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BSI Standards Publication

Photovoltaic (PV) arrays — Design requirements

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Photovoltaic (PV) arrays – Design requirements

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ELECTROTECHNICAL
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PHOTOVOLTAIC (PV) ARRAYS – DESIGN REQUIREMENTS

FOREWORD

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- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

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

IEC 62548, which is a technical specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The present Technical Specification is intended to be withdrawn as soon as an International Standard in the IEC 60364 series, under joint development by IEC technical committees 64 and 82, will be published.

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

Enquiry draft	Report on voting
82/746/DTS	82/765A/RVC

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

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

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

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- withdrawn,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

A bilingual version of this publication may be issued at a later date.

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PHOTOVOLTAIC (PV) ARRAYS – DESIGN REQUIREMENTS

1 Scope and object

This Technical Specification sets out design requirements for photovoltaic (PV) arrays including d.c. 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.

The object of this Technical Specification 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 a.c. 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 Technical Specification 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 IEC 60364 series (see Clause 4).

PV arrays of less than 100 W and less than 35 V d.c. open circuit voltage at STC are not covered by this Technical Specification.

Attention is drawn to Annex D describing arc fault detection and interruption in PV arrays. It is expected that requirements for the use of this type of equipment will be included in this Technical Specification when reliable commercial equipment for detection of arcs in PV systems is available.

NOTE 1 This Technical Specification covers the protection requirements of PV arrays which develop as a result of the use of batteries in PV systems.

NOTE 2 Additional requirements may be needed for more specialized installations e.g. concentrating systems, tracking systems or building integrated PV.

2 Normative references

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

IEC 60228:2004, *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*

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

IEC 60332-1-2:2004, *Tests on electric and optical fibre cables under fire conditions – Part 1-2: Test for vertical flame propagation for a single insulated wire or cable – Procedure for 1 kW pre-mixed flame*

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

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

IEC 60364-5-54:2011, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

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

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

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

IEC 60947-1, *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 61215:2005, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval*

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

IEC 61730-1:2004, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC 61730-2:2004, *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 62305-4, *Protection against lightning – Part 4: Electrical and electronic systems within structures*

IEC 62446, *Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection*

EN 50521, *Connectors for photovoltaic systems – Safety requirements and tests*

3 Terms and definitions, symbols and abbreviations

3.1 Terms, definitions and symbols

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

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 fibres, with a protective covering and possibly filling, insulating and protective material

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

3.1.5
cable core
the conductor with its insulation but not including any mechanical protective covering

3.1.6
Class A: General access, hazardous voltage, hazardous power applications
modules rated for use in this application class may be used in systems operating at greater than 50 V d.c. or 240 W, where general contact access is anticipated. Modules qualified for safety through IEC 61730-1 and IEC 61730-2 within this application class are considered to meet the requirements for safety class II.

[SOURCE: IEC 61730-1:2004]

3.1.7
Class B: Restricted access, hazardous voltage, hazardous power applications

modules rated for use in this application class are restricted to systems protected from public access by fences, location, etc. Modules evaluated within this application class provide protection by basic insulation, are considered to meet the requirements for safety class 0.

[SOURCE: IEC 61730-1:2004]

3.1.8
Class C: Limited voltage, limited power applications

modules rated for use in this application class are restricted to systems operating at less than 50 V d.c. and 240 W, where general contact access is anticipated. Modules qualified for safety through IEC 61730-1 and IEC 61730-2 within this application class are considered to meet the requirements for safety class III.

Note 1 to entry: Safety classes are defined in IEC 61140.

[SOURCE: IEC 61730-1:2004]

3.1.9
competent person
a 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

3.1.10
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. Refer also to switch-disconnector.

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
a conductive part liable to introduce a potential, generally earth potential, and not forming part of the electrical installation

3.1.13
functionally earthed PV array
a PV array that has one conductor intentionally connected to earth for purposes other than safety, by means not complying with the requirements for protective bonding

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 an inverter 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
switching action using 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 60050-441:1984, 441-16-16, modified]

3.1.15
irradiance
G (Unit: W/m^2)

electromagnetic radiated solar power per unit of area

[SOURCE: IEC 61836:2007, modified]

3.1.16
$I_{MOD\_MAX\_OCPR}$
the 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.

3.1.17
I_n
the nominal rating of an overcurrent protection device

3.1.18
$I_{SC\ ARRAY}$
the short circuit current of the PV array at Standard Test Conditions (STC), and is equal to:

$$I_{SC\ ARRAY} = I_{SC\ MOD} \times S_A$$

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

3.1.19
$I_{SC\ MOD}$
the short circuit current of a PV module or PV string at Standard Test Conditions (STC), as specified by the manufacturer in the product specification plate

Note 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
$I_{SC\ S\text{-}ARRAY}$
the short circuit current of a PV sub-array at Standard Test Conditions (STC), and equal to:

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

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

3.1.21
isolated PCE
a PCE with at least simple separation between the main power output circuits and PV circuits and having leakage currents less than the limits required to be classified as an isolated PCE.

Note 1 to entry: Inverter requirements are as set out in IEC 62109-2. The separation/isolation may be either integral to the PCE or provided externally e.g. an inverter with an external isolation transformer. If the isolation is provided externally there must be no other equipment connected to the same circuit as the PCE.

Note 2 to entry: In a PCE with more than two external circuits, there may be isolation between some pairs of circuits and no isolation between others. For example, an inverter with PV, battery, and mains circuits may provide isolation between the mains circuit and the PV circuit, but no isolation between the PV and battery circuits. In this Technical Specification, the term isolated PCE is used as defined above in general – referring to isolation between the main power output circuit and the PV circuits.

Note 3 to entry: For a PCE that does not have internal isolation between the main power output circuit and PV circuits, but is required to be used with a dedicated isolation means, with no other equipment connected to the PCE side of that isolation means, the combination may be treated as an isolated PCE.

Note 4 to entry: In the case of an inverter required to be used with a dedicated external isolation transformer, the requirement to have no other equipment connected between the inverter and the inverter-side winding allows designs having more than one inverter connected to the same transformer, as long as each inverter is connected to a separate transformer winding. If more than one inverter is intended to be connected to a single winding, the inverters must be treated as non-isolated inverters.

3.1.22
junction box
closed or protected connecting device allowing making of one or several junctions

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

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.

3.1.24
low voltage
voltage exceeding DVC-A, but not exceeding 1 000 V a.c. or 1 500 V d.c.

3.1.25
main earthing terminal
the 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-isolated PCE
a PCE without the minimum separation between the main power output and PV circuits or with leakage currents greater than the requirements for an isolated PCE

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 midpoint 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
a system that converts the electrical power delivered by the PV array into the appropriate frequency and/or voltage values to be delivered to the load, or stored in a battery or injected into the electricity grid (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 Technical Specification a PV array is all components up to the d.c. input terminals of the inverter or other power conversion equipment or d.c. loads.

A PV array does not include its foundation, tracking apparatus, thermal control, and other such components.

Note 2 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 Technical Specification the boundary of a PV array is the output side of the PV array disconnecting device.

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

3.1.35
PV cell
the 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".

[SOURCE: IEC 61836:2007, 3.1.43, modified]

3.1.36
PV array combiner box
a 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
$V_{OC\ ARRAY}$ corrected for the worst-case conditions of ambient temperature. Refer to 7.2.

3.1.38
PV module
the smallest complete environmentally protected assembly of interconnected cells

[SOURCE: IEC 60904-3:2008]

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

[SOURCE: IEC 61836:2007]

3.1.40
PV string cable
a cable interconnecting the modules in a PV string, or connecting the string to a, combiner box, PCE or other d.c. loads (see Figure 2 to Figure 4)

3.1.41
PV string combiner box
a junction box where PV strings are connected which may also contain overcurrent protection devices and/or switch-disconnectors (see Figure 4)

Note 1 to entry: PV string combiner boxes are only relevant for PV arrays that are divided into sub-arrays.

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

3.1.43
PV sub-array cable
the 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
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]

3.1.45
residual current monitor
RCM
device or association of devices which monitors the residual current in an electrical installation, and which indicates a fault when the residual current exceeds the operating value of the device or when a defined step change is detected

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

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

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

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

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

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

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

3.1.50
standard test conditions
STC
a standard set of reference conditions used for the testing and rating of photovoltaic cells and modules. The standard test conditions are:

a) PV cell temperature of 25 °C;

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

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

[SOURCE: IEC 61215:2005]

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. In addition, it is able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions. Moreover, it complies with the requirements for a disconnector.

Note 1 to entry: Switch-disconnectors provide a load break isolation function. In this Technical Specification these switches will be identified on warning signs and labels as “Isolators” for simplicity in interpretation by the public.

3.1.53
$\boldsymbol{V}_{\textbf{OC ARRAY}}$
the open circuit voltage at standard test conditions of a PV array, and is equal to:

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

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

Note 1 to entry: This Technical Specification assumes that all strings within a PV array are connected in parallel; hence the open circuit voltage of PV sub-arrays and PV strings is equal to $V_{\text{OC ARRAY}}$.

3.1.54
$\boldsymbol{V}_{\textbf{OC MOD}}$
the 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

The design, erection and verification of the PV system shall comply with the requirements of IEC 60364, including IEC 60364-7-712. IEC 60364-7-712 contains requirements which supplement, modify or replace certain of the requirements of the general parts of IEC 60364.

NOTE In IEC 60364-7-712, the absence of a reference to the exclusion of a part, a chapter or a clause of a general part of IEC 60364 means that the corresponding clauses of the general part are applicable.

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.

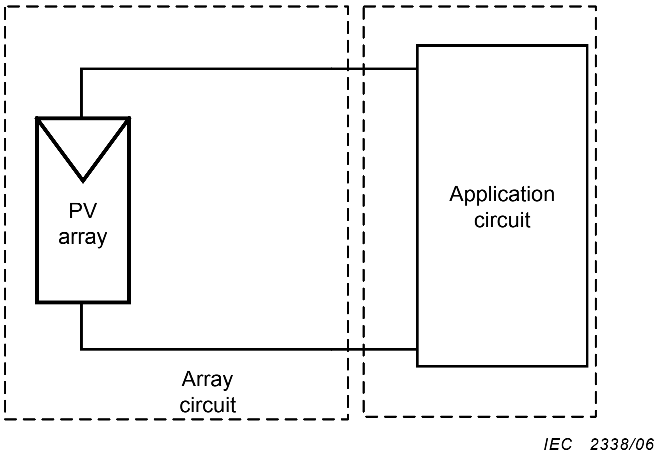


Figure 1 – General functional configuration of a PV powered system

Three kinds of application circuit are considered:

– PV array is connected to d.c. loads;
– PV array is connected to a.c. system via conversion equipment which includes at least simple separation;
– PV array is connected to a.c. 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).

