

INTERNATIONAL STANDARD



Low voltage electrical installations ~~of buildings~~ –
Part 7-712: Requirements for special installations or locations – Solar
photovoltaic (PV) power supply systems



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INTERNATIONAL STANDARD



**Low voltage electrical installations of buildings –
Part 7-712: Requirements for special installations or locations – Solar
photovoltaic (PV) power supply systems**

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ELECTROTECHNICAL COMMISSION

LOW VOLTAGE ELECTRICAL INSTALLATIONS ~~OF BUILDINGS~~ –

Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

FOREWORD

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International Standard IEC 60364-7-712 has been prepared by IEC technical committee 64: Electrical installations and protection against electric shock.

This second edition cancels and replaces the first edition, published in 2002. This edition constitutes a technical revision.

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

- a) The technical content has been extensively revised and expanded, taking into account experience gained in the construction and operation of PV installations, and developments made in technology, since the first edition of this standard was published.

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

FDIS	Report on voting
64/2154/FDIS	64/2163/RVD

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

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

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

A list of all parts in the IEC 60364 series, published under the general title *Low voltage electrical installations*, can be found on the IEC website.

The reader's attention is drawn to the fact that Annex F lists all of the “in-some-country” clauses on differing practices of a less permanent nature relating to the subject of this standard.

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

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

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INTRODUCTION

For the purpose of this part of IEC 60364 (IEC 60364-7-712), the requirements of the general parts 1 to 6 of IEC 60364 apply.

The IEC 60364-7-7XX parts of IEC 60364 contain particular requirements for special installations or locations which are based on the requirements of the general parts of IEC 60364 (IEC 60364-1 to IEC 60364-6). These IEC 60364-7-7XX parts are considered in conjunction with the requirements of the general parts.

The particular requirements of this part of IEC 60364 supplement, modify or replace certain of the requirements of the general parts of IEC 60364 being valid at the time of publication of this part. The absence of reference to the exclusion of a part or a clause of a general part means that the corresponding clauses of the general ~~requirements contained in parts 1 to 6 of IEC 60364~~ part are applicable (undated reference).

Requirements of other 7XX parts being relevant for installations covered by this part also apply. This part may therefore also supplement, modify or replace certain of these requirements valid at the time of publication of this part.

The clause numbering ~~appearing after 712 refers to the corresponding parts or clauses~~ of this part follows the pattern and corresponding references of IEC 60364. ~~Numbering of clauses does not, therefore, necessarily follow sequentially.~~ The numbers following the particular number of this part are those of the corresponding parts, or clauses of the other parts of the IEC 60364 series, valid at the time of publication of this part, as indicated in the normative references of this document (dated reference). If requirements or explanations additional to those of the other parts of the IEC 60364 series are needed, the numbering of such items appears as 712.101, 712.102, 712.103, etc.

Numbering of figures and tables takes the number of this part followed by a sequential number. For annexes, the numbering of figures and tables takes the letter of the annex, the number of the part and a sequential number.

In the case where new or amended general parts with modified numbering were published after this part was issued, the clause numbers referring to a general part in this 712 part may no longer align with the latest edition of the general part. Dated references should be observed.

LOW VOLTAGE ELECTRICAL INSTALLATIONS ~~OF BUILDINGS~~ –

Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

712 Solar photovoltaic (PV) power supply ~~systems~~ installations

NOTE The abbreviation “PV” is used for ~~“solar photovoltaic”~~ “Photovoltaic”. Photovoltaic installations are, hereafter, known as PV installations.

712.1 Scope

This part of IEC 60364 applies to the electrical installation of PV ~~power supply~~ systems ~~including systems with AC modules~~ intended to supply all or part of an installation.

~~NOTE 1 Standards for PV equipment are being prepared by TC 82.~~

~~NOTE 2 Requirements for PV power supply systems which are intended for stand-alone operation are under consideration.~~

The equipment of a PV installation, like any other item of equipment, is dealt with only so far as its selection and application in the installation is concerned.

A PV installation starts from a PV module or a set of PV modules connected in series with their cables, provided by the PV module manufacturer, up to the user installation or the utility supply point (point of common coupling).

Requirements of this document apply to

- PV installations not connected to a system for distribution of electricity to the public,
- PV installations in parallel with a system for distribution of electricity to the public,
- PV installations as an alternative to a system for distribution of electricity to the public,
- appropriate combinations of the above.

This document does not cover the specific installation requirements for batteries or other energy storage methods.

NOTE 1 Additional requirements for PV installations with battery storage capabilities on the DC side are under consideration.

NOTE 2 This document does cover the protection requirements of PV arrays which develop as a result of the use of batteries in PV installations.

For systems using DC-DC converters, additional requirements regarding voltage and current rating, switching, and protective devices can apply. These requirements are under consideration.

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

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

712.2 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 60050(826):1982, International Electrotechnical Vocabulary (IEV) — Chapter 826: Electrical installations of buildings~~

IEC 60228, *Conductors of insulated cables*

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

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

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

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

IEC 60364-4-43, *Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent*

IEC 60364-4-44, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

~~IEC 60439-1, Low-voltage switchgear and controlgear assemblies – Part 1: Type-tested and partially type-tested assemblies~~

IEC 60670 (all parts), *Boxes and enclosures for electrical accessories for household and similar fixed electrical installations*

~~IEC/TR 60755, General requirements for residual current operated protective devices Amendment 2 (1992)~~

IEC 60898 (all parts), *Electrical accessories – Circuit-breakers for overcurrent protection for household and similar installations*

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

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

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

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

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

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

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

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

IEC 61439 (all parts), *Low-voltage switchgear and controlgear assemblies*

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

IEC 61557-8:2014, *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures – Part 8: Insulation monitoring devices for IT systems*

IEC 62109 (all parts), *Safety of power converters for use in photovoltaic power systems*

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 62262, *Degrees of protection provided by enclosures for electrical equipment against external mechanical impacts (IK code)*

IEC 62423, *Type F and type B residual current operated circuit-breakers with and without integral overcurrent protection for household and similar uses*

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

IEC 62852:2014, *Connectors for DC-application in photovoltaic systems – Safety requirements and tests*

712.3 Terms and definitions

~~(See also figures 712.1 and 712.2).~~

For the purposes of this document, ~~the definitions of IEC 60050(826) as well as~~ the following terms and definitions apply.

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

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

712.3.1

PV cell

photovoltaic cell

solar cell

solar photovoltaic cell

~~basic PV device which can generate electricity when exposed to light such as solar radiation~~
most elementary device that exhibits the photovoltaic effect, i.e the direct non-thermal conversion of radiant energy into electrical energy

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

[SOURCE: IEC 61836:2007, 3.1.43 a), modified — "that exhibits ... electrical energy" has been added]

712.3.2

PV module

smallest complete environmentally protected assembly of interconnected ~~PV~~ cells

Note 1 to entry: See IEC 60904-3.

712.3.3

PV string

~~circuit in which PV modules are connected in series, in order for a PV array to generate the required output voltage~~ of one or more series-connected modules

[SOURCE: IEC 61836:2007, modified – "or one or more" has been added]

712.3.4

PV array

~~mechanically and electrically integrated assembly of electrically interconnected PV modules, PV strings or PV sub-arrays and other necessary components, to form a DC power supply unit~~

Note 1 to entry: For the purposes of this document a PV array is all components up to the DC input terminals of an inverter 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 (see Figure 712.2 to Figure 712.4). For the purposes of this document the boundary of a PV array is the output side of the PV array disconnecting device.

712.3.5

~~PV array junction box~~

~~enclosure where all PV strings of any PV array are electrically connected and where protection devices can be located if necessary~~

712.3.6

~~PV generator~~

~~assembly of PV arrays~~

712.3.7

~~PV generator junction box~~

~~enclosure where all PV arrays are electrically connected and where protection devices can be located if necessary~~

712.3.5

PV sub-array

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

712.3.6

PV string cable

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

Note 1 to entry: Examples of PV string cable are shown in Figure 712.3 and Figure 712.4.

712.3.7

PV array cable

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

712.3.10

~~PV DC main cable~~

~~cable connecting the PV generator junction box to the DC terminals of the PV inverter~~

712.3.11

~~PV inverter~~

~~device which converts DC voltage and DC current into AC voltage and AC current~~

712.3.8

PV AC supply cable

cable connecting the AC terminals of the PV ~~inverter~~ PCE to a distribution ~~circuit~~ board of the electrical installation

712.3.9

PV AC supply circuit

circuit connecting the AC terminals of the PV PCE to a distribution board of the electrical installation

712.3.10

PV AC module

integrated module/~~inverter~~ PCE assembly where the electrical interface terminals are ~~AC~~ alternating current only and where no access is provided to the DC side

712.3.11

PV installation

erected equipment of a PV power supply ~~system~~ installation

712.3.12

standard test conditions

STC

~~test conditions specified in IEC 60904-3 for PV cells and PV modules~~

standard set of reference conditions used for the testing and rating of photovoltaic cells and modules as given in the relevant product standard for example IEC 61215

Note 1 to entry: The standard test conditions given in IEC 61215 for PV modules are:

- a) PV cell temperature of 25 °C;
- b) irradiance in the plane of the PV cell or module of 1 000 W/m²;
- c) light spectrum corresponding to an atmospheric air mass of 1,5.

Note 2 to entry: This note applies to the French language only.

712.3.13

open-circuit voltage under standard test conditions

$U_{OC\ STC}$

voltage under standard test conditions across an unloaded (open) PV module, PV string or PV array, ~~PV generator~~, or on the DC side of the PV ~~inverter~~ PCE

712.3.14 open-circuit maximum voltage

$U_{OC\ MAX}$
maximum voltage across an unloaded (open) PV module, PV 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 B.

712.3.15 short-circuit current under standard test conditions

$I_{SC\ STC}$
short-circuit current of a PV module, PV string or PV array ~~or PV generator~~ under standard test conditions

712.3.16 short-circuit maximum current

$I_{SC\ MAX}$
maximum short-circuit current of a PV module, PV string or PV array

Note 1 to entry: The method for determining $I_{SC\ MAX}$ is given in Annex B.

712.3.17 backfeed current

maximum current that can pass from PCE to the PV array and its wiring under normal or single fault conditions

712.3.18 reverse current

current that can backfeed into a PV circuit from parallel connected strings or sub-arrays as the result of a fault, for example a short-circuit in the affected circuit

712.3.19 short-circuit current rating

$I_{SCP\ V}$
maximum prospective short-circuit current from the PV array for which the SPD, in conjunction with the disconnectors specified, is rated

712.3.20 DC side

part of a PV installation from ~~a PV cell~~ the PV modules to the DC terminals of the PV ~~inverter~~ PCE

712.3.21 AC side

part of a PV installation from the AC terminals of the PV ~~inverter~~ PCE to the point of connection of the PV supply cable to the electrical installation

~~712.3.20 simple separation~~

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

712.3.22 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

Note 1 to entry: This note applies to the French language only.

