for all cables thus protected.

NOTE 2 This provision of a single overcurrent device is allowed for floating systems under these circumstances because of the requirement for detection and alarm on a single earth fault and because of the double insulation required on conductors in all array circuits.

6.6 Protection against effects of lightning and overvoltage

6.6.1 General

The installation of a PV array on a building often 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.

If a lightning protection system (LPS) is already installed on the building, the PV system should be integrated into the LPS as appropriate in accordance with IEC 62305-3.

In the case where no lightning system is required on a building or in a case of a free-standing array, overvoltage protection may still be required to protect the array and the inverter and all parts of the installation.

6.6.2 Protection against overvoltage

6.6.2.1 General

All DC cables should be installed so that positive and negative cables of the same string and the main array cable should be bundled together, avoiding the creation of loops in the system. Refer to 7.4.3.3. The requirement for bundling includes any associated earth/bonding conductors.

Long cables (e.g. PV main DC cables over about 50 m) should be either

- installed in earthed metallic conduit or trunking, where the conduit or trunking is connected to the equipotential bonding,
- be buried in the ground (using appropriate mechanical protection),
- be cables incorporating mechanical protection which will provide a screen, where the screen is connected to the equipotential bonding, or
- be protected by a surge protective device (SPD).

These measures will act to both shield the cables from inductive surges and, by increasing inductance, attenuate surge transmission. Be aware of the need to allow any water or condensation that may accumulate in the conduit or trunking to escape through properly designed and installed vents.

NOTE 1 To protect the DC system as a whole, surge protective devices can be fitted between active conductors and between active conductors and earth at the inverter end of the DC cabling and at the array. To protect specific equipment, surge protective devices can be fitted as close as is practical to the device.

The need for surge protective devices should be assessed according to IEC 62305 (all parts) and appropriate protective measures implemented. IEC 62305-4 can provide a methodology for protection of electrical and electronic systems in a lightning environment.

NOTE 2 IEC 61643-32, regarding low-voltage surge protective devices for photovoltaic installations, is currently under development.

6.6.2.2 Surge protection devices (SPDs)

6.6.2.2.1 General

SPDs are incorporated into electrical installations to limit transient overvoltages of atmospheric origin transmitted via the supply distribution system, whether a.c or DC or both, and against switching surges.

Some grid connect inverters (PCEs) have some form of in-built SPD; however discrete devices may also be required. In such cases, the coordination between the two SPDs should be verified with the equipment supplier.

To protect specific equipment, SPDs should be fitted as close as is practical to the equipment intended to be protected.

These measures are included here as a guide. Overvoltage protection is a complex issue and a full evaluation should be undertaken particularly in areas where lightning is common.

6.6.2.2.2 Surge protection devices (SPDs) DC

For the protection of the DC side, SPDs shall be compliant with EN 50539-11 and be explicitly rated for use on the DC side of a PV system. If the PV system is connected to other incoming networks (such as telecommunication and signalling services), SPDs will be required to protect the information technology equipment.

6.6.2.2.3 Surge protection devices (SPDs) information technology equipment

For the protection of information technology equipment SPDs shall be selected according to the requirements of IEC 61643-22. These SPDs shall comply with IEC 61643-21.

7 Selection and erection of electrical equipment

7.1 General

All power conversion equipment shall be qualified to IEC 62109-1 and any other relevant parts according to the equipment type.

PV array wiring and associated components are often exposed to UV, wind, water, snow and other environmental testing conditions. Wiring and components should be fit for purpose and erected in such a way as to minimise exposure to detrimental environmental affects.

PCE shall be selected according to the environmental requirements in IEC 62109-1:2010, Clause 6.

Particular attention is drawn to the need for prevention of water accumulation in cable/module support systems.

The future publication IEC TS 62738 documents requirement variations and additional considerations for several parts of this Clause 7 as they apply to large-scale PV power plants. These include requirements related to:

- equipment certification;
- PV array maximum design voltage;
- component ratings;
- disconnector requirements and locations;
- cable selection and erection.

7.2 PV array maximum voltage

The PV array maximum voltage is considered to be equal to $U_{OC\ ARRAY}$ corrected for the lowest expected operating temperature.

Correction of the voltage for the lowest expected operating temperature shall be calculated according to PV module manufacturer's instructions. Where PV module manufacturer's instructions are not available for crystalline and multi-crystalline silicon modules, $V_{OC\ ARRAY}$ shall be multiplied by a correction factor according to Table 4 using the lowest daily ambient temperature as a reference.

NOTE The cell temperature early in the morning is very close to ambient.

Deviations from these methods that account for the coincidence of irradiance and lowest expected operating temperatures may be permitted with engineering justification and approval by the applicable manufacturers and local approving authorities.

Where the lowest expected ambient temperature is below –40 °C, or where technologies other than crystalline or multi-crystalline silicon are in use, voltage correction shall only be made in accordance with PV module manufacturer's instructions.

PV strings constructed using DC conditioning units shall have a PV array maximum voltage in accordance with 5.1.5.

Table 4 – Voltage correction factors for crystalline and multi-crystalline silicon PV modules

Lowest expected operating temperature °C	Correction factor
24 to 20	1,02
19 to 15	1,04
14 to 10	1,06
9 to 5	1,08
4 to 0	1,10
–1 to –5	1,12
–6 to –10	1,14
–11 to –15	1,16
–16 to –20	1,18
–21 to –25	1,20
–26 to –30	1,21
–31 to –35	1,23
–36 to –40	1,25

NOTE Temperature of modules facing open sky can be up to 5 °C lower than ambient (air) temperature in some locations.

7.3 Component requirements

7.3.1 General

All components, shall comply with the following requirements:

- be rated for DC use;

- have a voltage rating equal to or greater than the PV array maximum voltage determined in 7.2;
- have a current rating equal to or greater than that shown in Table 5;
- have an IP rating suitable for their location and environment;
- have a temperature rating appropriate to their location and application.

For some PV technologies the I_{SC} current available during the first few weeks of operation is considerably greater than the normal rated value. In some technologies the I_{sc} increases over time. Equipment should be rated for the highest expected current value.

NOTE PV arrays are installed in full sun and ambient temperatures and temperatures inside enclosures can be very high. This is an important consideration when selecting components.

Where DCUs are used in the design of a PV array, attention is drawn to the voltage and current ratings related to DCUs described in 5.1.5.2.

All components used in salt mist conditions should be suitable for use in these conditions.

To avoid series arcs it is important to select terminals and connection equipment which can ensure contact pressure over the lifetime of the system.

7.3.2 PV modules

7.3.2.1 Operational conditions and external influences

PV modules shall comply with the relevant parts of the IEC 61215 series. Systems with voltages above 50 V DC should include bypass diodes.

Some thin film modules do not require bypass diodes installed. Module manufacturer's instructions should be followed to ensure bypass diodes are used where required.

7.3.2.2 Equipment class

PV modules shall be qualified to IEC 61730-1 and IEC 61730-2 and shall only be used in applications applicable to their class rating.

For building mounted applications, local building codes and regulations should be taken into account.

For protection against electric shock,

- class II modules according to IEC 61730-1 shall be used where system voltages exceed DVC-A.

7.3.3 PV array and PV string combiner boxes

7.3.3.1 Environmental effects

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

Higher IP ratings should be considered for tropical regions.

Any enclosure IP rating shall suit the environmental conditions. This IP rating shall apply for the relevant mounting position and orientation. Gasket materials chosen should be rated for the environment and duration of use and a replacement schedule identified if applicable.

7.3.3.2 Location of PV array and PV string combiner boxes

PV array and PV string combiner boxes which contain overcurrent and or switching devices shall be capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like.

NOTE 1 Under some conditions, combiner boxes can be part of the PCE. See 7.4.1.2.

NOTE 2 There is a growing trend to use pre-manufactured string wiring assemblies commonly referred to as “harnesses.” Harnesses aggregate the output of multiple PV string conductors along a single main conductor. The harnesses are secured within the array, and can or cannot include fusing on the individual string conductors that tap off the main conductor, depending on over-current protection requirements. These are in a sense similar to combiner boxes in function and are used most commonly with thin film systems due to the very low string currents in each string. The purpose is to reduce balance of system components and cost for systems with large numbers of parallel low-current strings. In larger systems, the harness main conductors are then combined in a sub-array combiner box with larger fuses (e.g. 20 A to 30 A).

7.3.4 Circuit breakers

Circuit breakers used for overcurrent protection in PV arrays shall

a) be certified to either IEC 60898-2 or IEC 60947-2,
b) not be polarity sensitive (fault currents in a PV array may flow in the opposite direction of normal operating currents),
c) 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, and
d) be rated for overcurrent according to 6.5.5.

7.3.5 Fuses

7.3.5.1 Accessibility

Where fuses are used they shall be only accessible with the use of a tool or key. i.e. only accessible by trained service personnel.

7.3.5.2 Fuse links

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

- be rated to interrupt 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 circuit current protective type suitable for PV complying with IEC 60269-6.

When fuses are provided as means of isolation, where load breaking capabilities are required, the use of fused switch-disconnectors (fuse-combination units) is recommended.