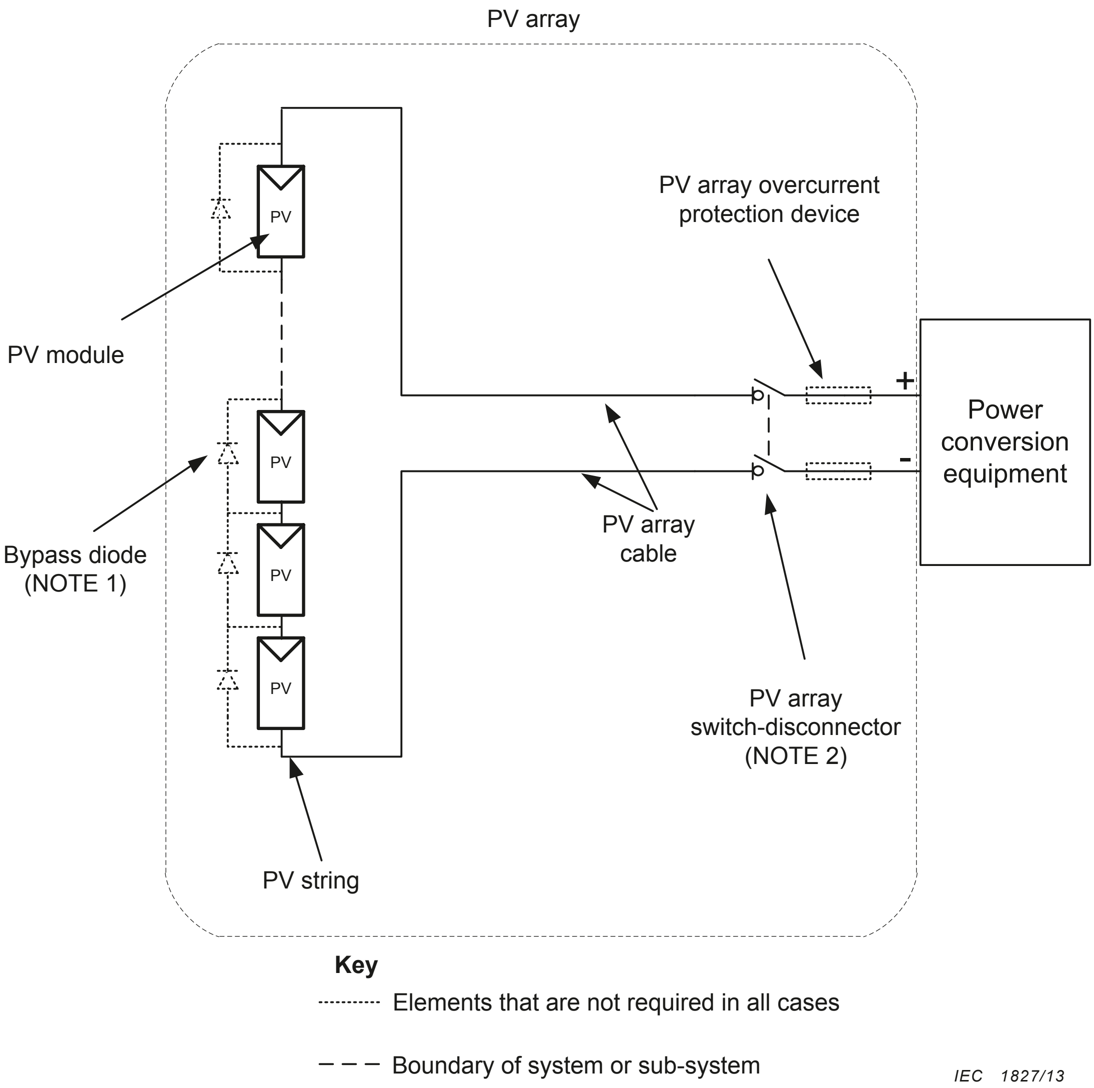
The requirements of manufacturers of PV modules and manufacturers of power conversion equipment to which the PV array is connected shall be taken into account in determining the most appropriate system earthing arrangement.

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 from mains earth provided either internally in the PCE or externally via a separate transformer.

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

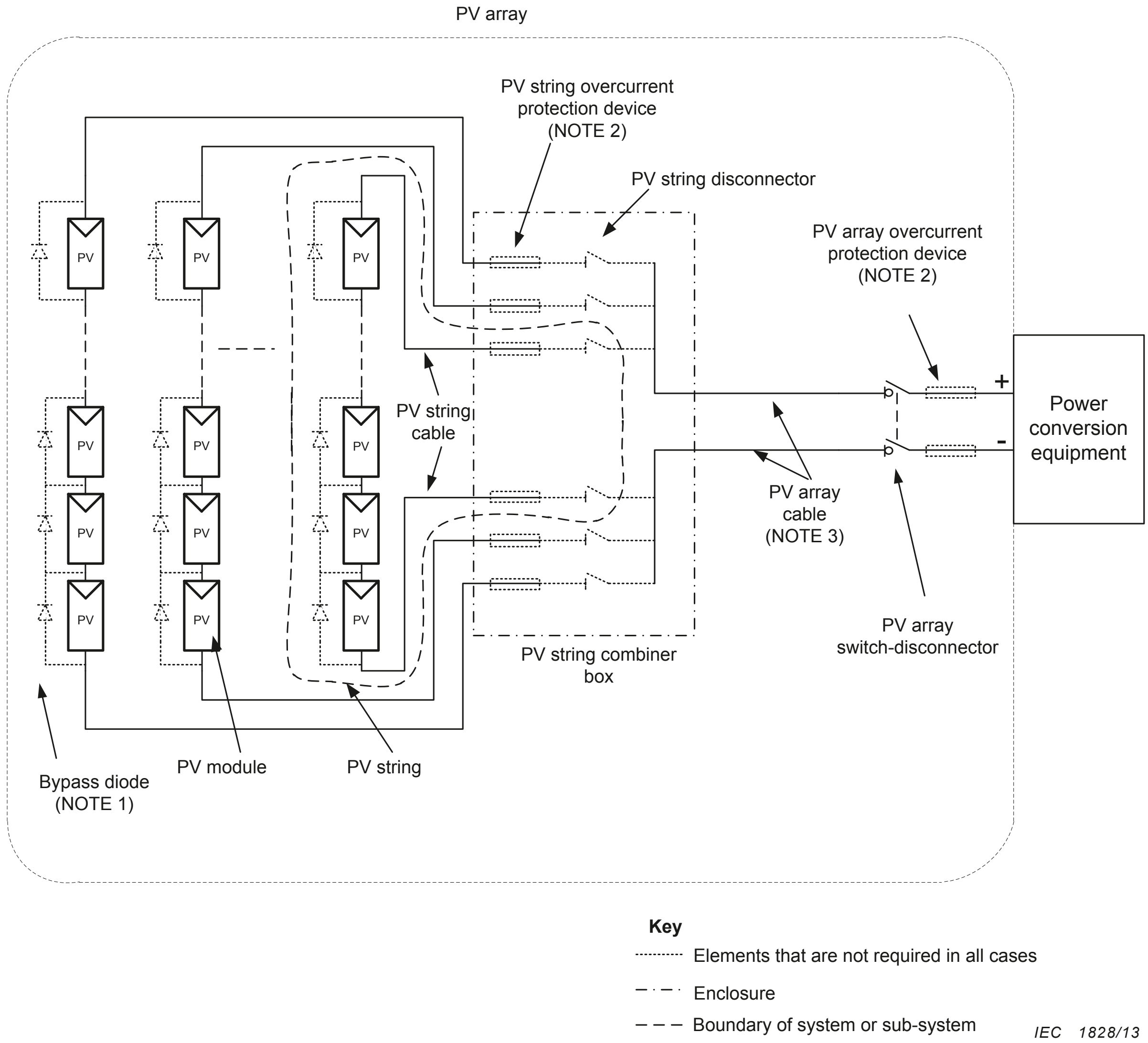
The diagrams in Figure 2 to Figure 4 show the basic electrical configurations of single string, multiple parallel string and multi-sub-array PV respectively.



NOTE 1 If required, bypass diodes are generally incorporated as standard elements of the PV modules by manufacturers.

NOTE 2 Refer to 7.3.5 and 7.4.1 for PV array isolator/switch-disconnector requirements.

Figure 2 – PV array diagram – single string case

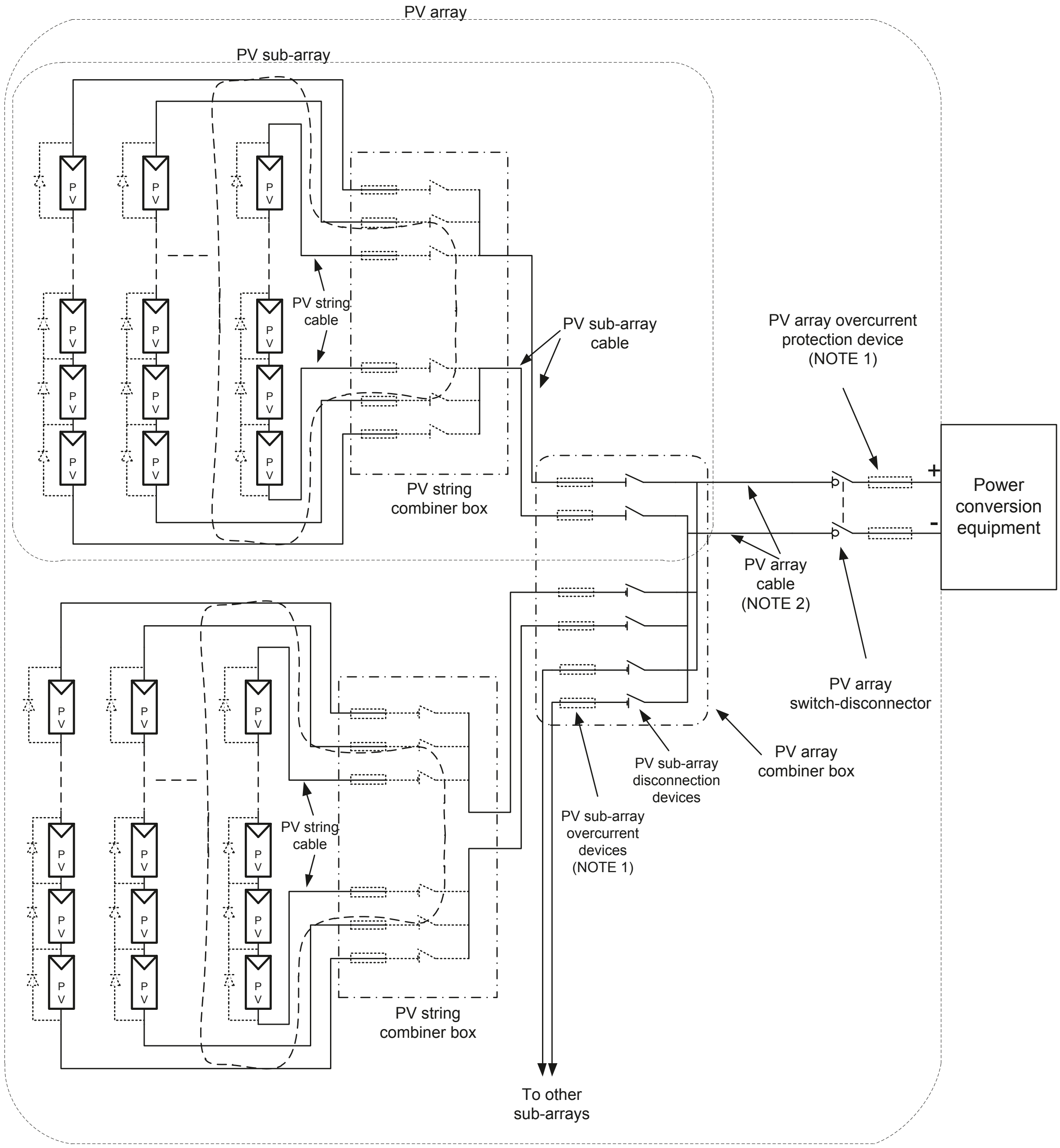


NOTE 1 If required, bypass diodes are generally incorporated as standard elements of the PV modules by manufacturers.

