

INTERNATIONAL STANDARD



**Photovoltaic (PV) arrays –
Part 1: Design requirements**

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INTERNATIONAL STANDARD



**Photovoltaic (PV) arrays –
Part 1: Design requirements**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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**PHOTOVOLTAIC (PV) ARRAYS –
Part 1: DESIGN REQUIREMENTS****FOREWORD**

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IEC 62548-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems. It is an International Standard.

This first edition cancels and replaces IEC 62548 published in 2016. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Revised provisions for systems including DC to DC conditioning units.
- b) Revision of mounting structure requirements.
- c) Revised cable requirements.
- d) Revision of Clause 6 on safety issues which includes provisions for protection against electric shock including array insulation monitoring and earth fault detection.
- e) Revision of 7.2.7 and 7.3 with respect to isolation means.

- f) Provisions for use of bifacial modules and modules mounted in non-optimal orientations.
- g) New Annex F containing: K_f factor calculations for bifacial and non-optimally oriented systems; anti-PID equipment and arc flash.

The text of this International Standard is based on the following documents:

Draft	Report on voting
82/2174/FDIS	82/2193/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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PHOTOVOLTAIC (PV) ARRAYS – Part 1: DESIGN REQUIREMENTS

1 Scope

This document sets out design requirements for photovoltaic (PV) arrays including DC array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array and final power conversion equipment (PCE), but not including energy storage devices, loads or AC or DC distribution network supplying loads.

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

In systems supplying AC loads or circuits, the safety requirements mentioned in this document are however critically dependent on the inverters associated with PV arrays complying with the requirements of IEC 62109-1, IEC 62109-2 and IEC 62109-3.

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

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

PV arrays in grid interconnected systems connected to medium or high voltage systems are not covered in this document, except as required by IEC TS 62738. Variations and additional requirements for large-scale ground mounted PV power plants with restricted access to personnel are addressed in IEC TS 62738.

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

This document also includes extra protection requirements of PV arrays when they are directly connected with batteries at the DC level.

Attention is drawn to the co-existence of IEC 60364-7-712 and IEC 62548. Both standards have been developed in close coordination, respectively by IEC technical committees 64 and 82.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60228, *Conductors of insulated cables*

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

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

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

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

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*
IEC 60364-4-41:2005/AMD1:2017

IEC 60364-4-44:2007, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*
IEC 60364-4-44:2007/AMD1:2015
IEC 60364-4-44:2007/AMD2:2018

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

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

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

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

IEC 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 AC and DC operation*

IEC 60898-3, *Circuit-breakers for overcurrent protection for household and similar installations – Part 3: Circuit-breakers for DC operation*

IEC 60947-1:2020, *Low-voltage switchgear and controlgear – Part 1: General rules*

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

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

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

IEC 61439-1, *Low-voltage switchgear and controlgear assemblies – Part 1: General rules*

IEC 61439-2, *Low-voltage switchgear and controlgear assemblies – Part 2: Power switchgear and controlgear assemblies*

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

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

IEC 61643-31:2018, *Low-voltage surge protective devices – Part 31: Requirements and test methods for SPDs for photovoltaic installations*

IEC 61701, *Photovoltaic (PV) modules – Salt mist corrosion testing*

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

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

IEC TS 61836:2016, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 61984, *Connectors – Safety Requirements and tests*

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 62109-3, *Safety of power converters for use in photovoltaic power systems – Part 3: Particular requirements for electronic devices in combination with photovoltaic elements*

IEC 62305-2:2010, *Protection against lightning – Part 2: Risk management*

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

IEC 62440:2008, *Electric cables with a rated voltage not exceeding 450/750 V – Guide to use*

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

IEC 62446-2, *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance – Part 2: Grid connected systems – Maintenance of PV systems*

IEC 62716, *Photovoltaic (PV) modules – Ammonia corrosion testing*

IEC TS 62738, *Ground-mounted photovoltaic power plants – Design guidelines and recommendations*

IEC TS 62804-1, *Photovoltaic (PV) modules – Test methods for the detection of potential-induced degradation – Part 1: Crystalline silicon*

IEC 62817, *Photovoltaic systems – Design qualification of solar trackers*

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

IEC 62930:2017, *Electric cables for photovoltaic systems with a voltage rating of 1,5 kV DC*

IEC 62938, *Photovoltaic (PV) modules – Non-uniform snow load testing*

IEC 62941, *Terrestrial photovoltaic (PV) modules – Quality system for PV module manufacturing*

IEC 63027, *Photovoltaic power systems – DC arc detection and interruption*

IEC 63104, *Solar trackers – Safety requirements*

IEC 63112:2021, *Photovoltaic (PV) arrays – Earth fault protection equipment – Safety and safety-related functionality*

IEC TS 63126:2020, *Guideline for qualifying PV modules, components and materials for operation at high temperatures*

IEC TS 63209-1, *Photovoltaic modules – Extended-stress testing – Part 1: Modules*

IEC TR 63226:2021, *Managing risk related to photovoltaic (PV) systems on buildings*

IEC TR 63227, *Lightning and surge voltage protection for photovoltaic (PV) power supply systems*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions in IEC TS 61836 and the following apply.

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

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

3.1.1

blocking diode

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

3.1.2

bifacial nameplate irradiance

BNPI

higher irradiance at which nameplate verification is performed for bifacial modules. Bifacial nameplate irradiance (BNPI) is that which corresponds to 1 000 W/m² on the module front, and 135 W/m² on the module rear

Note 1 to entry: BNPI may be applied in any method allowed by IEC TS 60904-1-2.

[SOURCE: IEC 61215-1:2021, 3.11]

3.1.3

bonding conductor

conductor provided for functional or protective equipotential bonding

3.1.4

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

3.1.5

charge controller

power conversion equipment used between a battery and a PV array to regulate charge delivered to the battery

3.1.6

DC conditioning units

DCU

DC to DC power conversion equipment connected to individual PV modules or groups of PV modules or PV strings to modify the voltage and or current of the PV output

3.1.7

decisive voltage class

DVC

classification of voltage range used to determine the protective means against electric shock and the requirements of protection between circuits

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

[SOURCE: IEC 62477-1:2022, 3.15]

3.1.8

disconnecter

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

Note 1 to entry: A disconnecter 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 disconnecter occurs. It is also capable of carrying currents under normal circuit conditions and carrying currents for a specified time under abnormal conditions such as those of short circuit.

[SOURCE: IEC 60050-441:1984, 441-14-05]

3.1.9

double insulation

insulation comprising both basic insulation and supplementary insulation

[SOURCE: IEC 60050-195:2021, 195-06-08]

3.1.10

earth fault

ground fault (US)

occurrence of an accidental conductive path between a live part and the Earth

Note 1 to entry: The conductive path can consist of faulty insulation, structures (e.g. poles, scaffoldings, cranes, ladders), or vegetation (e.g. trees, bushes) and can have a significant impedance.

[SOURCE: IEC 60050-195:2021, 195-04-14]

3.1.11**extraneous conductive part**

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

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

3.1.12**extreme annual mean minimum dry bulb temperature**

average of at least 5 years of the lowest yearly measured dry bulb temperatures at a location

3.1.13**independent manual operation****independent manual operation of a mechanical switching device**

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

Note 1 to entry: See Annex F for calculation of K_f .

[SOURCE: IEC 60050-441:1984, 441-16-16, modified – The brackets have been added to the definition.]

3.1.14**live part**

conductive part intended to be energized under normal operating conditions, including the neutral conductor and mid-point conductor, but excluding the PEN conductor, PEM conductor and PEL conductor

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

[SOURCE: IEC 60050-195:2021, 195-02-19]

3.1.15**low voltage**

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

3.1.16**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

3.1.17**non-separated PCE**

PCE without at least simple separation between the input and output circuits

3.1.18**partial DCU strings**

PV string where some but not all PV modules have DCUs fitted

Note 1 to entry: These configurations are sometimes used where some, but not all, modules are subject to shading on a regular basis.

3.1.19**DCU strings**

string of DCUs connected in series on the output side of the DCUs where all PV modules or groups of PV modules have DCUs fitted

3.1.20

power conversion equipment

PCE

electrical device converting one kind of electrical power from a voltage or current source into another kind of electrical power with respect to voltage, current and frequency

Note 1 to entry: Examples include AC-DC converters, DC-AC inverters, DC-DC converters, DC-DC charge controllers, frequency converters, etc. DCUs are a subset of PCEs.

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

3.1.21

prospective short-circuit current

RMS value of the available current which would flow from a source connected to a port of the PCE, if the supply conductors from the source are short-circuited by a conductor of negligible impedance located as near as practicable to the supply terminals of the PCE

Note 1 to entry: In general, the prospective short circuit current is represented by the symbol I_{CP} . In the particular case of a PV port, this document uses $I_{CP\ PV}$. See 3.2.11.

[SOURCE: IEC 62477-1:2022, 3.58, modified – The symbol has been removed and an explanation has been added in the note to entry, added the word “available” before “current”. Added “from a source connected to a port of the PCE” after “flow”. Replaced “to the circuit” with “from the source” and replaced “PECS” with “PCE”.]

3.1.22

PV array

assembly of electrically interconnected PV modules, PV strings or PV sub-arrays and support structure, including DCU strings and partial DCU strings up to:

- the input of the final power conversion equipment (PCE) which supplies loads or an AC or DC distribution network
- DC loads or DC distribution system

Note 1 to entry: For the purposes of this document a PV array is all components up to the DC input terminals of a final PCE or DC 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, including DC-DC converters up to the terminals of the final power conversion equipment (see Figure 2 to Figure 11).

3.1.23

PV array main cable

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

3.1.24

PV array combiner box

enclosure where PV sub-arrays are connected and which may also contain overcurrent protection and/or isolation means

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.

3.1.25

PV module

complete and environmentally protected assembly of interconnected photovoltaic cells

[SOURCE: IEC TS 61836:2016, 3.1.48.7, modified – The adjective “photovoltaic” has been replaced by “PV” in the term.]

3.1.26**PV power generation plant**

type of ground mounted PV installation, which is operated under supervision with restricted access solely for the purpose of providing electrical energy to the distribution system

Note 1 to entry: "Under supervision" means that PV power plants are restricted from access by non-qualified personnel and are continuously monitored for safety and protection, either by on-site personnel or by active remote monitoring. In some documents such as IEC 62109, this type of area is referred to as a "closed electrical operating area".

Note 2 to entry: PV systems on buildings do not fall under the definition of PV power generation plants

3.1.27**PV reverse current**

current supplied by parallel PV strings or sub-arrays into a fault on a string or sub-array and does not include backfeed current

3.1.28**PV string**

circuit of one or more series-connected modules

[SOURCE: IEC TS 61836:2016, 3.3.59.6, modified – The adjective "photovoltaic" has been replaced by "PV", and the words "one or more" have been added for clarity.]

3.1.29**PV string cable**

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

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

3.1.30**PV string combiner box**

enclosure where PV strings are connected which may also contain overcurrent protection devices and/or isolation means

Note 1 to entry: See Figure 4.

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

3.1.31**PV sub-array**

electrical subset of a PV array formed of parallel connected PV strings

3.1.32**PV sub-array cable**

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

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

3.1.33**reinforced insulation**

insulation 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 60050-195:2021, 195-06-09]

3.1.34

shield

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

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

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

3.1.35

separation

prevention of electrical conduction between two circuits or between a circuit and a conductive metal part

Note 1 to entry: Separation in the context of this document means galvanic isolation.

Note 2 to entry: Separation may be achieved to different degrees, e.g. simple separation, protective separation.

3.1.36

simultaneously accessible parts

conductive parts that can be touched simultaneously by a human being or by livestock

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

[SOURCE: IEC 60050-826:2022, 826-12-12, modified – In the note, the words "soil or conductive floor" have been replaced by "earth electrodes".]

3.1.37

standard test conditions

STC

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

[SOURCE: IEC TS 61836:2016, 3.4.16.5]

3.1.38

switch-disconnector

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

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

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

3.1.39**system (functionally-earthed)**

system where the PV array has one conductor intentionally connected to earth for purposes other than electrical safety, by means not complying with the requirements for protective bonding

Note 1 to entry: Examples of functional array earthing include earthing one conductor through an impedance, relay, or overcurrent protective device, or systems in which the array is not permanently earthed (opening the earth connection periodically or under fault conditions). Examples shown in Figure B.1.

Note 2 to entry: Use of a resistive network connected between the array and earth to measure the array insulation resistance (impedance monitoring) does not create a functionally-earthed array, as the impedance of such measurement networks is normally very high.

3.1.40**system (non-earth-referenced)**

system where the PV array has none of its conductors intentionally referenced to earth either directly or through the power conversion equipment (PCE)

Note 1 to entry: Examples shown in Figure B.2.

3.1.41**system (non-separated)**

system where the PV array is connected to an intentionally earth-referenced system through a non-separated PCE

Note 1 to entry: Typically this refers to a system with a non-separated inverter, connecting to an earth-referenced AC system, so that when the inverter's connection relay (or other switching device) is closed, the entire system including the PV array is earth-referenced.

Note 2 to entry: Examples shown in Figure B.3.

3.2 Symbols**3.2.1** **$I_{BF\text{ TOTAL}}$**

total continuous backfeed current from all sources other than the PV array itself

Note 1 to entry: This typically includes backfeed from the PCE and any energy storage system that is directly connected to a PV array.

Note 2 to entry: The current that can flow from parallel PV sub-arrays or strings into a faulty sub-array or string is referred to as "PV reverse current" to differentiate it from PCE backfeed current.

Note 3 to entry: In IEC 62109-1:2010 (Ed 1) the backfeed current from the PCE includes reverse currents from all other connected PV inputs. It is planned to change this in Edition 2 of IEC 62109-1."

3.2.2**irradiance** **G**

electromagnetic radiated solar power per unit of area

Note 1 to entry: Expressed in W/m².

[SOURCE: IEC TS 61836:2016, 3.6.25, modified – The adjective "solar" has been added to the definition, and the note has been replaced.]

3.2.3**rated short circuit making capacity** **I_{cm}**

short-circuit making capacity of the equipment at the rated operational voltage

Note 1 to entry: Definition derived from IEC 60947-1:2020.

3.2.4 rated short circuit breaking capacity

I_{cn}

short-circuit breaking capacity of the equipment at the rated operational voltage

Note 1 to entry: Definition derived from IEC 60947-1:2020.

3.2.5 rated operational current

I_e

rated operational current of an equipment stated by the manufacturer and taking into account the rated operational voltage the rated frequency the rated duty, the utilization category and the type of protective enclosure, if appropriate

Note 1 to entry: Definition derived from IEC 60947-1:2020.

3.2.6 conventional enclosed thermal current

I_{the}

value of current stated by the manufacturer used for temperature-rise tests of an equipment when mounted in a specified enclosure

Note 1 to entry: Definition derived from IEC 60947-1:2020.

3.2.7

$I_{MOD_MAX_OCPR}$

PV module maximum overcurrent protection rating determined by IEC 61730-2

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

3.2.8

I_n

rated current

3.2.9

$I_{SC\ MOD}$

short circuit current of a monofacial PV module or PV string at standard test conditions (STC), as specified by the manufacturer on the product name-plate

Note 1 to entry: For the purposes of this document the short circuit current of a string is taken as equal to $I_{SC\ MOD}$.

3.2.10

$I_{SC\ BNPI}$

short circuit current of a bifacial PV module or PV string at BNPI test conditions, (see 3.1.2) as specified by the manufacturer in the product specification plate

3.2.11 **$I_{CP\ PV}$**

PCE maximum rated prospective short circuit current at the PV input terminals; i.e. the absolute maximum current the PV input to the PCE is designed to withstand or carry under normal and fault conditions, for that input

Note 1 to entry: At the system design level, this rating would typically be coordinated with the total I_{SC} of the connected PV strings, adjusted for temperature, excess irradiance, etc. as required by installation standards (i.e. not simply the sum of the marked I_{SC} ratings of the connected PV modules, since those markings are based on short-circuit conditions under standard test conditions (STC), and may be exceeded in actual use).

Note 2 to entry: $I_{CP\ PV}$ is used in this document and replaces the previous $I_{SC\ PV}$. The committee is attempting to create a consistent definition across a range of standards. IEC 62109-1:2010, Ed1 uses the symbol $I_{SC\ PV}$, but is being revised in Ed2 under development to use $I_{CP\ PV}$. The current version of the data sheet standard IEC 62894 uses the term $I_{SC\ MAX}$, but is under revision.

3.2.12 **K_I**

DC current rating adjustment factor dependent on site PV module type and installation properties such as module orientation, module shading or module rear side irradiance

3.2.13 **N_S**

total number of parallel-connected PV strings in the PV array

3.2.14 **N_{SA}**

number of parallel-connected PV strings in the PV sub-array

3.2.15 **I_{DCU_OCPR}**

DCU maximum overcurrent protection on the DCU string output side

Note 1 to entry: This may be given as a fuse rating.

3.2.16 **I_{DCU_max}**

DCU maximum output current

3.2.17 **$I_{F\ STRING}$**

fault current that may flow in a string due to other parallel connected strings in the array

3.2.18 **$I_{F\ S-ARRAY}$**

fault current that may flow in a sub-array cable due to parallel connected strings in the array

3.2.19 **$I_{F\ ARRAY}$**

fault current that may flow in an array cable due to parallel connected strings in the array

3.2.20 **U_{DCU_max}**

DCU maximum output voltage

3.2.21 open-circuit maximum voltage

$U_{OC\ MAX}$

maximum voltage across an unloaded (open) PV-module -string, DCU string, partial DCU string or PV array, or on the DC side of the PV PCE

Note 1 to entry: The method for determining $U_{OC\ MAX}$ is given in Annex F.

3.2.22

R_{iso}

insulation resistance (isolation) between the PV array and earth

3.2.23

$U_{BUS-MAX}$

maximum voltage output of a group of DCUs

Note 1 to entry: See Annex J for test requirements.

3.2.24

$U_{OC\ ARRAY}$

open circuit voltage at standard test conditions of a PV array, and is equal to:

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

where

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

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

3.2.25

$U_{OC\ MOD}$

open circuit voltage of a PV module at standard test conditions, as specified by the manufacturer in the product specification

3.3 Abbreviated terms

3.3.1

PV-EFP

photovoltaic earth fault protection

3.3.2

PV-EFPE

photovoltaic earth fault protection equipment

4 Compliance with IEC 60364 series

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

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

5 PV array system configuration

5.1 General

5.1.1 Functional configuration of a PV system

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

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

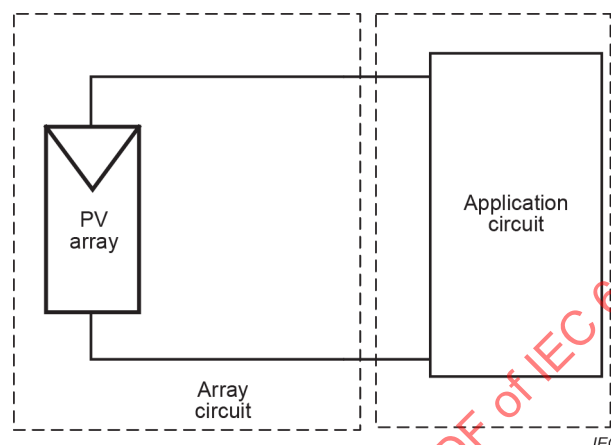


Figure 1 – General functional configuration of a PV powered system

Three kinds of application circuits are considered:

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

5.1.2 PV system topologies

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. These aspects and the location of an earth connection all affect safety of a PV array (refer to Annex B for examples of earthed and unearthed configurations).

The requirements of manufacturers of PV modules and manufacturers of PCE to which the PV array is connected shall be considered in determining the most appropriate system earthing arrangement.

The system may be separated or non-separated between the PV array and the application circuit. If separated, the separation may be either integral to the PCE or provided externally by a transformer or other PCE with at least simple separation.

Protective earthing of any of the line or midpoint conductors of the PV array is not permitted.

Functional earthing of one of the line or midpoint conductors of the PV array is permitted where there is at least simple separation between PV array DC power circuits and the AC mains or other earthed power system. The separation may be provided either internally in the PCE or externally via a separate transformer.

Temporary functional earthing is allowed for anti-PID purposes as shown in Annex H. Where a non separated PCE is in use the temporary functional earth connection may be applied only after the PCE is disconnected from the AC mains or other earthed power system.

Where the PCE functionally earths the PV array and provides separation using an external transformer:

- all conductors and equipment located on the AC link between the PCE and the external transformer shall be rated for the common-mode voltage to earth specified by the PCE manufacturer, or shall be separated by a transformer or other equipment such that the common-mode voltage is not present;
- the transformer(s) used shall be rated for the common-mode voltage.