7.3.5.3 Fuse bases and fuse holders

Fuse bases and fuse holders shall comply with the following requirements:

- have a current rating equal to or greater than the corresponding fuse link;
- shall not change fuse ratings or characteristics
- provide a degree of protection suitable for the location and not less than IP2X even when the fuse link or carrier is removed. In locations which require a tool for access if the fuse holder provides a degree of protection of less than IP2X, an additional protective cover may be used to provide the IP2X protection.

7.3.6 Disconnectors and switch-disconnectors

All disconnectors, shall comply with the following requirements:

- not have exposed live metal parts in connected or disconnected state;
- 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 minimum required current carrying capacity of the circuit to which they are fitted according to Table 5.

Switch-disconnectors shall be certified to IEC 60947-1 and IEC 60947-3 and have mechanisms that have independent manual operation.

In addition, load breaking switch-disconnectors used for protection and/or disconnecting means shall comply with the following requirements:

a) not be polarity sensitive (fault currents in a PV array may flow in the opposite direction of normal operating currents);
b) 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;
c) when overcurrent protection is incorporated, it shall be rated according to 6.5.5;
d) interrupt all live conductors simultaneously.

PV array switch-disconnectors shall interrupt all conductors (including functionally earthed conductors).

Plug connections for interruption under load may also be used in place of switch disconnectors, provided that equivalent level of safety can be assured.

NOTE Only specially constructed plugs and sockets are capable of interrupting load safely. 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.

7.3.7 Cables

7.3.7.1 Size

7.3.7.1.1 General

Cable sizes for PV string cables, PV sub-array cables and PV array main cable shall be determined with regard to:

a) overcurrent protection ratings where in use,
b) the minimum current rating (refer to Table 5),
c) the voltage drop and prospective fault current.

The largest cable size obtained from these criteria shall be applied.

PV arrays not connected to batteries are current limited systems but because of parallel connection of strings, and sub-arrays, abnormally high currents may flow in array wiring under fault conditions. Overcurrent protection is specified where required and cables need to be capable of handling the worst case current from any remote part of the array through the nearest overcurrent protection device plus the worst case current available from any adjacent parallel strings.

7.3.7.1.2 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 5, and the current carrying capacity of cables as specified in IEC 60287 (all parts). Cable derating factors taking into consideration cable location and installation method, according to IEC 60364-5-52, shall be applied.

Variations and additional considerations for large-scale ground mounted PV power plants with restricted access to personnel are addressed in the future publication IEC TS 62738.

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

Table 5 – Minimum current rating of circuits

Relevant circuit	Protection	Minimum current upon which cable cross-sectional area and or other circuit ratings should be chosen [a, b]
PV string	**PV string overcurrent protection not provided**	**Systems not using DCUs:** For a single string array 1,25 × $I_{SC\ MOD}$ For all other casess: I_n + 1,25 × $I_{SC\ MOD}$ × (N_{PO} – 1) where I_n is the current rating of the nearest downstream overcurrent protection device; N_{PO} is the total number of parallel connected strings protected by the nearest overcurrent protection device. NOTE a) The nearest downstream overcurrent protection may be the sub-array protection and if this is not present then it may be the array overcurrent protection if present. b) When no overcurrent protection is used in the complete array then N_{PO} is the total number of parallel connected strings in the complete PV array; and the rated current (In) of the nearest overcurrent protection device is replaced by zero.
		Systems where modules are connected via a DCU: For strings using DCUs, the minimum current rating shall be according to 5.1.5.2
	PV string overcurrent protection provided	Current rating (I_n) of the PV string overcurrent protection device (refer to 6.5)
PV sub-array	**PV sub-array overcurrent protection not provided**	The greater of the following: a) current rating (I_n) of the PV array overcurrent protection device + 1,25 × sum of short circuit current of all other sub-arrays b) 1,25 × $I_{SC\ S\text{-}ARRAY}$ (of relevant array) NOTE When PV array overcurrent protection is not used, then I_n is replaced by zero in equation (a)
	PV sub-array overcurrent protection provided	Current rating (I_n) of the PV sub-array overcurrent protection device (refer to 6.5)
PV array	**PV array overcurrent protection not provided**	1,25 × $I_{SC\ ARRAY}$
	PV array overcurrent protection provided	Current rating (I_n) of the PV array overcurrent protection device (refer to 6.5)

[a] The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature. A minimum operating temperature equal to the 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 need to be considered in establishing a cable rating. Cable manufacturer's recommendations need to be taken into account in establishing the rating according to installation method.

Where an inverter or other power conversion equipment is capable of providing backfeed current into the array under fault conditions, the value of this backfeed current shall be taken into account in all calculations of circuit current ratings. In some circumstances, the backfeed current will have to be added to the circuit rating as calculated in Table 5.

NOTE Power conversion equipment backfeed current rating is a required rating under IEC 62109-1.

7.3.7.2 Type

Cables used within the PV array shall

- be suitable for DC application,
- have a voltage rating equal to or greater than the PV array maximum voltage determined in 7.2, and
- have a temperature rating according to the application.

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 shall be rated accordingly.

- If exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection, or be installed in UV-resistant conduit.
- Be water resistant.
- In all systems operating at voltages above DVC-A, cables shall be selected so as to minimise the risk of earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables, particularly for cables that are exposed or laid in metallic tray or conduit. This can also be achieved by reinforcing the protection of the wiring as shown in the examples of Figure 9.
- Where movement of the cable is expected, the conductor of the cable shall be flexible (class 5 of IEC 60228). Examples where such cables are required are: string cables; trackers, and where cables are connected using plugs and sockets.
- Where no movement of the cable is expected, the conductor of the cable can be stranded (class 2 of IEC 60228) or flexible (class 5 of IEC 60228).

Cables for non fixed installation, i.e. flexible cables, should comply with EN 50618, or UL 4703.

NOTE IEC 62930, regarding electric cables for photovoltaic systems, is under development.

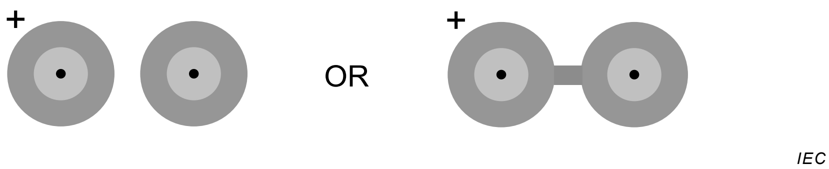


Figure 9a – Single or multi-conductor cable where each conductor is both insulated and sheathed

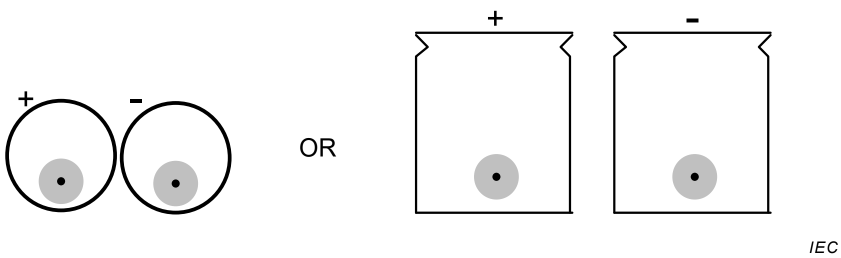


Figure 9b – Single conductor cable – in suitable insulated conduit/trunking

Figure 9 – Examples of reinforced protection of wiring

7.3.7.3 Erection method

The general requirements of IEC 60364-5-52 shall be considered.

Cables shall be supported so they do not suffer fatigue due to wind/snow affects. They shall also be protected from sharp edges. Methods of securement shall prevent cable damage due to excessive stress or tension due to loading or sharp radii bends. (Refer to manufacturer's instructions for minimum permissable bend radius). Cables shall be supported so that their properties and installation requirements are maintained over the stated life of the PV plant. All non-metalic conduit and ducting exposed to sunlight shall be of a UV resistant type.

Cable ties shall not be used as a primary means of support unless they have a lifetime greater than or equal to the life of the system or the scheduled maintenance period. Where cable ties are used as a means of support, they shall be installed such that they do not damage the cable.

NOTE Conduit, ducting and cable ties installed under an array can still be exposed to reflected UV radiation. Metalic cable ties can have sharp edges which over time and subject to wind affects can cause cable damage.

7.3.8 Segregation of AC and DC circuits

In addition to the requirements detailed in IEC 60364, segregation shall be provided between DC and AC circuits to the same requirements as for segregation of different voltage levels.

NOTE This requirement is so that double insulation to the highest voltage present is maintained between AC and DC circuits.

7.3.9 Plugs, sockets and connectors

Plugs and socket connectors mated together in a PV system shall be of the same type from the same manufacturer, i.e. a plug from one manufacturer and a socket from another manufacturer or vice versa shall not be used to make a connection.