NOTE 2 Overcurrent protection devices where required see 6.3.

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

Figure 3 – PV array diagram – multiple parallel string case



Key

Elements that are not required in all cases

Enclosure

Boundary of system or sub-system

IEC 1829/13

NOTE 1 Overcurrent protection devices where required see 6.3.

NOTE 2 In some systems the PV array cable may not exist and all the PV strings or PV sub-arrays may be terminated in a combiner box immediately adjacent to the power conversion equipment.

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

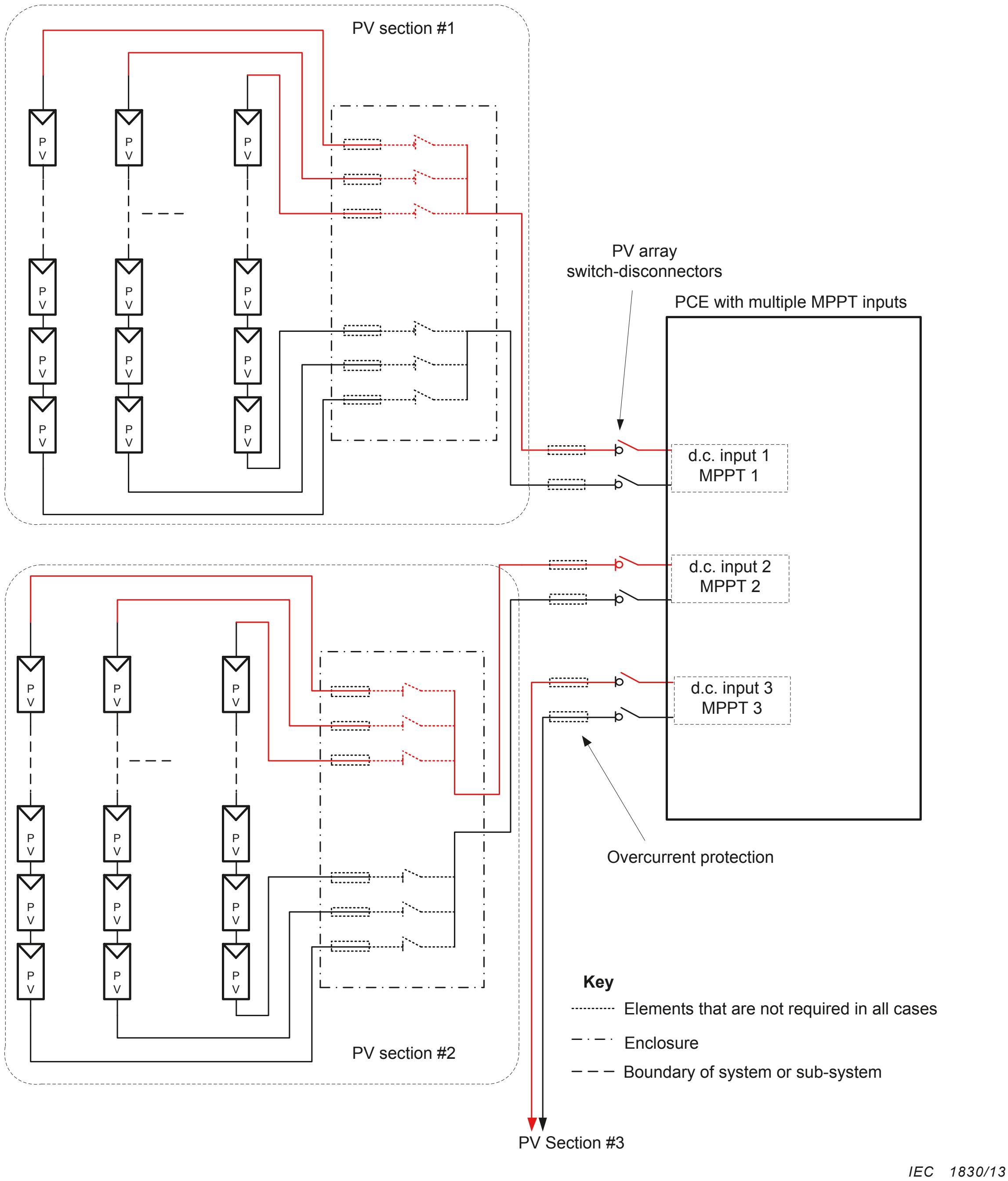


Figure 5 – PV array using a PCE with multiple MPPT d.c. inputs

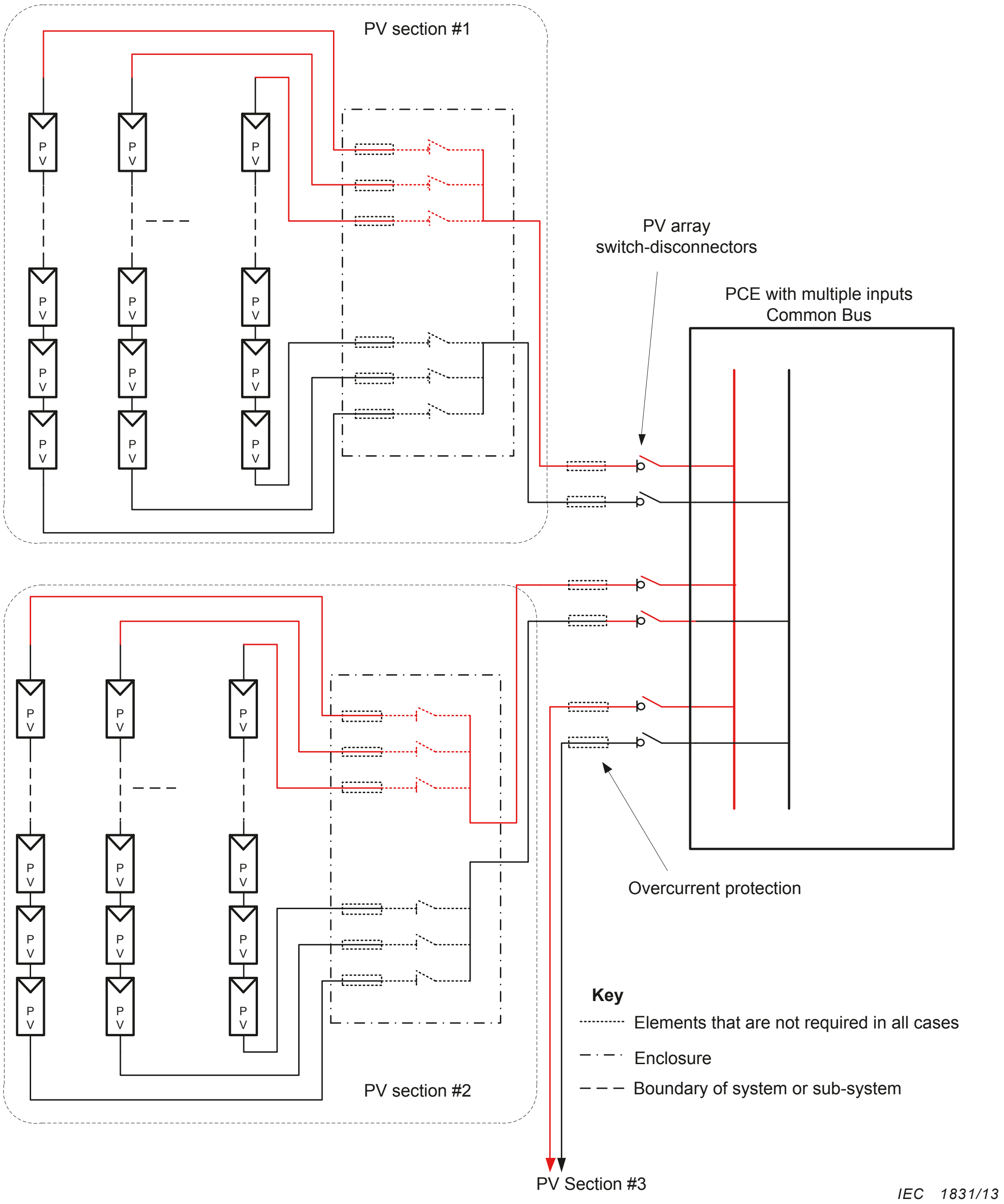


Figure 6 – PV array using a PCE with multiple d.c. inputs internally connected to a common d.c. bus

5.1.4 Use of PCE with multiple d.c. inputs

5.1.4.1 General

PV arrays are often connected to PCEs with multiple d.c. inputs. Refer to Figures 5 and 6. If multiple d.c. 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 a PCE's input circuits 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.

Each PV section connected to an input (refer to Figure 5) may be treated for the purposes of this Technical Specification as a separate PV array. Each PV array shall have a switch-disconnector to provide isolation of the inverter. The provisions of multiple switch-disconnectors in 7.4.1.3 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 d.c. bus, each PV section connected to one of those inputs (refer to Figure 6) shall be treated for the purposes of this Technical Specification as a sub-array and all the PV sections combined shall be classified as the complete PV array. Each PV sub-array shall have a switch-disconnector to provide isolation of the inverter. 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 Series-parallel configuration

All PV strings within a PV array connected in parallel shall be of the same technology and have the same number of series connected PV modules (see Figure 2 to Figure 4). In addition, all PV modules in parallel within the PV array shall have similar rated electrical characteristics including short circuit current, open circuit voltage, maximum power current, maximum power voltage and rated power (all at STC).

