

AS/NZS 5033:2021



Australian/New Zealand Standard™

Installation and safety requirements for photovoltaic (PV) arrays



AS/NZS 5033:2021

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Australian/New Zealand Standard™

Installation and safety requirements for photovoltaic (PV) arrays

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Preface

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EL-042, Renewable Energy Power Supply Systems and Equipment, to supersede AS/NZS 5033:2014.

AS/NZS 5033:2014 will also remain current for SIX MONTHS and after this time it will be superseded by AS/NZS 5033:2021. Regulatory authorities that reference this standard in regulation may apply these requirements at a different time. Users of this standard should consult with these authorities to confirm their requirements.

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

At the time of publication there were limited Standards for arc detection and prevention for PV arrays. As standards develop, there will be a revision of this document, which will require the use of this technology for PV arrays.

Many new protection features for arrays when used in grid connected applications will be implemented in inverter systems and are required by the International Standard for inverters — IEC 62109-2. Both this document and AS/NZS 4777 require inverters that conform to IEC 62109-2 for grid connected PV systems.

There are a number of changes in requirements in this revision. They include but are not limited to —

- (a) change in the scope of this document with respect to maximum PV array power limit;
- (b) additions of provisions relating to d.c. conditioning units regarding voltage and current calculations;
- (c) changes to requirements for overcurrent protection and earthing;
- (d) changes to methods of PV isolation including for d.c conditioning units;
- (e) changes to requirements for wiring systems and connector requirements;
- (f) new signs, verification and commissioning requirements.

This document necessarily deals with existing types of systems but is not intended to discourage innovation or to exclude materials equipment and methods that may be developed in the future.

Revisions will be made from time to time in view of such developments, and amendments to this edition will be made when necessary.

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Statements expressed in mandatory terms in Notes to Tables and Figures are deemed to be requirements of this document.

The terms “normative” and “informative” have been used in this document to define the application of the Appendix to which they apply. A “normative” Appendix is an integral part of a document, whereas an “informative” Appendix is only for information and guidance.

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NOTES

Australian/New Zealand Standard

Installation and safety requirements for photovoltaic (PV) arrays

1 Scope and general

1.1 Scope

This document sets out general installation and safety requirements for electrical installations of PV arrays, including d.c. array wiring, electrical protection devices, switching and earthing provisions. The scope includes all parts of the PV array up to but not including energy storage devices, power conversion equipment or loads. This document also includes d.c. safety issues related to any associated power conversion equipment.

NOTE 1 Examples of d.c. safety issues related to power conversion equipment include integrated d.c. load break disconnection devices, earth fault detection, alarm and backfeed currents.

The interconnection of d.c. conditioning units intended for connection to PV modules are also included.

This document does not apply to PV arrays in the following electrical installation types:

- (a) Less than 100 W and less than 35 V d.c. open circuit voltage at STC.
- (b) Transportable structures and vehicles that are in accordance with AS/NZS 3001.
- (c) Boats in accordance with AS/NZS 3004.

This document does not apply to PV arrays on large-scale ground mounted PV power plants with restricted access to personnel and connected to dedicated high voltage systems. However, in the absence of an Australian Standard, this document should be used as guidance, subject to appropriate engineering principles being applied.

NOTE 2 Local jurisdictional requirements apply where applicable. 35V d.c. relates to the Decisive Voltage Classification A (DVC-A), as defined in IEC 62109-1.

NOTE 3 Attention is drawn to the fundamental safety principle of isolation described in AS/NZS 3000. Use of non-separated PCE means there is no isolation of ac or dc voltages between the input and output of the non-separated PCE. Safety designs and work principles needs to consider that any ac or dc voltage present on one side of the non-separated PCE is deemed present on the other side of the non-separated PCE.

The safety requirements of this document are critically dependent on the inverters associated with PV arrays conforming to the requirements of IEC 62109-1 and IEC 62109-2 and all power conversion equipment conforming to IEC 62109 series Standards.

This document shall be read in conjunction with AS/NZS 3000.

When the installation of PV arrays is connected to the grid, this document shall be read in conjunction with the AS/NZS 4777 series. When the installation of PV arrays forms part of a stand-alone power system, this document shall be read in conjunction with the AS/NZS 4509 series. When the installation of PV arrays includes battery energy storage systems, this document shall be read in conjunction with AS/NZS 5139.