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

- IEC 62852;
- be rated for DC use;
- have a voltage rating equal to or greater than the PV array maximum voltage determined in 7.2;
- 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 current carrying capacity for the circuit to which they are fitted (refer to Table 5);
- be capable of accepting the cable used for the circuit to which they are fitted;
- require a deliberate force to separate;
- if accessible by untrained people then shall be of the locking type where two independent actions or a tool are required to disconnect;
- have a temperature rating suitable for their installation location;
- if multi-polar, be polarised;
- comply with class II for systems operating above DVC-A voltages;
- if exposed to the environment, be rated for outdoor use, be UV-resistant and be of an IP rating suitable for the location;
- shall be installed in such a way as to minimise strain on the connectors (e.g. supporting the cable on either side of the connector);
- plugs and socket outlets normally used for the connection of household equipment to low voltage AC power shall not be used in PV arrays.

  NOTE The purpose of this requirement is to prevent confusion between AC and DC circuits within an installation.

7.3.10 Wiring in combiner boxes

Wherever possible, there should be segregation between positive and negative conductors within combiner boxes to minimise the risks of DC arcs occurring between these conductors.

7.3.11 Bypass diodes

Bypass diodes may be used to prevent PV modules from being reverse biased and consequent hot spot heating. If external bypass diodes are used, and they are not embedded in the PV module encapsulation or not part of factory mounted junction boxes, they shall comply with the following requirements:

- have a voltage rating at least 2 × $U_{\text{OC MOD}}$ of the protected module;
- have a current rating of at least 1,4 × $I_{\text{SC MOD}}$;
- be installed according to PV module manufacturer's recommendations;
- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

7.3.12 Blocking diodes

Blocking diodes may be used to prevent reverse currents in sections of a PV array.

In some countries, blocking diodes are permitted as a replacement for overcurrent protection. In other countries, diodes are not considered reliable enough to replace overcurrent protection because their failure mode is generally to a short-circuited state when subjected to voltage transients. Local country requirements should be taken into account in system designs.

In systems containing batteries it is recommended that some device should 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 × PV array maximum voltage determined in 7.2;
- have a current rating I_{MAX} of at least 1,4 times the short circuit current at STC of the circuit that they are intended to protect; that is:
  - 1,4 × $I_{\text{SC MOD}}$ for PV strings;
  - 1,4 × $I_{\text{SC S-ARRAY}}$ for PV sub-arrays;
  - 1,4 × $I_{\text{SC ARRAY}}$ for PV arrays;
- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

When there is a possibility of high short-circuit current of the PV module due to reflection from the snow or other conditions, the factor for calculation of I_{MAX} should be larger than 1,4. For example in the snow case, short circuit current is affected by ambient temperature, incline angle and azimuth angle of PV module, reflection of snow, geographical features and so on. I_{MAX} is decided according to the climatic condition, etc.

The use of blocking diodes is shown in detail in Annex C.

7.3.13 Power conversion equipment (PCE) including DC conditioning units (DCUs)

All PCEs and DCUs shall comply with IEC 62109-1, and additionally inverters shall comply with IEC 62109-2.

The PV input of DCUs and PCEs shall be rated for

- the maximum open circuit voltage of the input circuit connected.

The PV input of DCUs and PCEs shall have an $I_{SC\ PV}$ rating as defined in IEC 62109-1 of

- at least 1,25 × the short circuit current of the input circuit connected at STC, unless additional overcurrent protection is provided that is rated to protect the PCE.

7.4 Location and installation requirements

7.4.1 Disconnecting means

7.4.1.1 General

Disconnecting means shall be provided in PV arrays according to Table 6 to isolate the PV array from the power conversion equipment and vice versa and to allow for maintenance and inspection tasks to be carried out safely.

The disconnecting means for PCEs shall be accessible and meet the requirements of a switch-disconnector (refer to 7.3.6).

NOTE Local installation codes can allow certain types of systems to be installed without a DC switch disconnector between modules and the PCE, for example below certain voltage and current thresholds, where DC switch disconnectors are provided elsewhere in the system, or where a plug and connector system is used that is either rated for disconnection under load or provided with a means to ensure no load current is flowing before opening the connector.

7.3.6 allows the use of load breaking connectors in place of switch disconnectors provided stated conditions of 7.3.6 are met.

7.4.1.2 Switch-disconnector for power conversion equipment (PCE)

Except for module integrated PCEs without disconnection means between the PV module and the PCE, it shall be possible to isolate the PCE from all poles of the PV array such that maintenance of the PCE is possible without risk of electrical hazards.

NOTE Module integrated PCEs are ones that are permanently attached to a PV module. (e.g. is a PCEs bonded to a PV backsheet).

Smaller PCEs are often repaired by replacing the PCE; whereas larger PCEs are often repaired by replacing internal components. For PCEs repaired by replacement, one of the following disconnecting methods shall be used:

a) an adjacent and physically separate switch-disconnector; or
b) a switch-disconnector that is mechanically connected to the PCE and allows the PCE to be removed from the section containing the switch-disconnector without risk of electrical hazards; or
c) a switch-disconnector located within the PCE, if the PCE includes a means of isolation only operable when the switch-disconnector is in the open position; i.e. the maintainable section of the PCE can only be opened or withdrawn if the switch-disconnector is in the open position; or
d) a switch-disconnector located within the PCE, if the PCE includes a means of isolation which can only be operated with a tool and is labeled with a readily visible warning sign or text indicating "Do not disconnect under load”.

For PCEs repaired by replacing internal components, the switch-disconnector shall be located such that maintenance of the PCE (e.g. change of an inverter module, change of fans, cleaning of filters) is possible without risk of electrical hazards. This switch-disconnector may be in the same enclosure with the PCE, provided that protection is provided against inadvertent contact with any parts that remain energized with the switch-disconnector opened.

7.4.1.3 Installation

Suitably rated circuit-breakers, having the characteristics described in 7.3.4 and used for overcurrent protection may also provide load breaking disconnecting means.

The location of overcurrent protection devices shall be according to 6.5.7.

Table 6 – Disconnection device requirements in PV array installations

PV array voltage	Circuit or sub-circuit	Means of isolation	Requirement
DVC-A	String cable	Disconnection device	Recommended [a]
	Sub-array cable	Disconnection device	Required
	Array main cable	Switch-disconnector	Required
DVC-B and C	String cable	Disconnection device [a]	Recommended [a]
	Sub-array cable	Disconnection device [a]	Required
		Switch-disconnector	Recommended
	Array main cable	Switch-disconnector	Required

[a] Sheathed (touch safe) plug and socket connector, fuse combination unit, fuseholder and withdrawable fuse-link, or isolator are examples of suitable disconnection devices. The ability of these devices to break load current needs to be according to the table.

Disconnection devices not capable of breaking load current should be marked as no-load break and should not be generally accessible.

An additional DC switch-disconnector may be specified for systems with long DC cable runs through buildings. This switch is generally used at the point of cable entry into the building.

Where multiple sub-array disconnection devices are installed close to (i.e. within 2 m and within line of sight of) the power conversion equipment there is no need for a PV array main cable and therefore no need for a PV array load breaking switch. In this case the switches for the sub-arrays shall all be load breaking switches. This is also applicable for remote sub-array disconnection devices, where the sub-array combiners are not close to the PCE. In this case remote disconnection is allowed where an indication of the proper operation of the disconnection function is given at the PCE.

Where multiple disconnection devices are required to isolate power conversion equipment they shall all be switch disconnectors and shall either

- be ganged so that they all operate simultaneously, or
- they shall all be grouped in a common location and there shall be a warning sign indicating the need to isolate multiple supplies to isolate the equipment.

Where required in Table 6, disconnection devices shall be installed in all live conductors, with the exception of the PV array switch-disconnector which shall operate in all conductors including the functional earthed conductor.

Where load breaking (switch-disconnector) is a requirement this capability shall be in each conductor and the switching devices shall be ganged so that all switch poles in all conductors operate simultaneously.

7.4.2 Earthing and bonding arrangements

7.4.2.1 General

The following options for earthing or bonding of parts of a PV array exist.

a) Functional earthing of conductive non-current carrying parts (e.g. to allow for better detection of leakage paths to earth). Earthing/bonding of exposed conductive parts of a PV array shall be performed in accordance with Figure 10 requirements.

b) Earthing for lightning protection.

c) Equipotential bonding to avoid uneven potentials across an installation.

d) Functional earthing of one current carrying pole of the PV array, so called functionally earthed PV array. Refer to 7.4.2.4.3 and 7.4.2.4.4 for further details.

NOTE Some module types require earthing for proper operation. This earthing is considered to be functional earthing only.

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.