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

5.1.6 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 and as close as practical to the battery. This protection can be used to provide overcurrent protection for PV array cables provided the PV array 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.

5.1.7 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 5.1.6).

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 as follows.

a) The possibility of line-to-line faults, earth faults and inadvertent wire disconnections in the PV array need to be minimized more than for conventional electrical installations.

   NOTE 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.

b) Earth fault detection and disable could be required as part of the system protection functions, depending on the array size and location, to eliminate the risk of fire.

Refer to 6.3 for overcurrent protection requirements and to 6.4 for earth fault protection requirements.

5.1.8 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 operating at the maximum power point 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 some 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.

5.1.9 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;
– 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 any shadowing be reduced as much as is practical. Note that even a small shadow on the array can significantly limit its performance.

Issues of performance degradation due to temperature rise and the need for good ventilation are described in 5.2.2. Care should be taken to keep modules as cool as practicable.

In the design process the sizing of cables within the array and in cable connections from the array to the application circuit affect the voltage drop in those cables under load. This can be particularly significant in systems with low output voltage and high output current. It is recommended that under maximum load conditions the voltage drop from the most remote module in the array to the terminals of the application circuit should not exceed 3 % of the PV array voltage at its maximum power point.

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 should comply with applicable building codes regulations and standards and module manufacturer's mounting requirements.

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.

5.2.3 Mechanical loads on PV structures

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 and snow loads on PV arrays.

5.2.4 Wind

PV modules, module mounting frames, and the methods used for attaching frames to buildings or to the ground shall be rated for 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.

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

5.2.6 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. e.g. 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; e.g. 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

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

6.2 Protection against electric shock

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

PV module exposed metal earthing and bonding shall be according to 7.4.2 of this Technical Specification.

6.3 Protection against overcurrent

6.3.1 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.

6.3.2 Requirement for overcurrent protection

Overcurrent protection shall be provided in accordance with 6.3.3 to 6.3.6 and with PV module manufacturer's requirements.

Overcurrent protection devices required for the protection of PV modules and/or wiring shall be selected to reliably and consistently operate within 2 h when an overcurrent of 135 % of the nominal device current rating is applied.

6.3.3 Overcurrent protection in PV systems connected to batteries

Overcurrent protection shall be provided in all PV systems connected to batteries. The main array 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 main array cable to protect this cable from fault currents originating from the battery system. See 6.3.5 for overcurrent protection sizing. All overcurrent protection used shall be capable of interrupting the maximum prospective fault current from the battery.

6.3.4 Requirement for string overcurrent protection

String overcurrent protection shall be used if:

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

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

Where fuses are applied, these fuses need to meet the requirements as described in IEC 60269-6 (Type “gPV”)”.

6.3.5 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.

6.3.6 Overcurrent protection sizing

6.3.6.1 PV string overcurrent protection

Where string overcurrent protection is required, either (see Figure 7):

a) each PV string shall be protected with an overcurrent protection device, where the nominal overcurrent protection 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 under the protection of one overcurrent device provided:

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

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

Where

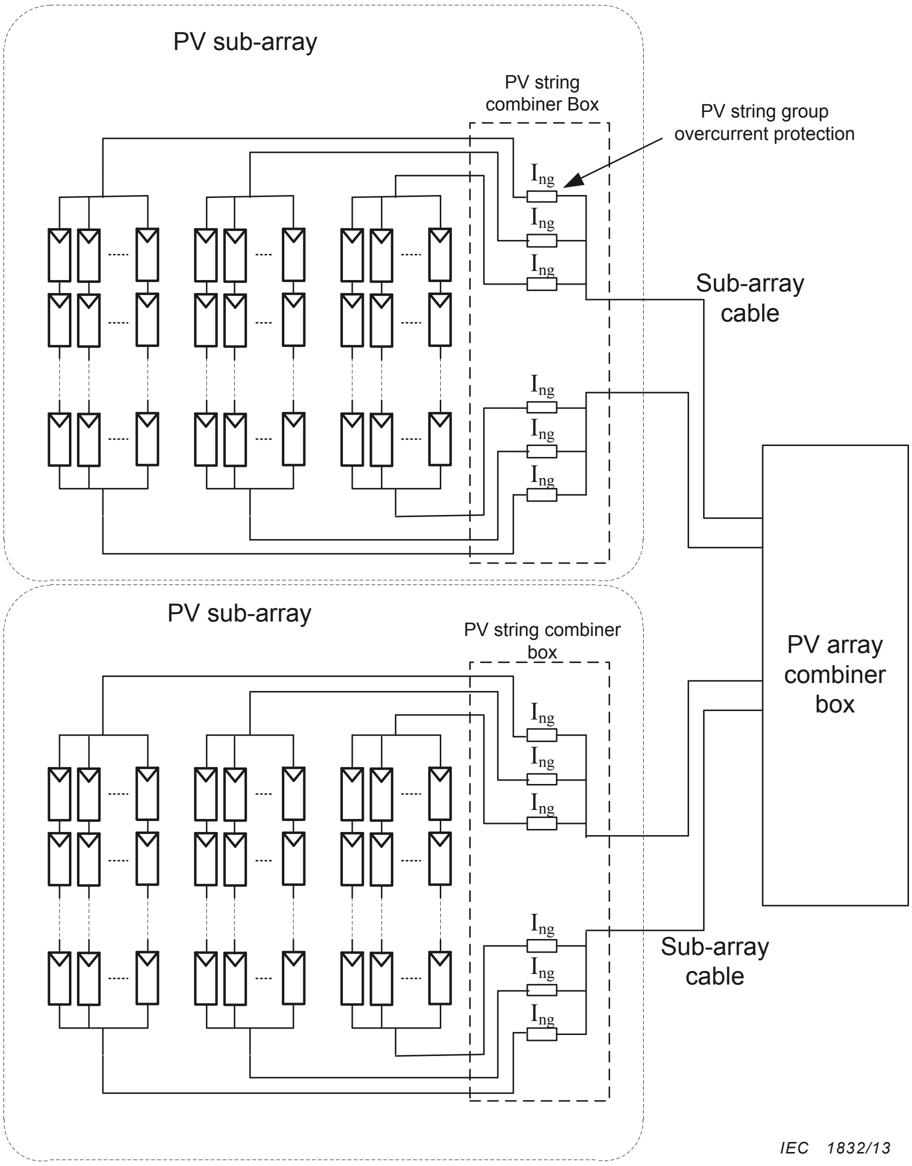
S_G is the number of strings in a group under the protection of the one overcurrent device;

I_n is the the nominal overcurrent protection rating of the group overcurrent protection device.

Where circuit breakers are used as the overcurrent protection device these may also fulfil the role of a disconnecting means as required by 7.4.1.

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 1 Strings can generally only be grouped under one overcurrent protection device if $I_{MOD\_MAX\_OCPR}$ is greater than 4 × I_{SC_MOD} .



NOTE 2 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 3 This is only an example and other switching, disconnecting and/or overcurrent protection devices may be required in individual cases, but for simplicity are not shown in this figure.

Figure 7 – Example of a PV array diagram where strings are grouped under one overcurrent protection device per group

6.3.6.2 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:

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

6.3.6.3 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:

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

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

The PV array 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 cable. In such cases, no further PV array cable overcurrent protection between the PV array and the charge controller is required.

6.3.6.4 PV arrays with direct functional earth connections

PV arrays that have one conductor directly connected to a functional earth (i.e. not via a resistance) shall be provided with a functional earth fault interrupter which operates to interrupt earth fault current if an earth fault occurs in the PV array. This may be achieved by interruption of the functional earth of the array. The nominal overcurrent rating of the functional earth fault interrupter is shown in Table 1.

The functional earth fault interrupter shall not interrupt the connection of exposed metal parts to earth.

When the functional earth fault interrupter operates an earth fault alarm shall be initiated according to 6.4.2.

Table 1 – Nominal overcurrent rating of functional earth fault interrupter

Total PV array power rating kWp	**Rated current** A
0 – 25	≤ 1
>25 – 50	≤ 2
>50 – 100	≤ 3
>100 – 250	≤ 4
>250	≤ 5

6.3.7 Overcurrent protection location

Overcurrent protection devices where required by 6.3 for PV array, PV sub-array, and PV strings shall be placed:

- For string overcurrent protection devices, they shall be where the string cables join the sub-array or array cables in the string combiner box (refer to Figures 3 and 4).
- For sub-array overcurrent protection devices, they shall be where the sub-array cables join the array cables in the array combiner box (refer to Figure 4).
- For array overcurrent protection devices, they shall be where the array cables join the application circuit or the PCE (refer to Figures 2 to 4).

NOTE 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.

In systems that include a functional earth, overcurrent protective devices required for string and sub-array cables shall be placed in all unearthed conductors (i.e. all circuits not directly connected to the functional earth).

In systems not connected to a functional earth the overcurrent protective devices required for string and sub-array cables shall be placed in one of the active conductors.

This provision of a single overcurrent device is allowed for floating systems 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.

6.4 Requirements for PV arrays operating at DVC-B and DVC-C voltages

6.4.1 Detection and alarm requirements

6.4.1.1 General

Requirements for detection of earth faults, actions required and alarms depend on the type of system earthing and whether the PCE provides electrical separation of the PV array from the the output circuit (e.g. the grid). Table 2 shows the requirements for measurements of PV array earth insulation resistance and PV array RCM as well as the actions and indications required if a fault is detected.

Table 2 – Requirements for different system types based on PCE isolation and PV array functional earthing

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="3">System type</th></tr>
<tr><th>Non-isolated PCE +
No functional earth on PV array</th><th>Isolated PCE +
No functional earth on PV array</th><th>Isolated PCE +
Functionally earthed PV array</th></tr>
<tr><td rowspan="3">PV array earth insulation resistance</td><td>Measurement</td><td colspan="3">According to 6.4.1.2</td></tr>
<tr><td>Action on fault</td><td>Shutdown PCE
And
Disconnect all poles of the output circuit or all poles of the PV array from the PCE</td><td colspan="2">Connection to the output circuit <u>is</u> allowed
(PCE is allowed to operate)</td></tr>
<tr><td>Indication on fault</td><td colspan="3">Indicate a fault in accordance with 6.4.2</td></tr>
<tr><td rowspan="3">PV array residual current monitoring</td><td>Measurement</td><td>According to 6.4.1.3</td><td rowspan="3">Not Required</td><td>According to 6.4.1.3</td></tr>
<tr><td>Action on fault</td><td>Shutdown PCE
And
Disconnect all poles of the output circuit or all poles of the PV array from the PCE</td><td>Functional earth connection shall be disconnected (see 6.4.1.3) connection to the output circuit <u>is</u> allowed.
(PCE is allowed to operate)</td></tr>
<tr><td>Indication on fault</td><td>Indicate a fault in accordance with 6.4.2</td><td>Indicate a fault in accordance with 6.4.2</td></tr>
<tr><td colspan="5">NOTE 1 Instead of shutting down the PCE and disconnecting the output circuit it is allowed to isolate the faulted parts of the PV array.