712.3.23

$I_{MOD_MAX_OCPR}$
PV module maximum overcurrent protection rating

Note 1 to entry: See IEC 61730-2.

712.3.24

blocking diode

diode connected in series with module(s), strings and sub-array(s) to block reverse current

712.3.25

bypass diode

diode connected across one or more cells in the forward current direction

Note 1 to entry: The purpose is 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.

712.3.26

functional earthing

FE

earthing a point or points in a system or in an installation or in equipment for purposes other than electrical safety

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

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

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

Note 4 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-826:2004, 826-13-10, modified – the notes have been added]

712.3.27

irradiance

G

electromagnetic radiated solar power per unit of area

Note 1 to entry: Irradiance is expressed in W/m^2 .

[SOURCE: IEC 61836:2007, 3.6.25 modified – the note and sub-entries have been deleted]

712.3.28

$I_{SC\ ARRAY}$
short-circuit current of the PV array at standard test conditions

712.3.29

$I_{SC\ MOD}$
short-circuit current of a PV module or PV string at standard test conditions (STC), as specified by the manufacturer in the product specification plate

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

712.3.30

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

712.3.31**power conversion equipment****PCE**

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

SEE: Figure 712.2 to Figure 712.4.

Note 1 to entry: This note applies to the French language only.

712.3.32**inverter**

PCE which converts DC voltage and DC current of the PV array into AC voltage and AC current

Note 1 to entry: This note applies to the French language only.

712.3.33**isolated PCE**

PCE with at least simple separation between the main power output circuits and PV circuits

Note 1 to entry: The simple separation may be either integral to the PCE or provided externally, for example a PCE with an external isolating transformer.

Note 2 to entry: In a PCE with more than two external circuits, there may be isolation between some pairs of circuits and no isolation between others. For example, an inverter with PV, battery, and mains circuits may provide isolation between the mains circuit and the PV circuit, but no isolation between the PV and battery circuits.

712.3.34**non-isolated PCE**

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

712.3.35**PV array combiner box**

enclosure where PV sub-arrays are connected and which may also contain overcurrent protection and/or switch-disconnection devices

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

712.3.36**PV string combiner box**

enclosure where PV strings are connected which may also contain overcurrent protective devices and/or switch-disconnectors

712.3.37**PV sub-array cable**

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

712.3.38 **U_{OC} ARRAY**

open-circuit voltage at standard test conditions of a PV array

712.3.39 **V_{OC} MOD**

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

712.30 Assessment of general characteristics

712.31 Purposes, supplies and structure

712.31.101 PV array configuration

712.31.101.1 General

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

Figure 712.1 illustrates the general functional configuration of a PV installation.

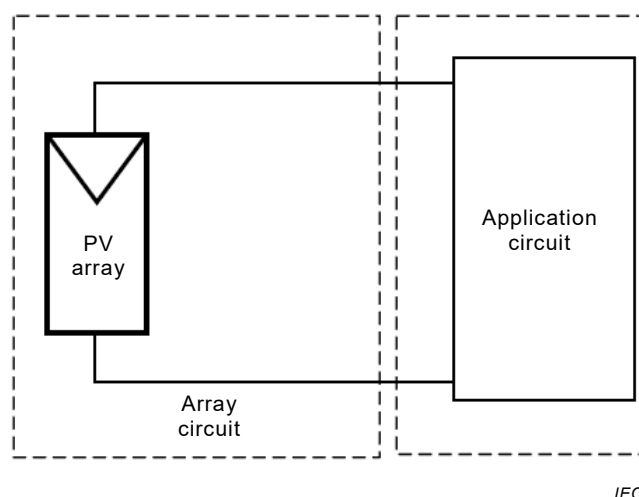


Figure 712.1 – General functional configuration of a PV installation

Three kinds of application circuit are considered:

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

712.31.101.1.1 PV Installation architectures

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

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

Protective earthing of any of the conductors of the PV array is not permitted. Earthing of one of the conductors of the PV array for functional reasons is not allowed unless there is at least simple separation from mains earth provided either internally in the PCE or externally via a separate transformer.

If the simple separation is provided externally there shall be no other equipment connected to the same circuit as the PCE.

NOTE A DC current-carrying conductor that is connected to earth is considered to be a live conductor.

712.31.101.1.2 Array electrical diagrams

The diagrams in Figure 712.2 to Figure 712.4 show the basic electrical configurations of single-string, multiple parallel-string and multi-sub-array PV respectively.

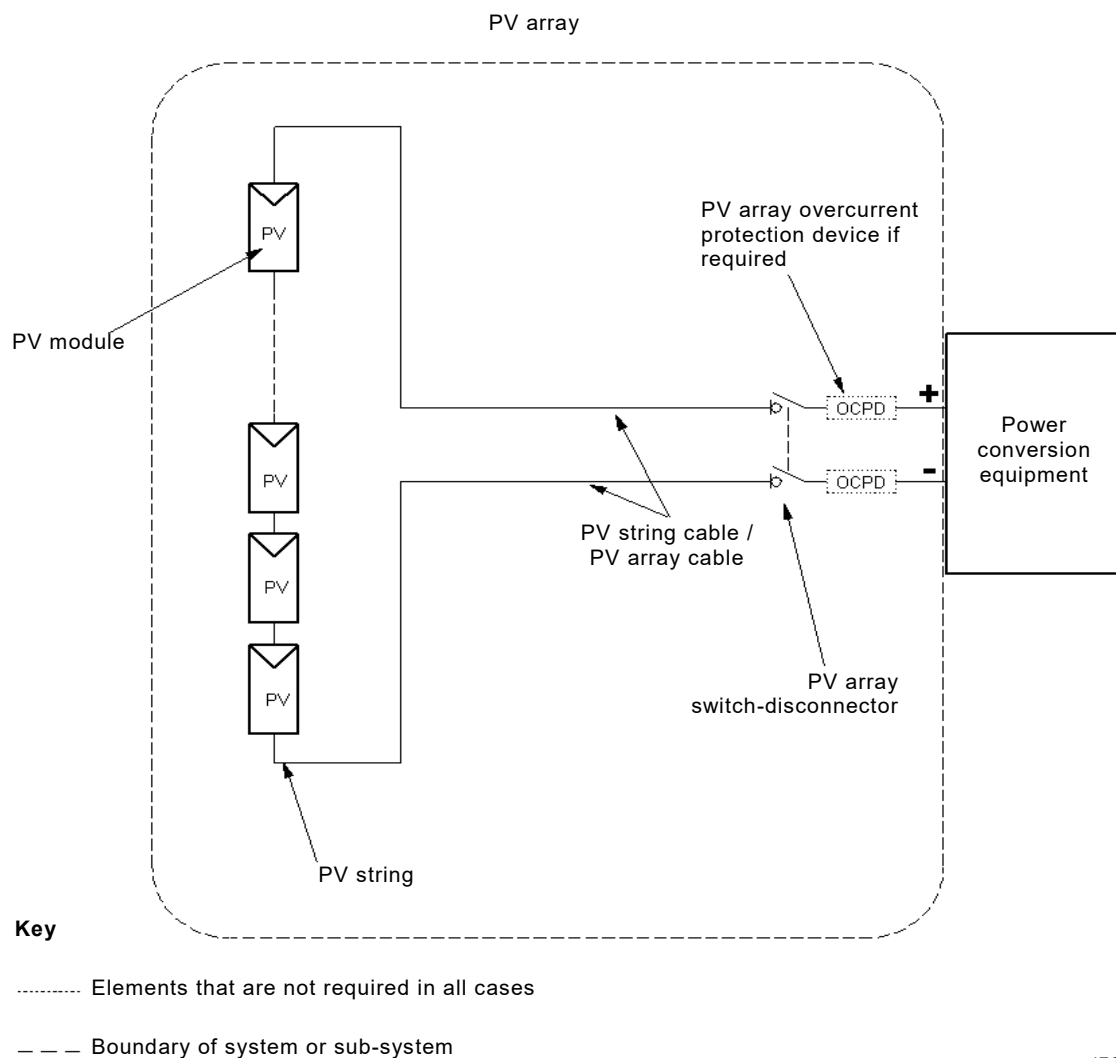
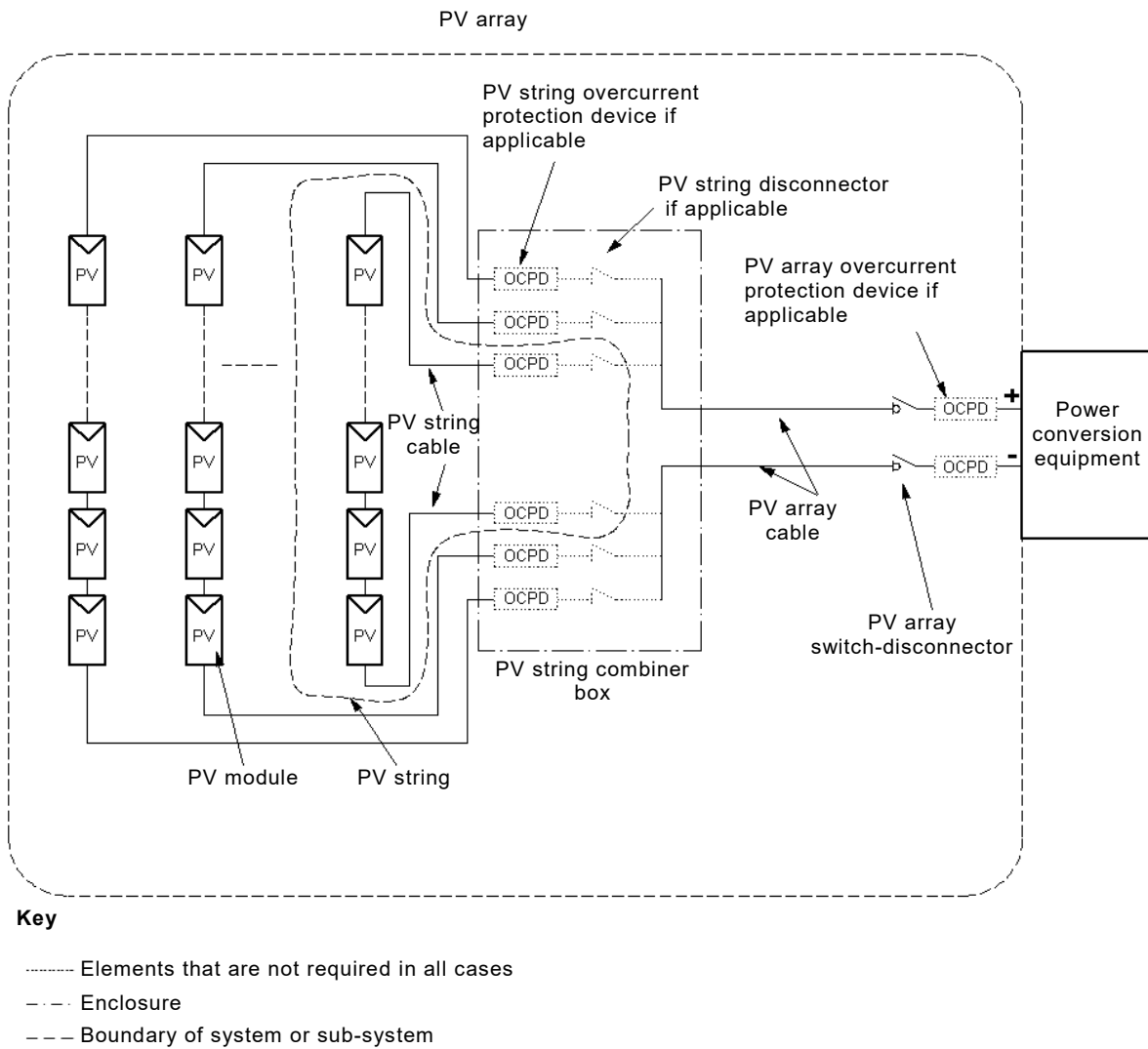
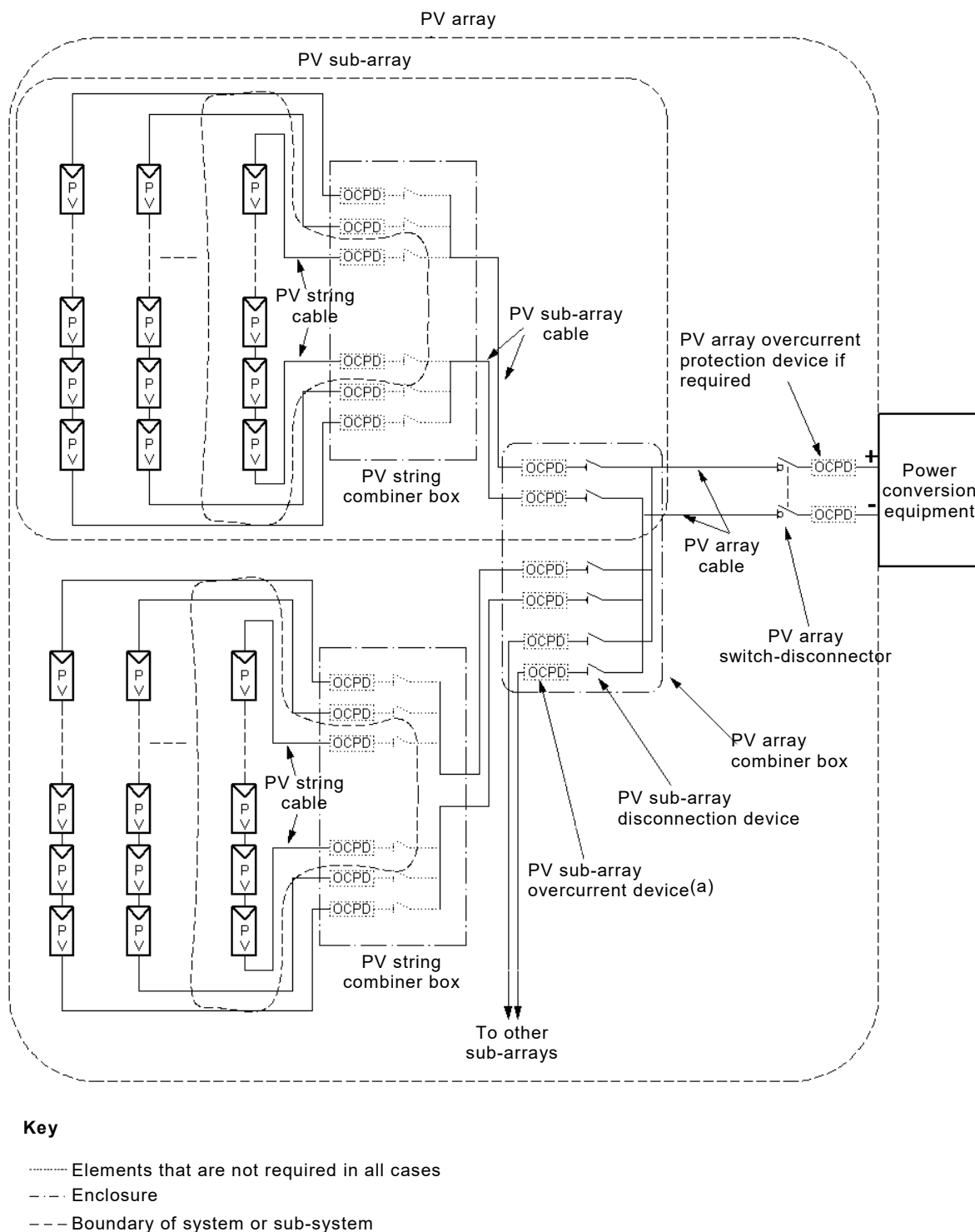