PV arrays that fall within the scope shall be installed in accordance with AS/NZS 3000 except as varied herein, and with the requirement of this document.

1.2 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:

NOTE Documents for informative purposes are listed in the Bibliography.

AS 1768, *Lightning protection*

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

AS 60947.3, *Low-voltage switchgear and control gear, Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units (IEC 60947-3:2015 (ED. 3.2) MOD)*

AS 61386.1, *Conduit systems for cable management, Part 1: General requirements*

AS/NZS 1170.2, *Structural design actions, Part 2: Wind actions*

AS/NZS 3000, *Electrical installations (known as the Australian/New Zealand Wiring Rules)*

AS/NZS 3008.1.1, *Electrical installations — Selection of cables. Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV — Typical Australian installation conditions*

AS/NZS 3008.1.2, *Electrical installations — Selection of cables, Part 1.2: Cables for alternating voltages up to and including 0.6/1 kV — Typical New Zealand conditions*

AS/NZS 4509.1, *Stand-alone power systems, Part 1: Safety and installation*

AS/NZS 4777.1, *Grid connection of energy systems via inverters, Part 1: Installation requirements*

AS/NZS 4777.2, *Grid connection of energy systems via inverters, Part 2: Inverter requirements*

AS/NZS 5139, *Electrical installations — Safety of battery systems for use with power conversion equipment*

AS/NZS 60898.2, *Circuit-breakers for overcurrent protection for household and similar installations, Part 2: Circuit-breakers for a.c. and d.c. operation (IEC 60898-2, Ed. 1.1 (2003) MOD)*

AS/NZS 62852, *Connectors for d.c.-application in photovoltaic systems — Safety requirements and tests*

AS/NZS IEC 60947-2, *Low-voltage switchgear and control gear, Part 2: Circuit-breakers*

NZS 4219, *Seismic performance of engineering systems in buildings*

IEC 60068-2-5:2018, *Environmental testing — Part 2-5: Tests — Test S: Simulated solar radiation at ground level and guidance for solar radiation testing and weathering*

IEC 60228, *Conductors of insulated cables*

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

IEC 61386-1, *Conduit systems for cable management, Part 1: General requirements*

IEC 61439-1:2020, *Low-voltage switchgear and controlgear assemblies — Part 1: General rules*

IEC 61439-2:2020, *Low-voltage switchgear and controlgear assemblies — Part 2: Power switchgear and controlgear assemblies*

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

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

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

IEC 62109-1, *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 62548, *Photovoltaic (PV) arrays — Design requirements*

IEC 62930, *Electric cables for photovoltaic systems with a voltage rating of 1,5 kV d.c.*

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

IEV, International Electrotechnical Vocabulary (Electropedia)

ISO 4892-4, *Plastics — Methods of exposure to laboratory light sources — Part 4: Open-flame carbon-arc lamps*

ANSI/UL 790, *Standard for Standard Test Methods for Fire Tests of Roof Coverings*

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

1.3 Terms and definitions

For the purposes of this document, the following definitions and those of AS/NZS 3000 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>

1.3.1

A.C. module inverter

inverter mechanically secured to a PV module in such a way that the connection between the PV module d.c. output and the inverter input is internal to the a.c. module inverter and there are no external d.c. connections

1.3.2

application circuit

final circuit supplied by the PV array

Note 1 to entry: See [Clause 2.1.1](#).

1.3.3

bifacial nameplate irradiance

BNPI

higher irradiance at which nameplate verification is performed for bifacial modules. Bifacial nameplate irradiance (BNPI) is that which corresponds to 1000 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, such as single-side illumination at equivalent irradiance, or double-side illumination.

1.3.4

blocking diode

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

[SOURCE: IEC TS 61836, 3.2.5]

1.3.5

bypass diode

diode connected across one or more PV cells in the forward current direction to allow the PV 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 PV module

[SOURCE: IEC TS 61836, 3.1.11]

1.3.6

class 0

equipment with basic insulation as provision for basic protection and with no provisions for fault protection

1.3.7

combiner box

junction box where PV circuits are connected, which may also contains overcurrent protection devices or disconnectors, or both

Note 1 to entry: See [Figure 2.4](#).