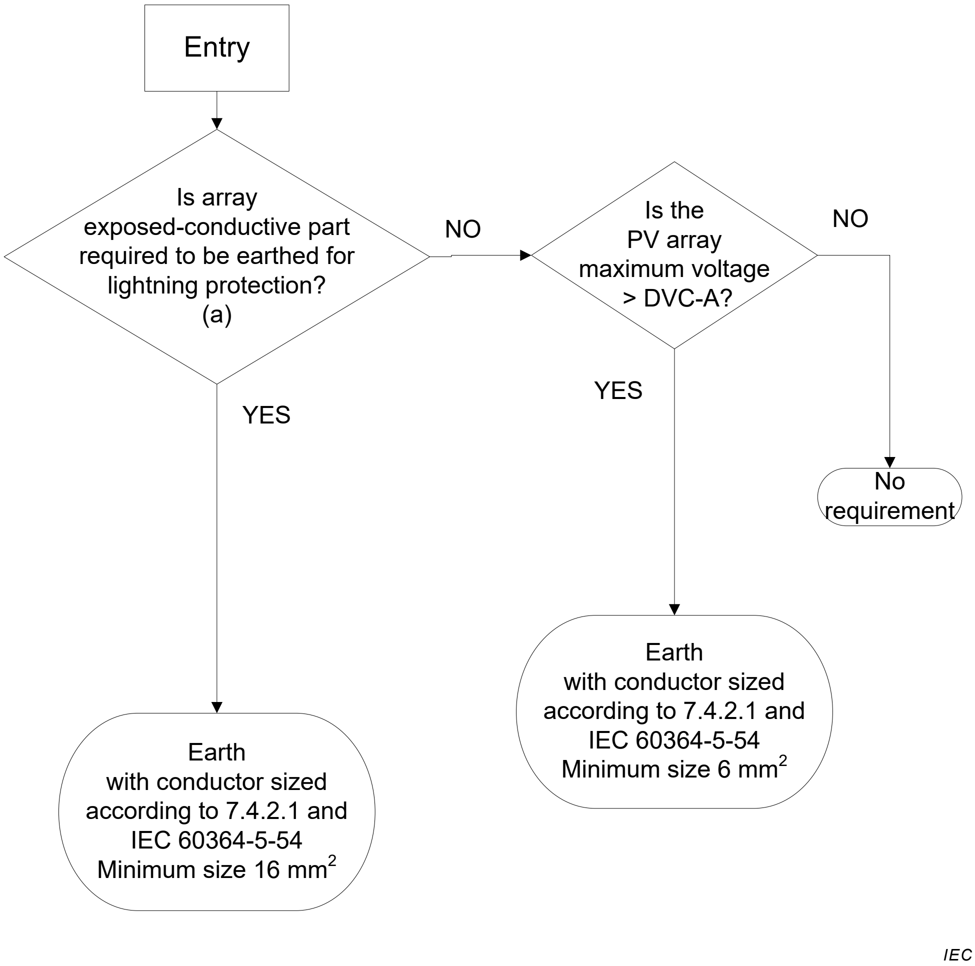
Annex B contains examples of functionally earthed PV systems.

7.4.2.2 Bonding conductor size

The conductor used to earth exposed metallic frames of the PV array shall have a minimum size of 6 mm^2 copper or equivalent.

For some system configurations the minimum conductor size may need to be larger due to lightning system requirements (refer to Figure 10).

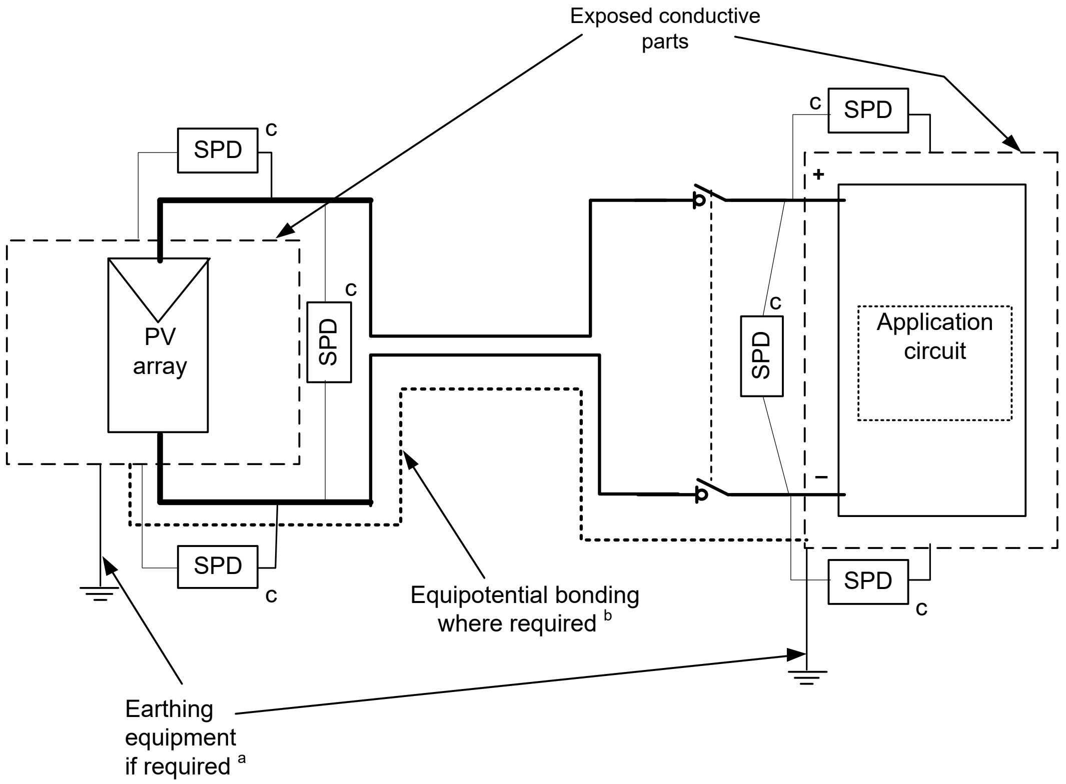
Figure 11 shows an example of earthing requirements of exposed conductive parts on a PV array.



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

a To answer this question, see the recommendations of IEC 62305-2 and IEC 62305-3 or refer to local information such as number of thunder days per year or other lightning characteristics. Assessment should include relative position of the PV array to other buildings, and structures able to protect the PV array from lightning strikes.

Figure 10 – PV array exposed conductive parts functional earthing/bonding decision tree



a The earth connections shown in this diagram are all functional earth connections. The exposed metal frame connections may also be required for lightning protection.

b Equipotential bonding between the PV array and application circuit is essential in protecting electrical equipment against lightning overvoltages. The equipotential bonding conductor should be run as physically close as possible to the live conductors to reduce wiring loops.

c Overvoltage protection surge protective devices (SPDs).

Figure 11 – Exposed conductive parts earthing in a PV array

A high impedance shall exist between all live conductors and the equipment earthing conductors.

7.4.2.3 Separate earth electrode

If a separate earth electrode is provided for the PV array, this electrode shall be connected to the main earthing terminal of the electrical installation by main equipotential bonding conductors.

See recommendations on the design of electrodes for lightning protection in IEC 62305-3.

7.4.2.4 Equipotential bonding

7.4.2.4.1 General

There are two forms of equipotential bonding: main equipotential bonding and supplementary equipotential bonding.

Main equipotential bonding is the connection of exposed conductive parts to the main earthing terminal. These conductors are termed “main equipotential bonding conductors”.

Supplementary equipotential bonding is the connection of exposed conductive parts to exposed conductive parts and/or extraneous conductive parts. Supplementary equipotential bonding may be required in order to keep the magnitude of the voltages between simultaneously accessible exposed conductive parts and/or extraneous conductive parts sufficiently low to prevent electric shock.

PV array frame bonding shall be done in accordance with the decision tree presented in Figure 10.

7.4.2.4.2 PV array bonding conductors

PV array bonding conductors shall be run as close to the positive and negative PV array and or sub-array conductors as possible to reduce induced voltages due to lightning.

7.4.2.4.3 Functional earthing terminal of PV array

When the PV array is earthed as described in 7.4.2.1 d), the connection to earth shall be made at a single point and this point shall be connected to the main earthing terminal of the electrical installation.

Some electrical installations may have sub-earthing terminals. Connection of the PV functional earth to sub-earthing terminals is acceptable provided it has been considered for this use.

The functional earth connection may be established inside the PCE.

In systems without batteries, the connection to earth shall be between the PV array and the power conversion equipment and as close as possible to the power conversion equipment.

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

NOTE If in some countries disconnection devices are required/allowed to interrupt functional earth conductors, the location of the earth connection is important to interruption.

7.4.2.4.4 Functional earthing conductor of PV array

Where a functional earth (either a direct earth connection or via a resistor) is used to connect one of the main PV array conductors to earth, the minimum current carrying capacity of the functional earth conductor shall be

- no less than the nominal rating of the earth fault interrupting means (refer to 6.4.2.4) for a system with direct functional earth connection without a resistor, or
- no less than (PV array maximum voltage)/R, where R is the resistance value used in series with the functional earth connection for a system which has a functional earth connection via a series resistor.

With respect to material and type, insulation, identification, installation and connections, functional earthing conductors shall comply with the provisions for functional earthing conductors specified in national wiring standards, or in absence of such standards, with the provisions set out in IEC 60364-5-54.

Some module technologies require a functional earth on either the positive or negative main conductor of the system to bleed charge away from the PV cells. This is a functional/operational requirement or it may be required to prevent degradation of the cells. It is recommended that manufacturer’s instructions be followed. It is also recommended that where possible the functional earthing to bleed charge from the cells be via a resistor and not directly to earth. The recommended resistor value should be the highest resistor value allowable as per manufacturer’s instructions.

7.4.3 Wiring system

7.4.3.1 General

Wiring of PV arrays shall be undertaken with care (to prevent damage occurring) such 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, operation and future maintenance.