NOTE 2 Functional earthing has to be carried out according to 7.4.2.1d.

NOTE 3 Systems using non-isolated PCEs where the output circuit is referenced to earth are not allowed to use functional earthing on the PV side of the PCE see Error! Reference source not found..</td></tr>
</table>

6.4.1.2 Array insulation resistance detection

The requirements in this subclause regarding detection and response to abnormal array insulation resistance to earth are intended to reduce hazards due to degradation of the insulation system.

In a non-isolated PCE connected to an earthed output circuit (e.g. mains), an array earth fault will result in potentially hazardous current flow as soon as the PCE connects to the earthed circuit. E.g. an inverter connected to the mains, due to the earthed neutral on the mains, so the inverter shall not connect to the mains. In an isolated PCE, if a earth fault in a floating or functionally earthed PV array goes undetected, a subsequent earth fault can cause hazardous current to flow. The detection and indication of the original earth fault is required.

A means shall be provided to measure the insulation resistance from the PV array to earth before starting operation and at least once every 24 h.

NOTE This functionality for insulation resistance measurement may be provided within the PCE.

Minimum threshold values for detection shall be according to Table 3.

Table 3 – Minimum insulation resistance thresholds for detection of failure of insulation to earth

System size 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 where possible be set at values greater than the minimum values specified in these calculations. A higher value will increase the safety of the system by detecting potential faults earlier.

The measurement circuit shall be capable of detecting insulation resistance to earth of the PV array below the limit above. It is permitted to remove the PV array functional earth connection during the measurement.

The action on fault required is dependent on the type of PCE in use, as follows:

– for isolated PCEs, shall indicate a fault in accordance with 6.4.2 (operation is allowed); the fault indication shall be maintained until the array insulation resistance has recovered to a value higher than the limit above;
– for non-isolated PCEs, shall indicate a fault in accordance with 6.4.2, and shall not connect to any earthed output circuit (e.g. the mains); the device may continue to make the measurement, may stop indicating a fault and may allow connection to the output circuit if the array insulation resistance has recovered to a value higher than the limit above.

6.4.1.3 Protection by residual current monitoring system

Where required by Table 2, residual current monitoring shall be provided that functions whenever the PCE is connected to an earth referenced output circuit with the automatic disconnection means closed. The residual current monitoring means shall measure the total (both a.c. and d.c. components) RMS residual current.

If the inverter AC output connects to a circuit that is isolated from earth, and the PV array is not functionally earthed, residual current monitoring is not required.

Detection shall be provided to monitor for excessive continuous residual current, and excessive sudden changes in residual current according to the following limits:

a) Continuous residual current: The RCM system shall cause disconnection within 0,3 s and indicate a fault in accordance with 6.4.2 if the continuous residual current exceeds:
   – maximum 300 mA for PCEs with continuous output power rating ≤ 30 kVA;
   – maximum 10 mA per kVA of rated continuous output power for PCEs with continuous output power rating > 30 kVA.

   NOTE 1 It is possible to implement distributed residual current monitoring 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 may be affected.

   The RCM system may attempt to re-connect if the leakage threshold is below that specified in 6.4.1.3 and the array insulation resistance meets the limit in 6.4.1.2.

b) Sudden changes in residual current: The PCE shall disconnect from any earth referenced output circuits (e.g. the mains) within the time specified in Table 4 and indicate a fault in accordance with 6.4.2 if a sudden increase in the RMS residual current is detected exceeding the value in the table.

Table 4 – Response time limits for sudden changes in residual current

Residual current sudden change mA	**Max time for disconnection from earth referenced circuit** s
30	0,3
60	0,15
150	0,04

NOTE 2 These values of residual current and time were originally taken from the residual current operated circuit-breaker standard IEC 61008-1 but are no longer related to protection against electric shock in the meaning of this Technical Specification.

The RCM system may attempt to re-connect if the leakage threshold is below that specified in 6.4.1.3 and the array insulation resistance meets the limit in 6.4.1.2.

6.4.2 Earth fault alarm

As required by 6.4.1 an earth fault alarm system shall be installed. When activated the alarm system is to continue its operation until the system is shutdown and/or the earth fault is corrected.

The alarm shall be of a form that ensures that the system operator or owner of the system becomes aware of the fault. For example, the alarm 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 Email, 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 externally.

6.5 Protection against effects of lightning and overvoltage

6.5.1 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.

6.5.2 Protection against overvoltage

All d.c. 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 d.c. cables over about 50 m) should be either:

- installed in earthed metallic conduit or trunking,
- be buried in the ground (using appropriate mechanical protection),
- be cables incorporating mechanical protection which will provide a screen, 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.

To protect the d.c. 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 d.c. cabling and at the array. To protect specific equipment, surge protective devices may be fitted as close as is practical to the device.

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

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.

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.

7.2 PV array maximum voltage

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

Correction of the voltage for the lowest expected operating temperature shall be calculated according to manufacturer's instructions. Where 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 5 using the lowest expected operating temperature as a reference.

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 manufacturer's instructions.

Table 5 – 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 d.c. 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 6.

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.

7.3.2 PV modules

7.3.2.1 Operational conditions and external influences

Crystalline silicon PV modules shall comply with IEC 61215. Thin film PV modules shall comply with IEC 61646. Systems with voltages above 50 V d.c. 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 and be classified by class according to IEC 61730-1 and IEC 61730-2 and shall only be used in applications applicable to their class rating.

For protection against electric shock:

- Class A modules according to IEC 61730-1 shall be used where system voltages exceed DVC-A.
- Class C modules according to IEC 61730-1 may be used in applications where voltages are in the DVC-A range.

Class B Modules shall not be used.

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.

Any enclosure IP rating shall suit the environmental conditions. This IP rating shall apply for the relevant mounting position and orientation.

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.

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 and
b) not be polarity sensitive;
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;
d) be rated for overcurrent according to 6.3.5.

7.3.5 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 6.

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

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

- not be polarity sensitive (fault currents in a PV array may flow in the opposite direction of normal operating currents);
- be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present;
- when overcurrent protection is incorporated, it shall be rated according to 6.3.

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

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

7.3.6 Cables

7.3.6.1 Size

7.3.6.1.1 General

Cable sizes for PV string cables, PV sub-array cables and PV array cable shall be determined with regard to overcurrent protection ratings where in use, the minimum current rating (refer to Table 6), 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 shall 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.

7.3.6.1.2 Current carrying capacity (CCC)

The minimum cable sizes for PV array wiring, based on CCC, shall be based upon a current rating calculated from Table 6, and the current carrying capacity of cables as specified in IEC 60287 series. Cable derating factors taking into consideration cable location and installation method, according to IEC 60364, shall be applied.

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 6 – 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 <u>not</u> provided**	Current rating (I_n) of the nearest downstream overcurrent protection device + 1,25 × $I_{SC\ MOD}$ × (S_{PO} – 1) Where: S_{PO} is the total number of parallel connected strings protected by the nearest overcurrent protection device. NOTE 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. When no overcurrent protection is used in the complete array then S_{PO} is the total number of parallel connected strings in the complete PV array; and the rated current (I_n) of the nearest overcurrent protection device is replaced by zero.
	PV string overcurrent protection provided	Current rating (I_n) of the PV string overcurrent protection device (refer to 6.3)
PV sub-array	**PV sub-array overcurrent protection <u>not</u> provided**	The greater of the following: 1) Current rating (I_n) of the PV array overcurrent protection device + 1,25 × Sum of short circuit current of all other sub-arrays 2) 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 mathematical formula in item 1) above.
	PV sub-array overcurrent protection provided	Current rating (I_n) of the PV sub-array overcurrent protection device (refer to 6.3)
PV array	**PV array overcurrent protection <u>not</u> provided**	1,25 × $I_{SC\ ARRAY}$
	PV array overcurrent protection provided	Current rating (I_n) of the PV array overcurrent protection device (refer to 6.3)

[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 device 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 6.

NOTE Power converter backfeed current rating is a required rating under IEC 62109.

7.3.6.2 Type

Cables used within the PV array shall:

– be suitable for d.c. application,

– have a voltage rating equal to or greater than the PV array maximum voltage determined in 7.2,

– 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,
– if exposed to salt environments be tinned copper, multistranded conductors to reduce degradation of the cable over time,
– 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 Figure 8,
– cables shall be flame retardant as defined in IEC 60332-1-2.

Standards for PV cables are under development at international (IEC) level. It is recommended that in the interim cables should comply with relevant national documents, or be selected and installed according to the manufacturer's recommendations.

String cables

– it is recommended that string cables be flexible (class 5 of IEC 60228) to allow for thermal/wind movement of arrays/modules.

An IEC standard for PV string cables is under development. It is recommended that in the interim cables should comply with UL 4703, or VDE-AR-E 2283-4.

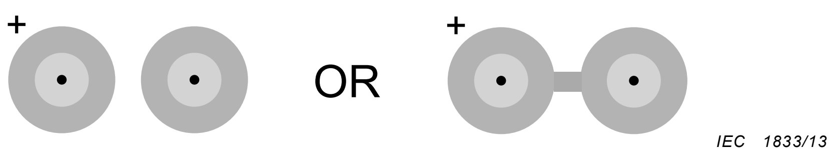


Figure 8a – Single or multi-conductor cable where each conductor is both insulated and sheathed

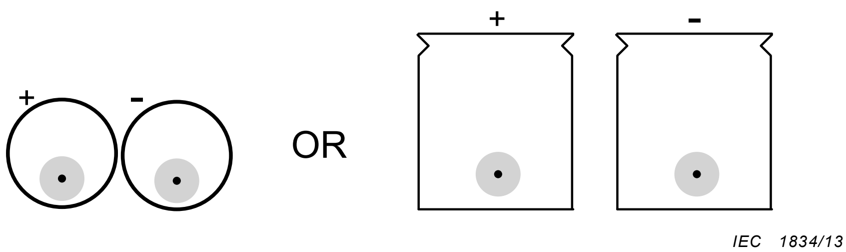


Figure 8b – Single conductor cable – in suitable insulated conduit/trunking

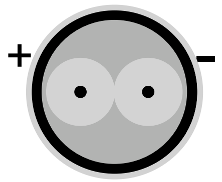


Figure 8c – Steel wire armoured SWA (usually suitable only for main d.c. cable)

Figure 8 – Reinforced protection of wiring

7.3.6.3 Erection method

Cables shall be supported so they do not suffer fatigue due to wind/snow affects. They shall also be protected from sharp edges. 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.