1.3.8

d.c. conditioning units

DCU

d.c. to d.c. power conversion equipment connected to individual PV modules or groups of PV modules to modify the voltage and or current of the PV output

Note 1 to entry: DCUs are not considered to be PCEs for the purposes of this Standard.

1.3.9

DCU strings

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

1.3.10

partial DCU strings

PV string where some but not all 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.

1.3.11

disconnection point

non-load break d.c. disconnection device

Note 1 to entry: See [Clause 4.3.5.2.1](#).

1.3.12

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.

Note 2 to entry: A load break disconnection device, such as switch disconnectors and some circuit breakers, provides a load break isolation function. In this Standard these devices are identified on warning signs and labels as "Isolators" for simplicity in interpretation by the public.

1.3.13**dedicated individual enclosure**

enclosure for use with disconnectors, such as switch disconnectors. It includes enclosures for use with one or multiple disconnectors in the one enclosure with or without other minor components. It does not include enclosures for assemblies

Note 1 to entry: Minor components may include, for example but not limited to, indicator lights, fuses or other small electrical or non-electrical parts not related to the installed switch disconnector.

Note 2 to entry: One enclosure includes enclosures where one part of the enclosure is common to the assembly, for example but not limited to, one back enclosure moulding with multiple individual front mouldings of enclosure for each installed switch disconnector.

1.3.14**electromagnetic compatibility****EMC**

ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[SOURCE: IEC 161-01-07]

1.3.15**electromagnetic disturbance**

electromagnetic phenomena that can degrade the performance of a device, equipment or system, or adversely affect living or inert matter

Note 1 to entry: An electromagnetic disturbance can be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.

Note 2 to entry: The terms “electromagnetic disturbance” and “electromagnetic interference” designate respectively the cause and the effect, and should not be used indiscriminately

[SOURCE: IEC 161-01-05]

1.3.16**electromagnetic environment**

totality of electromagnetic phenomena existing at a given location

Note 1 to entry: In general, the electromagnetic environment is time-dependent, and its description can need a statistical approach.

[SOURCE: IEC 161-01-01]

1.3.17**electromagnetic interference****EMI**

degradation in the performance of equipment or transmission channel or a system caused by an electromagnetic disturbance

Note 1 to entry: The terms “electromagnetic disturbance” and “electromagnetic interference” designate respectively the cause and the effect and should not be used indiscriminately.

[SOURCE: IEC 161-01-06]

1.3.18**enclosures for assemblies**

enclosure for use in an outdoor location with one or more installed disconnectors, such as switch disconnectors, with or without other components installed in the enclosure

1.3.19**indoor**

location that is dry, free from condensation, is fully covered by a building to protect it from rain, sun and radiation, to the cold night sky, and is generally conditioned in terms of temperature and humidity

1.3.20**irradiance**

radiant solar power incident upon unit area of surface, measured in watts per square metre

1.3.21**lightning ground flash density**

N_g

number of lightning flashes to ground, per square kilometre, per annum

1.3.22**lightning protection system**

LPS

complete system, inclusive of air terminals, downconductors, earth network and bonding, used to reduce physical damage due to lightning flashes to a structure or its contents

1.3.23**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

1.3.24**maximum power voltage**

V_{mp}

voltage at the maximum power point of a PV module under STC

1.3.25**may**

indicates the existence of an option

1.3.26**outdoor**

any location that is not indoor as specified in [Clause 1.3.19](#)

1.3.27**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 d.c./a.c. inverters, d.c./d.c. converters, charge controllers, etc.

Note 2 to entry: DCUs are not considered to be PCEs for the purposes of this Standard.

1.3.28**power conversion equipment, non-separated**

power conversion equipment where there is no electrical separation between the input and output circuits

Note 1 to entry: An example of a non-separated PCE is a transformerless inverter.

1.3.29**power conversion equipment, separated**

power conversion equipment where there is at least simple separation between the input and output circuits

Note 1 to entry: For a PCE that does not have internal separation/isolation between the input and output circuits, but is required to be used with a dedicated isolation transformer, with no other equipment connected to the PCE side of that isolation transformer, the combination may be treated as a separated PCE. Other configurations require analysis at the system level and are beyond the scope of this Standard. However, the principles in this Standard may be used.

1.3.30**PV array**

assembly of electrically interconnected PV modules, PV strings or PV sub-arrays comprising all components up to the d.c. input terminals of the inverter or other power conversion equipment or d.c. loads

Note 1 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 [Figures 2.2](#) to [2.8](#)).