7.4.3.2 Compliance with wiring standards

The PV array wiring shall comply with the cable and installation requirements in this document and 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 IEC 60364 (all parts).

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

7.4.3.3 Wiring loops

To reduce the magnitude of lightning-induced overvoltages, the PV array wiring should be laid in such a way that the area of conductive loops is minimum, par exemple by laying cables in parallel as shown in Figure 12.

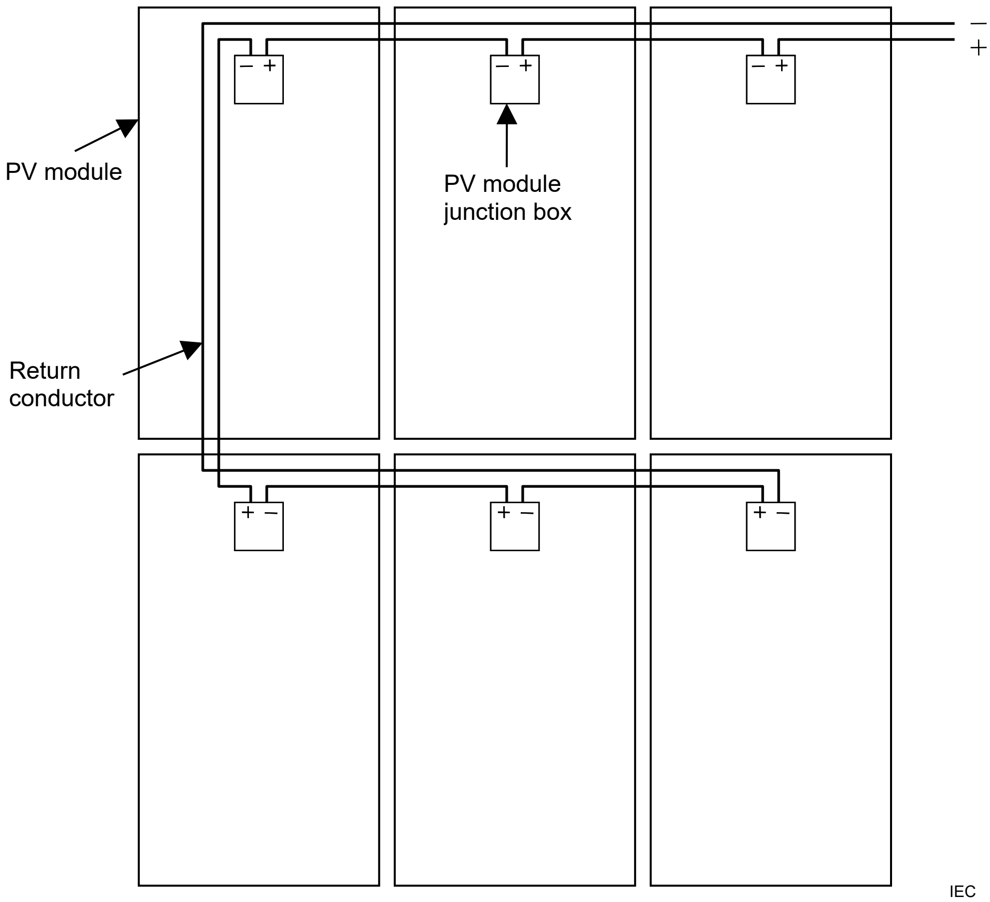


Figure 12 a) – Wiring minimum loop area example 1

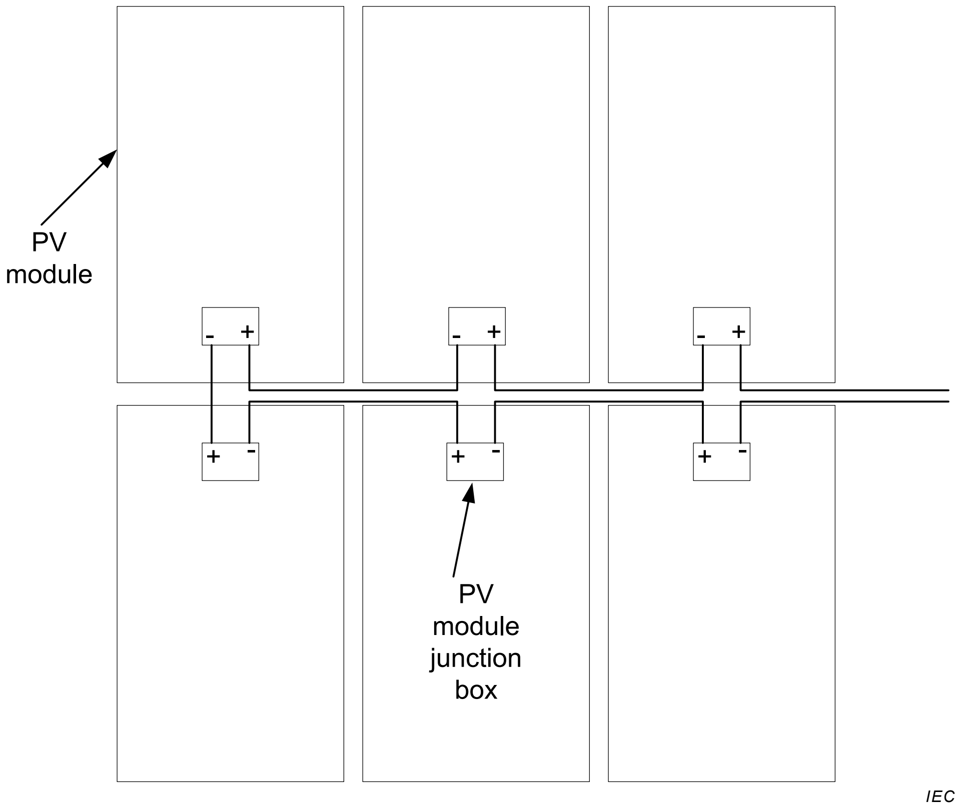


Figure 12 b) – Wiring minimum loop area example 2

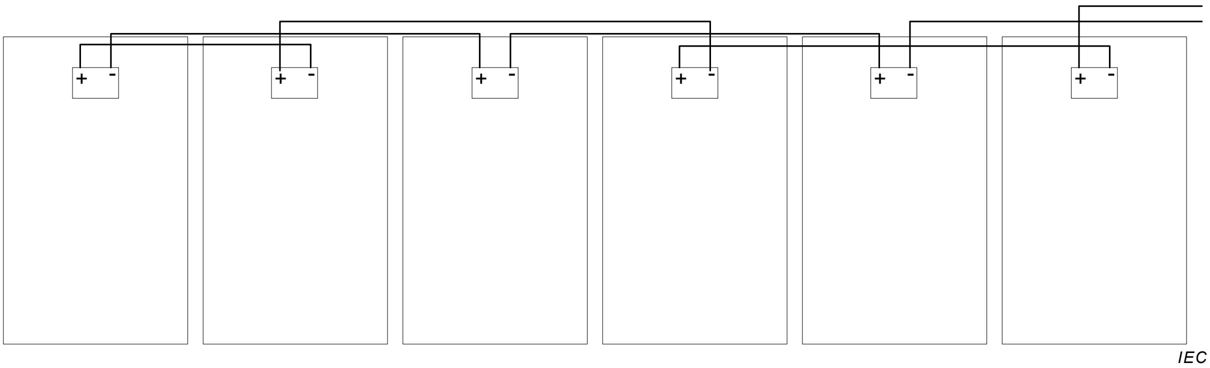


Figure 12 c) – Wiring minimum loop area example 3

Figure 12 – Examples of PV string wiring with minimum loop area

7.4.3.4 String wiring

In the case where wiring of PV strings between modules is not protected by conduit or other enclosures, in addition to the requirements for all array wiring the following requirements shall also apply:

- 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.

7.4.3.5 Wiring installation in combiner boxes

The following provisions apply to the installation of wiring systems combiner boxes.

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

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

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

For PV arrays operating at a voltage greater than DVC-A, where any return conductor is routed through module junction boxes and/or combiner boxes, such return conductor(s) shall be a double-insulated cable, and the cable and its insulation shall maintain double insulation status over its entire length, particularly through junction and combiner boxes (i.e. these provisions also apply to any joints).

7.4.3.6 Wiring identification

Except where the wiring is concealed in a wall, permanent indelible identification shall be provided for PV array cabling installed in or on buildings. PV array (and sub-array) cabling shall be identified by one of the following methods.

- PV cabling using distinctively marked PV cables shall be permanently, legibly and indelibly marked (e.g. cables to IEC 62930).
- Where cabling is not distinctively marked, distinctive coloured labels marked with the words 'SOLAR DC' shall be attached at an interval not exceeding 5 m under normal conditions and not exceeding 10 m on straight runs where a clear view is possible between labels.
- Where cable is enclosed in a conduit or ducting, labelling shall be attached to the exterior of the enclosure at intervals not exceeding 5 m.

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

Colour coding for DC systems required by IEC 60445:2010 is not required for PV systems.

NOTE PV cables are commonly black in colour to assist in UV resistance.