NOTE 1 In a system where the PCE is separated using an external transformer, the AC link between the inverter AC output and the transformer is often unearthed to allow flexibility regarding functional earthing of the PV array. If the PV array is functionally earthed in the PCE, some inverter topologies will impose a high common-mode voltage to earth on the unearthed AC link circuit.

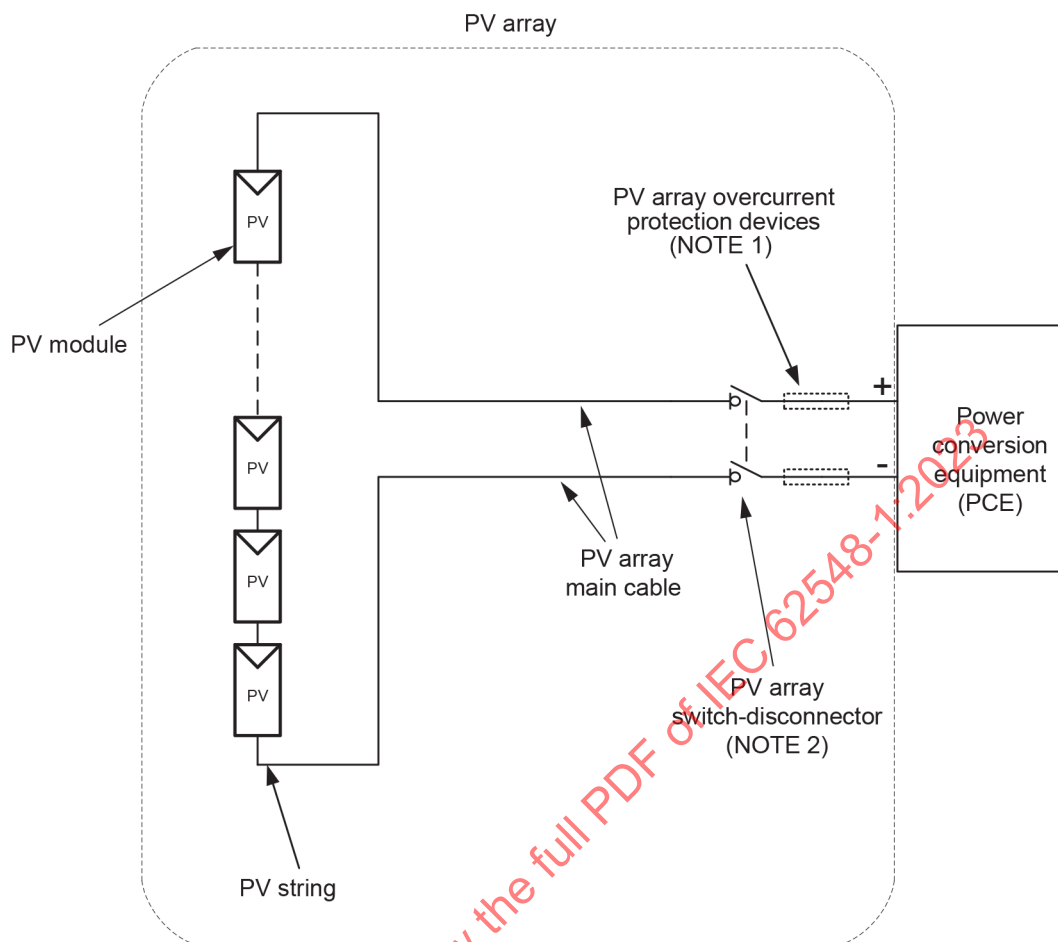
Where the PCE provides separation using an external transformer and more than one PCE is connected in parallel to a common winding, the PCEs shall be specifically rated for parallel connection with each other.

NOTE 2 Parallel connection of PCEs may cause circulating currents through earth if the PCEs are not designed to mitigate such currents.

5.1.3 Array electrical diagrams

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

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**Key**

- Elements that are not required in all cases
- Boundary of system or sub-system

IEC

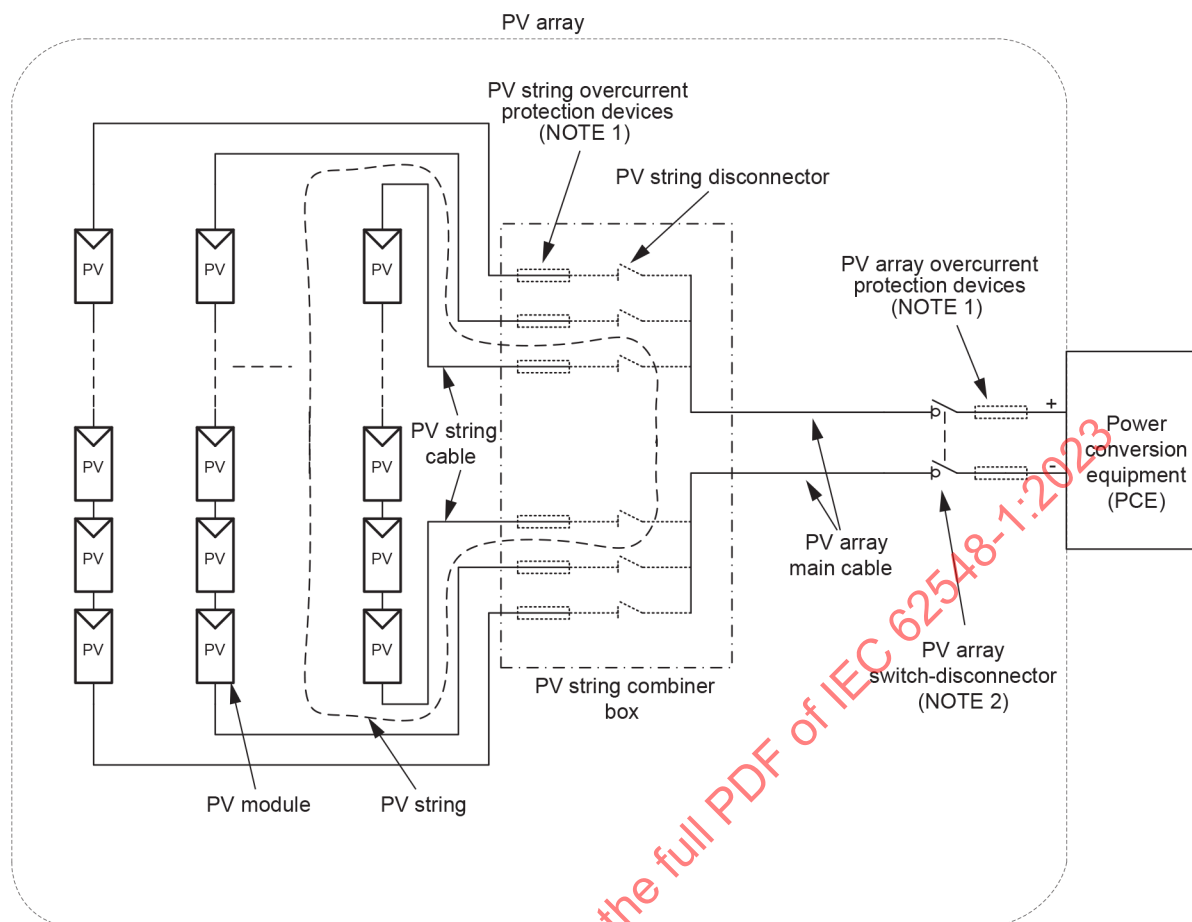
NOTE 1 Overcurrent protection devices where required (see 6.5).

NOTE 2 See 7.2.6 and 7.3.1 for PV array isolator/ isolation means with breaking capabilities requirements.

NOTE 3 Overcurrent protection devices and isolation means with breaking capabilities may be located inside the PCE under certain conditions (see 7.3.1.2).

NOTE 4 In this example there is only one string so the string cable is also the PV array main cable.

Figure 2 – PV array diagram – single string example



Key

- Elements that are not required in all cases
- - - Enclosure
- - - Boundary of system or sub-system

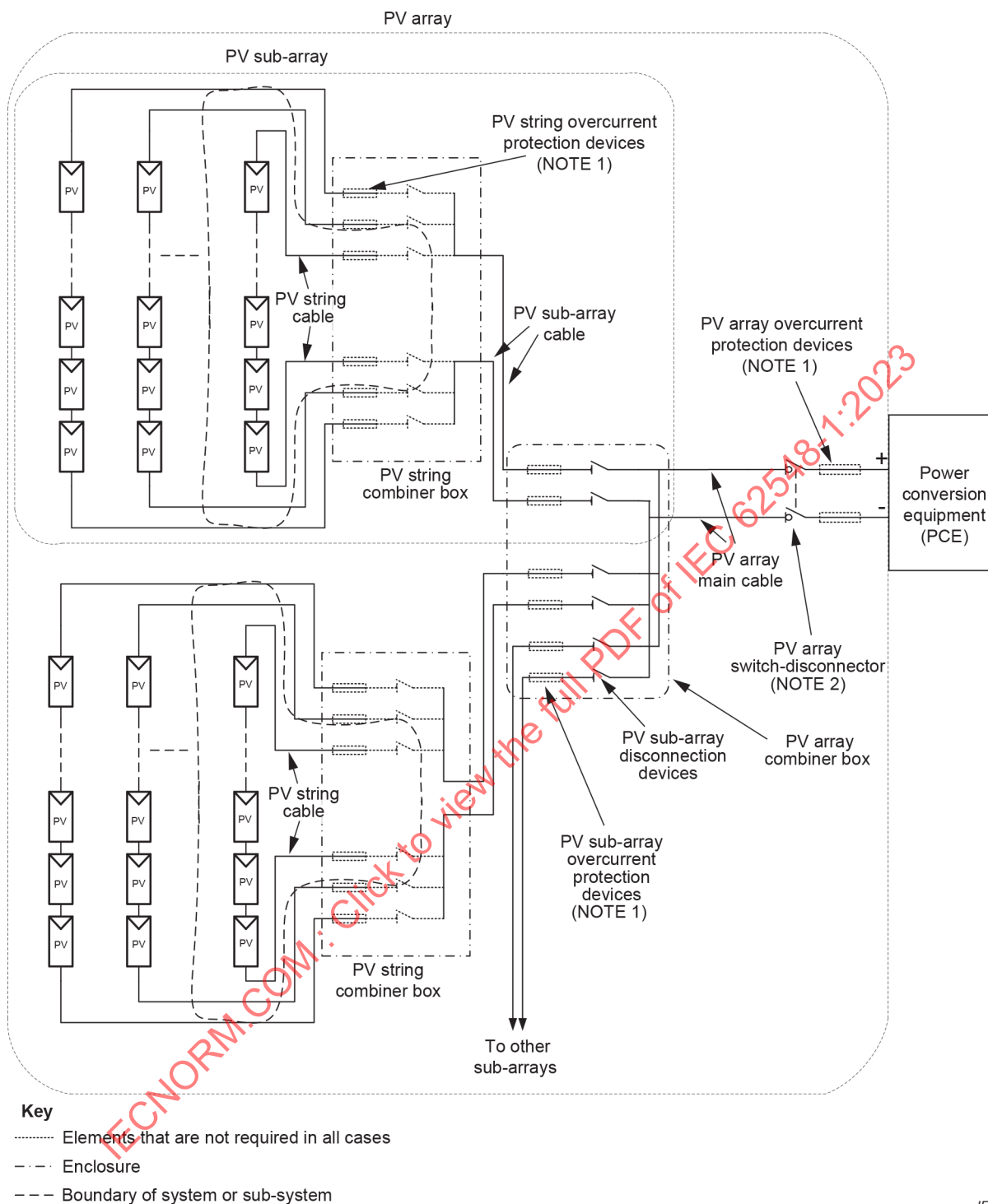
IEC

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

NOTE 2 See 7.2.6 and 7.3.1 for PV array isolator/ isolation means with breaking capabilities requirements.

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

Figure 3 – PV array diagram – multiple parallel string example

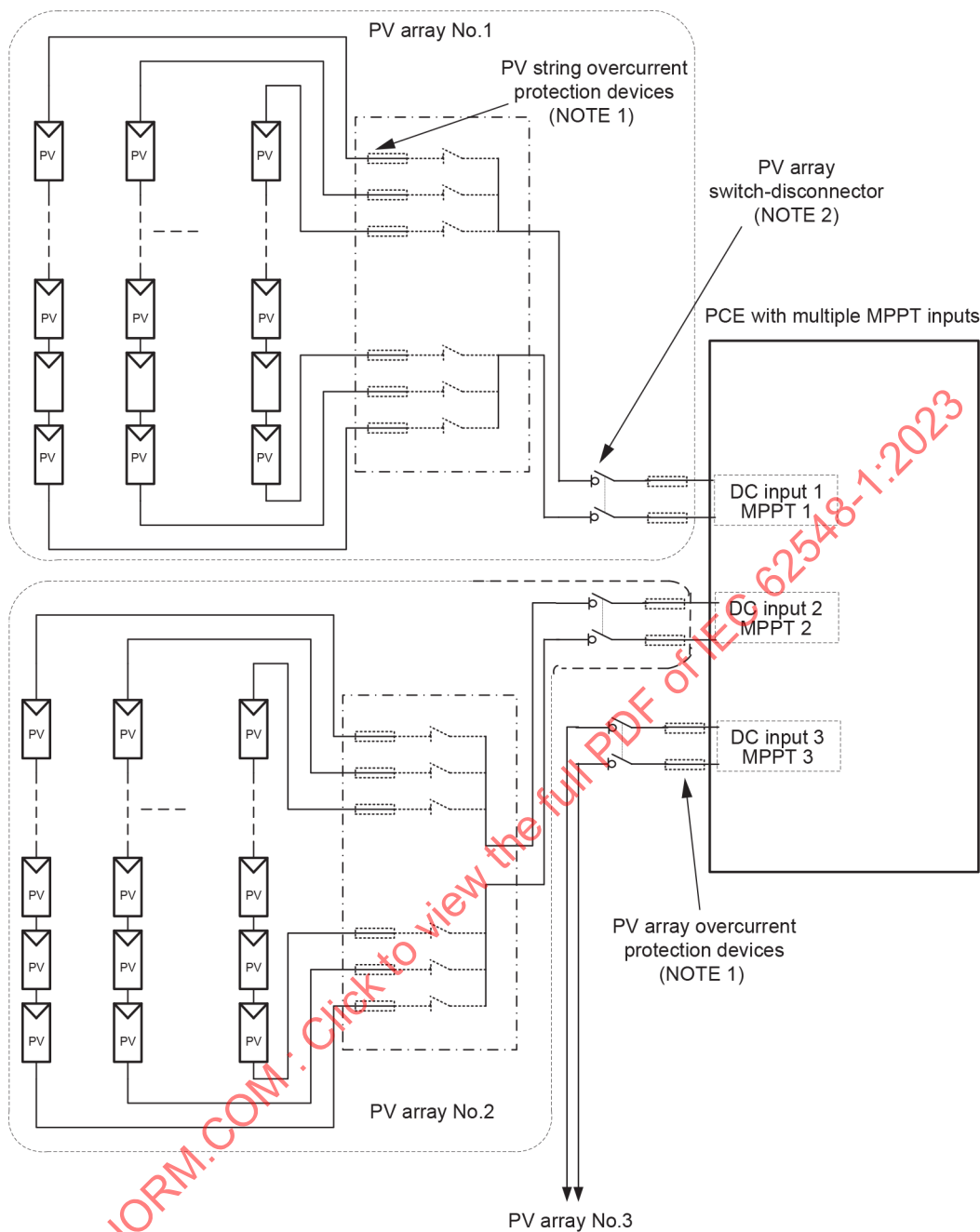


NOTE 1 Overcurrent protection devices where required (see 6.5).

NOTE 2 See 7.2.6 and 7.3.1 for PV array isolator/ isolation means with breaking capabilities requirements.

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

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



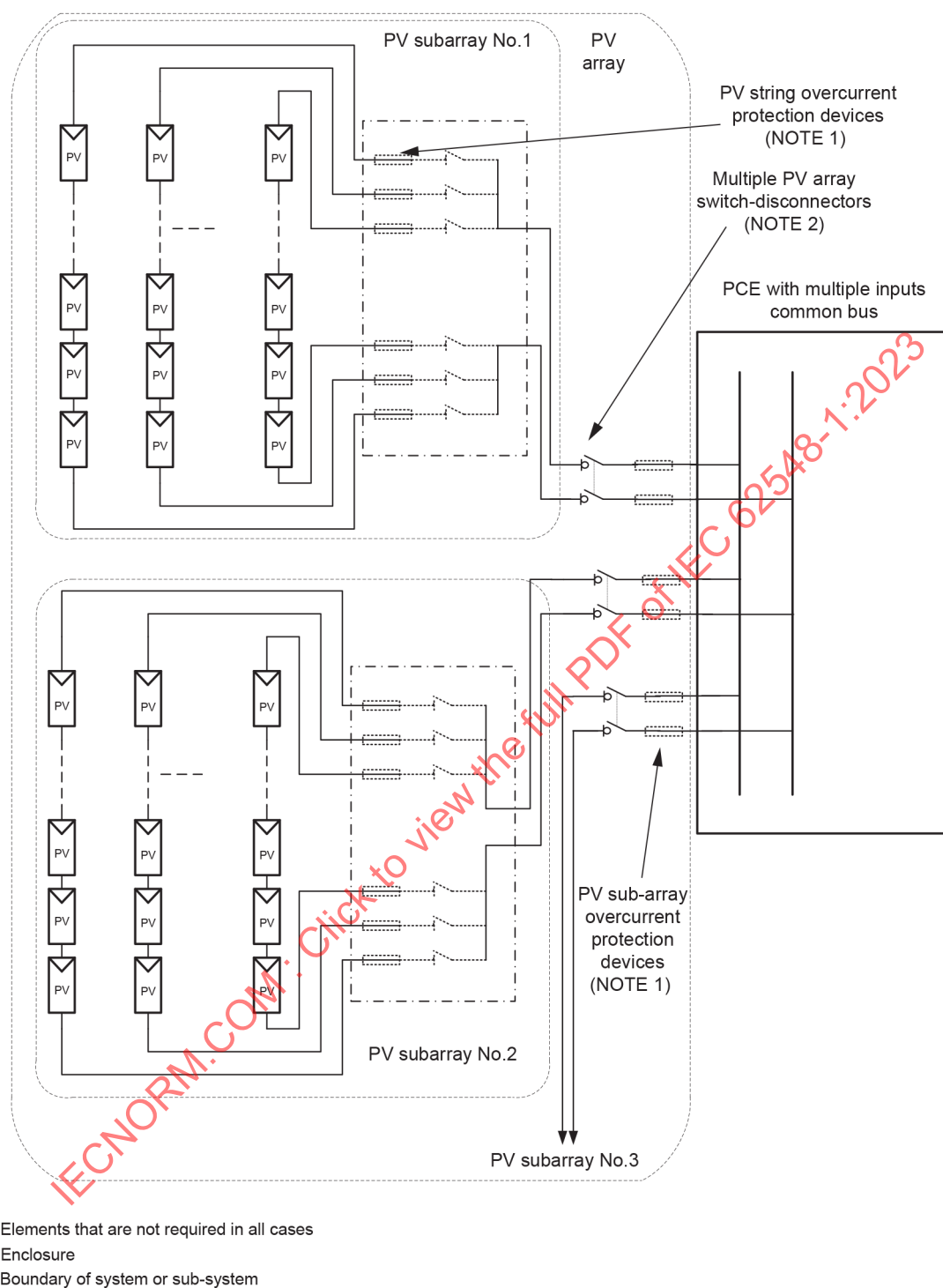
Key

- Elements that are not required in all cases
- - - Enclosure
- . - Boundary of system or sub-system

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

NOTE 2 See 7.2.6 and 7.3.1 for PV array isolator/ isolation means with breaking capabilities requirements.

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



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

NOTE 2 See 7.2.6 and 7.3.1 for PV array isolator/ isolation means with breaking capabilities requirements.

5.1.4 Use of PCE with multiple DC inputs

5.1.4.1 General

PV arrays are often connected to PCEs with multiple DC inputs. If multiple DC inputs are in use, overcurrent protection and cable sizing within the various sections of the PV array(s) are critically dependent on the limiting of any possible backfeed and/or PV reverse currents. Backfeed currents may be provided by other energy sources (i.e. other than PV) connected to the PCE. Reverse currents may be provided from parallel PV strings or sub-arrays. Both backfeed and PV reverse currents, may feed into a faulty section of the array. (See to Figure 5 and Figure 6).