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

1.3.31**PV array cable**

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

1.3.32**PV cell**

most elementary device that exhibits the photovoltaic effect (i.e. the direct non-thermal conversion of radiant energy into electrical energy)

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

[SOURCE: IEC TS 61836, 3.1.48.1]

[SOURCE: IEC TS 61836, 3.1.48.4]

1.3.33**PV module**

complete and environmentally protected assembly of interconnected photovoltaic cells

[SOURCE: IEC TS 61836, 3.1.48.7]

Note 1 to entry: A PV module is colloquially referred to as a “solar panel”.

1.3.34**PV string**

circuit of one or more series-connected PV modules

[SOURCE: IEC TS 61836]

1.3.35**PV sub-array**

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

1.3.36**PV sub-array cable**

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

Note 1 to entry: PV sub-array cables are only relevant for PV arrays that are divided into sub-arrays (see [Figure 2.4](#) for details).

1.3.37**restricted access**

access restricted —

- (a) by a barrier (e.g. by a perimeter fence or barrier with access only via a padlocked or equivalently secured gate or door)
- (b) by location (e.g. roof where there is no fixed ladder or other ready means of access)
- (c) by enclosure (e.g. cables in a wiring enclosure that are not accessible without the use of a tool)
- (d) by installation height — greater than 2.5 m above the ground, floor or platform

1.3.38**shall**

indicates that a statement is mandatory

1.3.39**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 461-03-04]

1.3.40**should**

indicates a recommendation

1.3.41**simple separation**

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

Note 1 to entry: Simple separation therefore means that there is no electrical connection between circuits or between circuits and earth.

[SOURCE: IEC 826-12-28]

1.3.42**standard test conditions****STC**

reference values of in-plane irradiance ($G_{l,ref} = 1000 \text{ W}\cdot\text{m}^{-2}$), 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, 3.4.16.5]

1.3.43**string cable**

cable interconnecting the PV modules in a PV string or connecting the string to a junction box, combiner box, PCE or other d.c. loads

[SOURCE: IEC TS 61836, 3.2.21.2]

Note 1 to entry: See [Figure 2.2](#) to [Figure 2.4](#).

1.3.44**surge protective device****SPD**

device that is intended to limit transient overvoltage and divert surge currents. It contains at least one non-linear component

1.3.45**SPD-disconnector**

device for disconnecting an SPD from the power system

1.3.46**switch-disconnector**

mechanical switching device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions

Note 1 to entry: Switch disconnectors are able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions.

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

1.4 Notations

For the purpose of this document, the following notations apply:

γ_v	=	Voltage temperature co-efficient, V/°C/module supplied by the manufacturer (negative value for crystalline silicon)
G_I	=	Plane of array irradiance (W/m ²)
I_{ARRAY}	=	total current on the circuit that carries the total output current of the array
$I_{BF\ TOTAL}$	=	total continuous backfeed current from all sources not originating at the PV modules
$I_{c(break)}$	=	as determined by AS 60947.3
I_{DCU_max}	=	DCU maximum output current
$I_{DCU\ STRING\ MAX}$	=	DCU maximum overcurrent protection on the DCU string side
$I_{DCU\ S-ARRAY\ MAX}$	=	DCU maximum overcurrent protection on the DCU sub-array
$I_{DCU\ OCPR}$	=	DCU maximum overcurrent protection rating as determined by the DCU manufacturer
I_e	=	as determined by AS 60947.3
$I_{F\ STRING}$	=	potential fault current in a string from other parallel strings
$I_{F\ S-ARRAY}$	=	potential fault current in a sub array from other sub-array circuits
$I_{(make)}$	=	as determined by AS 60947.3
$I_{MOD\ MAX\ OCPR}$	=	PV module maximum overcurrent protection rating as determined by IEC 61730-2
I_n	=	the nominal overcurrent protection rating of the overcurrent protection device