8 Acceptance

Acceptance testing should be performed according to the requirements of IEC 62446-1.

9 Operation/maintenance

Refer to the operation and maintenance requirements in IEC 62446-1.

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 Clause 10 shall

i) comply with IEC,
ii) be indelible,
iii) be legible from at least 0,8 m unless otherwise specified in the relevant clauses (or see examples of signs in Annex A),

iv) be constructed and affixed to remain legible for the life of the equipment it is attached or related to, and

v) be understandable by the operators.

Examples of signs are given in Annex A.

10.3 Identification of a PV installation

For reasons of safety of the various operators (maintenance, personnel, inspectors, public distribution network operators, emergency aid services, etc.), it is essential to indicate the presence of a photovoltaic installation on a building.

A sign, such as shown in Figure A.2, shall be fixed

- at the origin of the electrical installation,
- at the metering position, if remote from the origin,
- at the consumer unit or distribution board to which the supply from the inverter is connected, and
- at all points of isolation of all sources of supply.

10.4 Labelling of PV array and PV string combiner boxes

A sign containing the text ‘SOLAR DC’ shall be attached to PV array and PV string combiner boxes as well as labels indicating “live during daylight” to DC combiner boxes and switches.

10.5 Labelling of disconnection devices

10.5.1 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.

10.5.2 PV array disconnecting device

The PV array DC switch disconnector shall be identified by a sign affixed in a prominent location adjacent to the switch disconnector.

Where multiple disconnection devices are used that are not ganged (refer to 7.4.1.3) signage shall be provided warning of multiple DC sources and the need to turn off all switch disconnectors to safely isolate equipment.

10.6 Documentation

Documentation shall be provided in accordance with IEC 62446-1 specifications for PV arrays.

Annex A
(informative)

Examples of signs

Annex A provides examples (see Figures A.1 and A.2) of appropriate signs as specified in Clause 10.

Figure A.1 – Example of sign required on PV array combiner boxes (10.4)

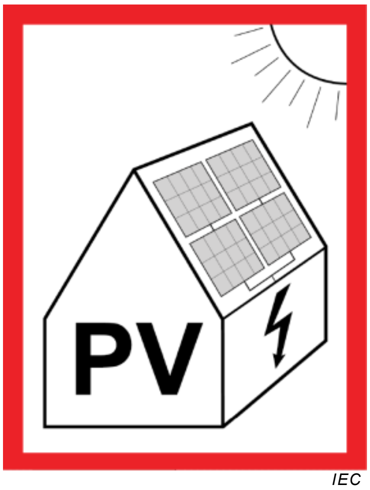


Figure A.2 – Example of switchboard sign for identification of PV on a building

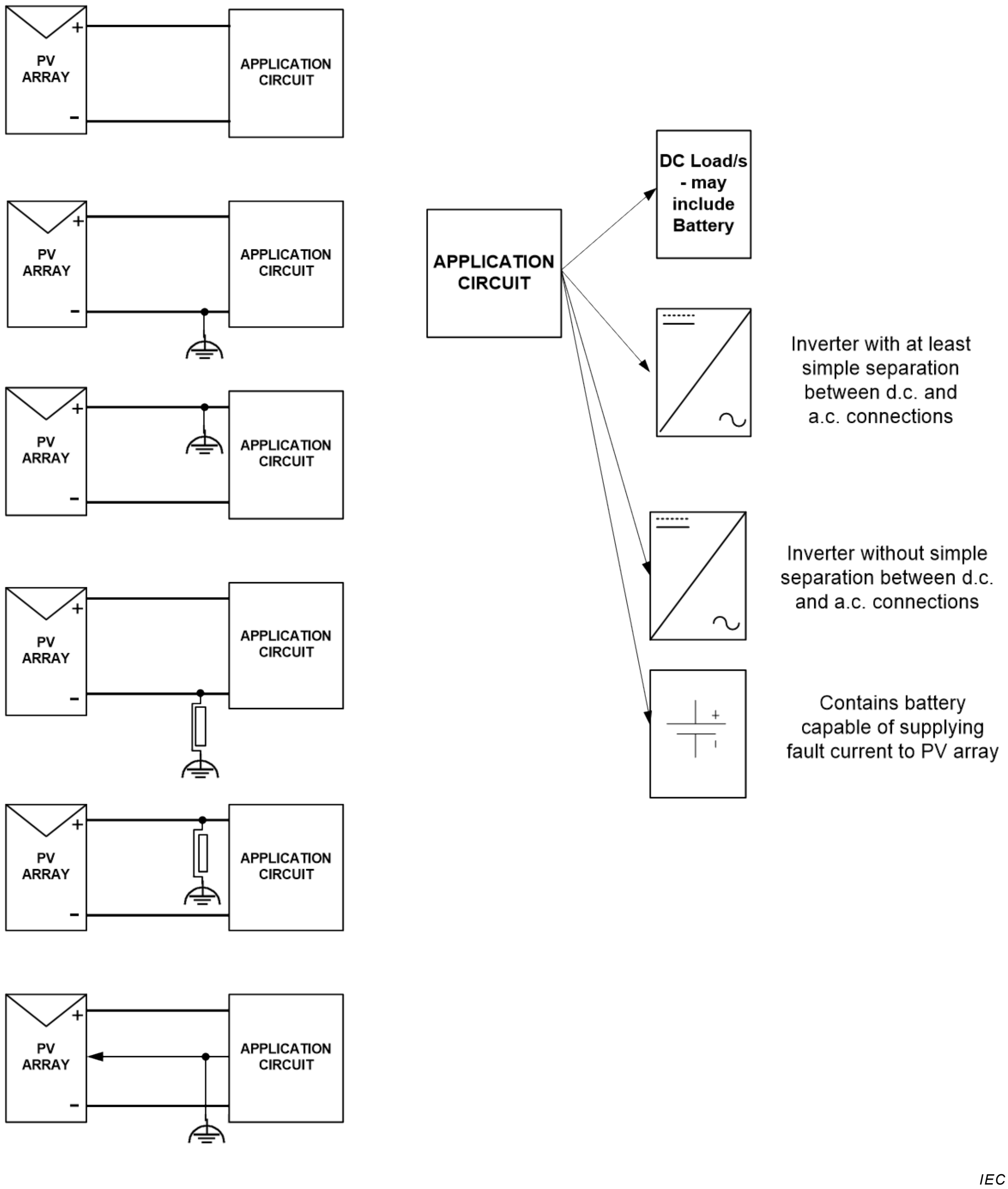
The sign should comply with the local fire services information requirements.

National committees or national regulations should decide on the labels and locations of such markings.

Annex B
(informative)