5.1.4.2 PCEs with DC-DC converters on the PV inputs

In the case of PCEs which have multiple PV inputs, where each input is provided with a DC-DC converter (for MPPT or other purposes), and the DC-DC converter is specified by the manufacturer as preventing PV reverse current, the PV section connected to each input (see Figure 5) may be treated for the purposes of this document as a separate PV array.

NOTE 1 The above applies whether the DC-DC converters have internal separation or not provided the PCE manufacturer specifies the ability to block PV reverse current.

NOTE 2 IEC 62109-1 Ed. 2 in preparation includes requirements for qualifying and documenting the ability of DC-DC converters to block PV reverse current.

The overcurrent protection and cable sizing of the array connected to each of those inputs shall take into account any backfeed current from the PCE as required to be specified by the IEC 62109 series.

Each PV array shall have an isolation means with load breaking capabilities to provide isolation of the PCE. The provisions of multiple isolation device with breaking capabilities in 7.3.1 apply, and a warning sign as required in 10.5.2 shall be provided.

5.1.4.3 PCEs with multiple inputs internally connected together in the PCE

Where a PCE's multiple input circuits are internally paralleled onto a common DC bus, without DC-DC converters, each PV section connected to one of those inputs (refer to Figure 6) shall be considered for the purposes of this document as sub-arrays, and all the PV sections combined shall be classified as the complete PV array.

The overcurrent protection and cable sizing of each sub-array shall take into account any backfeed current from the PCE as required to be specified by the IEC 62109 series, and reverse current from the parallel sub-arrays and strings.

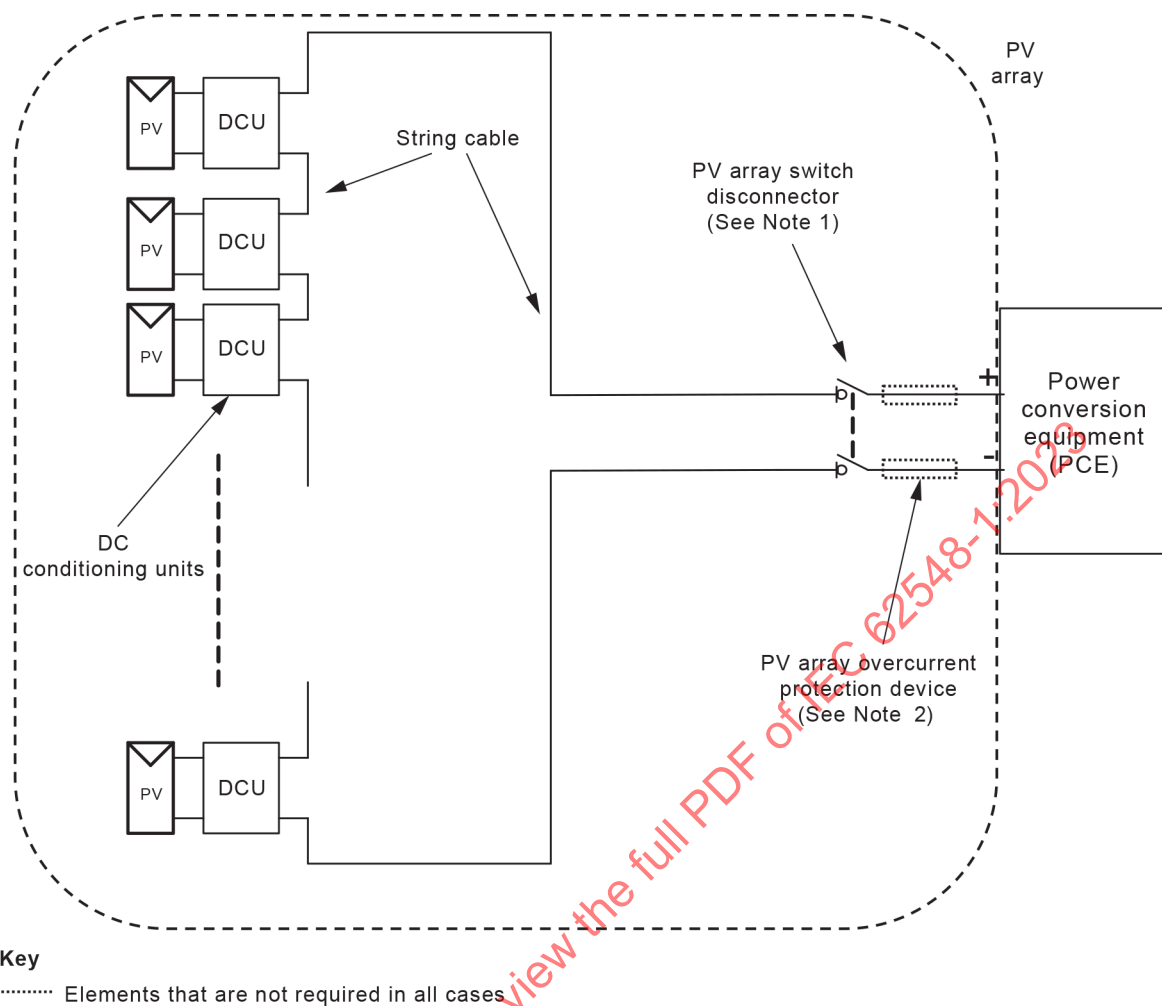
Each PV sub-array shall have an isolation means with load breaking capabilities to provide isolation of the PCE. The provisions of multiple isolation device with breaking capabilities in 7.3.1 apply, and a warning sign as required in 10.5.2 shall be provided.

5.1.5 PV arrays using DCUs

DCUs may be connected to individual PV modules, small groups of PV modules or whole PV strings to allow DC conditioning of the PV output. Figure 7 to Figure 10 show examples of some configurations in use. In some circumstances only some of the PV modules in a string may have DCUs connected (partial DCU string) to provide for modules that have shading on a regular basis. An example is shown in Figure 8.

DCUs shall be qualified to the relevant parts of IEC 62109 series.

The deployment of DCUs has implications for the voltage and current ratings within the PV-array. Refer to Clauses F.1, and F.2.



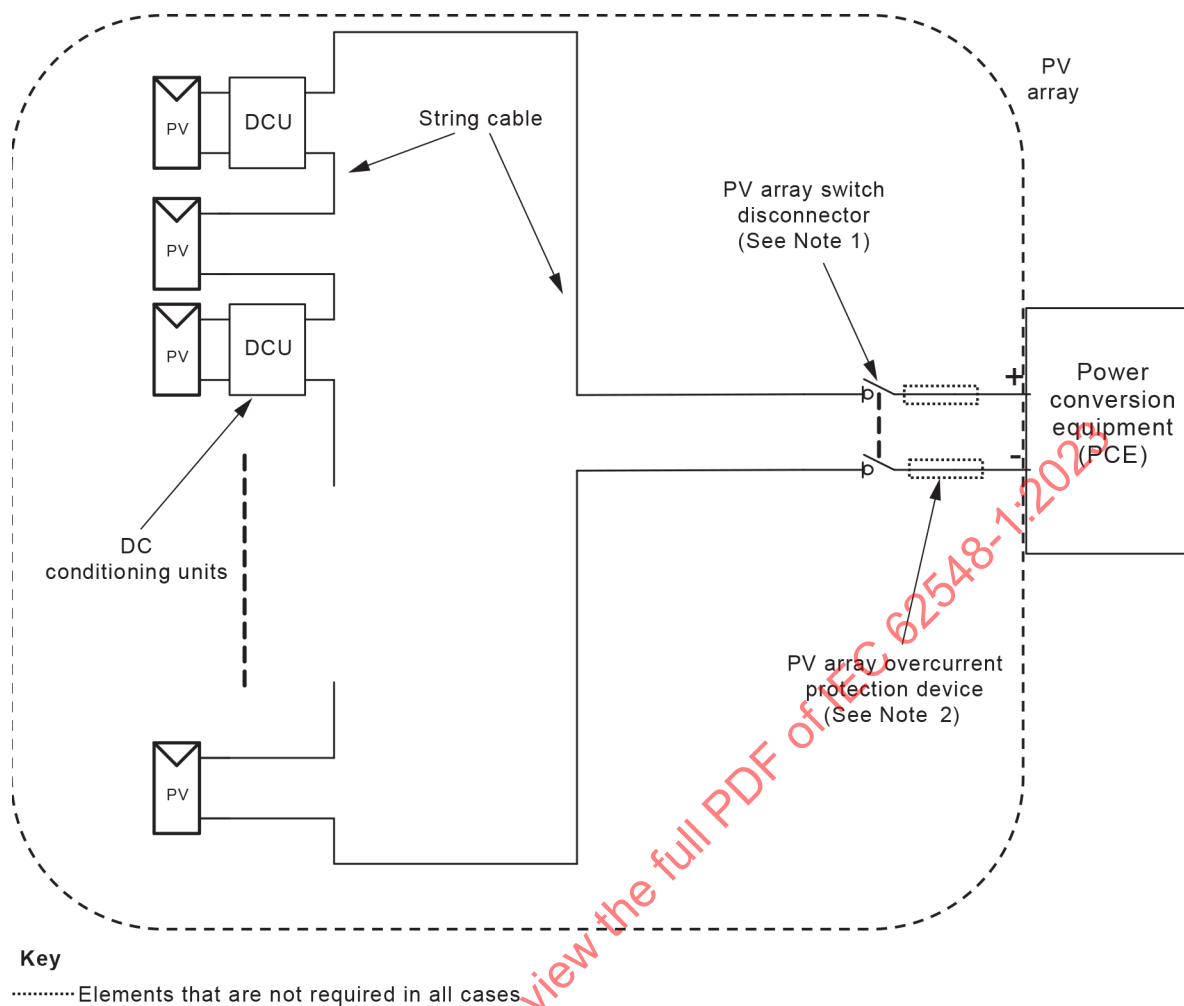
IEC

NOTE 1 See 7.2.6 and 7.3.1 for PV array isolation device with breaking capabilities requirements.

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

NOTE 3 The individual PV modules in this diagram may be replaced by multiple PV modules in series or parallel.

Figure 7 – PV string constructed using DCUs



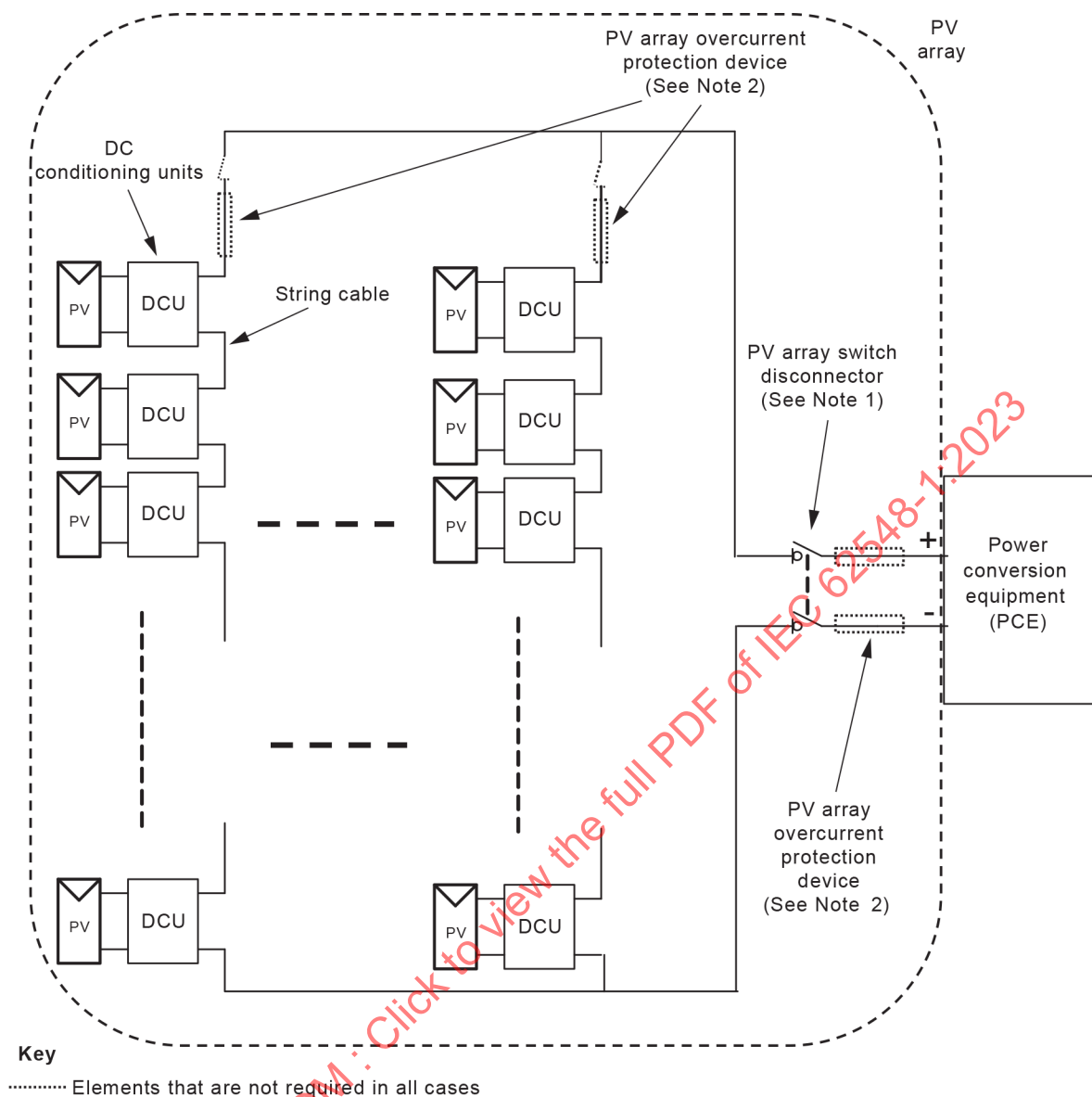
IEC

NOTE 1 See 7.2.6 and 7.3.1 for PV array isolation device with breaking capabilities requirements.

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

NOTE 3 The individual PV modules in this diagram may be replaced by multiple PV modules in series or parallel.

Figure 8 – Example of partial DCU string

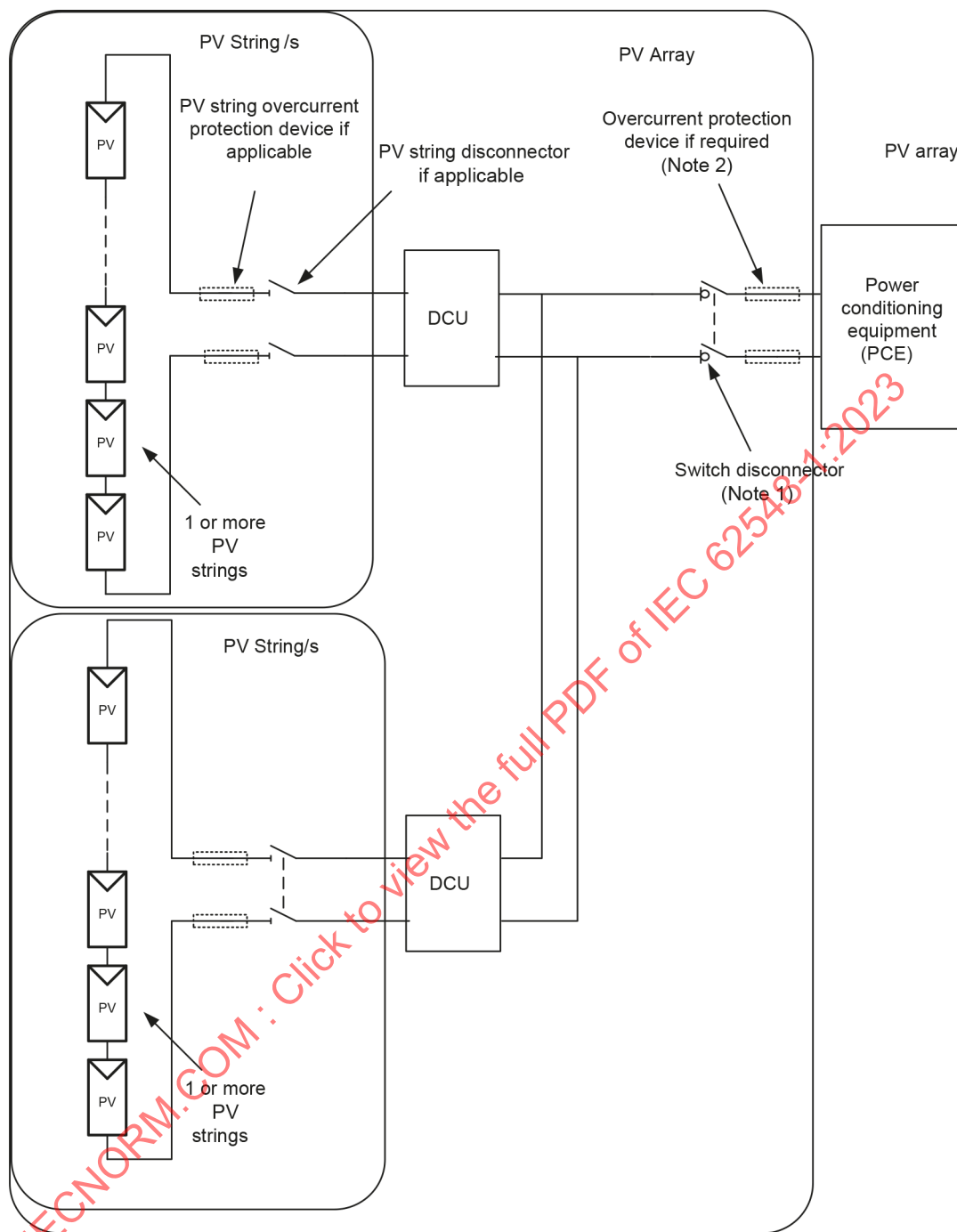


NOTE 1 See 7.2.6 and 7.3.1 for PV array isolation device with breaking capabilities requirements.

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

NOTE 3 The individual PV modules in this diagram may be replaced by multiple PV modules in series or parallel.

Figure 9 – PV parallel strings constructed using DCUs



Key

..... Elements that are not required in all cases

--- Boundary of system of sub-system

IEC

NOTE 1 See 7.2.6 and 7.3.1 for PV array isolation device requirements.

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

Figure 10 – PV string(s) connected to DCUs

Where whole strings are connected to DCUs (see Figure 10), the ratings of the output circuit/s of the DCU shall take into account the maximum output voltage of the DCU (U_{DCU_max}) and the the maximum output current of the DCU (I_{DCU_max}) and any relevant backfeed currents from parallel and downstream circuits.

5.1.6 Series-parallel configuration

An important safety issue exists if strings that are connected in parallel have different voltages. In this situation circulating currents will result especially if the main array DC disconnect is in the open position. Circulating currents represent a hazard if series connections are broken.

PV arrays shall be designed to minimize circulating currents within the array at open circuit. The lowest calculated open circuit voltage of a PV string shall be within 10 % of the highest calculated open circuit voltage of a PV string (all calculations based on PV module STC ratings).

NOTE 1 PV circuit currents should always be measured before opening any connection especially in parallel connected circuits.

All PV strings within a PV array connected in parallel should be of compatible technology with similar module/string characteristics per manufacturer recommendations unless such modules are being tracked by separate DCUs or separate MPPT inputs of a PCE. All PV strings within a PV array connected in parallel shall have similar rated electrical characteristics of open circuit voltage and maximum power voltage at STC, and temperature coefficients.

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

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

In the case of replacement of PV modules under maintenance where similar rated PV modules are not available, PV module or PV string level electronics or other measures may be allowed under engineering supervision to meet the similar rated electrical characteristics. When replacing PV modules connector compatibility shall be ensured for all connections.

PV modules that are electrically in the same string should be all in the same orientation with a maximum overall angular difference of 10° to avoid mismatch losses (azimuth and tilt angle).

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

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

5.1.7 Batteries in systems

Batteries connected to the DC side of PV systems via charge controllers or PCEs can be a source of high prospective fault currents and shall have overcurrent protection installed which is rated to interrupt this prospective fault current. The location of overcurrent protection related to battery systems shall be close to the battery.

Battery overcurrent protection should be placed in all active (non-earthed) conductors including conductors that are only functionally earthed.

The rating of overcurrent protection on the battery shall take into account both the load and charge currents required for the battery system. When a PCE or charge controller is used between the battery and the PV array the PCE's backfeed current is important in determining protection ratings for the array see Annex G on backfeed current.

If a battery charge controller is used between a PV array and a battery system the full battery current may need to be considered if the charge controller does not protect against or limit currents that flow from the battery to the PV array under fault conditions (i.e. backfeed currents).