$I_{S-ARRAY}$	=	total current on a sub-array circuit
$I_{SC ARRAY}$	=	short circuit current of the array at STC
	=	$I_{SC MOD} \times S_A$
$I_{SC BNPI}$	=	short circuit current of a PV module or PV string at BNPI test conditions as specified by the manufacturer in the product specification plate
$I_{SC EXPECTED}$	=	expected short circuit current of the segment under test
$I_{SC S-ARRAY}$	=	short circuit current of the sub-array at STC
	=	$I_{SC MOD} \times S_{SA}$
$I_{SC MOD}$	=	short circuit current of a PV module or PV string at STC, as specified by the manufacturer in the product specification plate
$I_{SC PV}$	=	as defined in IEC 62109-1
I_{STRING}	=	total current on a string circuit
$I_{STRING MAX}$	=	maximum current in a string, dependant on the PV system configuration
K_I	=	d.c. current rating adjustment factor for bi-facial PV modules dependent installation properties such as module orientation, module shading or module rear side irradiance
M	=	number of series-connected PV modules in any PV string of the PV array
m	=	number of series-connected PV modules not connected to DCUs in a partial DCU string
n	=	number of parallel connected strings in the segment under test
S_A	=	total number of parallel connected PV strings in the PV array
S_{SA}	=	total number of parallel connected PV strings in the PV sub- array
T_{min}	=	expected minimum daily cell temperature in degrees Celsius
T_{STC}	=	cell temperature at Standard test conditions, in degrees Celsius
$V_{DCU max}$	=	DCU maximum output voltage as determined by the DCU manufacturer
$V_{DCU string max}$	=	DCU string maximum output voltage
$V_{MOD MAX}$	=	PV module maximum output voltage
$V_{OC MOD}$	=	open circuit voltage of a PV module at STC, as specified by the manufacturer in the product specification
V_{mp}	=	voltage at the maximum power point of a PV module under STC

2 PV array system configuration

2.1 Configuration

2.1.1 General

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

[Figure 2.1](#) illustrates the general functional configuration of a PV powered system.

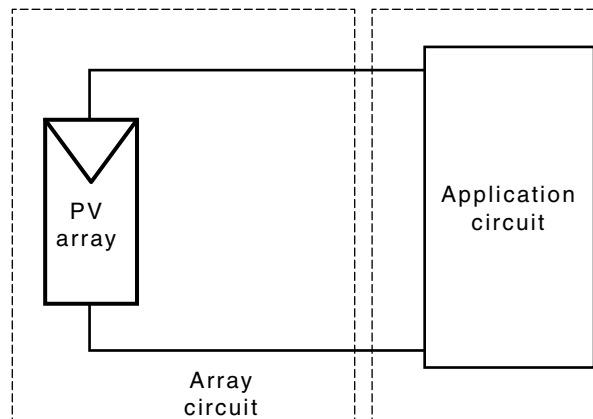


Figure 2.1 — General functional configuration of a PV powered system

The following application circuit types are considered in this document:

- (a) PV array connected to d.c. loads.
- (b) PV array connected to an a.c. system via a separated PCE.
- (c) PV array connected to an a.c. system via a non-separated PCE

2.1.2 PV system architectures

The relation of a PV array to earth is determined by—

- (a) any functional earthing of the array in use; and
- (b) the earth status of the application circuit to which the array is connected.

Both these issues affect safety of the array.