Figure 712.2 – PV array diagram – single string case



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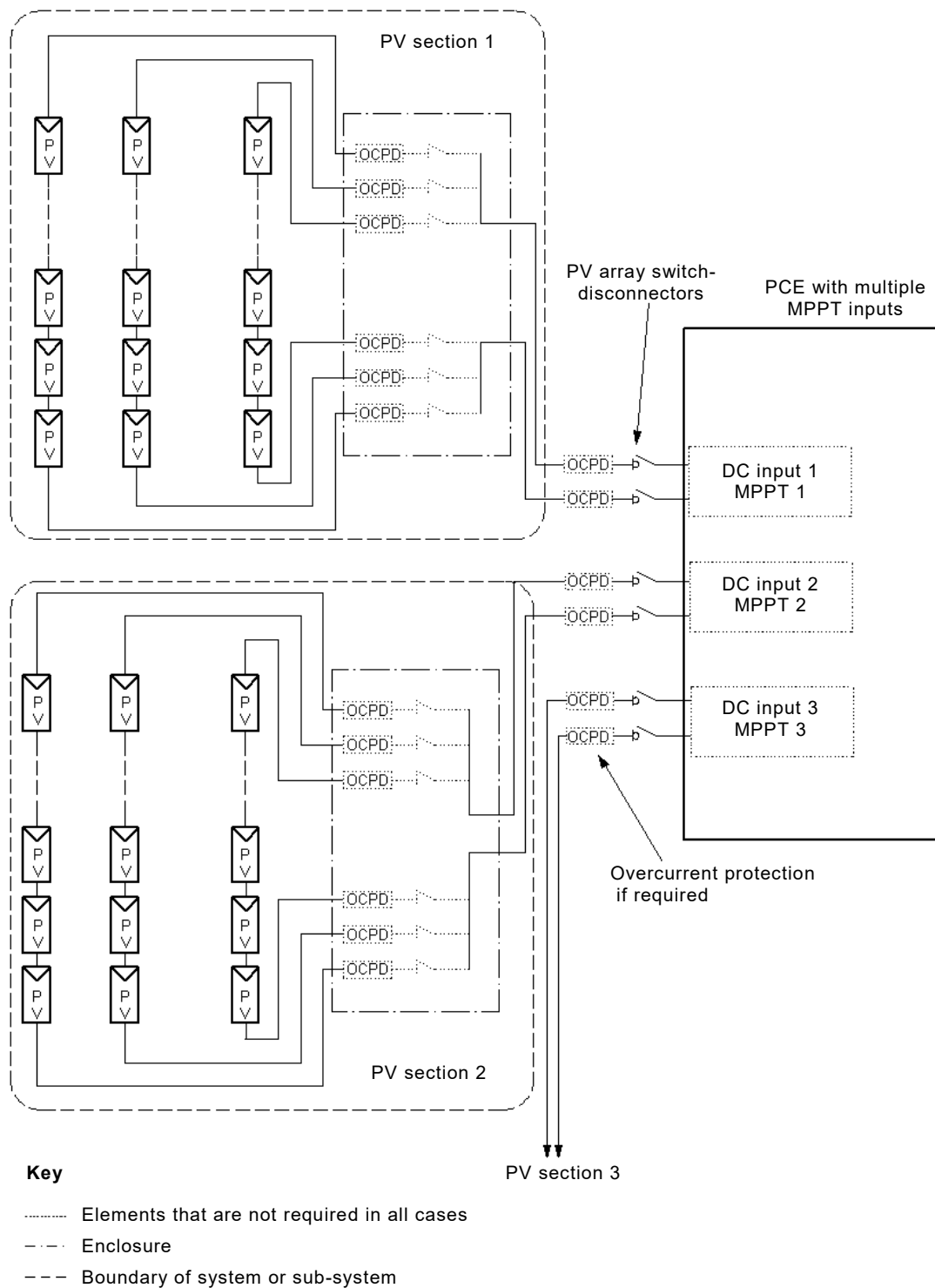
Figure 712.3 – PV array diagram – multiple parallel string case



IEC

Figure 712.4 – PV array diagram – multiple parallel string case with array divided into subarrays

In Figures 712.2, 712.3 and 712.4, components drawn in dotted format are not needed in all cases. The figures indicate the location in the circuit when they are needed.