5.1.8 Backfeed and reverse currents

A faulted PV array may be subject to backfeed current and/or PV reverse current feeding into the faulty circuit.

Backfeed current is supplied by energy sources other than PV, connected either to the array or to a PCE, such that fault current is able to flow back into the PV array faulty circuit.

PV reverse current into the faulty circuit is supplied by parallel PV strings or sub-arrays within the same array.

PV array conductor sizing and the need for PV array overcurrent protection shall consider the available backfeed current and PV reverse current. Refer to Clause F.3 addressing PV reverse currents and Annex G addressing backfeed currents. Backfeed current may affect systems at the string, subarray and array level and may be present in systems connected to single input or multiple input PCEs.

$I_{BF\ TOTAL}$ is used in this document to represent the total backfeed current, consisting of the backfeed through PCEs (as required to be specified by the IEC 62109 series) and backfeed from any other energy source connected to the PV array without a PCE, and excluding any PV reverse current.

5.1.9 Considerations due to prospective fault current conditions within a PV array

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

Systems containing batteries may have high prospective fault currents due to the battery characteristic (see 5.1.7). These high prospective fault currents need to be considered in all sections of an array. These fault currents are usually exhibited as backfeed currents, and the overcurrent protection needs to be coordinated across the whole array. See Annex G for further information. 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 and protection within a PV array very difficult. Short circuits and arcing faults can be formed in a PV array with fault currents that would not operate an overcurrent device.

The implications that arise from these PV array characteristics are that the possibility of line-to-line faults, earth faults and inadvertent wire disconnections in the PV array need to be minimized more than for other electrical installations.

NOTE In other electrical installations, the large inherent fault current capability of the system will generally trigger the protection system (e.g. fuses, circuit breakers or other), as long as the impedance is low enough. In PV-systems the short circuit current is limited to the maximum short circuit current of the PV modules..

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

5.1.10 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 to 30 °C is common with respect to the ambient temperature for crystalline silicon PV modules under 1 000 W/m² solar irradiance and with adequate ventilation. The temperature rise can be considerably higher when irradiance levels are greater than 1 000 W/m² and when modules have poor ventilation. In high temperature regions or confined mounting configurations modules require assessment for qualification at higher temperatures in accordance with IEC TS 63126:2020.

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

- a) For PV technologies, the efficiency reduces as the operating temperature increases. Therefore adequate ventilation of the PV array should be a design goal, in order to ensure optimum performance for both modules and associated components.
- b) All the components and equipment that may be in direct contact or near the PV array (conductors, inverters, connectors, etc.) need to be capable of withstanding the expected maximum operating temperature of the PV array.
- c) Any heat dissipating component that is mounted in proximity to the PV array or has direct contact to it shall not lead to a local temperature increase that exceeds the maximum operating temperature limits of the PV array. The required minimal clearance under the modules as mandated by the module manufacturer shall be maintained.
- d) Under cold conditions, for crystalline silicon technology based cells, the voltage increases (see F.1.1 for further considerations).

NOTE For crystalline silicon solar cells, the maximum power typically decreases between 0,25 % to 0,4 % per each °C rise in operating temperature.

5.1.11 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 mismatch;
- PV module degradation.

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

It is important to consider the affects of shadowing in any array design. Designs should be optimized to consider the impact of module shading using suitable engineering analysis. Module manufacturer guidance should be consulted for acceptable and unacceptable shading scenarios.

NOTE 1 Even a small shadow on the array can in some cases significantly limit its performance.

NOTE 2 Some modules may suffer permanent damage under some shading conditions. IEC TS 63140 provides test methods for quantifying possible permanent power output change in monolithically integrated PV modules resulting from some potential partial shade conditions.

Issues of performance degradation due to temperature rise and the need for good ventilation are important for some module technologies. Care should be taken to keep modules as cool as practicable.

In the design process, the sizing of cables within the array and in cable connections from the array to the application circuit affect the voltage drop in those cables under load. This can be particularly significant in systems with low output voltage and high output current.

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.

5.1.12 Potential induced degradation

Potential induced degradation (PID) is a performance degradation in some types of photovoltaic modules.

The main factors influencing PID are the environment (e.g. humidity and temperature), the system structure (e.g. type of earthing, system voltage), the module structure and the cells.

A measurable and controllable factor is the voltage of the PV modules to earth, that may be positive or negative. PID occurs mostly at negative voltage with respect to earth potential.

Some PV module technologies may recover from degradation, if the PV modules are dc biased at night. Some technologies require constant bias during daylight to prevent permanent damage.

Examples of typical anti PID solutions are given in Annex H. This annex also includes important considerations to be taken into account in design and installation of these systems.

5.1.13 Corrosion

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

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

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

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

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

5.1.14 Mechanical design

5.1.14.1 General

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

PV module mounting methods should be prescribed in the module manufacturer mounting guidelines. The fasteners, fastener locations, location of mounting rails and type of mounting fittings will all significantly affect the module allowed maximum mechanical loads.

5.1.14.2 Thermal aspects

Provisions should be taken in the mounting arrangement of PV modules to allow for the maximum expansion/contraction of the modules under expected operating temperatures, according to the manufacturer's recommendations. Similar provisions should be taken for other applicable metallic components, including mounting structures, conduits and cable trays.

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

5.1.15 Mechanical loads on PV structures

5.1.15.1 General

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

5.1.15.2 Mounting structures

Consideration should be given to: strength of mounting structures; soil conditions with respect to anchoring mounting frames; site drainage and, in areas where the ground freezes, the freeze-thaw characteristics of the soil shall also be taken into account.

5.1.15.3 Wind

5.1.15.3.1 General

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

The system designer or installer shall ensure the system module/mounting structure static and dynamic loads and safety factors are appropriate for the site as per the applicable building code and/or engineering design, e.g. considering relevant wind tunnel derived coefficients for the mounting structure.

Particular attention is drawn to the static and dynamic stability of trackers. Issues such as: fluid-elastic instabilities; buffeting; vortex-induced vibrations (VIV); rain-wind-induced vibrations; wake-induced vibrations have all been identified as issues affecting dynamic stability.

Stability issues depend on many factors including: tracker design and field layout, e.g. spacing between trackers.

Trackers should comply with the design qualification standard IEC 62817 and also the safety standard IEC 63513 (in preparation).

In assessing the wind forces, 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.

Module manufacturers are required to provide maximum uplift and downforce loads for specific mounting configurations (fastening methods and locations) of their product.

Due consideration should be given to the module dead load (module mass) when estimating the effective downward and uplift loads for the site.

5.1.15.3.2 Use outside of typical applications requiring further analysis

Per the prevailing local codes many large photovoltaic installations of today are designed, engineered and installed by qualified experts in their structural, mechanical and electrical field. When applications have requirements that deviate from the typical module uniform pressure ratings of 2 400 Pa, structure designers may use engineering studies such as boundary layer wind tunnel studies of that specific structure per allowances in building codes to enable the use of non-uniform pressure ratings.

Example scenarios are differentiating designs for interior vs exterior rows, structures in hurricane areas and or high snow load areas.

In the overall system design approach, boundary layer studies, manufacturer's mounting configurations, stated design loads and test safety factors may be utilized. In such studies, the licensed professional engineer should consider the factors listed below for the combined site specific wind and snow loads.

- Pressure coefficients should be derived based on an effective wind area equal to one PV module, from boundary layer wind tunnel tests on the specific mounting system used to support the PV module.
- Boundary layer wind tunnel tests should be conducted in accordance with recognized industry guidance (Example: ASCE 7: 2022 and ASCE 49: 2022 in the USA).
- Additionally for systems using PV trackers:
 - Mounting system vibrations with natural frequencies less than 10 Hz may result in loads higher than predicted from static load calculations, depending on wind speed and damping ratio of the vibration mode, and should be considered to assess dynamic amplification factors;
 - Some mounting systems may be susceptible to instabilities due to vortex shedding which may not be addressed in building codes; guidance from qualified experts in boundary layer wind tunnel testing of PV systems may be required to address this risk;
 - Modules when mounted on trackers that rely on being operational or stowing at a specified angle in extreme wind or snow conditions should be verified to limit loads below the design load threshold considering the design controls implemented in such trackers.

5.1.15.4 Material accumulation on PV array

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

NOTE 1 Immediately after snow falls, these loads are often evenly distributed. After some time, they can be very unevenly distributed as the snow starts to slide down. This can lead to significant damage to the module and support structure. See IEC 62938 which provides a method for determining how well a framed PV module performs mechanically under the influence of inclined non-uniform snow loads.

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

6 Safety issues

6.1 General

There are many issues that affect the design, site selection and safety measures used in a PV system. IEC TR 63226:2021 may assist in design decisions related to managing risks for PV systems on buildings.

NOTE IEC TR 63226:2021 includes measures for reducing the risk of starting a fire and measures supporting emergency personnel in case of a fire.

6.2 Protection against electric shock

6.2.1 General

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

One of the following protective measures shall be used in the PV array and the DC bus:

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

6.2.2 Protective measure: double or reinforced insulation

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

All equipment used in a PV array (up to the DC terminals of the final PCE), shall be class II or equivalent insulation.

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

The requirements of IEC 60364-4-41:2005, Clause 414.4.5, shall apply with the following additions.

Basic protection is not required if the nominal voltage does not exceed 35 V DC as given by DVC A for wet locations (see Annex E and also IEC 62109-1).

6.3 Protection against thermal effects

6.3.1 General

Applicable national or local fire requirements shall be taken into account.

Protection against thermal effects is provided in this document by:

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

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

- all connections are correctly tightened to avoid points of failure over time,
- all connectors are properly locked into place, and

- all crimp connections are performed according to manufacturer's instructions. Special care should be taken in the case where DC connectors and wire harnesses are assembled on site.

NOTE 1 Failure of connectors (due to poor assembly or crimping or mismatch of connectors from different manufacturers) has been identified as a statistically significant failure mode.

NOTE 2 For connector requirements see 7.2.9.

6.3.2 Protection against fire caused by arcs

It is recommended that special measures be taken to protect against the effects of arc faults (refer to Annex D) in circuits on the DC side for installations of:

- building integrated PV systems.

Examples of such special measures include:

- Arc fault protection equipment (AFPE) in compliance with IEC 63027 or
- non-combustible material in proximity to parts on the DC side, e.g. stone tile roofing, fire-protected cable management systems.

NOTE 1 National committees may decide if the use of AFPEs is made a requirement or a recommendation in their national standard.

NOTE 2 A material is considered to be non-combustible if in compliance with ISO 1182 and ISO 1716, it does not support combustion.

Where an AFPE is in use and not integrated into the PCE the designer shall ensure that the AFPE is compatible with the PCE as required by IEC 63027.

NOTE 3 It is important that cabling loops be minimised in all connections to the AFPE to reduce noise which may cause nuisance tripping.

6.3.3 Protection against arc flash

Installers should be aware of the risk of arc flash in installations. An informative guide to arc flash in an installation is included in Annex I. Local codes and regulations may apply regarding protective equipment for installers and maintenance staff working on an installation. Installers and system designers may be required by local regulations to perform arc flash calculations and to provide signage providing operators and maintenance workers with information such as arc flash energy levels, approach boundaries, and PPE requirements.

6.4 Protection against the effects of insulation faults

6.4.1 General

The protective measures to be applied depend on how the PV system's DC circuits are earth referenced. Examples of earth configurations are given in Annex B, Figure B.1, Figure B.2 and Figure B.3.

PV arrays may be categorised as:

- functionally earthed PV arrays, i.e. an array with one of the main DC conductors connected to a functional earth, Figure B.1,
- non earth referenced PV arrays, i.e. a PV array that has none of its main DC conductors referenced to earth either directly or through the PCE. Figure B.2, and
- non separated PV arrays, i.e. PV arrays where PV DC circuits are connected to an earth referenced system via a PCE without separation, Figure B.3.

NOTE 1 System types are categorised by the type of earth referencing of the main DC PV array circuits in 6.4.1. This is independent of any frame earthing requirements.

NOTE 2 Functionally earthed systems include PV arrays connected via a protection/isolation means to the system earth or connected via a resistance to the system earth.

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

6.4.2 Segregation of PV circuits from other circuits

PV circuit conductors shall be separated from other conductors by:

- insulation on both sets of conductors, rated for the highest voltage of either circuit, or
- double insulation on either set of conductors, rated for the highest voltage circuit (e.g. a PV circuit double insulated to 1 500 V adjacent to a communications circuit insulated to 5 V. The double insulation on the PV circuit is sufficient to satisfy this requirement), or
- mechanical barriers that are either earthed or non-conductive, or
- a minimum distance of 25 mm to prevent contact between circuits and maintained by mechanical cable management means (e.g. cable ties, loom, etc.).

6.4.3 Earth fault detection and indication requirements

6.4.3.1 General

6.4.3.1.1 Overview

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

The following aspects of the system topology affect the approaches needed to protect against earth faults in the PV array:

- the PV system may or may not have separation between the PV array and the AC mains or other earthed power system,
- the PV array may or may not be functionally-earthed,
- the AC mains or other power system that the PV system output connects to may or may not be an earthed system.

In consideration of the above aspects, this document uses system types described in 6.4.1, to define requirements for protection against earth faults.

Earth fault detection may not function properly when electronic equipment (e.g. DCUs) is located between the PV-EFPE and the fault location. Manufacturers of the PV-EFPE and/or the electronic equipment should be contacted to ensure that the equipment is compatible with respect to earth fault detection.

Earth fault monitoring is achieved by a combination of measuring the insulation resistance of the array to earth and where applicable measuring earth fault currents from the array. This may be achieved either centrally at the main PV conductors as they enter the PCE or it may be achieved in a decentralised fashion by monitoring each set of sub array conductors. In large arrays it is helpful to be able to split the array into sections to increase the sensitivity of the detection system but decentralised systems require careful design to ensure proper operation.

The detection system shall be able to detect a fault at any location within the array, e.g. including a mid point or on a functionally earthed conductor.

6.4.3.1.2 Systems with more than one sub-array

Where the PV-EFP thresholds in this document are based on the PV array power rating, the system topology determines whether the thresholds are based on the total PV array power rating, or the rating of each sub-array, as follows in 6.4.3.1.3 and 6.4.3.1.4.

6.4.3.1.3 Separated sub-arrays

Where the PV sub-arrays are separated from each other throughout the system, including in the PCE, the PV-EFP thresholds apply to each sub-array based on its power rating.

6.4.3.1.4 Non-separated sub-arrays

Where the PV sub-arrays are not separated from each other, the PV-EFP insulation resistance measurement thresholds apply to the complete array and are based on the total power rating.

If the residual current monitoring is achieved by residual current measurements at the sub-array level the thresholds apply to each sub-array based on its power rating.

If the residual current monitoring is achieved by residual current measurements at the array level the thresholds apply based on the total array power rating.

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

System type	Non-separated Figure B.3	Functionally-earthed Figure B.1		Non-earth-referenced Figure B.2	
Earthing on the PV side	Unearthed	Functionally earthed		Unearthed	
Separation	Non-separated	Separated	Non-separated	Separated	Non-separated
Earthing on the load side ³ (AC mains or DC)	Earthed ²	Earthed or unearthed	Unearthed	Earthed ² or unearthed	Unearthed ²
PV array to earth insulation resistance measurement (insulation monitoring)	Measurement: According to IEC 63112 and 6.4.3.2		Measurement: According to IEC 63112 and 6.4.3.2		Measurement: According to IEC 63112 and 6.4.3.2
	Response: 1. According to IEC 63112 and 2. Indicate an earth fault in accordance with 6.4.3.6				
	Reset: If the insulation resistance of the PV array to earth has recovered to a value higher than the threshold setting, the system is allowed to automatically (re-)establish its normal connections and begin/resume operation				
PV array residual or earth current monitoring	Monitoring: Residual or earth current monitoring according to IEC 63112 and 6.4.3.3 and 6.4.3.4		Monitoring: Residual or earth current monitoring according to IEC 63112 and 6.4.3.3 and 6.4.3.4 or a functional earthing overcurrent protective device in accordance with IEC 63112 and 6.4.3.5		Detection/protection: Not required
	Response: 1. According to IEC 63112 ¹ and 2. Indicate an earth fault in accordance with 6.4.3.6.				Response: Not applicable
	Reset: If: 1. the residual or earth current has returned to a level below the limit in 6.4.3.3 and 6.4.3.4 or 6.4.3.5 or the protective device has reset or been replaced, and 2. the insulation resistance has recovered to a value higher than threshold setting, then the system is allowed to automatically re-establish its normal connections and resume operation.				Reset: Not applicable

¹ In a system with more than one sub-array IEC 63112 allows disconnection of the faulty sub-array from the PCE, therefore isolating the fault from earth, and allows continued operation of the system using the remaining unfaulted sub-arrays. IEC 63112 also in some cases allows the system to continue to operate from the full array, after interrupting the earth fault current by isolating the array from earth. Prompt servicing is essential to reduce the likelihood of a second fault occurring.

² It is generally not acceptable to functionally earth the PV array in a non-separated system connected to an earthed power system, as installation codes and standards do not allow a system to be earthed in more than one place (to prevent operational currents from flowing through earth).

³ "Load" side of the system refers to the output of the final PCE to which the PV array supplies power (e.g. the AC mains for a grid-interactive system or the DC load circuits for a DC system).

NOTE In this table separation means galvanically isolated.

6.4.3.2 Array insulation resistance detection

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

A means compliant with IEC 63112 shall be provided to measure the DC insulation resistance from the PV array to earth before starting operation:

- for PV-EFPE for functionally-earthed systems, in no case less often than once every 24 h,
- for PV-EFPE for non-separated systems, in no case less often than once every 24 h except for PV-EFPE incorporating fire hazard current monitoring according to 6.4.3.4 or 6.4.3.5, the monitoring interval may be adjustable to a value not exceeding 72 h in a large ground-mounted PV plant with continuous supervision by qualified on-site staff,
- for PV-EFPE for non-earth-referenced systems, the insulation shall be monitored continuously, except for equipment in which the operational power is derived from the PV array, monitoring is not required during periods where irradiance is inadequate for the PV-EFPE to function.

The functionality for insulation resistance monitoring or measurement may be provided within the PCE or other DC side equipment according to IEC 63112.

The insulation monitoring equipment shall be capable of detecting insulation resistance below its threshold (setting). The threshold or setting of the equipment shall be in accordance with the applicable limit in Table 2, based on rated system size.

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

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

PV array rating ¹ 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
¹ PV array rating is at the maximum power point at STC.	

For PV arrays for more than 500 kW, capacitance to earth should be estimated and taken into account for comparison to the maximum capacitance to earth rating of the IMD. Selection of an IMD with an inadequate capacitance rating may lead to improper IMD operation.

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

NOTE The values in Table 2 for PV array insulation resistance are significantly lower than typical thresholds for other types of systems. This is a necessary result of the characteristics of PV arrays. For more information refer to IEC 63112:2021, Annex B.

For functionally earthed and non-separated PV arrays, the earth reference shall be automatically disconnected during the measurement.

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

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

6.4.3.3 Shock hazard protection by a residual or earth current monitoring system

6.4.3.3.1 General

Shock hazard current monitoring according to IEC 63112 shall be provided to detect sudden changes in residual or earth fault current that may indicate a person coming in contact with live parts and earth and provide protection against shock through low current thresholds and fast response times. The sudden change in residual or earth current is above whatever steady state (continuous) baseline current is flowing under normal conditions.

6.4.3.3.2 Provisions for reset

After a shock hazard current monitoring response, the PV-EFPE may stop indicating a fault and may allow the host system to resume operation in the normal state if:

- the PV-EFP continuous (fire hazard) residual or earth current monitoring function is not detecting a fault, and
- the PV-EFP insulation resistance R_{iso} monitoring function measures a value higher than the threshold set in the PV-EFPE.

6.4.3.4 Fire hazard protection by a residual or earth current monitoring system

Where required by Table 1 and where an earth fault interrupting means according to 6.4.3.5 is not provided, PV array residual or earth current monitoring according to IEC 63112 shall be provided that is active whenever the PV array is connected to an earth reference and the monitoring device has operating power. The residual or earth current monitoring means shall measure the total (both AC and DC components) RMS residual or earth current.

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

The system topology determines whether the limits are based on the total PV array power rating, or the rating of each sub-array, as per the requirements in 6.4.3.1.2.

The PV-EFP residual or earth current monitoring system shall respond in accordance with Table 1 within 0,3 s and indicate a fault in accordance with 6.4.3.6 if the residual or earth current for the relevant section of the array exceeds:

- maximum 300 mA for PV array or subarray power rating ≤ 30 kW;
- the lesser of 5 A or (10 mA per kW) of PV array or subarray power where the relevant PV array or sub-array power rating > 30 kW.