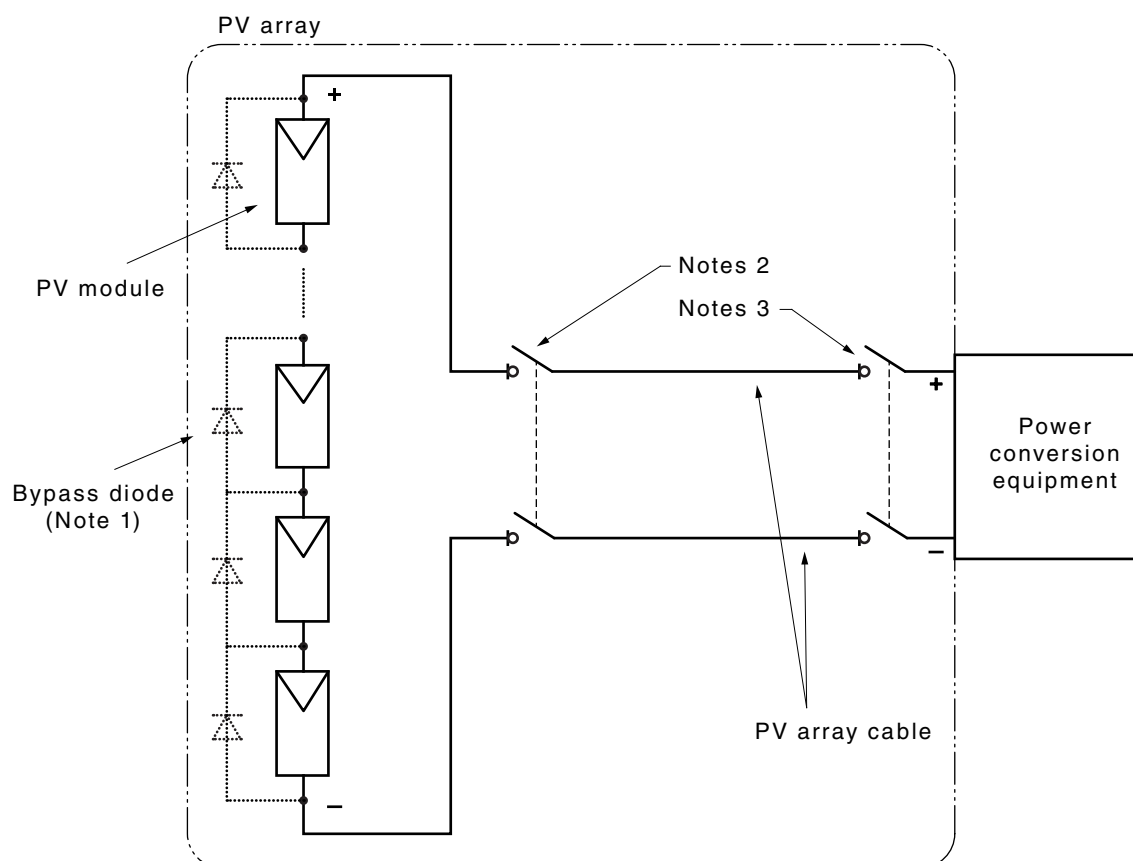
Manufacturer's instructions (including manufacturers of PCE) shall be taken into account in determining the most appropriate system earthing arrangement.

2.1.3 Array electrical diagrams

There are many possible configurations of PV systems. [Figure 2.2](#) to [Figure 2.4](#) show some basic typical electrical configurations of single string, multiple parallel string and multi-sub-array PV respectively.

Where SPDs are fitted, they should be installed as specified in [Appendix G](#).

NOTE In [Figures 2.2, 2.3](#) and [2.4](#), components drawn in dotted format are not required in all cases. The figures indicate the location in the circuit when they are required.