IEC

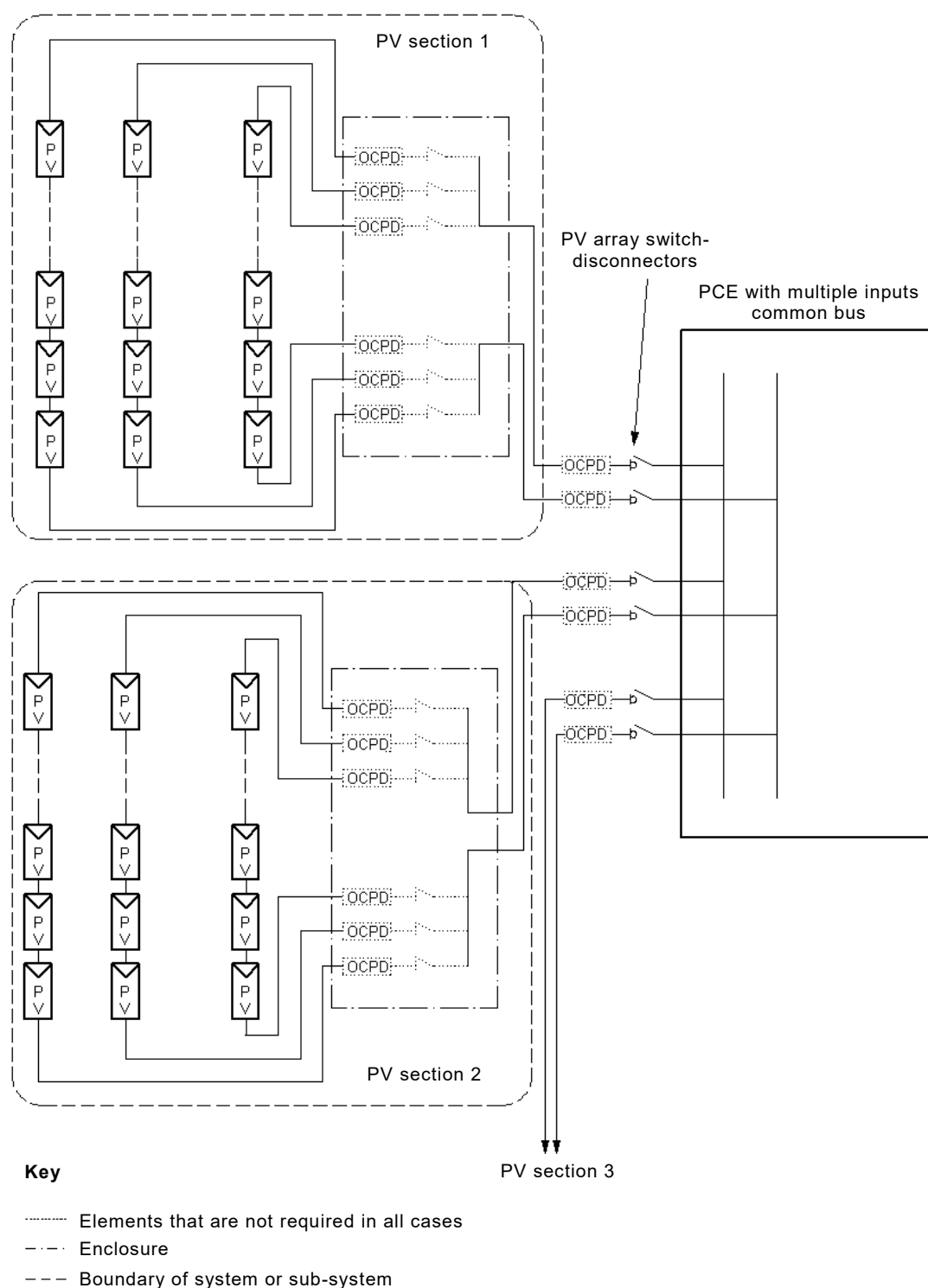


Figure 712.6 – PV array using a PCE with multiple DC inputs internally connected to a common DC bus

712.31.101.1.3 Use of PCE with multiple DC inputs

712.31.101.1.3.1 General

PV arrays are often connected to PCEs with multiple DC inputs. Refer to Figures 712.5 and 712.6. If multiple DC inputs are in use, overcurrent protection and cable sizing within the various sections of the PV array(s) are critically dependent on the limiting of backfeed currents.

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

Where a PCE's input circuits provide separate MPPT inputs, the overcurrent protection of the section of the array connected to those inputs shall take into account backfeed current.

Each PV section connected to an input (refer to Figure 712.5) may be treated for the purposes of this document as a separate PV array. Each PV array shall have a switch-disconnector to provide isolation of the PCE. The PV array switch disconnectors may be mechanically integrated in one device and commonly operated.

712.31.101.1.3.3 PCEs with multiple inputs internally connected together in the PCE

Where a PCE's multiple input circuits are internally paralleled onto a common DC bus, each PV section connected to one of those inputs (refer to Figure 712.6) shall be treated for the purposes of this document as a sub-array and all the PV sections combined shall be classified as the complete PV array. Each PV sub-array shall have a switch-disconnector to provide isolation of the PCE. This function may be provided by a common PV array switch disconnector.

712.31.101.1.4 Series-parallel configuration

All PV strings within a PV array connected in parallel shall be of the same technology and have the same number of series connected PV modules (see Figure 712.2 to Figure 712.4), unless such modules are being tracked by separate MPPTs. In addition, all PV modules in parallel within the PV array shall have similar rated electrical characteristics, including short-circuit current, open-circuit voltage, maximum power current, maximum power voltage and rated power (all at STC), unless such modules are being tracked by separate MPPTs.

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

712.31.101.1.5 Considerations due to prospective fault conditions within a PV array

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

PV installations containing batteries may have high prospective fault currents due to the battery characteristic.

In a PV installation without batteries, the PV cells (and consequently PV arrays) behave like current sources under low impedance faults. Consequently, fault currents may not be much greater than normal full load currents, even under short-circuit conditions.

The fault current depends on the number of strings, the fault location and the irradiance level. This makes short-circuit detection within a PV array very difficult. Electric arcs can be formed in a PV array with fault currents lower than the operating current of an overcurrent protective device.

712.31.101.1.6 Performance issues

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

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

- PV module degradation.

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

It is important that any shadowing be reduced as much as is practicable. Note that even a small shadow on the array can significantly limit its performance.

Issues of performance degradation due to temperature rise and the need for good ventilation are described in 712.515.101. 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 affects the voltage drop in those cables under load. This can be particularly significant in PV installations with low output voltage and high output current. It is recommended that under maximum load conditions the voltage drop from the most remote module in the array to the input terminals of the application circuit should not exceed 3 % of the PV array voltage at its maximum power point.

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

~~712.312 Types of distribution systems~~

~~712.312.2 Types of system earthing~~

~~Earthing of one of the live conductors of the DC side is permitted, if there is at least simple separation between the AC side and the DC side.~~

~~NOTE Any connections with earth on the DC side should be electrically connected so as to avoid corrosion.~~

712.4 Protection for safety

712.4.101 General

Calculation of $U_{OC\ MAX}$ and $I_{SC\ MAX}$ is performed in Annex B.

712.4.102 Functional earthing (FE) of a live part on the DC side

For functional reasons, some PV module technologies require a live part to be connected to earth.

Functional earthing of a live part of the DC side of a PCE is permitted, if there is at least simple separation between the AC side and the DC side by means of a transformer having electrically separate primary and secondary windings. The transformer may be either internal or external to the PCE. The transformer winding connected to the PCE shall not be earthed, and the PCE shall be suitable for this.

The functional earthing of a live part shall be performed at a single point of the DC side, near the DC input of the PCE or in the PCE itself.

The earthing should preferably be located between the disconnection device and the DC terminals of the PV PCE.

The requirements of 712.421.101.2.3 shall also be applied.

A cable used for functional earthing shall not be identified by the colour combination green-and-yellow. It is recommended to use the colour pink.

712.41 Protection against electric shock

712.410 Introduction

712.410.101 PV equipment on the DC side shall be considered to be energized, even when the ~~system~~ AC side is disconnected from the grid or when the PCE is disconnected from the ~~AC~~ DC side.

~~The selection and erection of equipment shall facilitate safe maintenance and shall not adversely affect provisions made by the manufacturer of the PV equipment to enable maintenance or service work to be carried out safely.~~

712.410.3.5

Replace the requirements as follows:

The protective measures specified in IEC 60364-4-41:2005, Annex B, i.e. the use of obstacles and placing out of reach, shall not be used.

712.410.3.6

Replace the requirements as follows:

The protective measures specified in IEC 60364-4-41:2005, Annex C, i.e.

- non-conducting location,
 - earth-free local equipotential bonding,
 - electrical separation for the supply of more than one item of current-using equipment,
- shall not be applied.

712.410.102 On the DC side, one of the following protective measures shall be used:

- double or reinforced insulation;
- SELV or PELV.

712.412 Protective measure: double or reinforced insulation

712.412.101 The equipment, for example PV modules, distribution boards or cabinets, used on the DC side shall be Class II or equivalent insulation, according to IEC 61140.

~~712.413 Fault protection~~

~~712.413.1 Protection by automatic disconnection of supply~~

~~NOTE Protection by automatic disconnection of supply on the DC side requires special measures which are under consideration.~~

~~**712.413.1.1.1.1** On the AC side, the PV supply cable shall be connected to the supply side of the protective device for automatic disconnection of circuits supplying current-using equipment.~~

~~**712.413.1.1.1.2** Where an electrical installation includes a PV power supply system without at least simple separation between the AC side and the DC side, an RCD installed to provide fault protection by automatic disconnection of supply shall be type B according to IEC 60755, amendment 2.~~

~~Where the PV inverter by construction is not able to feed DC fault currents into the electrical installation, an RCD of type B according to IEC 60755 amendment 2 is not required~~

~~712.413.2 Protection by use of class II or equivalent insulation should preferably be adopted on the DC side.~~

~~712.413.3 Protection by non-conducting locations is not permitted on the DC side.~~

~~712.413.4 Protection by earth-free local equipotential bonding is not permitted on the DC side.~~

712.414 Protective measure: extra-low-voltage provided by SELV and PELV

712.414.101 For the use of SELV and PELV protective measures on the DC side, $U_{OC\ MAX}$ shall not exceed 60 V DC.

712.414.102 The smooth DC voltage to be considered is the PV array maximum voltage $U_{OC\ MAX}$.

712.42 Protection against thermal effects

712.420.101 Fire safety of PV installations

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

712.421 Protection against fire caused by electrical equipment

712.421.101 Protection against the effects of insulation faults

712.421.101.1 Protection against the effects of insulation faults without at least simple separation inside the PCE or on the AC side

712.421.101.1.1 The functional earthing of a live part on the DC side is not permitted.

712.421.101.1.2 In the event of an insulation fault on the DC side, either:

- the PCE shall be automatically disconnected from the AC side, or
- the faulty part of the PV array shall be automatically disconnected from the PCE.

NOTE 1 Disconnection can be provided by the PCE; see IEC 62109 (all parts).

NOTE 2 Automatic disconnection can be provided by an RCD.

712.421.101.1.3 In the event of an insulation fault on the DC side, an alarm shall be automatically given (see 712.531.3.101.3).

NOTE If the insulation fault is detected by the PCE, according to IEC 62109 (all parts) an alarm is initiated by the PCE.

712.421.101.2 Protection against the effects of insulation faults with simple separation inside the PCE or on the AC side

712.421.101.2.1 The functional earthing of a live part on the DC side is permitted.

712.421.101.2.2 Without functional earthing of a live part on the DC side, an insulation monitoring device (IMD), or another device offering equally effective monitoring, shall be installed.

NOTE An inverter according to IEC 62109 (all parts) can be used to provide this function.

712.421.101.2.3 Except where the following paragraph applies, PV arrays that have one conductor connected to a functional earth shall be provided with a device or association of devices, in accordance with 712.532.102, that interrupts the current in the functional earthing conductor in the event of an insulation fault on the DC side. The device (or association of devices) shall also give an alarm according to 712.421.101.2.4.

The requirement of the previous paragraph does not apply where the functional earthing is connected to earth via a resistor having a resistance R which meets the following condition:

$$R \geq \frac{U_{oc \max}}{I_n}$$

where

I_n is the value of current given in Table 712.6.

NOTE In the event of an insulation fault, an immediate shut down of the PCE can be necessary for functional reasons.