If the PV array is functionally earthed via a resistor of high enough value such that the maximum residual or earth current that can occur on a single fault is less than the limits above, or where an earth fault interrupting device according to 6.4.3.5 is provided, then no fire hazard residual current monitoring is required. The resistor shall be rated for continuous application of the maximum voltage and power dissipation it will be subjected to under normal and fault conditions.

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

The residual or earth current monitoring system may attempt to re-connect in accordance with Table 1.

NOTE 2 This residual or earth current functionality may be integrated into a PCE or other DC side equipment. For non-separated PV arrays it may also be provided by a residual current circuit breaker according to IEC 61008 or IEC 61009 or residual current device according to IEC 60755 installed on the AC output circuit of the inverter.

6.4.3.5 Fire hazard protection by an overcurrent device in the PV array functional earthing path

Where required by Table 1, and where residual current monitoring according to 6.4.3.3 is not provided, a functionally earthed PV array shall be provided with an overcurrent protective device in the functional earthing path.

If the PV array is functionally earthed via a resistor of high enough value such that the maximum current through the array functional earthing path due to a single fault is less than the limits in Table 3 below, then a means of interrupting an earth fault is not required. The resistor shall be rated for continuous application of the maximum voltage and power dissipation it will be subjected to under normal and fault conditions.

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

- be rated for the maximum voltage of the PV array $U_{OC\ MAX}$, and
- have a rated breaking capacity not less than the maximum short circuit current of the PV array $I_{F\ ARRAY}$, (see F.3.4), and
- have a trip current not exceeding that given in Table 3.

Table 3 – Trip current of functional earthing overcurrent protection.

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

6.4.3.6 Earth fault indication

Earth faults shall be indicated as required by 6.4.3.1, Table 1.

PV-EFPE devices compliant with IEC 63112 provide both integral and remote means of fault indication.

Where operational staff and or system operators are in a location where the integral fault indication system will not readily be apparent then the remote indication system shall be implemented to ensure that the system operator or owner of the system becomes quickly aware of the fault. For example, the indication system may be a visible or audible signal placed in an area where operational staff or system owners will be aware of the signal or another form of fault communication like RS485, e-mail, SMS or similar. When implementing remote fault indication, manufacturer's instructions shall be followed.

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. Refer to 10.7.

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

6.5 Protection against overcurrent

6.5.1 General

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

PV modules are current limited sources but the modules and associated wiring can be subjected to overcurrents because they are typically connected in parallel and also may be connected to external sources (e.g. batteries). These parallel and additional sources increase available current into a downstream fault, and can cause backfeed (reverse) fault current into an upstream fault. The overcurrents can be caused by the sum of currents from

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

Refer to Annex G.

In order to determine the need for overcurrent protection and if required the size/rating of the protection it is necessary to know:

- The array configuration ie strings and subarrays where present
- The number of strings in the array and the number of strings in each sub-array
- Type of strings ie DCU strings only or strings with partial DCUs or no DCUs
- The K factor associated with the modules and module placement (See Annex F)
- The module short circuit current rating at STC
- DCU maximum current where DCUs are in use
- $I_{BF\ TOTAL}$ = sum of all backfeed currents not originating from the array itself (refer to Annex G)
- $I_{MOD_MAX_OCPR}$
- $I_{DCU\ OCPR}$ where applicable
- I_{STRING_MAX} see Clause F.2
- $I_{F\ STRING}$, $I_{F\ S-ARRAY}$, and $I_{F\ ARRAY}$ see F.3.1 to F.3.4.

6.5.2 Requirement for overcurrent protection

Overcurrent protection shall be provided in accordance with 6.5.3 to 6.5.5 and in accordance with PV module manufacturer's requirements.

The overcurrent protective devices of the DC side shall be either gPV fuses in accordance with the IEC 60269-6 standard or another devices in accordance with IEC 60947 (relevant parts) or IEC 60898-2 or IEC 60898-3. Overcurrent protective devices shall be selected such that the cable current carrying capacity, module maximum overcurrent protection rating and the maximum current of other equipment are not exceeded.

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

When circuit breakers with overcurrent protection elements are used, they may also provide the disconnecting means required in 7.3.1.

6.5.3 Requirements for overcurrent protection of circuits

6.5.3.1 Strings

String level protection aims at protecting the PV modules from damage due to reverse currents under fault conditions.

In the case where no DCUs are in use on a string then:

- a) If $(I_{F \text{ STRING}} + I_{BF \text{ TOTAL}}) > I_{MOD_MAX_OCPR}$ then string overcurrent protection shall be provided. Refer to Table 4.

Where DCUs are in use on all modules of a string then:

- b) If $(I_{F \text{ STRING}} + I_{BF \text{ TOTAL}}) > I_{DCU_OCPR}$ then string overcurrent protection shall be provided. Refer to Table 4.

Where strings contain DCUs on some modules but not all then both a) and b) above have to be checked.

6.5.3.2 Sub-arrays

Sub-array cable overcurrent protection is not compulsory. PV sub-array cables shall be protected under normal operation and under single fault conditions by either rating the cable to survive a worst case single fault condition (see 7.2.2) or have overcurrent protection according to Table 4 and cables according to 7.2.2.

6.5.3.3 Array

Array cable overcurrent protection is not compulsory. If no overcurrent protection is provided the cable size shall be as per Table 6 in the relevant section for no overcurrent protection. If overcurrent protection is provided then the rating shall be as per Table 4 and the cable size shall be as per Table 6 in the relevant section for protected by overcurrent protection.

In Table 4 the multiplier for the minimum overcurrent protection ratings is 1,0, but in situations where there is a high degree of variability such as frequent cloud focusing events consideration should be given to using a higher multiplier to avoid the situation where the overcurrent device trips frequently. Careful consideration should be given to fuse ratings especially when in enclosures as higher temperatures generally cause fusing current ratings to be reduced as temperature increases.

Table 4 – Overcurrent protection nominal rating

Circuit	Overcurrent protection nominal rating
PV string with no DCUs	$1,0 \times I_{\text{STRING MAX}} < I_n \leq I_{\text{MOD MAX OCPR}}$
For Partial DCU strings	$1,0 \times I_{\text{STRING MAX}} < I_n \leq I_{\text{MOD MAX OCPR}}$ and $I_n \leq I_{\text{DCU OCPR}}$
Full DCU strings	$1,0 \times I_{\text{STRING MAX}} < I_n \leq I_{\text{DCU OCPR}}$
Groups of strings	Where strings of PV modules either with or without DCUs are used, strings may be grouped in parallel (see Figure 11 for the case of PV strings) under the protection of one overcurrent device provided: $I_{ng} > 1,0 \times N_G \times I_{\text{STRING MAX}}; \text{ and}$ $I_{ng} < I_{\text{DEVICE_OCPR}} - ((N_G - 1) \times I_{\text{STRING MAX}})$ where N_G is the number of strings in a group under the protection of the one overcurrent device; I_{ng} is the overcurrent protection current rating of the group overcurrent protection device. $I_{\text{STRING MAX}}$ is the rating relevant to the type of group ie PV string, DCU string or partial DCU string. Refer to Clause F.1 $I_{\text{DEVICE_OCPR}} = I_{\text{MOD MAX OCPR}}$ for PV strings $I_{\text{DEVICE_OCPR}} = I_{\text{DCU OCPR}}$ for DCU strings $I_{\text{DEVICE_OCPR}} = I_{\text{MOD MAX OCPR}}$ or $I_{\text{DCU OCPR}}$ whichever is less for partial DCU strings
Sub-array	$I_n \geq 1,0 \times N_{\text{SA}} \times I_{\text{STRING MAX}}$
Array	$I_n \geq 1,0 \times N_S \times I_{\text{STRING MAX}}$
NOTE The row regarding "Groups of strings" is generally only applicable to thin film PV modules where the overcurrent protection rating is much higher than the short circuit rating.	

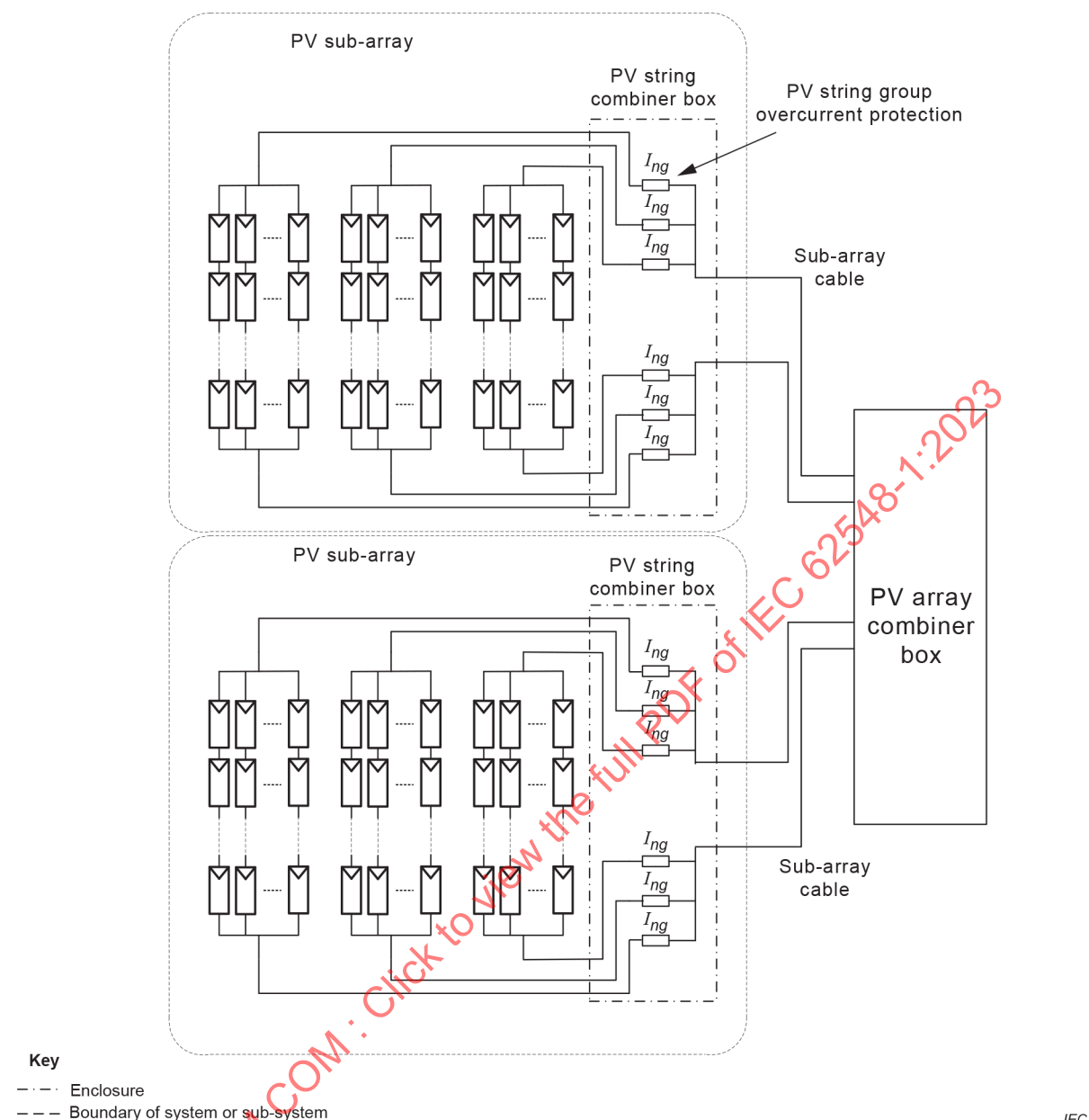


Figure 11 – Example of a PV array diagram where strings are grouped under one overcurrent protection device per group

6.5.4 Overcurrent protection for PV systems connected to batteries

Overcurrent protection for the PV array needs to take into account any backfeed from batteries. Refer to 5.1.9 and Annex G.

Overcurrent protection for the battery shall be placed in all active (non-earthed) conductors and located as close as practicable to the battery.

6.5.5 Overcurrent protection location

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

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

for array overcurrent protection devices, they shall be where the array main cables join the application circuit, energy storage device or the PCE (refer to Figure 2 to Figure 6).

NOTE 1 The location of the overcurrent protection devices at the end of those cables which are furthest away from the PV, sub-array or string is to protect the system and wiring from fault currents flowing from other sections of the PV array or from other sources such as batteries.

Overcurrent protection devices shall be in locations where they are capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, parts of the PV array, cupboards, benches or the like.

NOTE 2 For example a device behind a cover that requires a tool or key to open the cover for inspection satisfies this requirement.

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

An exception applies for systems that are not functionally earthed and that have only two active conductors per string (ie an array with no mid-point conductor) if:

- there is segregation by a physical barrier between string cables, sub-array cables and array cables, or
- there are no sub-array or array cables i.e. in small systems,
an overcurrent protective device need only be placed in one unearthed live conductor of the string cables, and the sub-array cables. The polarity of this conductor shall be the same for all cables thus protected.

The provision of a single overcurrent device is allowed for non earth referenced systems and non-separated systems under these circumstances because of the requirement for detection and alarm on a single earth fault and because of the double insulation required on conductors in all array circuits.

6.6 Protection against effects of lightning and overvoltage

6.6.1 General

The installation of a PV array on a building often has a negligible effect on the probability of direct lightning strikes; therefore it does not necessarily imply that a lightning protection system should be installed if none is already present. However, if the physical characteristics or prominence of the building do change significantly due to the installation of the PV array, it is recommended that the need for a lightning protection system be assessed in accordance with IEC 62305-2:2010 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. The type of any existing lightning protection system (LPS) shall be identified so that any integration of the PV installation into the LPS does not negate the performance of any isolated LPS, by defeating the required separation distance 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.

Guidance may be obtained by referring to IEC TR 63227.

6.6.2 Protection against overvoltage

6.6.2.1 General

All DC cables should be installed so that positive and negative cables of the same string and the main array cable should be bundled together, avoiding the creation of loops in the system. Refer to 7.3.3.3. The requirement for bundling includes any associated earth/bonding conductors.

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

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

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

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

NOTE 2 IEC 61643-32, describes selection and application principles for SPDs connected to photovoltaic installations

6.6.2.2 Risk assessment for lightning transient overvoltage

Where ground flash density data is available, a risk assessment should be carried out to evaluate whether protection against transient overvoltage is required. The method of risk assessment is based on the evaluation of the critical length:

L_{crit} and its comparison with L .

SPDs shall be installed on the DC side of the installation where: $L \geq L_{crit}$.

where

- L is the maximum route length (m) between the PCE and the connection points of the photovoltaic modules of the different strings, excluding any length of cable having an earthed metallic sheath, armour, screen or enclosure or any length of cable buried in the ground.
- L_{crit} (m) depends on the type of PV installation, and is calculated according to Table 5.

Table 5 – Calculation of the critical length L_{crit}

Type of installation	PV installation is attached to the building	PV installation is not attached to the building
L_{crit} (m)	$115/N_g$	$200/N_g$

- N_g is the lightning ground flash density (flash/km²/year) relevant to the location to the power line and connected structures. This value may be determined from ground flash location networks in many areas of the world (IEC 62305-2:2010, Clause A.1 or IEC 60364-4-44:2007, 443.5).

6.6.2.3 Surge protection devices (SPDs)

6.6.2.3.1 General

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

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

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

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

6.6.2.3.2 Surge protection devices (SPDs) DC

Where SPDs are required on the DC side of the PV installation, they shall comply with IEC 61643-31:2018 for the PV array circuit and be Class I or Class II tested.

Where SPDs are installed in a location where they may be subjected to high available short circuit current from a battery, the SPD shall have a short circuit withstand rating not less than the total available fault current at that location, or shall be protected by a current limiting fuse or other device that limits the fault current.

NOTE 1 PV SPDs are generally not rated for the high short-circuit currents normally associated with batteries.

NOTE 2 Batteries may be connected to a DC bus and may have dedicated SPDs for their protection.

If the PV system is connected to other incoming networks (such as telecommunication and signalling services), SPDs will be required to protect the information technology equipment.

6.6.2.3.3 Surge protection devices (SPDs) information technology equipment

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

7 Selection and erection of electrical equipment

7.1 General

All PV power conversion equipment shall be qualified to IEC 62109-1 and all other applicable parts of the IEC 62109 series according to the equipment type.

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

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 Component requirements

7.2.1 General

All components, wiring and equipment shall comply with the following requirements:

- be rated for DC use;
- in the case of PV circuits have a voltage rating equal to or greater than the PV array maximum voltage determined in F.1.1. For other circuits the voltage rating shall be equal to or greater than the maximum voltage rating of the circuit;
- all equipment shall be rated for the maximum common mode voltage to earth that will be experienced due to the location of the equipment in the circuit;

NOTE 1 Equipment may be used in a location within the system that imposes a voltage with respect to earth on the equipment that is different from its line to line voltage rating(s). For example, a DCU may be connected to a 65 V DC PV module that is part of a series string where the DC voltage to earth could be as much as 1 500 V.

- have a current carrying and (where applicable) interrupting rating equal to or greater than that shown in Table 6 or as given elsewhere in 7.2.6;
- have an IP rating suitable for their location and environment. Where equipment is exposed to the outside environment the IP rating shall be at least IP 54 compliant in accordance with IEC 60529.

In selecting the IP ratings humidity and dust are extremely important factors to be taken into account. Care should be taken in design to avoid condensation buildup within equipment while still excluding dust, and

- shall be UV resistant unless installed in a location protected against sunlight;
- have a temperature rating appropriate to their location and application;

NOTE 2 PV arrays are installed in full sun and ambient temperatures and temperatures inside enclosures can be very high. This is an important consideration when selecting components.

Where DCUs are used in the design of a PV array, attention is drawn to the voltage and current ratings related to DCUs described in F.1.2, and F.2.

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

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

7.2.2 Current rating of PV circuits

The current carrying capacity of PV circuits, shall be equal to or greater than the minimum current rating calculated from Table 6.

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 rating of circuits ie the minimum current upon which cable cross-sectional area and or other circuit ratings should be chosen ^{a, b}
PV string	PV string overcurrent protection not provided	Where there is only one string in the system, the string becomes the array. See requirements for the array. In all other cases: $I_{F \text{ STRING}} + I_{BF \text{ TOTAL}}$ NOTE 1 There are requirements in some cases to install overcurrent protection on strings, see 6.5.3.1. NOTE 2 There is always an option to install overcurrent protection on string cables to reduce cable size as a design option. NOTE 3 If the PV array cable is protected by an overcurrent device then $I_{BF \text{ TOTAL}}$ in the above formula may be replaced by the current rating (I_n) of that PV array overcurrent protection device whichever is the least. NOTE 4 If the PV sub-array cable is protected by an overcurrent device then the above formula may be replaced by $I_n + (N_{SA} - 1) \times I_{\text{STRING MAX}}$ Where N_{SA} is the number of parallel strings in that PV sub-array and I_n is the current rating of that PV sub-array overcurrent protection device.
	PV string overcurrent protection provided	Current rating (I_n) of the PV string or DCU string overcurrent protection device (refer to 6.5)
PV sub-array	PV sub-array overcurrent protection not provided	If the PV array cable is not protected by an overcurrent, the sub array cable rating shall be: $I_{F \text{ S-ARRAY}} + I_{BF \text{ TOTAL}}$ If the PV array cable is protected by an overcurrent device then $I_{BF \text{ TOTAL}}$ in the above formula may be replaced by the current rating (I_n) of that PV array overcurrent protection device
	PV sub-array overcurrent protection provided	Current rating (I_n) of the PV sub-array overcurrent protection device (refer to 6.5)
PV array	PV array overcurrent protection not provided	The greater of the following: a) $I_{F \text{ ARRAY}}$ refer to Clause F.3 b) $I_{BF \text{ TOTAL}}$ refer to Annex G
	PV array overcurrent protection provided	Current rating (I_n) of the PV array overcurrent protection device (refer to 6.5)
Battery	Battery overcurrent protection provided	Current rating (I_n) of the battery overcurrent protection device
^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 temperature at the site with ambient air temperature plus 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.		

7.2.3 PV modules

7.2.3.1 Operational conditions and external influences

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

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

7.2.3.2 Equipment class

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

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

For protection against electric shock,

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

7.2.3.3 Additional standards for PV modules

Guidance on additional PV module reliability may be provided by the following IEC standards.