Examples of system functional earthing configurations in PV arrays

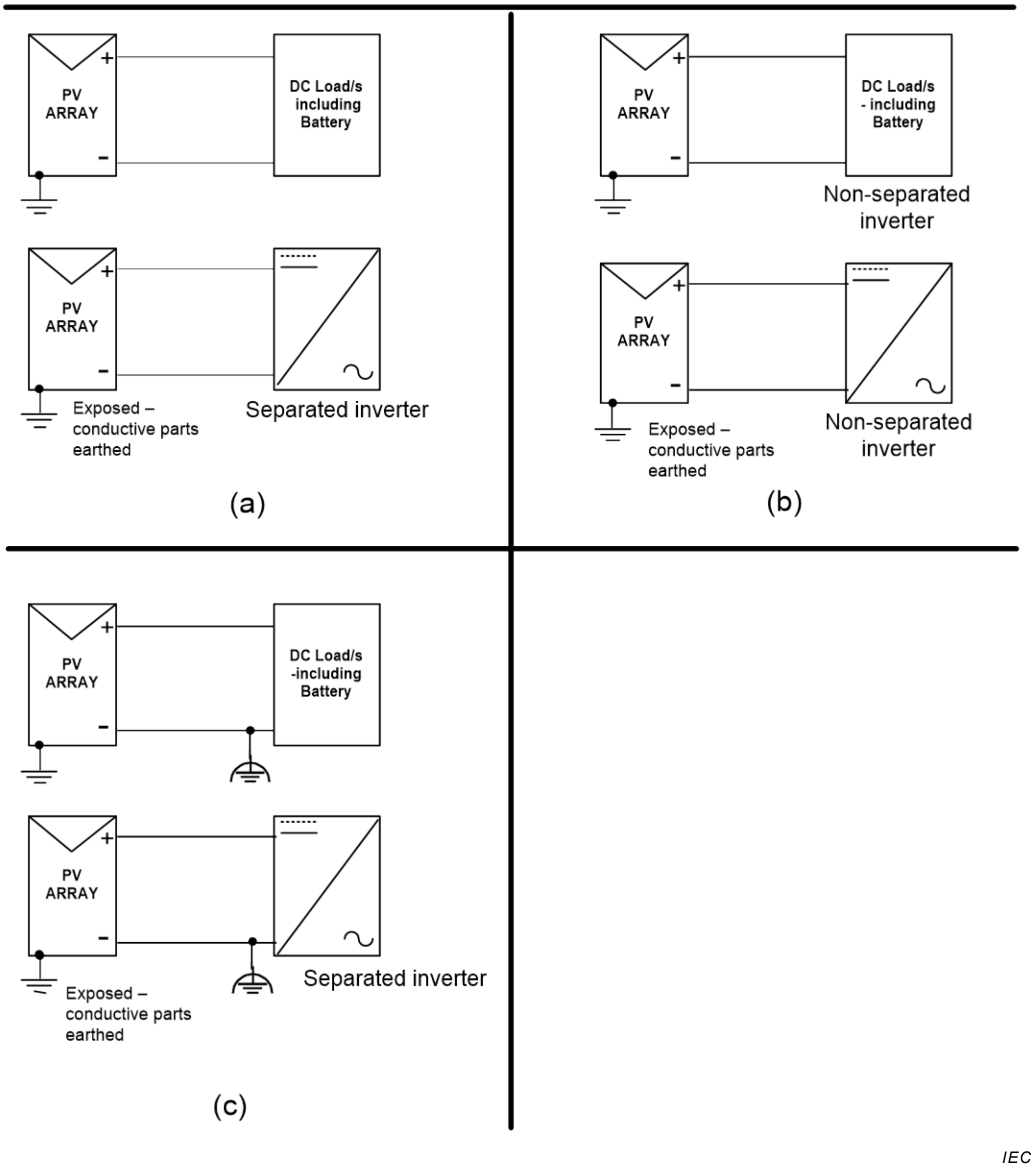
Refer to Figure B.1



NOTE The earth connections shown in this diagram are all functional earth connections.

Figure B.1 – System functional earthing/grounding

Examples of common PV system configurations are shown in Figures B.2 (a) to (c). These diagrams do not describe every possible PV system connection.



NOTE 1 (a) and (b) are the same circuit arrangements showing that for both separated and non-separated inverters the exposed conductive parts are earthed.

NOTE 2 The earth connections shown in this diagram are all functional earth connections. The exposed metal frame connections can also be required for lightning protection.

Figure B.2 – Examples different PV configurations in common use

Annex C
(informative)

Blocking diode

C.1 Introduction

This informative annex describes blocking diodes intended to be used to prevent reverse current in a PV array.

C.2 Use of blocking diodes to prevent overcurrent/fault current in arrays

A blocking diode is an effective means of stopping reverse current in PV arrays. Overcurrent/fault current in arrays is generally caused by current flowing from one section of an array operating normally into a section of an array containing a fault. The fault current is in the reverse direction. Provided correctly rated and functioning blocking diodes are in use in the PV array, reverse currents are prevented and fault currents either eliminated or significantly reduced (see examples in Figures C.1, C.2 and C.3).

In some countries, blocking diodes are allowed to replace overcurrent protection devices. This is an effective method of overcurrent/fault prevention provided the reliability of blocking diodes over time can be assured.

C.3 Examples of blocking diode use in fault situations

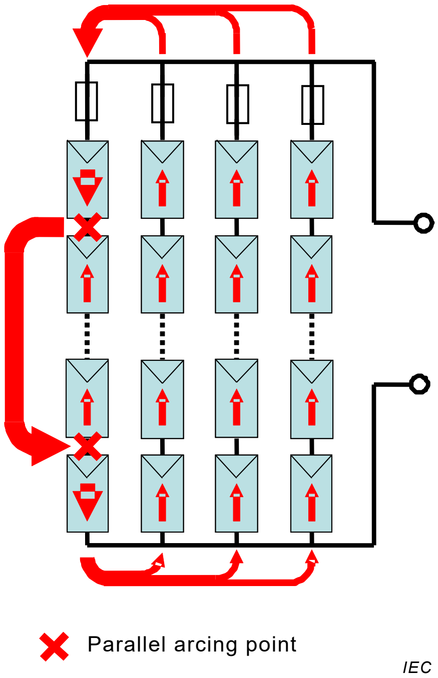
C.3.1 General

Article C.3 shows examples of the use of blocking diodes to prevent or significantly reduce fault current in PV arrays.

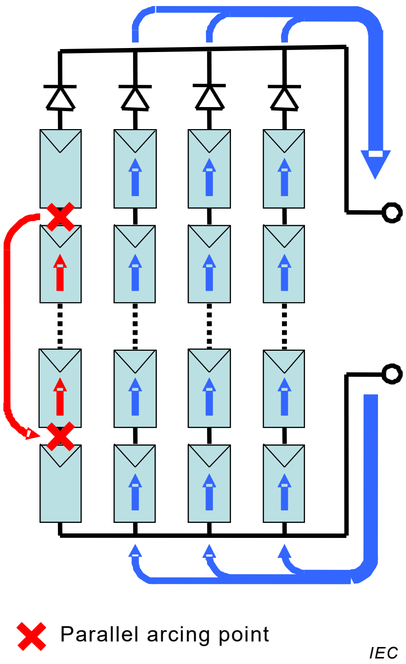
C.3.2 Short circuit in PV string

If a short circuit develops in a string without blocking diodes as shown in Figure C.1a), a fault current will flow around the faulted modules and extra fault current in the reverse direction will flow in some modules with the source of that current being from other strings. The reverse current can be interrupted by an overcurrent protection device provided the current is greater than the interrupting current of the overcurrent device. This may not be the case under low illumination conditions.

The situation of the same fault with an array with blocking diodes in each string is shown in Figure C.1b). In this case the fault current compared to case (a) is significantly reduced and as a result the fire hazard is reduced because the blocking diodes prevent a contribution to the fault current from other parallel strings. This functionality for this type of fault is useful for all systems types whether the PV array is earthed or not and whether the inverter is a separated inverter or not.



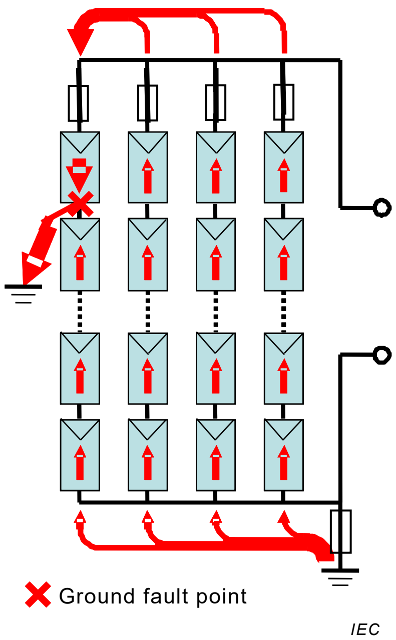
a) without a blocking diode



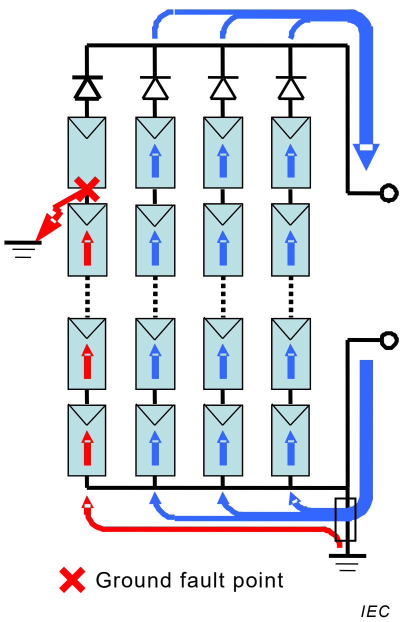
b) with a blocking diode at each string

Figure C.1 – Effect of blocking diode where there is a short circuit in PV string

Figure C.2 shows the fault current paths when an earth fault occurs in a string of a PV array which is installed with a negative side functional earth. The worst case fault occurs when the earth fault is closest to the top of the string (i.e. the side furthest away from earth). In this case the blocking diodes need to be installed in the positive side of the strings.



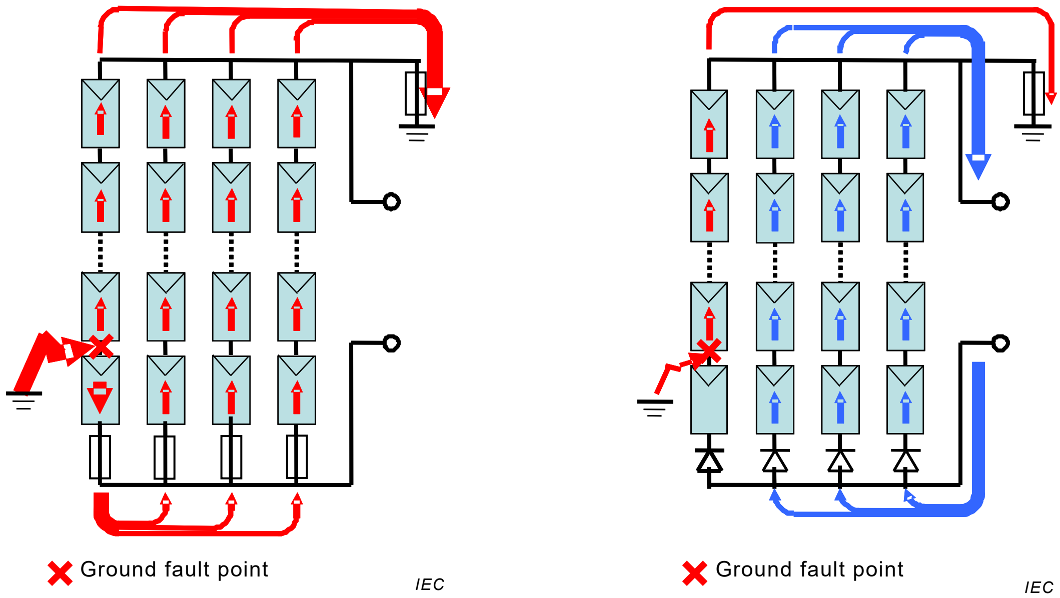
a) without a blocking diode



b) with a blocking diode in each strings

Figure C.2 – Effect of blocking diode where there is an earth fault on a system with earthing on the minus side