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

7.3.7 Segregation of a.c. and d.c. circuits

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

The different types of circuits shall be clearly identified (e.g. by labels or different coloured cables). Refer to 7.4.3.6.

7.3.8 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:

– EN 50521;
– be rated for d.c. 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 3);
– be capable of accepting the cable used for the circuit to which they are fitted;
– require a deliberate force to disconnect;
– if accessible by untrained people then shall be of the locking type where two independent actions 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 a.c. power shall not be used in PV arrays.

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

7.3.9 Wiring in combiner boxes

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

7.3.10 Fuses

7.3.10.1 General

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

- be rated for d.c. use;
- have a voltage rating equal or greater than the PV array maximum voltage determined in 7.2;
- 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 current protective type suitable for PV complying with IEC 60269-6.

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

7.3.10.2 Fuse holders

Fuse holders shall comply with the following requirements:

- 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 the corresponding fuse;
- provide a degree of protection suitable for the location and not less than IP 2X.

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

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 × $I_{SC\ MOD}$ for PV strings;
  - 1,4 × $I_{SC\ S\text{-}ARRAY}$ for PV sub-arrays;
  - 1,4 × $I_{SC\ ARRAY}$ 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.

7.4 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 7 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.

NOTE Local installation codes may allow certain types of systems to be installed without a DC disconnector between modules and the PCE, for example below certain voltage and current thresholds, where DC 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.

7.4.1.2 Switch-disconnector for power conversion equipment (PCE)

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.

7.4.1.3 Installation

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

Other disconnection and isolation devices having the characteristics described in 7.3.4 may be used as a disconnection means.

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

The location of overcurrent protection devices and/or load breaking disconnecting means should be at the end of the cable that is electrically most remote from the PV modules.

NOTE 1 The reason for this location is that fault currents in parts of an array originate from other parts of the array e.g. if an array was composed of 4 sub-arrays (a, b, c, and d) then if sub-array cable (a) was to experience overcurrent it could not originate from sub-array (a) as this is inherently current limited, the overcurrent would have to come from the sum total of sub-arrays b, c and d. The most effective place to interrupt that fault current is from the point where the sub-arrays are brought together i.e. at the end of the sub-array cable most electrically remote from the PV modules. Similar principles apply to string cables.

Table 7 – 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 cable	Switch-disconnector	Required
DVC-B and C	String cable	Disconnection device [a]	Recommended [a]
	Sub-array cable	Disconnection device [a]	Required
		Switch-disconnector [b]	Recommended
	Array cable	Switch-disconnector	Required

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

[b] Where a switch-disconnector is used this may also provide the isolation function i.e.only one switch is required.

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

NOTE 2 An additional d.c. switch-disconnector may be specified for systems with long d.c. 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 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.

Where multiple disconnection devices are required to isolate power conversion equipment they 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 7, disconnection devices shall be installed in all live conductors where a live conductor is one that is not directly connected to Earth.

Where load breaking (switch-disconnector) is a requirement this capability shall be on all poles of the device and all poles shall be ganged.

In the case of PV arrays with a direct earth connection for functional reasons, requirements for earth fault interrupters are specified in 6.3.6.4.

NOTE 3 In some countries interrupting a functional earth on the PV array (not the frames) may be allowed and may be used to increase safety for fire and emergency workers. In these instances the main PV array switch-disconnector may include an extra pole which disconnects the functional earth of the PV array.

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 9 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.

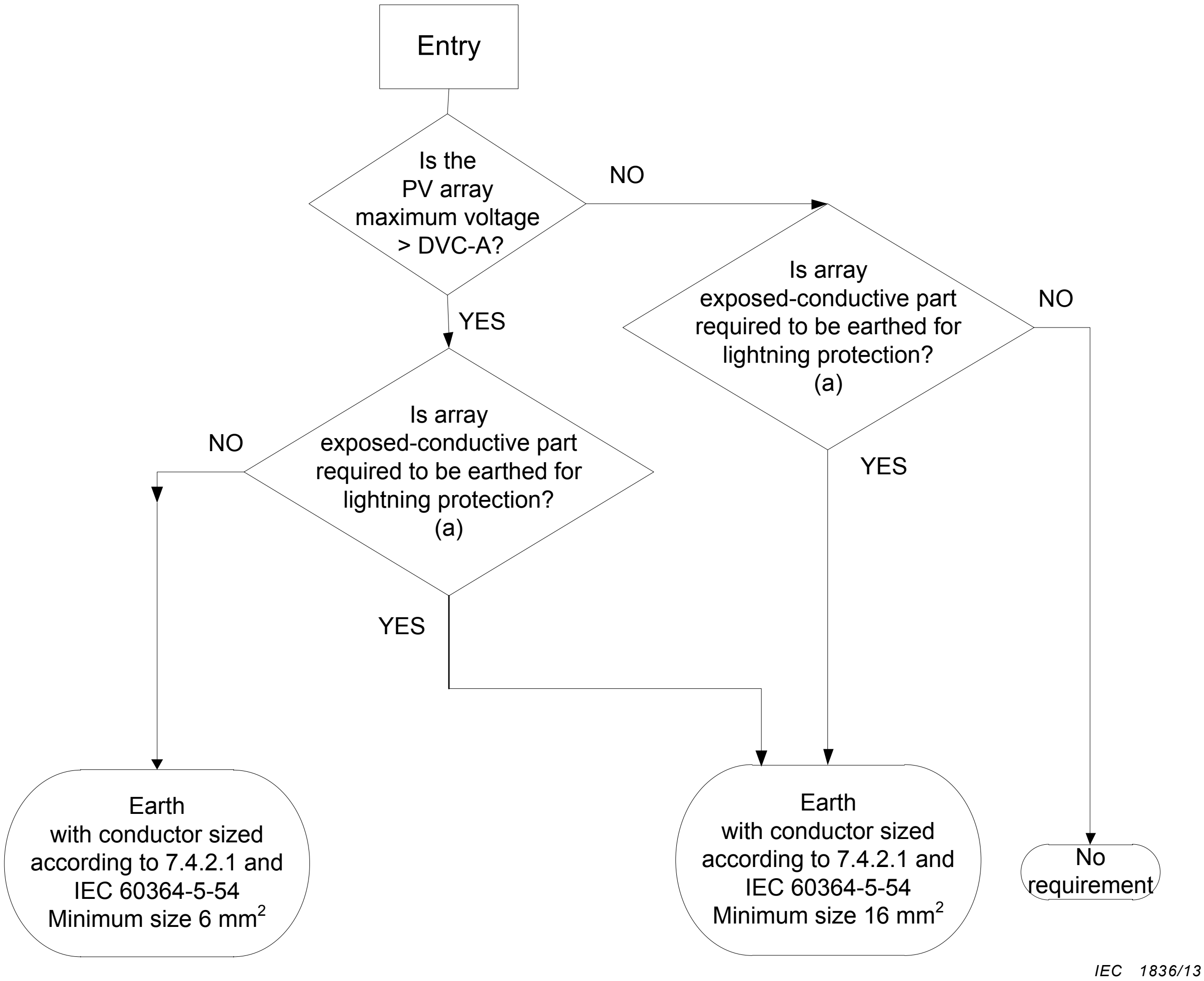
Refer to Annex B for further information.

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 9.

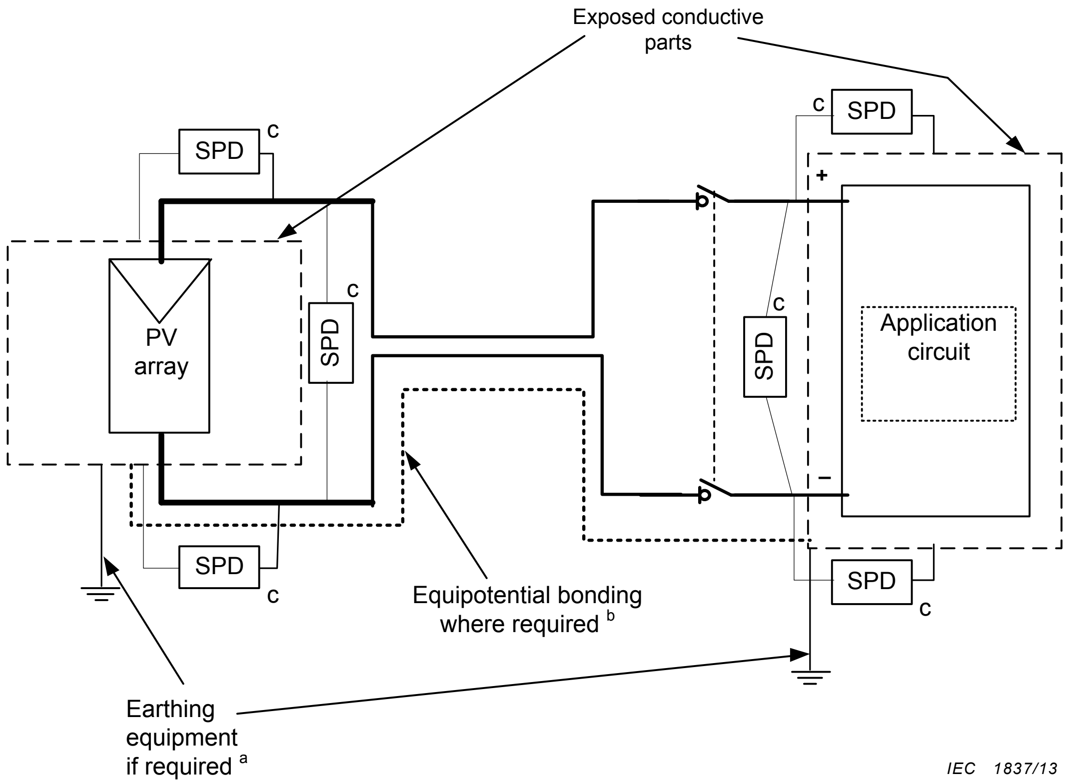
Figure 10 shows an example of earthing requirements of exposed conductive parts on a PV array.



[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.

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

Figure 9 – 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) should be placed where required according to manufacturer's recommendations.

Figure 10 – 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 9.

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, this connection point 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, this connection point 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 functional earth fault interrupter nominal rating for a system with direct earth connection without a resistor. Refer to 6.3.6.4 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, earthing conductors shall comply with the provisions for earthing conductors specified in national wiring standards, or in absence of such standards, with the provisions set out in IEC 60364-5-54.

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 standard 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 the IEC 60364 series.

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, e.g. by laying cables in parallel as shown in Figure 11.