- IEC 61701, Photovoltaic modules – salt mist corrosion testing (in coastal environments)
- IEC 62716, Photovoltaic modules – ammonia corrosion testing (in intensive livestock environments)
- IEC TS 62804-1, Photovoltaic (PV) modules – Test methods for detection of potential-induced degradation – Part 1: Crystalline silicon
- IEC 62938, Photovoltaic (PV) modules – Non-uniform snow load testing
- IEC 62941, Terrestrial photovoltaic (PV) modules – Quality system for PV module manufacturing
- IEC TS 63126, Guidelines for qualifying PV modules, components and materials for operation at high temperatures
- IEC TS 63209-1 Photovoltaic modules – Extended-stress testing – Part 1: Modules

7.2.4 PV array and PV string combiner boxes

7.2.4.1 Environmental effects

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

7.2.4.2 Location of PV array and PV string combiner boxes

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

NOTE 1 Under some conditions, combiner boxes can be part of the PCE. See 7.3.1.2.

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

7.2.5 Fuses

7.2.5.1 Accessibility

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

7.2.5.2 Fuse links

Fuse links used in PV arrays shall comply with the following requirements:

- be rated to interrupt fault currents from the PV array and any other connected power sources such as batteries, generators and the grid, if present;
- be of type gPV complying with IEC 60269-6 unless the prospective shortcircuit current due to sources such as batteries requires the use of higher rated fuses.

Overcurrent protection should be graded to ensure coordination between different current rated sections of the system..

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

Fuse ratings need to take into account the environment in which they are located. Fuses should typically be derated for higher temperatures and when enclosed.

Temperature derating factors should be considered while sizing any electrical equipment. Fuses in a different environment to the cable or equipment they are protecting may require careful rating assessment to avoid nuisance tripping or under protection.

NOTE Fuses when enclosed in a fuse holder may change their characteristic due to increases in operating temperature.

7.2.5.3 Fuse bases and fuse holders

Fuse bases and fuse holders shall have a current rating equal to or greater than the corresponding fuse link.

7.2.6 Circuit breakers used for overcurrent protection

Circuit breakers used for overcurrent protection in PV arrays shall:

- a) comply with IEC 60947-2,
- b) be rated to interrupt currents in both directions (fault currents in a PV array may flow in the opposite direction to normal operating currents,
- c) be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present, and
- d) be rated or set for overcurrent according to 6.5 for the relevant circuit,

The current ratings of circuit breakers shall be selected as follows:

The required nominal current rating I_n according to Table 4.

The nominal current rating I_n of the circuit breaker at the PV array maximum voltage shall be greater than or equal to the operational current for the circuit to which it is fitted.

NOTE In the case of a PV circuit without DCUs the operational current is the maximum power point current at the switch location. The maximum power point current could be limited by a PCE to a value lower than the maximum power point current of the PV array. In the case of a DCU output circuit the operational current is the sum of maximum output current rating of all parallel connected DCUs at the switch location.

The current making and breaking capacity of the circuit breaker at the PV array maximum voltage shall be rated as a minimum to make and interrupt the current rating of the circuit (refer to Table 6) to which it is fitted.

Temperature derating factors should be considered while sizing any electrical equipment. Circuit breakers in a different environment to the cable or equipment they are protecting may require careful rating assessment to avoid nuisance tripping or under protection.

7.2.7 Isolation means and isolation means with breaking capabilities

7.2.7.1 General

In the context of this document, "isolation means" is used as a general term to specify a method of electrical disconnection in a circuit which provides a method of electrical isolation but may not be load breaking. Examples include: fuse holders, plugs, sockets and connectors.

An "isolation means with breaking capabilities" provides both load breaking and isolation and may be:

- a) switch disconnectors according to 7.2.7.2 ,or
- b) circuit breakers with isolation according to 7.2.7.3 ,or
- c) in the case of PCE isolation, the isolation means with breaking capabilities may be according to 7.2.7.4,
- d) a load breaking plug connection according to 7.2.7.5

Devices providing an isolation means shall:

- comply with voltage and current ratings and environment protection according to 7.2.1;
- not have exposed live parts in connected or disconnected state.

Temperature derating factors should be considered while sizing any electrical equipment.

7.2.7.2 Switch-disconnector

A switch-disconnector used as an isolation means with breaking capabilities shall comply with IEC 60947-1 and IEC 60947-3 and have mechanisms that have independent manual operation.

NOTE 1 Independent manual operation refers to a mechanism in which the speed of separation of the contacts is independent of the way in which the user operates the actuator (handle, knob, etc.).

The ratings of switch disconnectors shall be selected as follows:

- a) The required current carrying capacity I_{the} (thermal enclosed current rating according to IEC 60947-3) of the switch shall be calculated according to:

$I_{the} \geq$ the current rating of the circuit to which they are fitted as calculated in Table 6.

The value of I_{the} will depend on the installation conditions where I_{the} shall be de-rated for temperature conditions at the installation location e.g. indoor, outdoor, exposed to sun, etc.

NOTE 2 The I_{the} value is not dependant on voltage ratings.

The current carrying capacity at the operating ambient temperature shall be rated according to IEC 61439-1 and IEC 61439-2 for enclosures for assemblies.

- b) The rated operational current I_e at the PV array maximum voltage shall be greater than or equal to the operational current for the circuit to which it is fitted.

NOTE 3 In the case of a PV circuit without DCUs the operational current is the maximum power point current at the switch location. The maximum operational current could be limited by a PCE to a value lower than the maximum power point current of the PV array. In the case of a DCU output circuit, the operational current for the switch is the sum of maximum output current ratings of all parallel connected DCUs at the switch location.

- c) The current making and breaking capacity at the PV array maximum voltage shall be rated as a minimum to make and interrupt the current rating of the circuit (refer to Table 6) to which it is fitted.

NOTE 4 The I_{cm} , I_{cn} and I_e values vary dependent on the voltage rating of the switch.

NOTE 5 The minimum current rating of the circuit includes fault current.

- d) It shall interrupt current and isolate all live conductors (including functionally earthed conductors if present).

In addition, switch-disconnectors shall comply with one of the following requirements:

- e) Switch-disconnector of utilisation category DC-PV2 (fault currents in a PV array may flow in the opposite direction to normal operating currents) according to IEC 60947-3.
- f) Switch-disconnector tested according to utilisation category DC-PV1 that has additionally been qualified to the IEC 60947-3 requirements for making and breaking fault currents in the reverse direction.
- g) where the switch-disconnector is used for a PCE where backfeed current is zero and no current can flow in the reverse direction from any other sources the utilisation category of the switch may be DC-PV1.

7.2.7.3 Circuit breakers used for isolation

Circuit breakers used for isolation shall:

- a) comply with IEC 60947-2 and marked as an isolation device,
- b) be rated to interrupt currents in both directions (fault currents in a PV array may flow in the opposite direction to normal operating currents),
- c) be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present,
- d) shall interrupt current and isolate all live conductors (including functionally earthed conductors if present).

The nominal current rating I_n of the circuit breaker at the PV array maximum voltage shall be greater than or equal to the operational current for the circuit to which it is fitted.

NOTE In the case of a PV circuit without DCUs the operational current is the maximum power point current at the switch location. The maximum power point current could be limited by a PCE to a value lower than the maximum power point current of the PV array. In the case of a DCU output circuit the operational current is the sum of maximum output current rating of all parallel connected DCUs at the switch location.

The current making and breaking capacity of the circuit breaker at the PV array maximum voltage shall be rated as a minimum to make and interrupt the current rating of the circuit (refer to Table 6) to which it is fitted.

Temperature derating factors should be considered while sizing any electrical equipment.

7.2.7.4 Isolation means with breaking capabilities incorporated in PCEs

7.2.7.4.1 General

Isolation means with breaking capability within a PCE shall be a switch disconnector according to 7.2.7.2 or a circuit breaker according to 7.2.7.3 or Isolation means with breaking capabilities using electronics according to 7.2.7.4.2.

7.2.7.4.2 Isolation means with breaking capabilities using electronics

Non-load-break rated isolation means may be used in combination with electronic load breaking means where:

- The load breaking electronics are integral to the PCE

- The electronic load breaking system is single-fault tolerant as indicated by the PCE manufacturer's installation documentation
- The interruption shall be initiated by not more than two deliberate actions by the user
- the interrupting means shall be rated to interrupt the maximum short circuit rating $I_{CP\ PV}$ (according to IEC 62109-1) of the PCE as indicated by the PCE manufacturer's installation documentation
- the non load break isolation means is labeled "Do Not Disconnect Under Load" and shall require either two independent actions, or the use of a tool to disconnect.

The electronic load breaking system single fault-tolerance requirement means that the current will be interrupted before the isolation means is operated, even with a single fault applied in the PCE and with no further action from the user.

NOTE 1 The fault tolerance requirement is intended to ensure that the non-load-break rated isolation means will not be subjected to making or breaking load current due to a fault in the electronic load breaking system.

NOTE 2 An example is a PCE in which initiation causes a power transistor to turn off, and fault tolerance is provided by a second independent device capable of interrupting the current in case of failure of the transistor.

NOTE 3 Requirements for the electronic load-breaking means included in a PCE are under consideration in the second edition of IEC 62109-1.

7.2.7.5 Load break plug connections

Plug connections compliant with both IEC 62852 for PV connector safety and IEC 61984 for interruption under load may also be used as an isolation means with breaking capabilities.

NOTE Only specially constructed plugs and sockets are capable of interrupting load safely. Plugs and sockets which are not specially constructed for load interruption if disconnected under load represent a safety risk and generally incur damage to the connection which will compromise the quality of the electrical connection and could lead to overheating of the connection.

7.2.8 Cables

7.2.8.1 Size

7.2.8.1.1 General

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

- overcurrent protection ratings where in use,
- the minimum current rating (refer to Table 6),
- voltage drop and prospective fault current.

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

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

7.2.8.1.2 Current carrying capacity (CCC)

The minimum cable sizes for PV array wiring, shall be based on the minimum current rating of the relevant circuit shown in Table 6, and the current carrying capacity of cables as specified in Table A.3 of IEC 62930:2017 taking into account the current rating conversion factors for different ambient temperatures in Table A.4 of IEC 62930:2017. Cable derating factors taking into consideration cable location and installation method, according to IEC 60364-5-52, shall

be applied. Where an inverter or other power conversion equipment is capable of providing backfeed current into the array under fault conditions, the value of this backfeed current shall be taken into account in all calculations of circuit current ratings. Refer to Annex G.

7.2.8.2 Type

Cables used within the PV array shall meet the following requirements:

- All PV cables shall:
 - have a voltage rating equal to or greater than the PV array maximum voltage determined in Clause F.1, and have a temperature rating according to the application.
 - where movement of the cable is expected, the conductor of the cable shall be flexible qualified to IEC 62930, and marked as IEC131 or IEC133. Examples where such cables are required are: string cables; trackers, and where cables are connected using plugs and sockets. Refer to IEC TS 62738 for more guidance on wire management for trackers.
 - where no movement of the cable is expected, the conductor of the cable can be stranded (class 2 of IEC 60228) or flexible (class 5 of IEC 60228).
 - where installed in buildings it is recommended that halogen free cables are used i.e. cables qualified to IEC 62930, and marked as IEC131 or IEC132.
- PV string cables shall comply with IEC 62930.
- PV sub-array and array cables that are not direct buried shall comply with IEC 62930, or shall:
 - In all systems operating at voltages above DVC A, be selected for the erection method so as to minimise the risk of earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables, particularly for cables that are exposed or laid in metallic tray or conduit. This can also be achieved by reinforcing the protection of the wiring as shown in the examples of Figure 12.
 - be suitable for DC application.
 - If exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection, or be installed in UV-resistant conduit.
- PV array and sub-array cables that are direct-buried shall be suitable for direct burial, or qualified to other national standards governing direct-buried cables. Special cables having a higher protection against mechanical stress and ingress of water or appropriate protection measures shall to be provided if a cable is required to be installed in ground. PV cables qualified to only IEC 62930 are not able to be direct buried. Cables used in situations where the cable may be permanently submersed in water shall be suitable for this type of application e.g. condition AD8 of IEC 62440:2008.

NOTE 1 Cables in buried conduit may be expected to contain water for long periods through condensation or water ingress.

NOTE 2 UL 493 may be useful for qualifying cables for use in direct buried applications.

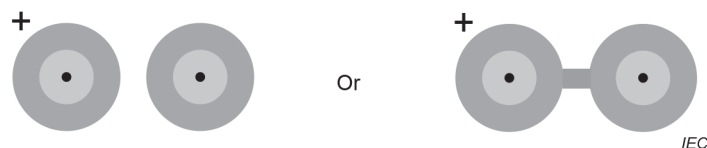


Figure 12a – Single or multi-conductor cable where each conductor is both insulated and sheathed

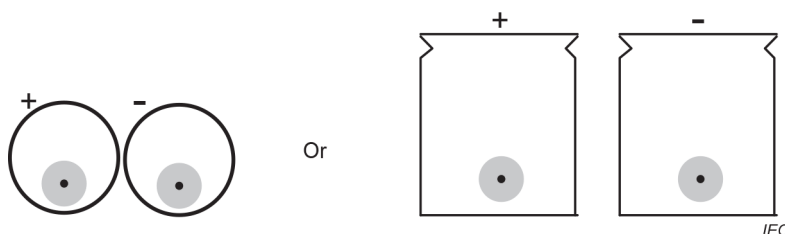


Figure 12b – Single conductor cable – in suitable insulated conduit/trunking

Figure 12 – Examples of reinforced protection of wiring

7.2.8.3 Erection method

The general requirements of IEC 60364-5-52 shall be considered. Additionally Annex A of IEC 62930:2017 shall be considered.

Cables shall be supported so they do not suffer fatigue due to wind/snow affects. They shall also be protected from sharp edges. Methods of securement shall prevent cable damage due to excessive stress or tension due to loading or sharp radii bends. (Refer to manufacturer's instructions for minimum permissible bend radius for recommended radii, see Table 3 of IEC 62440:2008).

Cables shall be supported so that their properties and installation requirements are maintained over the stated life of the PV plant. Allowance shall be made for expansion and contraction of cables. (Taut cables may cause strain on connections.)

All non-metallic conduit and ducting exposed to sunlight shall be of a UV resistant type.

Cables shall be protected from flora and fauna where these are a known problem at the installation site.

NOTE 1 In some locations rodents can cause cable damage with potential for earth faults and arc faults.

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

NOTE 2 Conduit, ducting and cable ties installed under an array can still be exposed to reflected UV radiation. Metallic cable ties can have sharp edges which over time and subject to wind affects can cause cable damage.

7.2.9 Plugs, sockets and connectors in PV circuits

Plugs and socket connectors mated together in a PV system shall be of the same product family 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, or
- a plug and socket of different product family from the same manufacturer shall not be used to make a connection.

NOTE 1 For more information regarding hazards and issues related to mismatched PV connectors refer to IEC TR 63225. When standards are in place regarding a common specification between connectors of two manufacturer's products, this will be considered for a future revision of IEC 62548.

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

- IEC 62852;
- be rated for DC use;
- have a voltage rating equal to or greater than the PV array maximum voltage determined in Clause F.1;
- 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 6);
- be capable of accepting the cable used for the circuit to which they are fitted;
- require a deliberate force to separate;
- if accessible by untrained people then shall be of the locking type where two independent actions or a tool are required to disconnect;
- have a temperature rating suitable for their installation location;
- if multi-polar, be polarised;
- comply with class II for systems operating above DVC-A voltages;
- if exposed to the environment, be rated for outdoor use, be UV-resistant and be of an IP rating suitable for the location;
- shall be installed in such a way as to minimise strain on the connectors (e.g. supporting the cable on either side of the connector);
- plugs and socket outlets normally used for the connection of household equipment to low voltage AC power shall not be used in PV arrays;

NOTE 2 The purpose of this requirement is to prevent confusion between AC and DC circuits within an installation.

- shall be installed in such a way as to minimize contamination by the environment (e.g. soil, standing water, insects, dust, stickers, paint, heat shrink tubing);
- unmated connectors (or "connectors not in use") shall be protected by a dust cap (or "protective cap") against ingress of pollution like dust or moisture.

The requirements of this section do not apply to connections that are designed as connectors and are located inside the housing of a piece of equipment, for example inside a PCE. In that case the requirements of the respective equipment standards apply.

7.2.10 Wiring in combiner boxes

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

7.2.11 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 $2 \times K_U \times U_{OC\ MOD}$ of the protected module;
- have a current rating of at least $1,4 \times K_I \times I_{SC\ MOD}$;
- be installed according to PV module manufacturer's recommendations;

- be installed so no live parts are exposed;
- be protected from degradation due to environmental factors.

NOTE For calculation of K_U and K_I refer to Annex F.

7.2.12 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 $1,3 \times$ PV array maximum voltage determined in F.1.1;
- 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:
 - $1,4 \times I_{SC\ MOD}$ for PV strings;
 - $1,4 \times I_{SC\ MOD} \times N_{SA}$ for PV sub-arrays;
 - $1,4 \times I_{SC\ MOD} \times N_S$ for PV arrays;
- be installed so that 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.

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

PCEs shall comply with IEC 62109-1 and any other applicable part of the IEC 62109 series.

NOTE At present IEC 62109-2 covers inverters, IEC 62109-3 covers PV module integrated PCEs.

The PV input of DCUs and PCEs shall be rated for:

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

The absolute maximum prospective short circuit current rating of a PCE's PV input port is $I_{CP\ PV}$. The PCE shall be selected with an $I_{CP\ PV}$ rating greater than the maximum short circuit current rating of the PV circuit to which it is connected.

7.3 Location and installation requirements

7.3.1 Isolation means

7.3.1.1 General

An isolation means shall be provided in PV arrays to isolate the PV strings, sub-arrays, and array from equipment and from other circuits to allow for maintenance and inspection tasks to be carried out safely. Refer to 7.2.6 for requirements related to isolation means and isolation means with breaking capabilities.

Devices shall be provided in accordance with Table 7.

Table 7 – Isolation means in PV array installations

Circuit or part of circuit	Type of isolation means	
PV string, DCU string	Isolation means ^a	Required
PV sub-array not directly connected to a PCE	Isolation means ^a	Required
	Isolation means with breaking capabilities ^{b,c}	Recommended
PV sub-array, directly connected to a PCE	Isolation means with breaking capabilities ^{b,c}	Required
PV array	Isolation means with breaking capabilities ^{b,c}	Required
PV modules directly connected to DCU within the PV array	Isolation means with breaking capabilities ^{b,c,d}	Required
^a Sheathed (touch safe) connector, fuse combination unit, or isolator are examples of suitable isolation means. ^b Fuse-switch disconnectors, switch disconnectors and circuit-breakers are examples of isolation means with breaking capabilities. ^c The device may be a single device or a combination of devices, providing isolation and breaking function. ^d In the case of one or two modules connected to a DCU refer to 7.3.1.2e) for breaking capability exceptions.		

Means of isolation that are not capable of breaking load current shall be marked "Do not disconnect under load" and shall be able to be opened only by use of a tool or key.

Multiple isolation means may be mechanically integrated in one device and commonly operated.

7.3.1.2 Isolation means for power conversion equipment (PCE)

Where required by 7.3.1.1 the isolation means for PCEs shall be accessible and meet the requirements of an isolation means with breaking capabilities (refer to 7.2.6).

NOTE 1 Local installation codes can allow certain types of systems to be installed without a DC isolation means with breaking capabilities between modules and the PCE, for example below certain voltage and current thresholds, where DC isolation means with breaking capabilities 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.

NOTE 2 While this document only deals with the PV side of the system, isolation of a PCE is critically dependent on also isolating other sources: e.g. the AC grid, aux AC source, battery, etc.

Where isolation means are required, they shall be installed in all current carrying conductors.

It shall be possible to isolate the PCE from all poles of the PV module/s such that maintenance of the PCE is possible without risk of electrical hazards, except for PCE permanently attached to a PV module in accordance with IEC 62109-3, such that servicing is only possible by replacing the combined assembly

NOTE 3 Module integrated PCEs are ones that are permanently attached to a PV module. (e.g. a PCE bonded to a PV module backsheet).

Smaller PCEs are often serviced by replacement, rather than being repaired in place,; whereas larger PCEs are usually repaired in place (i.e. by replacing internal components). Where a PCE or the main power electronic section of a PCE is removed the remaining wiring shall be touch safe.

For PCEs repaired by replacement, one of the following methods shall be used to allow safe isolation of the PCE:

- a) an adjacent isolation means with breaking capability, physically separate from the PCE; or
- b) an isolation means with breaking capability that is mechanically connected to the PCE and allows the PCE to be removed from the section containing the isolation means without risk of electrical hazards; or

NOTE 4 This method typically uses a fixed chassis containing the isolation means with load breaking capability and a removable section containing the serviceable electronic section of a PCE.