Figure C.3 shows the fault current paths when an earth fault occurs in a string of a PV array which is installed with a positive side functional earth. The worst case fault occurs when the earth fault is closest to the bottom of the string (i.e. the side furthest away from earth). In this case, the blocking diodes need to be installed in the negative side of the strings.



a) without a blocking diode b) with a blocking diode in each strings

Figure C.3 – Effect of blocking diode where there is an earth fault on a system with positive side earthing

Figures C.1 to C.3 show the operation of a blocking diode in eliminating the fault current contribution from adjacent strings of the array. In this document a method of detecting and interupting an earth fault is required and can be implemented using other means than blocking diodes. Figure C.2 shows the situation of a directly earthed array with no impedance in the earth connection. It is preferred in this document to install functional earths with limiting resistors in the earth connection. If this method is used, the potential fault current under these conditions is significantly reduced by the effect of the resistance limiting the maximum current.

C.4 Specification of blocking diode

Blocking diodes shall comply with the requirements in 7.3.12.

C.5 Heat dissipation design for blocking diode

Because the voltage drop of a blocking diode in forward current operation might become over 1 V, it is necessary to consider a heat dissipation design of diode for reliability. A heatsink may be required to keep diode junction temperatures within safe limits. A heat dissipation design methodology is shown in the following procedures.

- Calculate maximum current I_{MAX} by PV module current $I_{SC\ MOD}$ in STC.

  $I_{MAX} = 1,4 \times I_{SC\ MOD}$ (Use higher factor dependent on operating conditions)
- Obtain the operating forward voltage of the blocking diode U_{D_OP} at I_{MAX} from the operating characteristic of diode.
- Calculate power dissipation P_{CAL}

  $P_{CAL} = V_{D\_OP} \times I_{MAX}$
- Calculate the thermal resistance RTH as follows so that junction temperature TJ of blocking diode should not exceed the limit value in consideration of ambient temperature T_{AMB}.

$R_{TH} = (T_J - T_{AMB})/P_{CAL}$

- If the thermal resistance required is less than the diode's junction to case plus case to air thermal resistance, then a heatsink will be required.

When there is a possibility of increased short-circuit current of the PV module e.g. due to the reflection of snow or other conditions, the multiplier for the calculation of I_{MAX} should be larger than 1,4.

Annex D
(informative)

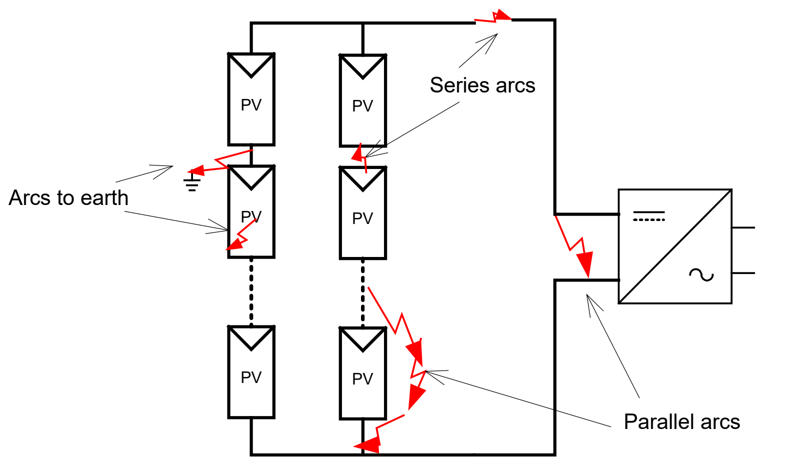
Arc fault detection and interruption in PV arrays

Unlike traditional electrical products, PV modules and wiring do not have an overall enclosure to contain arcs and fires resulting from component or system faults. Many PV systems operate at DC voltages which are very capable of sustaining DC arcs.

There are three main categories of arcs in PV systems (refer to Figure D.1):

- series arc which may result from a faulty connection or a series break in wiring;
- a parallel arc which may result as a partial short circuit between adjacent wiring which is at different potentials;
- arcs to earth which result from failure of insulation.

If an arc develops due to a fault in a PV array this can result in significant damage to the array and may also result in damage to adjacent wiring and building structures. The most serious arc is likely to be a parallel arc because of the energy that is available to feed this type of arc, especially when the arc is between the main PV array conductors. This document requires double insulation on cables used in PV array wiring and because of this double insulation requirement parallel arcs are very unlikely unless caused as a result of significant insulation damage due to fire damage or severe mechanical damage to cables. The most likely type of arc to occur in a PV system is a series arc. This is because PV systems typically contain a very large number of series connections. Series arcs are generally able to be stopped quickly by removing the electrical load from the PV array. In the case where a PCE is the only load for the section of the PV array experiencing a series arc, this may be accomplished by shutting down the PCE (e.g. grid connected inverter systems). Parallel arcs are much more difficult to extinguish but are also much less likely to occur.



IEC

Figure D.1 – Examples of types of arcs in PV arrays

If a series arc is not extinguished quickly it may propagate to involve other conductors and produce parallel arcs. It is therefore desirable to have a method of detecting and interrupting arcs in PV systems quickly. A standard has been developed by Underwriters Laboratories – UL1699B: *Photovoltaic (PV) DC Arc-Fault Circuit Protection* and manufacturers are in the process of developing equipment to meet this document. The purpose of the arc fault circuit protection equipment is to detect and discriminate accurately arcs in PV arrays and to take action to interrupt the arc.

NOTE IEC 63027, regarding DC arc detection and interruption in photovoltaic power system, is under development.

Annex E
(normative)

DVC limits

The voltage limits for each DVC level are given in Table E.1.

Table E.1 – Summary of the limits of the decisive voltage classes

Decisive voltage classification (DVC)	Limits of working voltage V		
	AC voltage (r.m.s.) U_{ACL}	AC voltage (peak) U_{ACPL}	DC voltage (mean) U_{DCL}
A[1]	≤ 25 (16)	≤ 35,4 (22,6)	≤ 60 (35)
B	> 25 and ≤ 50 (> 16 and ≤ 33)	> 35,4 and ≤ 71 (> 22,6 and ≤ 46,7)	> 60 and ≤ 120 (> 35 and ≤ 70)
C	> 50 (> 33)	> 71 (> 46,7)	> 120 (> 70)

The values in parentheses are to be used for wiring and components installed in wet locations.

1 DVC-A circuits are allowed under fault conditions to have voltages up to the DVC-B limits, for maximum 0,2 s.

NOTE For more information on DVC, refer to IEC 62109-1.

Bibliography

IEC 60050-151:2001, *International Electrotechnical Vocabulary – Part 151: Electrical and magnetic devices*

IEC 60050-195:1998, *International Electrotechnical Vocabulary – Part 195: Earthing and protection against electric shock*

IEC 60050-442:1998, *International Electrotechnical Vocabulary – Part 442: Electrical accessories*

IEC 60050-461:2008, *International Electro-technical Vocabulary – Part 461: Electric cables*

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

IEC 60050-826:2004, *International Electrotechnical Vocabulary – Part 826: Electrical installations*

IEC 60269-1, *Low-voltage fuses – Part 1: General requirements*

IEC 60364-5-53, *Electrical installations of buildings – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control*

IEC 60904-2:2015, *Photovoltaic devices – Part 2: Requirements for photovoltaic reference devices*

IEC 60904-3:2016, *Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*

IEC 61008-1:2010, *Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs) – Part 1: General rules*

IEC 61643-32[2], *Low-voltage surge protective devices – Surge protective devices for specific use including DC – Part 32: Selection and application principles – SPDs connected to photovoltaic installations*

IEC 61829, *Photovoltaic (PV) array – On-site measurement of current-voltage characteristics*

IEC TS 61836:2007, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62246-1:2015, *Reed switches – Part 1: Generic specification*

IEC 62305 (all parts), *Protection against lightning*

IEC 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC TS 62738[3], *Design guidelines and recommendations for ground-mounted photovoltaic power plants*

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2 Under preparation. Stage at the time of publication: IEC CCDV 61643-32:2016.

3 Under preparation. Stage at the time of publication: IEC 2CD 62738:2016.

IEC 63027[4], *DC arc detection and interruption in photovoltaic power systems*

EN 50618, *Electric cables for photovotaic systems*

UL1699B, *Photovoltaic (PV) DC Arc-Fault Circuit Protection*

UL 4703, *Photovoltaic wire*

4 Under preparation. Stage at the time of publication: IEC ANW 63027:2016.

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