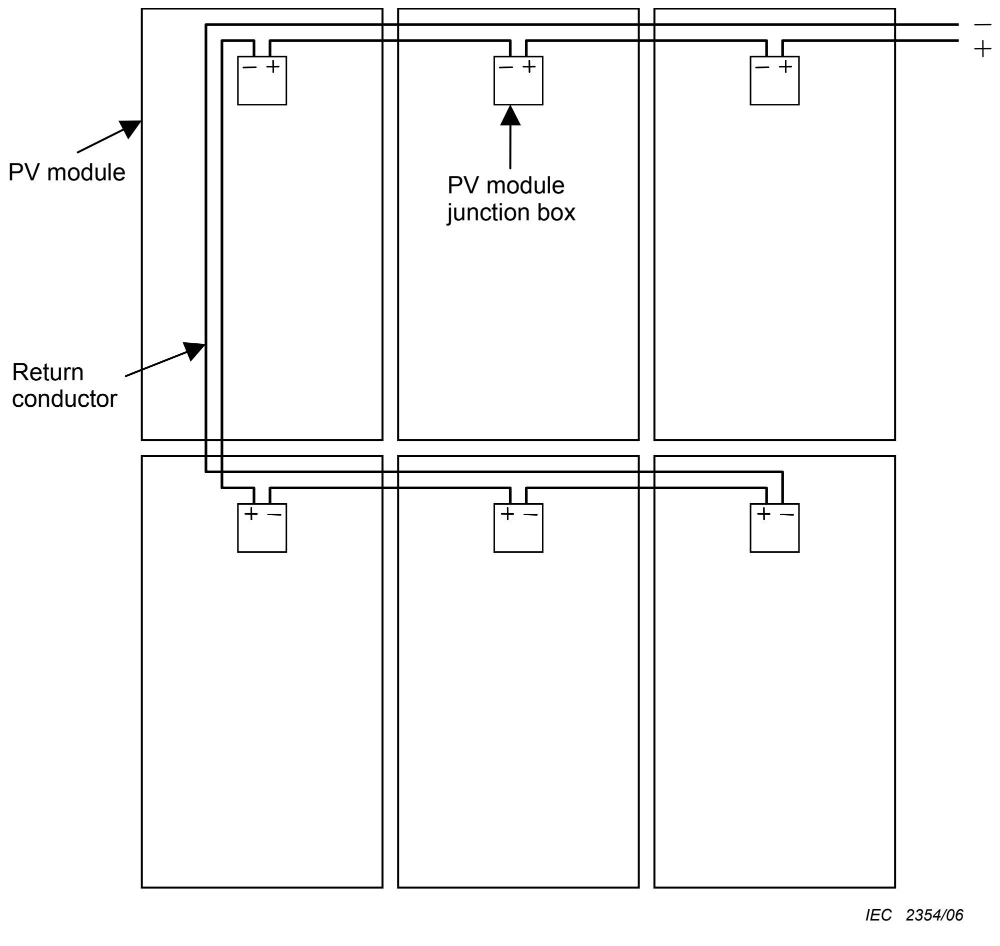


Figure 11 – PV string wiring with minimum loop area

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.

NOTE Water condensation inside combiner boxes may 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

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:

a) PV cabling using distinctively marked PV cables shall be permanently, legibly and indelibly marked (e.g. cables to TUV 2 pfg), or
b) 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.
c) 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 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 d.c. 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.

9 Operation/maintenance

Refer to the operation and maintenance requirements in IEC 62446.

10 Marking and documentation

10.1 Equipment marking

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

10.2 Requirements for signs

All signs required in this clause shall:

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

Examples of signs are given in Annex 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,
- 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 d.c. 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 d.c. 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 d.c. 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 specifications for PV arrays.

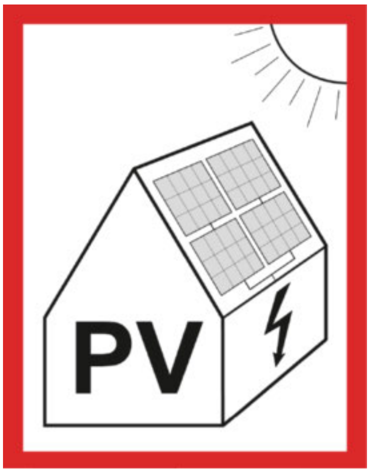
Annex A
(informative)

Examples of signs

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

IEC 1838/13

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



IEC 1839/13

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

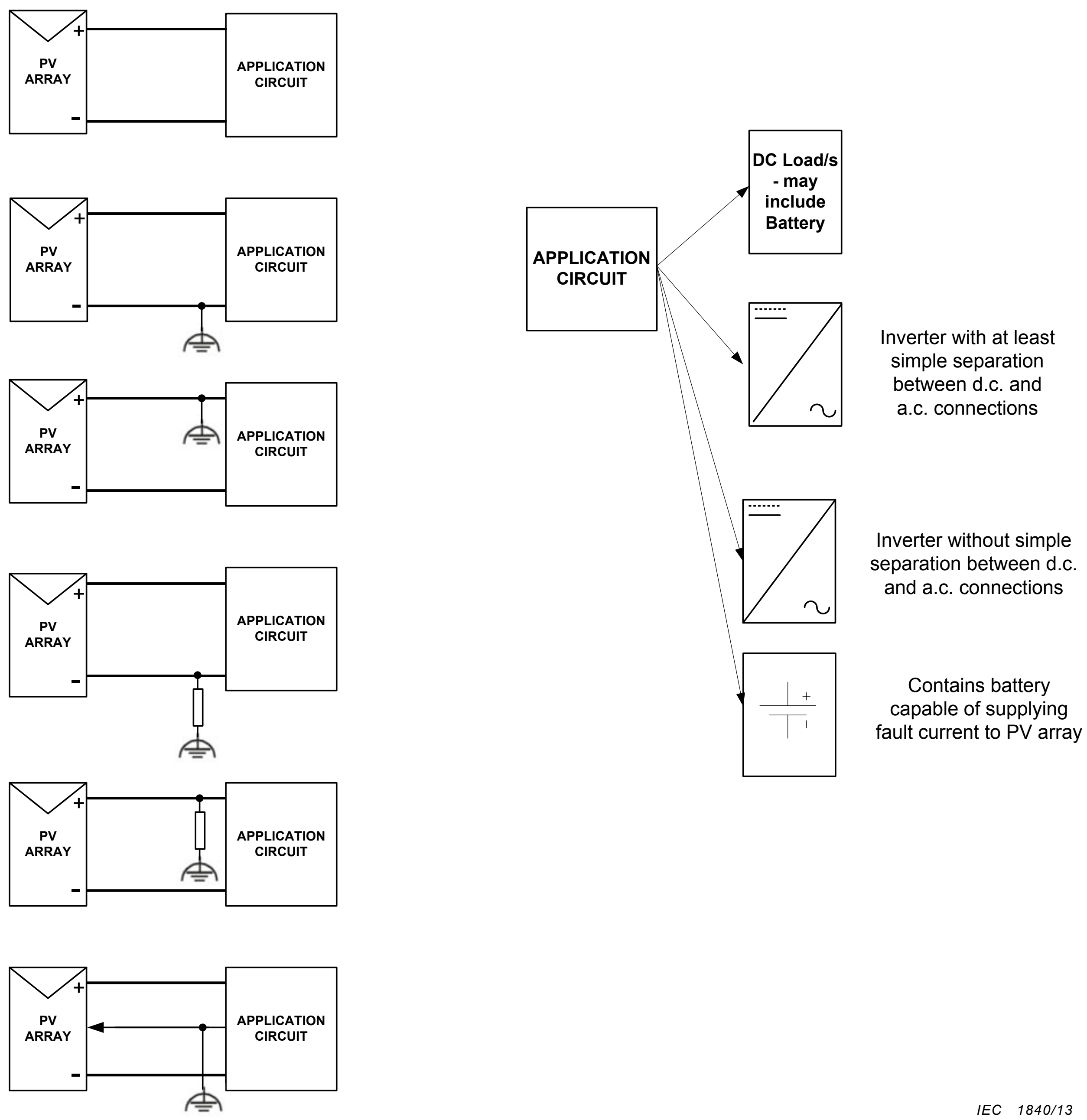


Figure B.1 – System functional earthing/grounding

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

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.

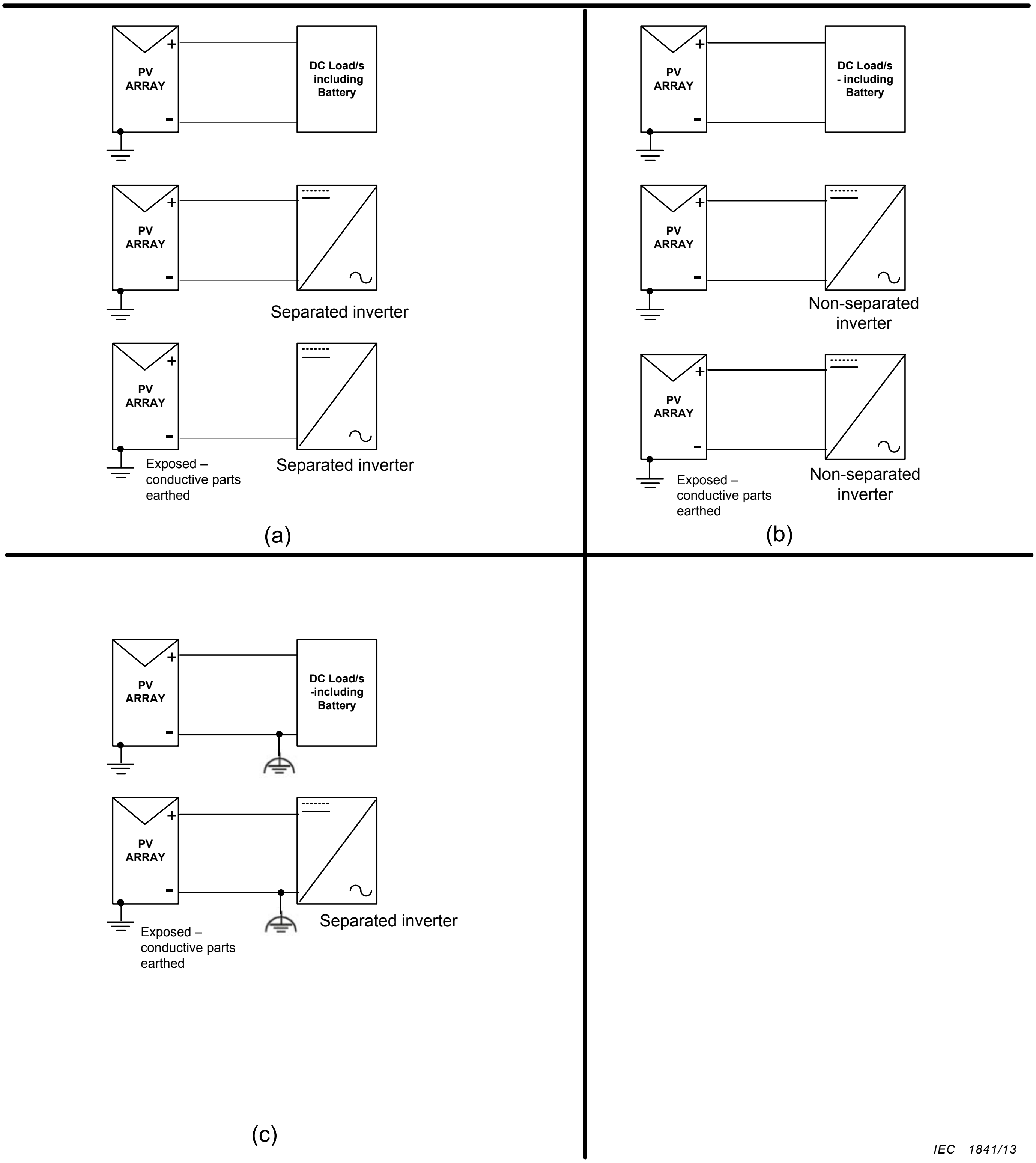


Figure B.2 – Examples different PV configurations in common use

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

Annex C
(informative)

Blocking diode

C.1 General

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 Figure 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 ensured.