- c) an isolation means with breaking capability located within the PCE, where the means of isolation can only be operated with a tool and is labeled with a readily visible warning sign or text indicating "Do not disconnect under load"; or

NOTE 5 This method is typically used where a PCE has a load breaking means internal to the PCE and plug connections for isolation.

- d) where a PCE is connected to only one or two modules, and where the load breaking capability is provided by covering one or two PV module/s to prevent the module/s from generating current. The PCE shall include 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". The documentation of the PV system shall include a description of a safe system of work and materials required to achieve safe load breaking.

NOTE 6 A detailed documentation of the covering procedure is very important. For example, turning a PV module top down may work for some module technologies, but may not work for others, like bifacial modules.

For PCEs repaired in place, the isolation means with breaking capability 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 isolation means with breaking capability may be in the same enclosure with the PCE, provided that protection is provided against inadvertent contact with any parts that remain energized with the isolation means opened.

Suitably rated circuit-breakers, having the characteristics described in 7.2.7.3 and used for overcurrent protection may also provide the function of an isolation means with breaking capabilities.

Isolation means not capable of breaking load current shall be marked "Do not disconnect under load".

An additional DC isolation means with breaking capabilities may be specified for systems with long DC cable runs through buildings. This isolation means with breaking capabilities is generally used at the point of cable entry into the building.

Where multiple sub-array isolation means are used to isolate a PCE they shall be installed close to (i.e. within 3 m and in line of sight of) the power conversion equipment. In this case the isolation means with load breaking capabilities for the sub-arrays shall all be load breaking isolation means. This distance is also applicable to initiators for remote controlled sub-array isolation means, where the sub-array combiners are not close to the PCE. In this case remote disconnection is allowed where an indication of the proper operation of the disconnection function is given at the PCE.

The distance between the isolation means and the PCE shall be measured from the outside boundary of the PCE to the isolation means.

Where multiple isolation means 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 within 3 m and in line of sight of the PCE and there shall be a warning sign indicating the need to isolate multiple supplies to isolate the equipment.

An exception for PV power generation plants is allowed where multiple sub-array isolation means are used to isolate a PCE. In the case of PV power generation plants the isolation means with load breaking capabilities for the sub-arrays do not need to be within 3 m and in line of sight provided they are all lockable.

When using isolation means for a PCE the conductors should always be tested to make sure they are not live before carrying out any maintenance.

7.3.2 Earthing and bonding arrangements

7.3.2.1 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, insulation monitoring and residual current detection). Earthing/bonding of exposed conductive parts of a PV array shall be performed in accordance with Figure 13 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 7.3.2.4.3 and 7.3.2.4.4 for further details.

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

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

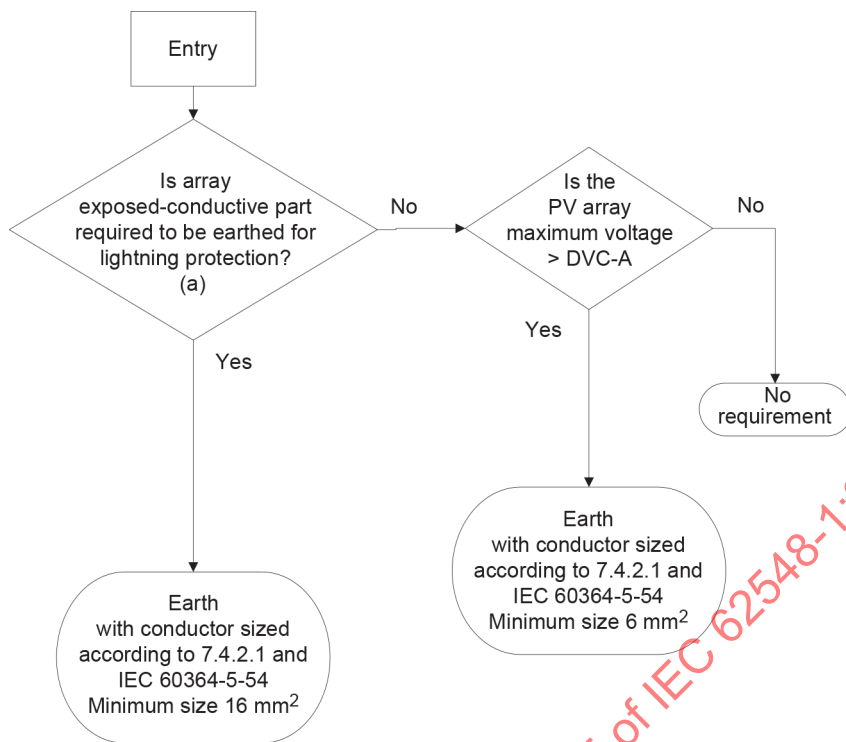
Annex B contains examples of functional earthing arrangements in PV systems.

7.3.2.2 Bonding conductor size – separated systems

The conductor used to earth exposed metallic support structure of the PV modules including cable trays shall have a minimum size of 4 mm² copper or equivalent.

For some system configurations the minimum conductor size may need to be larger due to lightning system requirements (refer to Figure 13).

Figure 14 shows an example of earthing requirements of exposed conductive parts on a PV array.

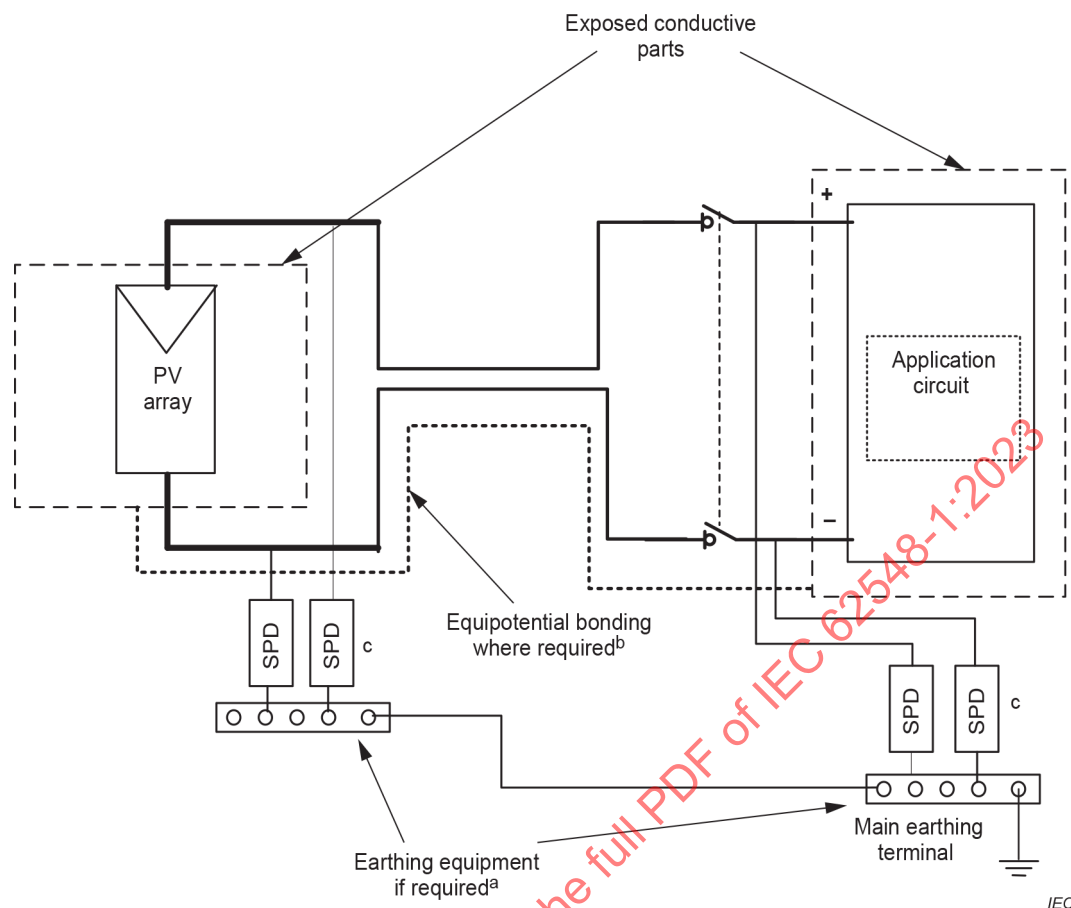


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NOTE To realize earthing in the field, see IEC 62305-3.

(a) To answer this question, see the recommendations of IEC 62305-2:2010 and IEC 62305-3 or refer to local information such as number of thunder days per year or other lightning characteristics. Assessment should include relative position of the PV array to other buildings, and structures able to protect the PV array from lightning strikes.

Figure 13 – PV array exposed conductive parts functional earthing/bonding decision tree



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

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

^c Overvoltage protection surge protective devices (SPDs).

Figure 14 – Exposed conductive parts earthing in a PV array

7.3.2.3 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.

7.3.2.4 Equipotential bonding

7.3.2.4.1 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 / 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 13.

7.3.2.4.2 PV array bonding conductors

To reduce induced voltages due to lightning, 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 the area of conductive loops.

7.3.2.4.3 Functional earthing terminal of PV array

When the PV array is earthed as described in 7.3.2.1d), the connection to earth shall be made at a single point and this point shall be connected directly or indirectly to the main earthing terminal of the electrical installation if present.

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

The functional earth connection may be established inside the PCE.

In systems without batteries, the connection to earth shall be on the load side of the PV array isolation device with breaking capabilities.

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

NOTE If in some countries isolation means are required/allowed to interrupt functional earth conductors, the location of the earth connection is important to interruption of earth fault currents.

7.3.2.4.4 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 lesser of:

- the nominal rating of the earth fault interrupting means (refer to 6.4.3.4 and 6.4.3.5), or
- where a resistor is used in the functional earth path (PV array maximum voltage)/ R , where R is the resistance value used in series with the functional earth connection.

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

7.3.3 Wiring system

7.3.3.1 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.

7.3.3.2 Compliance with wiring standards

The PV array wiring shall comply with the cable and installation requirements in this document and the wiring requirements mandated by local standards and regulations. In absence of national standards and or regulations, wiring systems used in PV arrays shall comply with IEC 60364 (all parts).

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

7.3.3.3 Wiring loops

To reduce the magnitude of transient-induced overvoltages and EMC interference with other installations, the PV array wiring should be laid in such a way that the area of conductive loops is minimum, for example by laying cables in parallel as shown in Figure 15.

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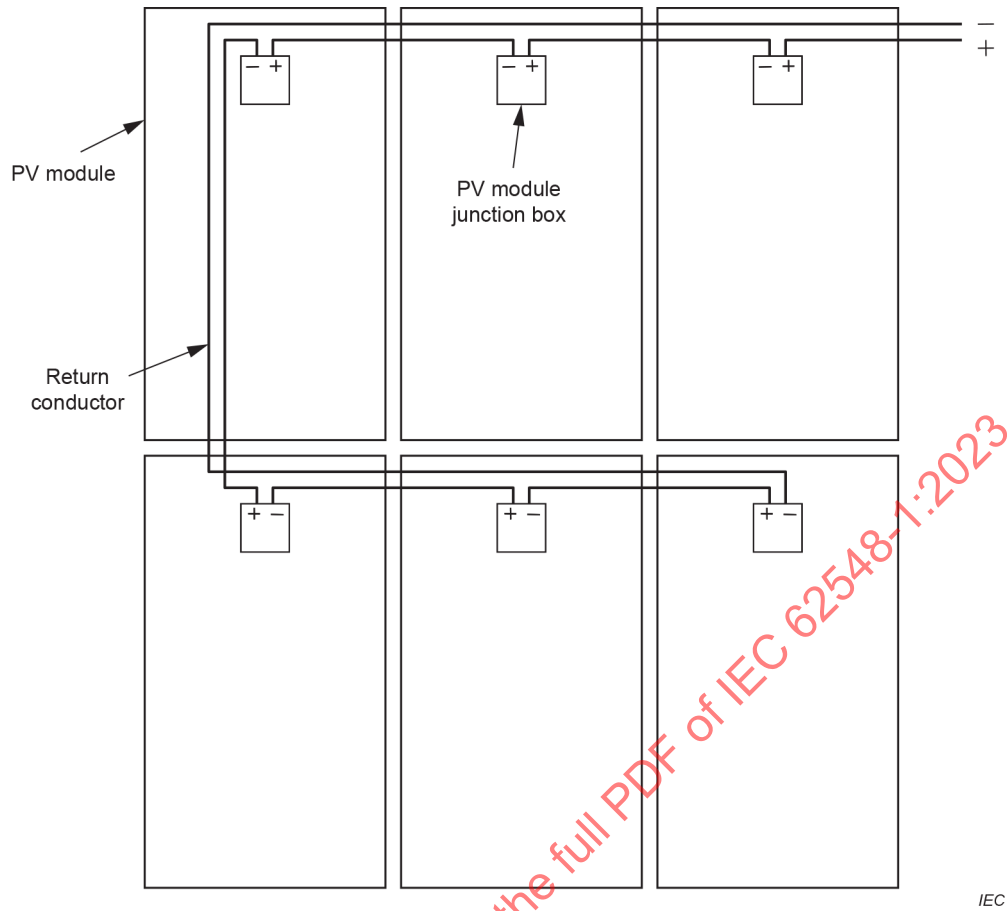


Figure 15a) – Wiring minimum loop area, example 1

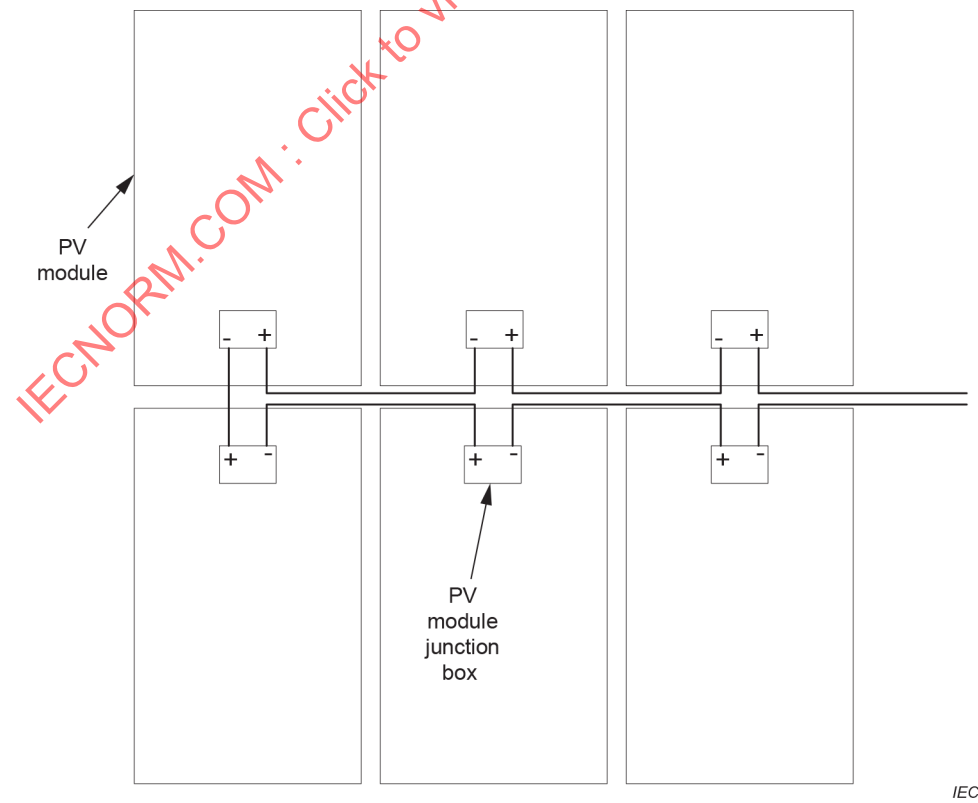


Figure 15b) – Wiring minimum loop area, example 2

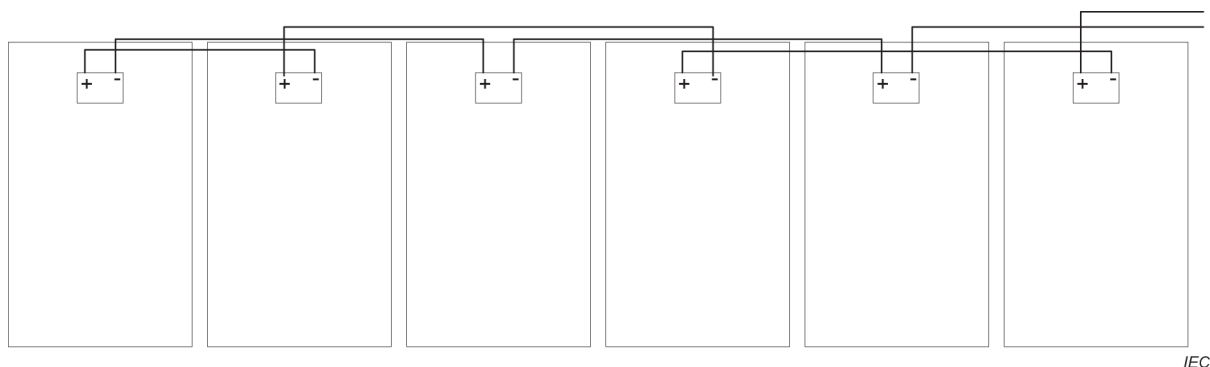


Figure 15c) – Wiring minimum loop area, example 3

Figure 15 – Examples of string wiring with minimum loop area

7.3.3.4 String wiring

In the case where wiring of strings between modules or DCUs 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.

7.3.3.5 Wiring of enclosures

The following provisions apply to the installation of wiring systems for equipment.

Where conductors enter enclosures without conduit, a tension relief system shall be used to avoid strain on connections inside the enclosures (for example by using a gland connector).

All cable entries when installed shall maintain the IP rating of the enclosure. Conduit openings shall be sealed according to manufacturer's instructions. Expanding foam shall not be used to seal conduit openings.

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

7.3.3.6 Wiring identification

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

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

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

8 Acceptance

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

9 Operation/maintenance

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

Provision should also be given during the design phase to the PV system's ongoing operation and maintenance requirements, per IEC 62446-2.

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 in Annex A.

10.2 Requirements for signs

All signs required in Clause 10 shall:

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

Two examples of signs are given in Annex A.

10.3 Identification of a PV installation

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

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

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

10.4 Labelling of PV array and PV string combiner boxes

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

10.5 Labelling of isolation means

10.5.1 General

Isolation means 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 isolation means with breaking capabilities

The PV array DC isolation means with breaking capabilities shall be identified by a sign affixed in a prominent location adjacent to the isolation means with breaking capabilities.

Where multiple isolation means are used that are not ganged (refer to 7.3.1.2) signage shall be provided warning of multiple DC sources and the need to turn off all isolation means with breaking capabilities to safely isolate equipment.

10.6 Warning sign for anti-PID equipment

A warning sign shall be displayed at all points of isolation indicating that anti-PID equipment is in use and needs to be isolated before working on the array.

10.7 Documentation

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

A warning shall be placed in the documentation to inform users the implication of an earth fault alarm on a system. This is particularly important in systems separated from the earth that are allowed to operate after the first fault because a second fault may be extremely dangerous. A warning shall be included stating that simply shutting down the array is not sufficient to remove any risk. It is extremely important after a fault condition is detected to initiate fault finding and remediation.