With functional earthing of a live part on the DC side via a resistor, an insulation monitoring device (IMD), or another device offering equal effective monitoring shall be installed (see 712.531.3).

NOTE A PCE according to IEC 62109 (all parts) can be used to provide this function.

712.421.101.2.4 In the event of an insulation fault on the DC side, an alarm shall be automatically given (see 712.531.3.101.3).

NOTE If the insulation fault is detected by the PCE, according to IEC 62109 (all parts), an alarm is initiated by the PCE.

According to IEC 60364-4-41:2005, 411.6.3.1 it is recommended that a fault be eliminated with the shortest practicable delay.

712.43 Protection against overcurrent

712.430.3 General requirements

712.430.3.101 General

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

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

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

712.430.3.102 Requirement for overcurrent protection

Overcurrent protection shall be provided in accordance with 712.430.3.102 to 712.433.1.101 and with PV module manufacturer's requirements.

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

712.430.3.103 Requirement for string overcurrent protection

String overcurrent protection shall be used if:

$$((N_s - 1) \times I_{SC_MAX}) > I_{MOD_MAX_OCPR}$$

where:

N_s is the total number of parallel connected strings protected by the nearest overcurrent protective device.

When circuit-breakers with overcurrent protection elements are used, they may also provide the disconnecting means required in 712.536.2.101 to 712.536.2.103.

712.430.3.104 Requirement for sub-array overcurrent protection

Sub-array overcurrent protection shall be provided if more than two sub-arrays are connected in parallel.

712.432 Nature of protective devices

712.432.101 Blocking diodes used to connect the PV strings in parallel shall not be relied upon as a means of protection against overcurrents.

712.432.102 The overcurrent protective devices of the DC side shall be either gPV fuses in accordance with IEC 60269-6 or another device in accordance with IEC 60947 (all parts) or IEC 60898 (all parts).

Devices in accordance with IEC 60947 (all parts) and IEC 60898 (all parts) shall be of types suitable for the expected conditions, in particular for operation with direct current, reverse current and critical current.

712.433 Protection against overload ~~on the DC side~~ current**712.433.1 Coordination between conductors and overload protective devices**

~~Overload protection may be omitted to PV string and PV array cables when the continuous current-carrying capacity of the cable is equal to or greater than 1,25 times I_{SC_STC} at any location.~~

712.433.1.101 Overload protection sizing**712.433.1.101.1 General**

The selected multiplier in 712.433.1.101.2 to 712.433.1.101.4 shall be adjusted to account for PV systems operating in climatic conditions where I_{SC} is expected to routinely exceed STC values.

NOTE Numerous climatic and environmental conditions can result in high short-circuit currents of the PV modules and arrays exceeding STC values, such as geographic locations with unusually high solar resource, reflection from the snow, or other conditions. 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, etc.

712.433.1.101.2 PV string overload protection

Where string overload protection is required, either:

- 1) each PV string shall be protected with an overload protective device, where the nominal overload protection rating of the string overload protective device shall be I_n where:

$$I_n > 1,5 \times I_{SC_MOD} \text{ and}$$

$$I_n < 2,4 \times I_{SC_MOD} \text{ and}$$

$$I_n \leq I_{\text{MOD_MAX_OCPR}}$$

or

- 2) strings may be grouped in parallel under the protection of one overload protective device provided:

$$I_{\text{ng}} > 1,5 \times N_{\text{TS}} \times I_{\text{SC_MOD}} \text{ and}$$

$$I_{\text{ng}} < I_{\text{MOD_MAX_OCPR}} - ((N_{\text{TS}} - 1) \times I_{\text{SC_MOD}})$$

where

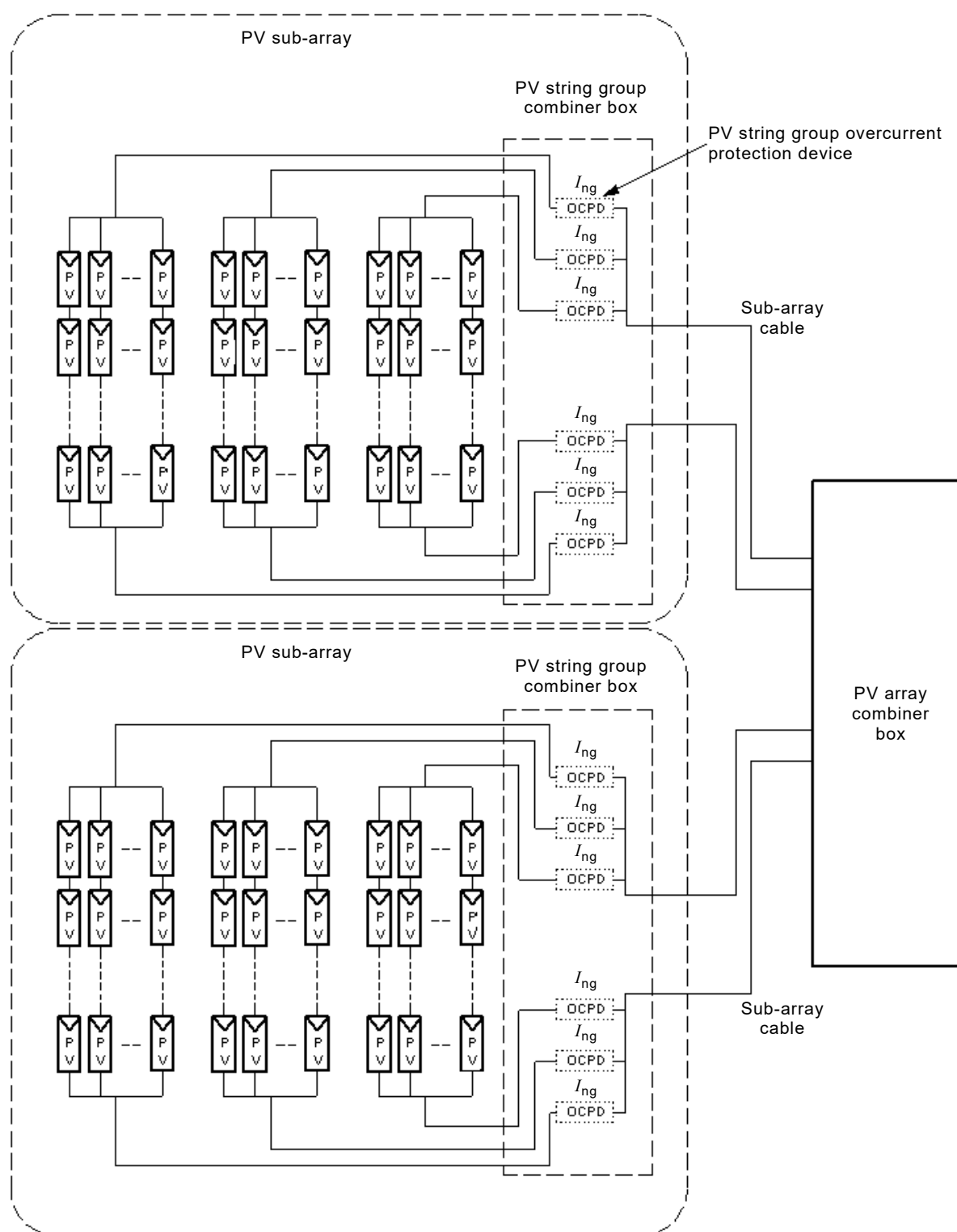
I_n is the rated current or current setting of the string overload protective device,

I_{ng} is the rated current or current setting of the group overload protective device,

N_{TS} is the total number of strings in a group under the protection of one overload device.

Where circuit-breakers are used as devices for overload protection, IEC 60364 (all parts) also permits these to fulfil the role of a disconnecting means as required by 712.536.2.101 to 712.536.2.103.

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



IEC

This is only an example and other switching, disconnecting and/or overload protective devices may be required in individual cases, but for simplicity these are not shown in this figure.

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

NOTE 2 In case of specific constraints such as side by side mounting of equipment used simultaneously at nominal current and/or high ambient temperature, the choice of rated current for the protective device could be affected.

Figure 712.7 – Example of a PV array diagram where strings are grouped under one overload protective device per group

712.433.1.101.3 PV sub-array overload protection

The rated current or current setting (I_n) of overload protective devices for PV sub-arrays shall be determined with the following formulae:

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

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

The 1,25 multiplier used here instead of the 1,5 multiplier used for strings is to allow designer flexibility. A multiplier of 1,25 should not be used in areas where heightened irradiance occurs frequently as this would be likely to cause nuisance overload protective device operation.

NOTE In case of specific constraints such as side by side mounting of equipment used simultaneously at nominal current and/or high ambient temperature, the choice of current rating of the protective device could be impacted.

712.433.1.101.4 PV array overload protection

PV array cable overload protection is only required for PV installations connected to batteries or where other sources of current may feed into the PV array under fault conditions. The rated current (I_n) of PV array overload protective devices shall be rated as follows:

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

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

The PV array overload protective devices are commonly installed between the battery or batteries and the charge controller as close as possible to the battery or batteries. If these devices are appropriately rated, they provide protection to both the charge controller and the PV array cable, and consequently no further PV array cable overload protection between the PV array and the charge controller is necessary. The 1,25 multiplier used here instead of the 1,5 multiplier used for strings is to allow designer flexibility. A multiplier of 1,25 should not be used in areas where heightened irradiance occurs frequently as this would be likely to cause nuisance overload operation.

NOTE In case of specific constraints such as side by side mounting of equipment used simultaneously at nominal current and/or high ambient temperature, the choice of current rating of the protective device could be impacted.

712.433.2 Position of devices for overload protection

~~Overload protection may be omitted to the PV main cable if the continuous current-carrying capacity is equal to or greater than 1,25 times $I_{SC \text{ STC}}$ of the PV generator.~~

~~NOTE The requirements of 712.433.1 and 712.433.2 are only relevant for protection of the cables. See as well the manufacturer's instructions for protection of PV modules.~~

712.433.2.101 Overload protection location

Overload protective devices where required by 712.430.3.101 to 712.430.3.104, and 712.433.1.101 for PV array, PV sub-array, and PV strings shall be placed as follows.

- For string overload protective devices, they shall be where the string cables join the sub-array or array cables in the string combiner box (refer to Figures 712.3 and 712.4).
- For sub-array overload protective devices, they shall be where the sub-array cables join the array cables in the array combiner box (refer to Figure 712.4).
- For array overload protective devices, they shall be where the array cables join the application circuit or the PCE (refer to Figures 712.2 to 712.4).

NOTE The location of the overload protective devices at the end of those cables furthest from the PV sub-array or string is to protect from fault currents flowing from other sections of the PV array or from other sources such as batteries. Due to the inherent current limiting characteristics of PV, there is insufficient fault current from the source in the faulted circuit itself to cause the overload protective device to operate.