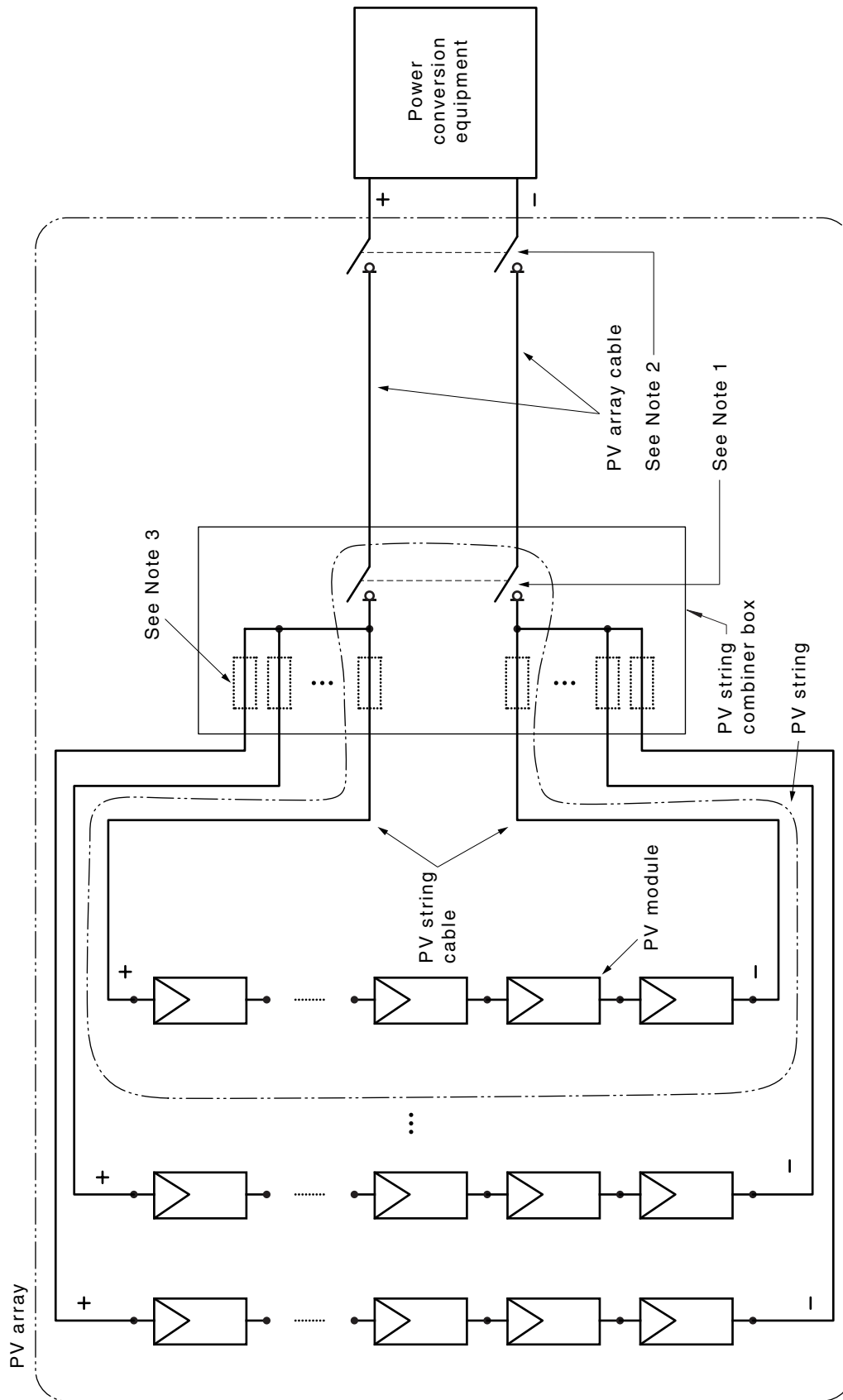


NOTE 1 Bypass diodes are typically incorporated into PV modules by module manufacturers.

NOTE 2 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 3 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