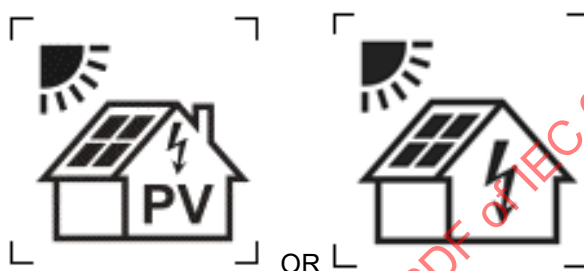
Annex A (informative)

Examples of signs

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



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



IEC 60417-6400 or 6400A: Photovoltaic array installation symbol

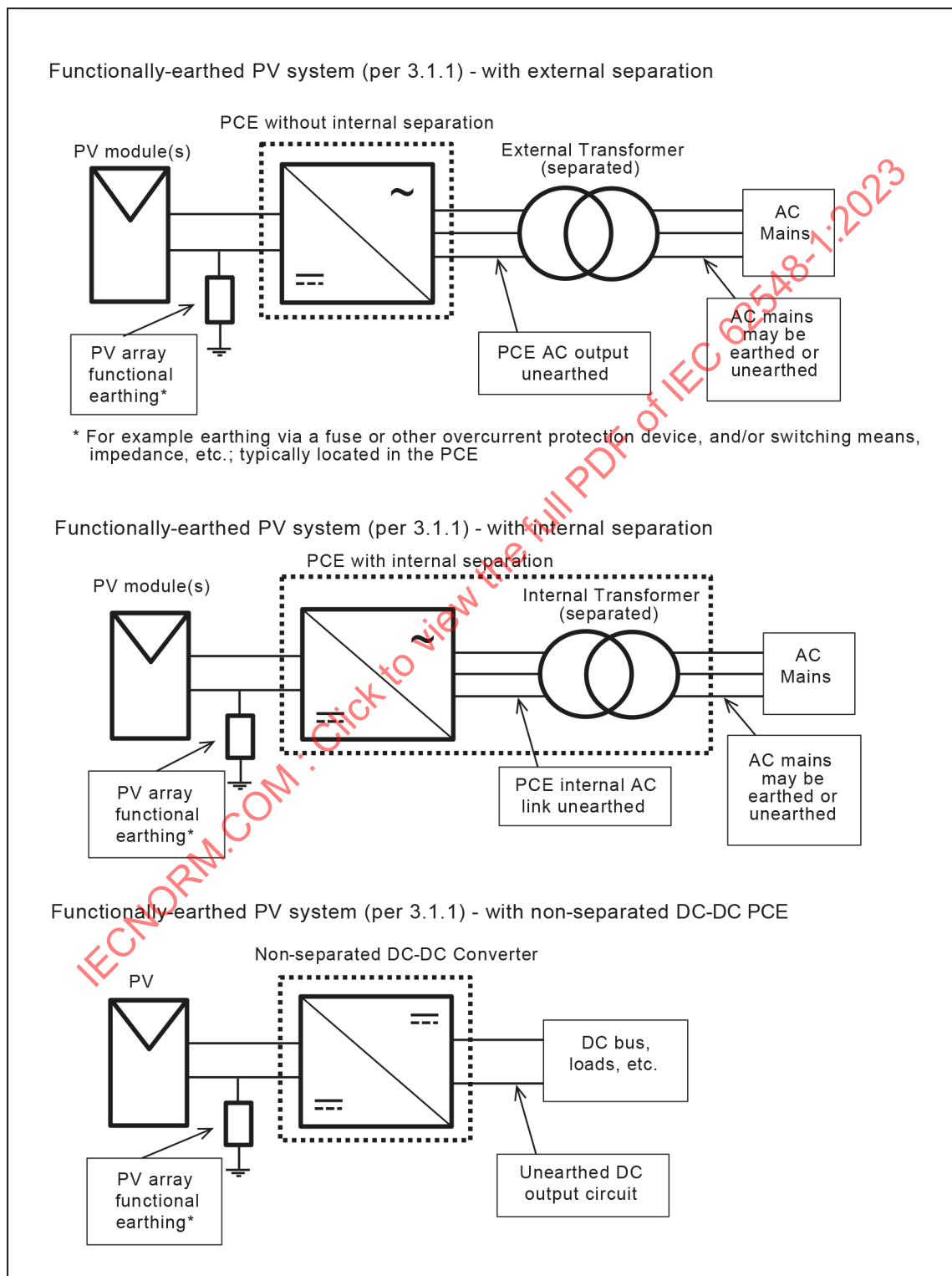
Figure A.2 – Example of switchboard sign for identification of PV on a building

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.

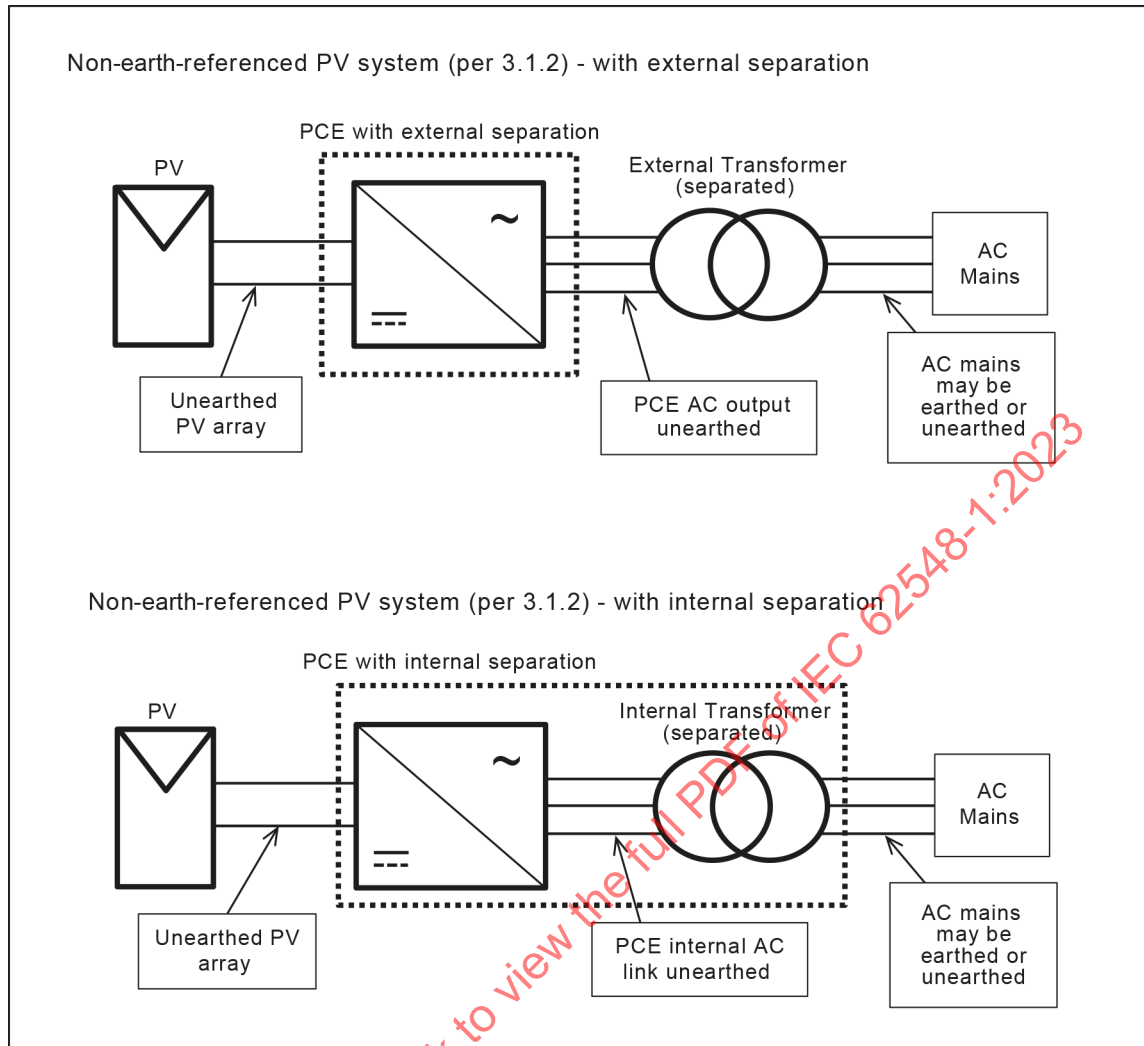
Annex B (informative)

Examples of system earthing configurations in PV arrays



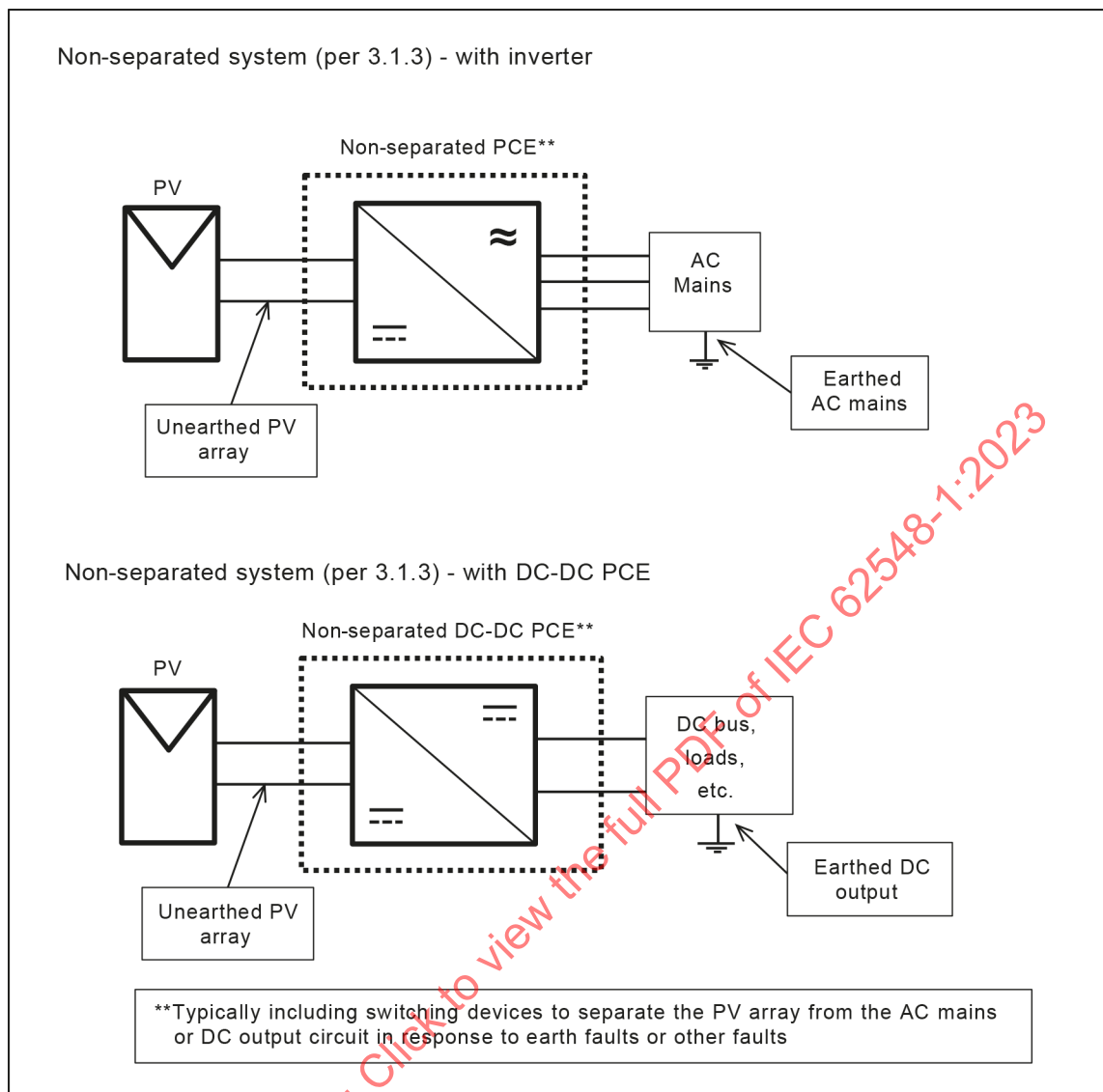
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Figure B.1 – Functionally earthed system topologies



IEC

Figure B.2 – Non-earth-referenced system topologies



IEC

Figure B.3 – Non-separated system topologies

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 PV 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.1, Figure C.2 and 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 assured.

C.3 Examples of blocking diode use in fault situations

C.3.1 General

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

C.3.2 Short circuit in PV string

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

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

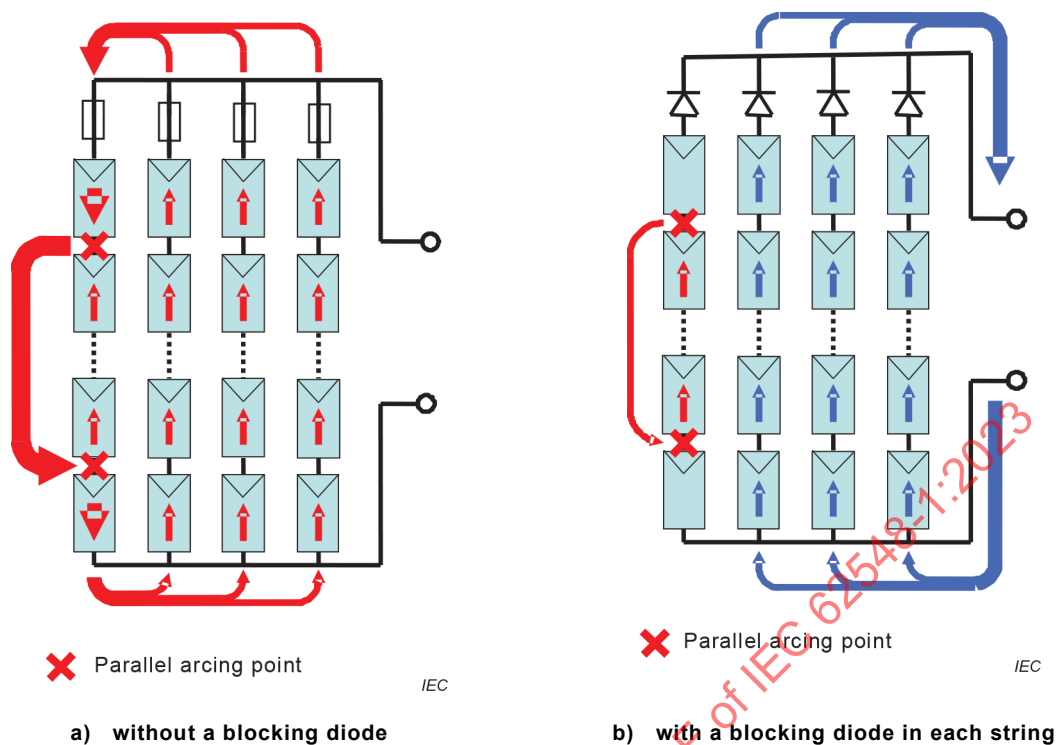


Figure C.1 – Effect of blocking diode where there is a short circuit in PV string

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

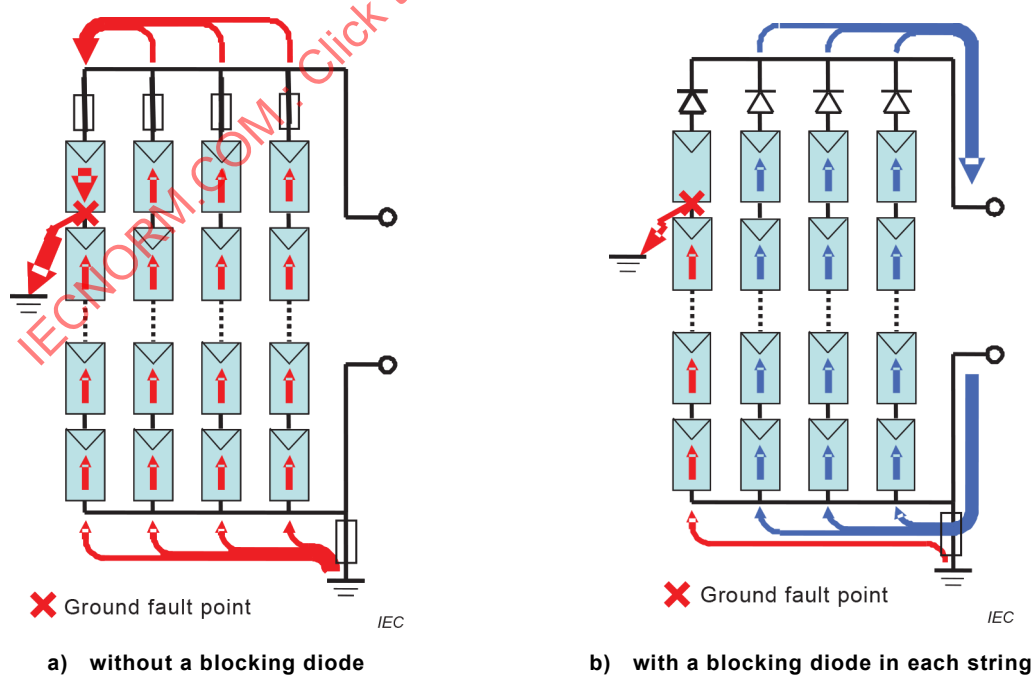


Figure C.2 – Effect of blocking diode where there is an earth fault on a system with earthing on the negative side

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.

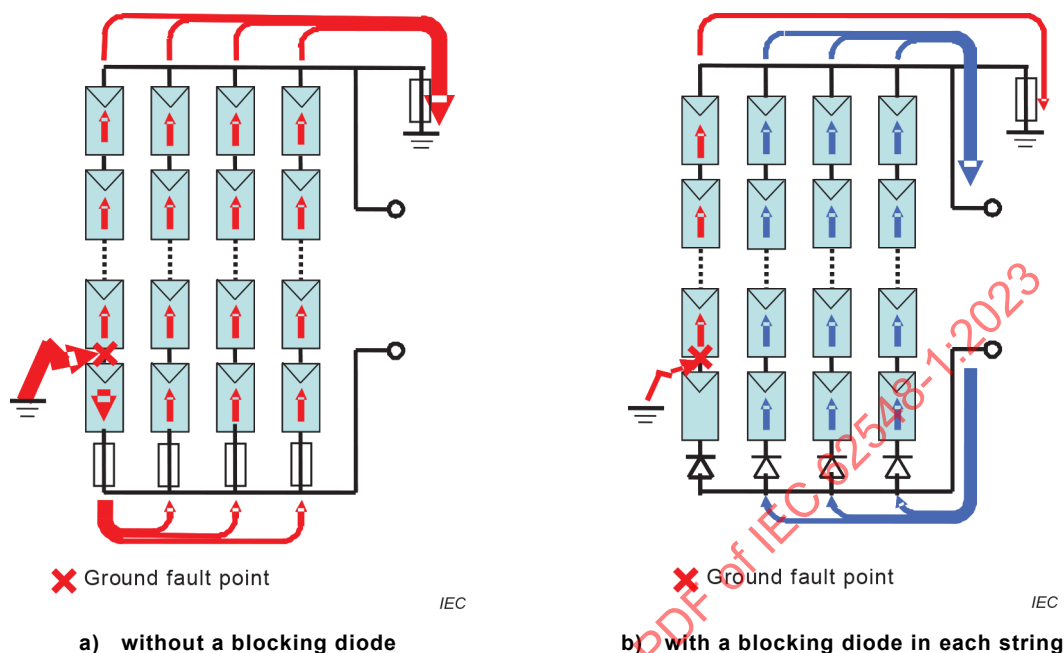


Figure C.3 – Effect of blocking diode where there is an earth fault on a system with positive side earthing

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

C.4 Specification of blocking diode

Blocking diodes shall comply with the requirements in 7.2.12.

C.5 Heat dissipation design for blocking diode

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

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

$$I_{MAX} = 1,4 \times K_I \times I_{SC\ MOD}$$
 (Use higher factor dependent on operating conditions).
Refer to Clause F.4 for K_I calculation.
- Obtain the operating forward voltage of the blocking diode U_{D_OP} at I_{MAX} from the operating characteristic of diode.

- Calculate power dissipation P_{CAL} .

$$P_{\text{CAL}} = V_{\text{D_OP}} \times I_{\text{MAX}}$$

- 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} .

$$R_{\text{TH}} = (T_{\text{J}} - T_{\text{AMB}})/P_{\text{CAL}}$$

- If the calculated 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.

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Annex D (informative)

Arc fault detection and interruption in PV arrays

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

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

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

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

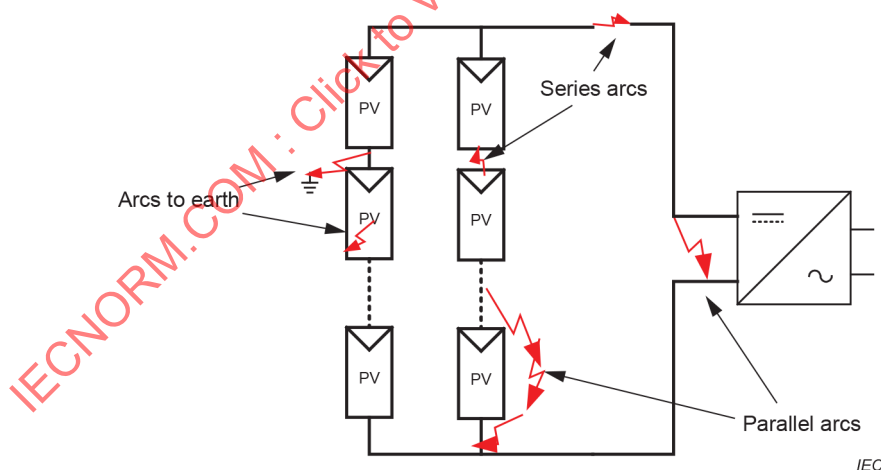


Figure D.1 – Examples of types of arcs in PV arrays

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.