An overload 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 a string cable not in the same wiring system as sub-array cables, and for a sub-array cable not in the same wiring system as string cables. In these cases, an overload protective device need only be placed in one unearthed live conductor of the string cable or each sub-array cable. The polarity of this conductor shall be the same for all cables thus protected.

712.433.101 Protection of PV array cable

The continuous current-carrying capacity (I_z) of the PV array cable shall be greater than or equal to the maximum short-circuit current of the PV array:

$$I_{SC \text{ MAX of the PV array}} \leq I_z$$

712.433.102 Protection of PV AC supply cable

The rated current for the overload protective device of the AC supply cable shall take into account the design current of the PCE. The PCE design current is the maximum AC current given by the PCE manufacturer or, failing that, 1,1 times its rated AC current.

712.434 Protection against short-circuit currents

712.434.101 The PV AC supply cable shall be protected ~~by~~ from the effects of short-circuit ~~or~~ by an overcurrent protective device installed at the connection to ~~the AC mains~~ the designated distribution board of the electrical installation.

712.44 Protection against voltage disturbances and electromagnetic disturbances

712.443 Protection against transient overvoltages of atmospheric origin or due to switching

712.443.101 Taking into account the sensitivity of the setting up of the photovoltaic modules, detailed attention should be paid to the protection of the structure itself (building) against direct effects of the lightning; this subject is covered in IEC 62305 (all parts).

712.443.4 Overvoltage control

712.443.4.101 Protection against transient overvoltage

Where protection against transient overvoltage is required by IEC 60364-4-44:2007, Clause 443, such protection shall also be applied to the DC side of the PV installation.

Depending on the distance between the PCE and the origin of the installation, further protection against transient overvoltage may be required on the AC side.

Where IEC 60364-4-44:2007, Clause 443 does not require protection against transient overvoltage, a risk assessment according to 712.443.5.101 shall be performed.

712.443.5 Risk assessment method

712.443.5.101 Risk assessment for PV installations

Where the relevant data is available, a risk assessment may be carried out to evaluate if 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.
- L_{crit} (m) depends on the type of PV installation, and is calculated according to Table 712.1:

Table 712.1 – 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)	$115/N_g$	$200/N_g$
$L \geq L_{crit}$ (m)	SPDs are required on the DC side	

- 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/AMD1:2015, 443.5)

712.444 **Protection Measures against electromagnetic interference (EMI) in buildings influences**

~~712.444.4.4 To minimize voltages induced by lightning, the area of all wiring loops shall be as small as possible.~~

712.444.5 Earthing and equipotential bonding

712.444.5.5 Functional earthing conductor

712.444.5.5.101 Functional earthing terminal of PV array

When the PV array is earthed as described in 712.4.102 the connection to earth shall be made at a single point and this point shall be connected to the main earthing terminal of the electrical installation.

NOTE 1 Some electrical installations can have sub-earthing terminals. Connection of the PV functional earth to sub-earthing terminals is acceptable provided it has been considered for this use.

NOTE 2 The functional earth connection can be established inside the PCE.

In PV installations without batteries, this connection point shall be between the PV array and the PCE and as close as possible to the PCE.

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

NOTE 3 If in some countries disconnection devices are required/allowed to interrupt functional earth conductors; the location of the earth connection is important in regards to interruption.

712.5 Selection and erection of electrical equipment

712.51 Common rules

712.51.101 The method of calculation of $U_{OC\ MAX}$ and $I_{SC\ MAX}$ is given in Annex B.

712.510.3 General

Add the following:

Equipment in outdoor locations shall have a degree of protection of at least IP 44 and a degree of protection against external mechanical impact not less than IK 07 in accordance with IEC 62262.

PV array wiring and associated components are often exposed to UV, wind, water, snow, heating due to direct solar radiation, and other environmental conditions. Particular attention is drawn to the need for measures to allow the escape of water that may accumulate even in watertight enclosures, and the need for measures against heating caused by direct solar radiation.

712.511 Compliance with standards

712.511.1

Add the following:

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

712.511.101 PV modules shall comply with the requirements of the relevant equipment standard, ~~e.g. either IEC 61215 for crystalline PV modules (all parts) or IEC 61646. PV modules of class II construction or with equivalent insulation are recommended if $U_{OC\ STC}$ of the PV strings exceeds 120 V DC.~~

~~The PV array junction box, PV generator junction box and switchgear assemblies shall be in compliance with IEC 60439-1.~~

712.511.102 PCEs shall comply with IEC 62109 (all parts).

According to the foreseeable environmental conditions, the PCE shall be selected according to IEC 62109-1:2010, Clause 6.

712.511.103 A combiner box shall comply with IEC 61439-2 or, for household and similar locations, may alternatively comply with IEC 60670 (relevant parts). Switchgear assemblies shall comply with IEC 61439 (relevant parts).

712.512 Operational conditions and external influences

712.512.1 Operational conditions

712.512.1.1 Voltage

~~Electrical equipment on the DC side shall be suitable for direct voltage and direct current.~~

~~PV modules may be connected in series up to the maximum allowed operating voltage of the PV modules and the PV inverter, whichever is lower. Specifications for this equipment shall be obtained from the equipment manufacturer.~~

~~If blocking diodes are used, their reverse voltage shall be rated for $2 \times U_{OC\ STG}$ of the PV string. The blocking diodes shall be connected in series with the PV strings.~~

712.512.1.1.101 Open-circuit maximum voltage $U_{OC\ MAX}$

The open-circuit maximum voltage $U_{OC\ MAX}$ is determined in accordance with Annex B, Clause B1.

712.512.1.1.102 Component requirements

712.512.1.1.102.1 General

All components shall comply with the following requirements:

- be rated for DC use where applicable;
- have a voltage rating equal to or greater than the open-circuit maximum voltage determined in 712.512.1.1.101;
- have a current rating equal to or greater than that shown in Table 712.2.

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

Where the DC voltage is conditioned (e.g. where a DC/DC converter is used), equipment shall be rated for the highest expected current and voltage values.

712.512.1.1.102.2 PV module class

Where the protective measure used on the DC side is double or reinforced insulation according to 712.412, PV modules shall be selected according to class II or equivalent insulation according to IEC 61140.

Where the protective measure used on the DC side is extra-low voltage by means of SELV or PELV, according to 712.414, PV modules shall be selected according to class III or class II or equivalent insulation according to IEC 61140.

712.512.1.1.102.3 Combiner box class

Where the protective measure used on the DC side is double or reinforced insulation according to 712.412, combiner boxes shall be selected according to class II or equivalent insulation according to IEC 61140.

Where the protective measure used on the DC side is extra-low voltage by means of SELV or PELV, according to 712.414, combiner boxes shall be selected according to class III or class II or equivalent insulation according to IEC 61140.

~~712.512.2.1 As specified by the manufacturer, the PV modules shall be installed in such a way that there is adequate heat dissipation under conditions of maximum solar radiation for the site.~~

712.513 Accessibility

712.513.101 The selection and erection of a PV installation shall facilitate safe maintenance and shall not adversely affect provisions made by the manufacturer of the electrical

equipment to enable maintenance or service work to be carried out safely. 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.

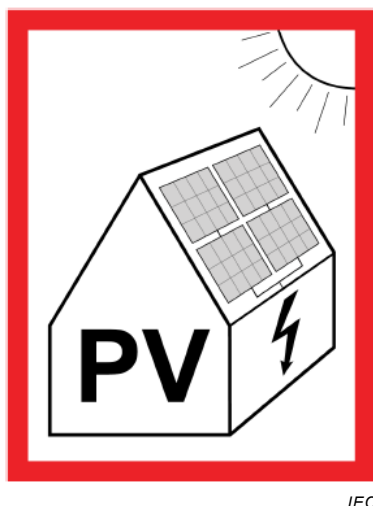
712.514 Identification

712.514.101 Safety marking

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 712.8, shall be fixed

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



IEC

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

Figure 712.8 – Example of an indication showing the presence of a photovoltaic installation on a building

712.514.102 Live parts marking

Each point of access to live parts on the DC side, such as distribution boards and cabinets, shall have a permanent marking for example bearing the text 'SOLAR DC – Live parts can remain energized after isolation'.

712.514.103 Isolation marking

All PCEs should bear a marking indicating that, before any servicing operation, the PCE shall be isolated from all supplies.

712.514.104 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 shall be in the local language or

use appropriate local warning symbols. English examples of sign texts are included in Annex C.

712.514.105 Requirements for signs

Examples of signs are given in Annex C.

712.514.106 Labelling of disconnection devices

712.514.106.1 General

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

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

712.514.106.2 PV array disconnecting device

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

Where multiple disconnection devices are used that are not ganged (refer to 712.536.2.103) signage shall be provided warning of multiple DC sources and the need to turn off all switch disconnectors to safely isolate equipment.

712.514.107 Documentation

Documentation shall be provided in accordance with IEC 62446-1.

A set of operational instructions for the insulation fault alarm referred to in 712.531.3.101.3 shall be provided to the PV installation owner, which explains the need for immediate action to investigate and to correct the fault.

712.514.2 Wiring systems

Add the following:

The identification of AC and DC circuits shall be such that they are clearly distinguishable from each other (e.g. by labels or different coloured cables).

712.515 Prevention of mutual detrimental influence

712.515.101 Selection and erection of PV modules in relation with external influences

712.515.101.1 Thermal aspects

Provisions shall be made 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 shall be made for other applicable metallic components, including mounting structures, conduits and cable trays.

712.515.101.2 Mechanical loads on PV structures

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

712.515.101.3 Wind

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

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

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

712.515.101.4 Material accumulation on PV array

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

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

712.515.101.5 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 equipment, for example aluminium, galvanized steel, treated timber.

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 equipment. Corrosive gases, such as ammonia in farming environments, also need to be taken into account.

Measures 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.