C.3 Examples of blocking diode use in fault situations

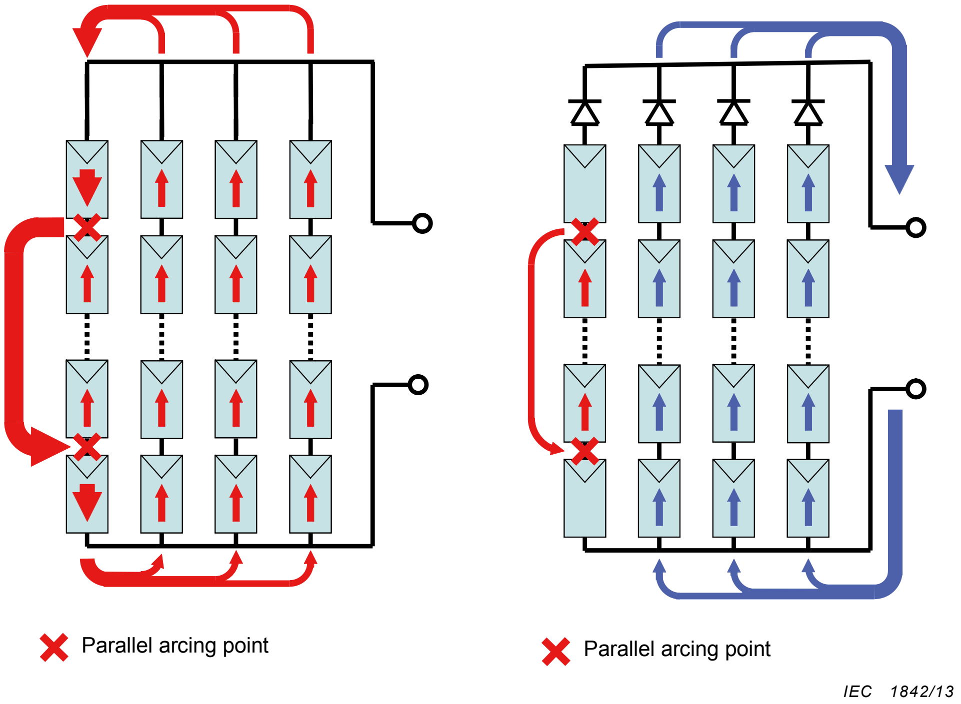
C.3.1 General

This clause 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). The fault current around the faulted modules cannot be intercepted with the blocking diode, however, the amount of fault current can be significantly reduced by the blocking diode obstructing the reverse current supplied from other strings as shown Figure C.1b). 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.

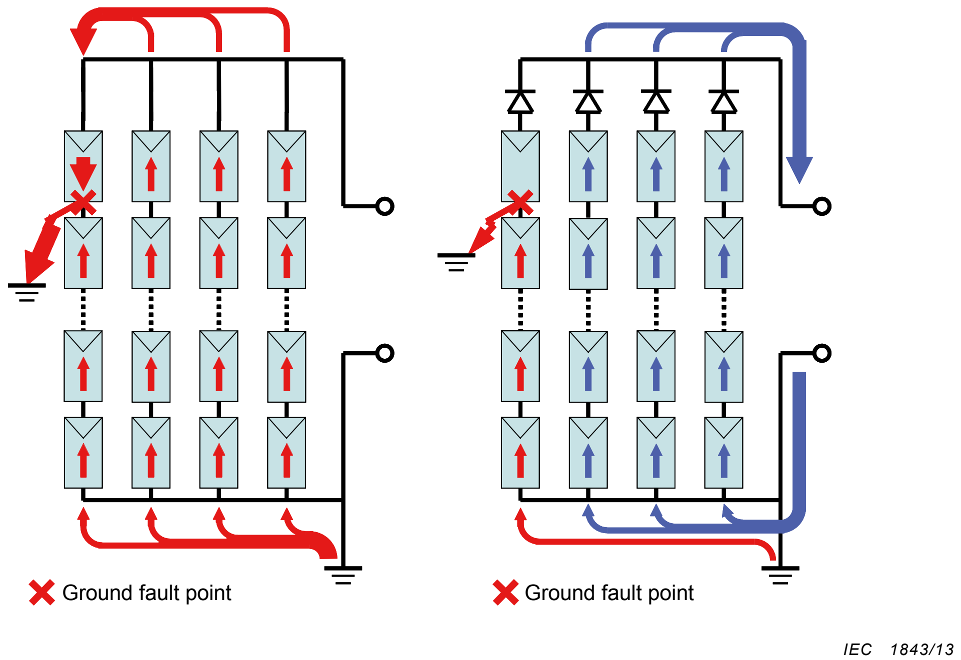


a) without a blocking diode b) with a blocking diode at each string

Figure C.1 – Effect of blocking diode at short circuit in PV string

C.3.3 Earth fault in PV string for the array with a functional earth

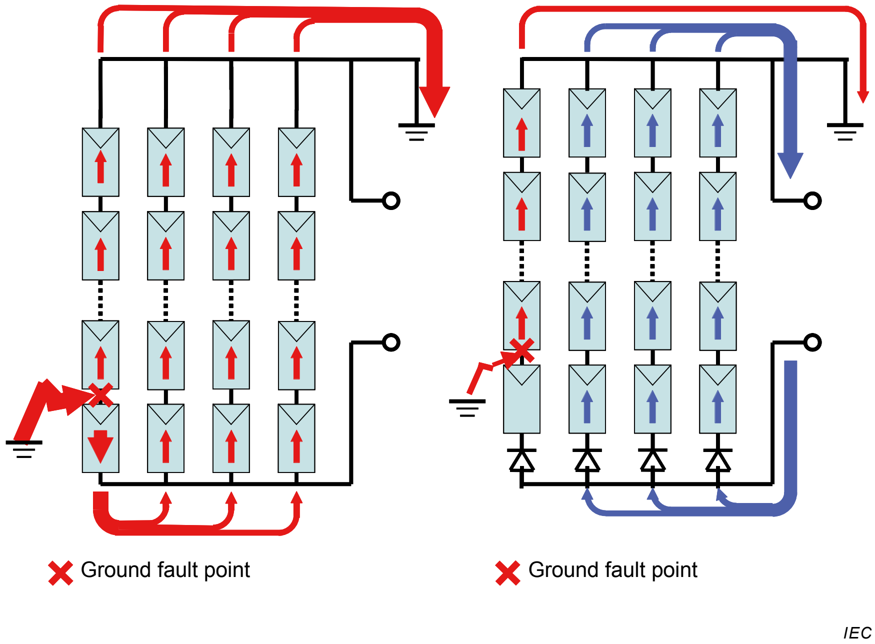
Figure C.2 shows the fault current paths when an earth fault occurs in a string of a PV array which is installed with a negative side functional earth. The worst case fault occurs when the earth fault is closest to the top of the string (i.e. the side furthest away from earth). In this case the blocking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

In these cases Figure C.2 and Figure C.3 clearly show the advantage of a blocking diode in eliminating the fault current contribution from adjacent strings of the array. This diagram shows the situation of a directly earthed array with no impedance in the earth connection. It is preferred in this Technical Specification 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 blocking diode in the 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 V_{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 R_{TH} as follows so that junction temperature T_J 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 d.c. voltages which are very capable of sustaining d.c. 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 standard 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 of grid connected systems this can be accomplished easily by shutting down the inverter system. Parallel arcs are much more difficult to extinguish but are also much less likely to occur.

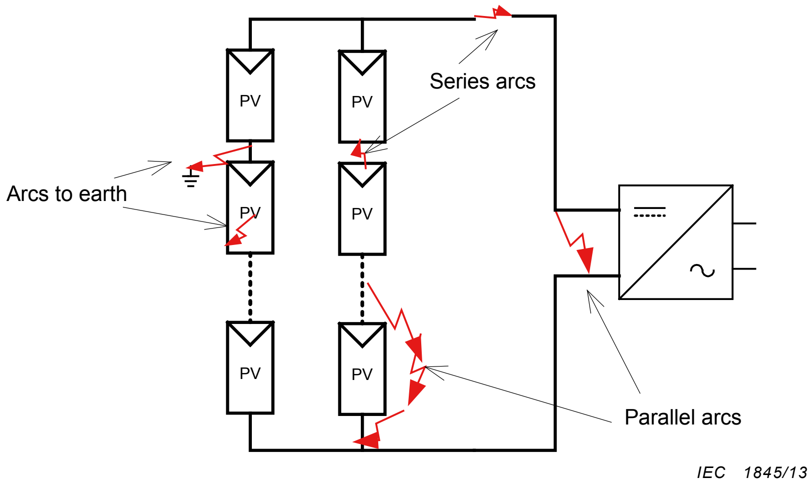


Figure D.1 – Examples of types of arcs in PV arrays

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 new 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 standard. 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.

It is proposed that as soon as reliable arc fault circuit protection equipment is commercially available this Technical Specification will be amended to include requirements for its use in a range of systems.

Annex E
(informative)

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		
	a.c. voltage (r.m.s.) U_{ACL}	**a.c. voltage (peak)** U_{ACPL}	**d.c. voltage (mean)** U_{DCL}
A*	≤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. * DVC-A circuits are allowed under fault conditions to have voltages up to the DVC-B limits, for maximum 0,2 s.			

NOTE This is a guide to DVC classification, for more information refer to IEC 62109-1.

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