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

712.52 Wiring systems**712.521 Types of wiring systems****712.521.101 Type**

712.521.101.1 Cables used within the PV array shall:

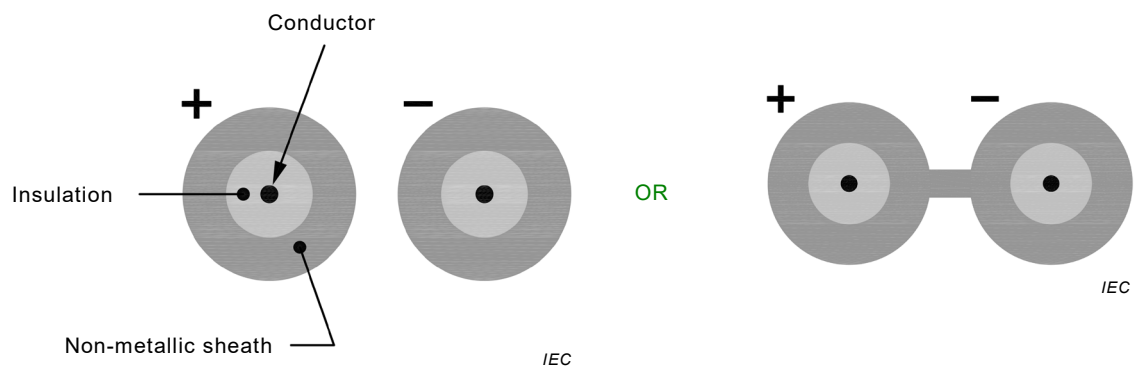
- be suitable for DC application;
- have a voltage rating of equal to or greater than the open-circuit maximum voltage determined in clause 712.512.1.1.101;
- have a temperature rating according to the application, taking into account that PV modules frequently operate at temperatures of the order of 40 K above ambient

temperature and therefore cable insulation of wiring installed in contact or near PV modules shall be rated accordingly;

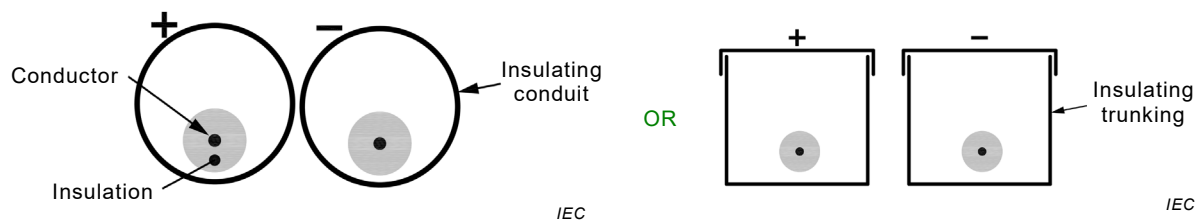
- if exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection, or be installed in UV-resistant conduit or trunking;
- be suitable for the expected conditions of exposure to water;
- where copper conductors are used, have tinned, multistranded conductors in order to reduce degradation of the cable over time;
- in all installations operating at voltages exceeding extra-low voltage, be selected so as to minimize the risk of insulation faults (This is commonly achieved using cables having insulation and a non-metallic sheath, selected and installed in accordance with IEC 60364-4-41:2005, 412.2.4.1, particularly for cables that are exposed or laid in metallic tray or conduit. This can also be achieved by reinforcing the protection of the wiring as shown in Figure 712.9);
- be flame retardant as defined in IEC 60332-1-2;
- have conductors classified according to minimum class 5 of IEC 60228 where subject to movement (such as for tracking installations or where string cables are exposed to wind), or a minimum of class 2 of IEC 60228 where not subject to movement.

NOTE 1 Some countries require halogen free cables when those cables are routed through a building

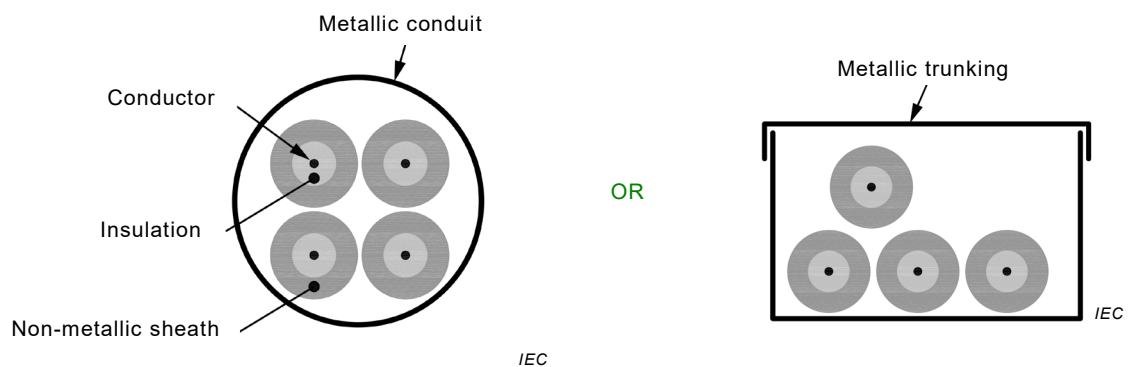
NOTE 2 IEC 62930, Electric cables for Photovoltaic systems, is under development.



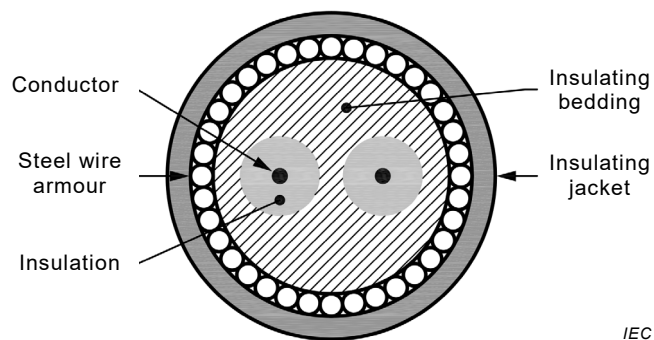
a) Single or multi conductor cable where each conductor is both insulated and sheathed



b) Insulated conductor cable – in insulated conduit/trunking



c) Single conductor cable – in metallic conduit/trunking



d) Steel wire armoured cable (usually suitable only for main DC cable)

Figure 712.9 – Examples of cables with reinforced protection

712.521.101.2 Cables on the DC side shall be selected and erected so as to minimize the risk of earth faults and short circuits.

712.521.102 General

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.

712.521.103 Wiring loops

To reduce the magnitude of transient overvoltages, the PV array wiring shall be laid in such a way that the area of conductive loops is minimum (e.g. by laying cables in parallel as shown in Figure 712.10)

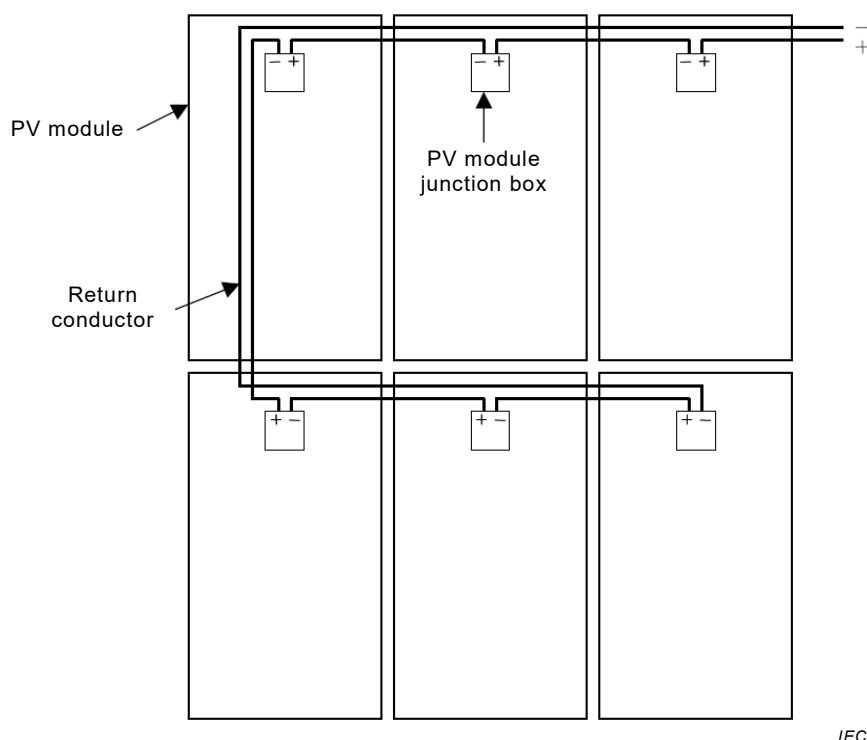


Figure 712.10 – PV string wiring with minimum loop area

712.521.104 String wiring

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

- cables are protected from mechanical damage, and
- the cable is so installed as to relieve tension in order to prevent the conductor from coming free from the connection.

712.522 Selection and erection of wiring systems in relation to external influences

~~712.522.8.1 PV string cables, PV array cables and PV DC main cables shall be selected and erected so as to minimize the risk of earth faults and short circuits.~~

~~NOTE This may be achieved for example by reinforcing the protection of the wiring against external influences by the use of single-core sheathed cables.~~

~~712.522.8.3 Wiring systems shall withstand the expected external influences such as wind, ice formation, temperature and solar radiation.~~

712.522.101 Installation method

Cables shall be supported so they do not suffer fatigue due to wind/snow affects. They shall also be protected from sharp edges. Cables shall be supported so that their properties and installation requirements are maintained over the stated life of the PV plant. All non-metallic cable management systems exposed to sunlight shall be of a UV resistant type.

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

712.523 Current-carrying capacities

712.523.101 The ambient temperature for cables subjected to direct heating from the underside of PV modules shall be considered to be at least 70 °C.

712.524 Cross-sectional areas of conductors

712.524.1

Add the following:

Cable sizes for PV string cables, PV sub-array cables and PV array cable shall be determined with regard to overcurrent protection ratings where in use, the minimum current rating (refer to Table 712.2), the voltage drop and prospective fault current. The largest cable size obtained from these criteria shall be applied.

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

712.524.1.101.1

The minimum cable sizes for PV array wiring, based on current-carrying capacity (I_z), shall be based upon a current rating calculated from Table 712.2.

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

Table 712.2 – Minimum current rating of circuits

Relevant circuit	Protection	Minimum current upon which cable cross sectional area and or other circuit ratings shall be chosen
PV string	PV string overcurrent protection not provided	Current rating (I_n) of the nearest downstream overcurrent protective device $+ 1,25 \times I_{SC\ MOD} \times (N_s - 1)$ where: N_s is the total number of parallel connected strings protected by the nearest overcurrent protective device. NOTE i) The nearest downstream overcurrent protection may be the sub-array protection and if this is not present then it may be the array overcurrent protection if present. ii) When no overcurrent protection is used in the complete array then N_s is the total number of parallel connected strings in the complete PV array; and the rated current (I_n) of the nearest overcurrent protective device is replaced by zero.
	PV string overcurrent protection provided	Current rating (I_n) of the PV string overcurrent protective device (refer to 712.430.3.101 to 712.430.3.104, 712.433.1.101 and 712.433.2.101)
PV sub-array	PV sub-array overcurrent protection not provided	The greater of the following: a) Current rating (I_n) of the PV array overcurrent protective device + $1,25 \times$ sum of short circuit current of all other sub-arrays b) $1,25 \times I_{SC\ S-ARRAY}$ (of relevant array) NOTE When PV array overcurrent protection is not used, the I_n is replaced by zero in Equation (a).
	PV sub-array overcurrent protection provided	Current rating (I_n) of the PV sub-array overcurrent protective device (refer to 712.430.3.101 to 712.430.3.104, 712.433.1.101 and 712.433.2.101)
PV array	PV array overcurrent protection not provided	$1,25 \times I_{SC\ ARRAY}$
	PV array overcurrent protection provided	Current rating (I_n) of the PV array overcurrent protective device (refer to 712.430.3.101 to 712.430.3.104, 712.433.1.101 and 712.433.2.101)

Where a PCE or other power conversion device is capable of providing backfeed current into the array under fault conditions, the value of this backfeed current shall be taken into account in all calculations of circuit current ratings. In some circumstances the backfeed current will have to be added to the circuit rating as calculated in Table 712.2.

NOTE The value of backfeed current provided by power conversion equipment (PCE) can be obtained from information provided by the PCE manufacturer.

712.525 Voltage drop in consumers installations

712.525.101 Voltage drop in PV installations

For efficiency reasons, other than electrical safety and correct functioning of equipment, consideration shall be given to the voltage drop in the PV installation. See 712.31.101.1.6. National requirements should be considered.

When the PV installation is generating power, the voltage at the PCE terminals is higher than the voltage at the grid connection point. This voltage difference should be kept to a minimum in order to prevent the PCE from nuisance tripping on overvoltage.

The recommendations of IEC 60364-5-52:2009, Annex G apply.

712.526 Electrical connections

712.526.1

Add the following:

Male and female connectors mated together shall be of the same type from the same manufacturer i.e. a male connector from one manufacturer and a female connector from another manufacturer or vice versa shall not be used to make a connection.

Connectors shall comply with the following requirements:

- be rated for DC use (IEC 62852);
- have a voltage rating equal to or greater than the open-circuit maximum voltage determined in 712.512.1.1.101;
- 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 712.2);
- be capable of accepting the cable used for the circuit to which they are fitted;
- require a deliberate force to disconnect;
- if accessible by untrained people, then shall be of the locking type where two independent actions are required to disconnect;
- have a temperature rating suitable for their installation location;
- if multi-polar, be polarized;
- comply with Class II for PV installations operating above 35 V;
- 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 minimize strain on the connectors (e.g. supporting the cable on either side of the connector);
- plugs and socket outlets normally used for the connection of household equipment to low voltage AC power shall not be used in PV arrays.

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

712.526.101 Connectors on the DC side

For PV installations not using SELV or PELV protective measures on the DC side, only connectors especially suitable for the DC side of PV installations shall be used.

Connectors in a location accessible to persons other than skilled or instructed persons shall either be of a type which can only be disconnected by means of a key or a tool or shall be installed within an enclosure which can only be opened by means of a key or a tool.

712.526.102 Wiring installation in combiner boxes

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

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

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

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

712.527 Selection and erection of wiring systems to minimize spread of fire

Under consideration.

712.528 Proximity of wiring systems to other services

Under consideration.

712.529 Selection and erection of wiring systems in relation to maintainability, including cleaning

Under consideration.

712.53 Isolation, switching and control

712.530.3 General and common requirements

712.530.3.101 Residual current devices

Where an RCD is used for protection of the PV AC supply circuit, the RCD shall be of type B in accordance with IEC 62423, unless:

- the manufacturer's instructions state that the inverter provides at least simple separation between the AC side and the DC side, or
- the installation provides at least simple separation between the inverter and the RCD by means of separate windings of a transformer, or
- the inverter is in accordance with IEC 62109-1 and the manufacturer's instructions do not require the use of a type B RCD, in which case the type of RCD shall be in accordance with the manufacturer's instructions.

712.531 Devices for protection against indirect contact (fault protection) by automatic disconnection of supply

712.531.101 Detection, disconnection and alarm requirements

Requirements for detection of insulation faults, actions required and alarms depend on the type of system earthing and whether the PCE provides electrical separation of the PV array from the output circuit (e.g. the grid). Table 712.3 shows the requirements for measurements of PV array insulation resistance to earth and PV array RCM as well as the actions and alarms required if a fault is detected.

Table 712.3 – Requirements for different system types based on PCE isolation and PV array functional earthing

		System type		
		Non-isolated PCE + No functional earth on PV array	Isolated PCE + No functional earth on PV array	Isolated PCE + Functionally earthed PV array
PV array insulation resistance to earth	Measurement	According to 712.531.3.101.1		
	Action on fault	a) If the AC side is not part of an IT system: Shut down PCE and disconnect all live conductors of the AC circuit or all poles of the faulty portion of the PV array from the PCE b) If the AC side is part of an IT system: No action (PCE is allowed to operate).	Connection to the AC circuit is allowed (PCE is allowed to operate)	
	Alarm on fault	Indicate a fault in accordance with 712.531.3.101.3		
PV array residual current monitoring	Measurement	According to 712.531.3.101.2	Not required	According to 712.531.3.101.2
	Action on fault	Shut down PCE and disconnect all live conductors of the AC circuit or all poles of the faulty portion of the PV array from the PCE		Functional earth connection shall be disconnected (see 712.531.3.101.2); connection to the AC circuit is allowed. (PCE is allowed to operate)
	Alarm on fault	Indicate a fault in accordance with 712.531.3.101.3		Indicate a fault in accordance with 712.531.3.101.3
Instead of shutting down the PCE and disconnecting the AC circuit it is allowed to isolate the faulted parts of the PV array.				
Functional earthing has to be carried out according to 712.4.102.				
Systems using non-isolated PCEs where the AC circuit is referenced to earth are not allowed to use functional earthing on the PV side of the PCE see 712.4.102.				

712.531.3 Insulation monitoring devices

712.531.3.101 Requirements for PV arrays operating at above 60 V

712.531.3.101.1 Array insulation resistance detection

The requirements in 712.531.3.101.1 regarding detection and response to abnormal array insulation resistance to earth are intended to reduce hazards due to degradation of insulation.

A means shall be provided to measure the insulation resistance from the PV array to earth before starting operation and at least once every 24 h. This can be done by an insulation measuring device according to IEC 61557-2, or by an insulation monitoring device (IMD) according to Annex C of IEC 61557-8:2014, to prevent a possible high risk of fire.

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

Minimum threshold values for detection shall be according to Table 712.4.

**Table 712.4 – Minimum insulation resistance thresholds
for detection of failure of insulation to earth**

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

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

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

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

- for isolated PCEs, shall indicate a fault in accordance with 712.531.3.101.3 (operation is allowed); the fault alarm shall be maintained until the array insulation resistance has recovered to a value higher than the limit above;
- for non-isolated PCEs, shall indicate a fault in accordance with 712.531.3.101.3, and shall not connect to any earthed output circuit (e.g. the mains); the device may continue to make the measurement, may stop indicating a fault and may allow connection to the output circuit if the array insulation resistance has recovered to a value higher than the limit above.

712.531.3.101.2 Residual current monitoring system

Where required by Table 712.3, residual current monitoring shall be provided that functions whenever the PCE is connected to an earth referenced output circuit with the automatic disconnection means closed. The residual current monitoring means shall measure the true RMS (both AC and DC components) residual current.

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

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

- Continuous residual current: where the RCM indicates a residual current above the limits, disconnection by a switching device shall operate within 0,3 s and indicate a fault in accordance with 712.531.3.101.3 if the continuous residual current exceeds:
 - maximum 300 mA for PCEs with continuous output power rating ≤ 30 kVA;
 - maximum 10 mA per kVA of rated continuous output power for PCEs with continuous output power rating > 30 kVA.

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

The RCM may attempt to initiate re-connection if the leakage current threshold is below that specified in this subclause and the array insulation resistance meets the limit in 712.531.3.101.1.

- b) Sudden changes in residual current: the PCE shall disconnect from any earth referenced output circuits (e.g. the mains) within the time specified in Table 712.5 and indicate a fault in accordance with 712.531.3.101.3 if a sudden increase in the RMS residual current is detected exceeding the value in the table.

Table 712.5 – Response time limits for sudden changes in residual current

Residual current sudden change	Maximum time for disconnection from earth referenced circuit
30 mA	0,3 s
60 mA	0,15 s
150 mA	0,04 s
NOTE These values of residual current and time were originally taken from the RCD standard IEC 61008-1 but are no longer related to protection against electric shock in the meaning of this document.	

The RCM may attempt to initiate re-connection if the leakage current threshold is below that specified in this subclause and the array insulation resistance meets the limit in 712.531.3.101.2.

712.531.3.101.3 Insulation fault alarm

To provide an indication as required by 712.531.3.101.1, an insulation fault alarm shall be installed. When activated the alarm is to continue its operation until the PV installation is shut down and/or the insulation fault is corrected.

The alarm shall be of a form that ensures that the operator or owner of the PV installation becomes aware of the fault. For example, the alarm may give a visible or audible signal placed in an area where operational staff or owners will be aware of the signal or another form of fault communication such as Email, SMS or similar.

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

712.532 Devices for protection against thermal effects

712.532.101 Protection against the effects of insulation faults which includes the use of an IMD

Where an IMD is used in connection with protection against the effects of insulation faults, it shall be in accordance with IEC 61557-8.

If the IMD is an integral part of the PCE, the insulation monitoring function has to be in accordance with Annex D of IEC 62109-2: 2014.

NOTE 1 Protection against the effects of insulation faults by IMD is a possible choice where AC and DC sides are galvanically separated without functional earthing of a live part on the DC side (see 712.532.102)

NOTE 2 An IMD can also be necessary for reasons other than fire prevention, for example for continuous operation without interruption by a first fault.

In PV arrays > 100 kWp an automatic insulation fault location system according to IEC 61557-9 is recommended.

712.532.102 Protection against the effects of insulation faults by disconnecting the functional earthing conductor

The device or association of devices required by 712.421.101.2.3 shall:

- meet the relevant requirements of IEC 60364-4-43,
- be rated for the maximum voltage of the PV array $U_{OC\ MAX}$,
- have a rated breaking capacity not less than the maximum short circuit current of the PV array $I_{SC\ MAX}$, and
- have a rated current not exceeding that given in Table 712.6.

Table 712.6 – Rated current of automatic disconnecting device in the functional earthing conductor

Total PV array power rating (kWp)	Rated current I_n (A)
0 to 25	1
>25 to 50	2
>50 to 100	3
>100 to 250	4
>250	5

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 the manufacturer's instructions be followed. It is also recommended that, where possible, the functional earthing to bleed charge from the cells be via a resistor and not directly to earth. The recommended resistor value should be the highest resistor value allowable as per the manufacturer's instructions.

712.533 Devices for protection against overcurrent

712.533.1 General requirements

712.533.101 Overcurrent protective devices of the DC side

The overcurrent protective devices of the DC side shall be:

- gPV fuses in accordance with IEC 60269-6, or ,
- circuit-breakers in accordance with IEC 60947-2 or IEC 60898-2 for which the manufacturer declares their suitability for use in PV installations.

These devices shall comply with the following specific measures:

- the rated operating voltage (U_e) shall be greater than or equal to the voltage $U_{OC\ MAX}$ of the PV array;
- the rated current I_n as defined in 712.433.1.101;
- the rated breaking capacity shall be at least equal to $I_{SC\ MAX}$ of the PV array and fault current from any other connected power sources, such as batteries or generators;