Figure 2.2 — Typical configuration for a single string

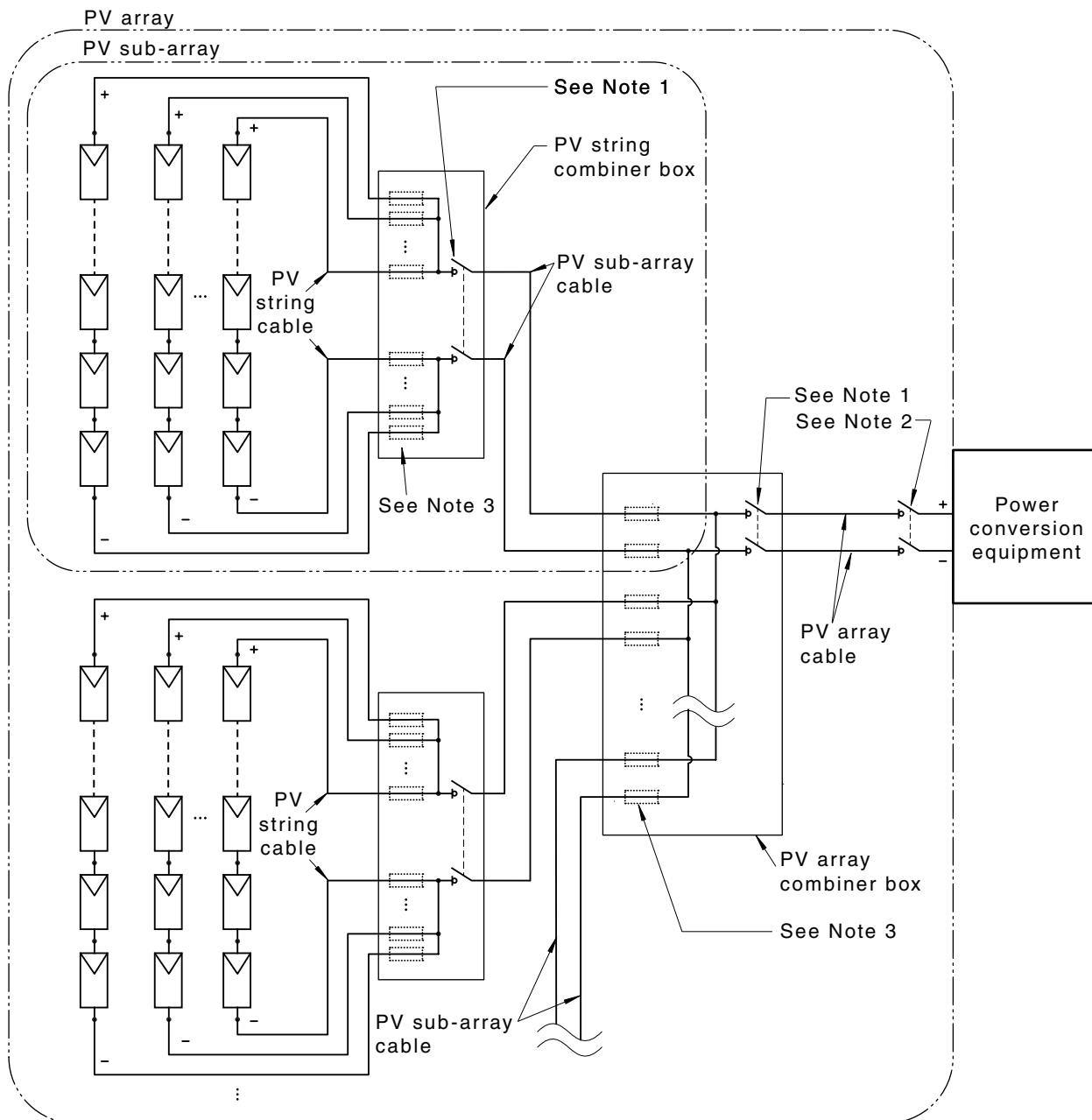


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

NOTE 3 Overcurrent protection devices where required, see [Clause 3.3](#).

Figure 2.3 — Typical configuration for multiple parallel strings



NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

NOTE 3 Overcurrent protection devices where required, see [Clause 3.3](#)

Figure 2.4 — Typical configuration for multiple parallel strings with array divided into sub-arrays

2.1.4 Use of PCE with multiple d.c. inputs

2.1.4.1 General

PV array(s) are often connected to PCEs with multiple d.c. inputs as shown in [Figure 2.5](#) and [Figure 2.6](#). If multiple d.c. inputs are in use, overcurrent protection and cable sizing within the various sections of the PV array(s) are critically dependent on the internal input circuits of the PCE.

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

Where a PCE's input circuit provides separate MPPT inputs, each PV section connected to a MPPT input (see [Figure 2.5](#)) may be treated as a separate PV array for the purposes of this document.

2.1.4.3 PCEs with multiple inputs internally connected in the PCE

Where multiple circuits are internally paralleled into the same MPPT, each PV section connected to one of those MPPT inputs (see [Figure 2.6](#)) shall be treated for the purposes of this document as a sub-array.

All the PV sections combined shall be classified as the complete PV array.

2.1.5 Strings constructed using d.c. conditioning units

DCUs may allow for d.c. conditioning of the PV output.

For example, DCUs can be used to optimize designs where some PV modules have shading on a regular basis or where there are different PV module orientations.

For the purposes of this document, module(s) on the input side of the DCUs are not considered to be an individual PV array. They are deemed to be a part of the PV array.

DCUs may either be connected to all PV modules (see [Figure 2.7](#)) or to some PV modules (partial DCU strings, see [Figure 2.8](#)).

2.1.6 Series-parallel configuration

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

NOTE 1 This is an important safety issue. If strings which are connected in parallel have different voltages, circulating currents will result. When the array d.c. disconnect is in the open position, those circulating currents may still flow representing a hazard if series connections are broken.

To reduce mismatch and improve PV array yield, all PV modules connected to the same PCE maximum power point tracking (MPPT) input should be of the same technology and have the same number of series-connected PV modules (see [Figures 2.2](#) to [2.4](#)). In addition, all PV modules connected to the same PCE MPPT input should have similar rated electrical characteristics including short circuit current, open circuit voltage, maximum power current, maximum power voltage and rated power and temperature coefficients.

NOTE 2 This is a design issue which should be considered by designer/installer, particularly when replacing PV modules or modifying an existing system.

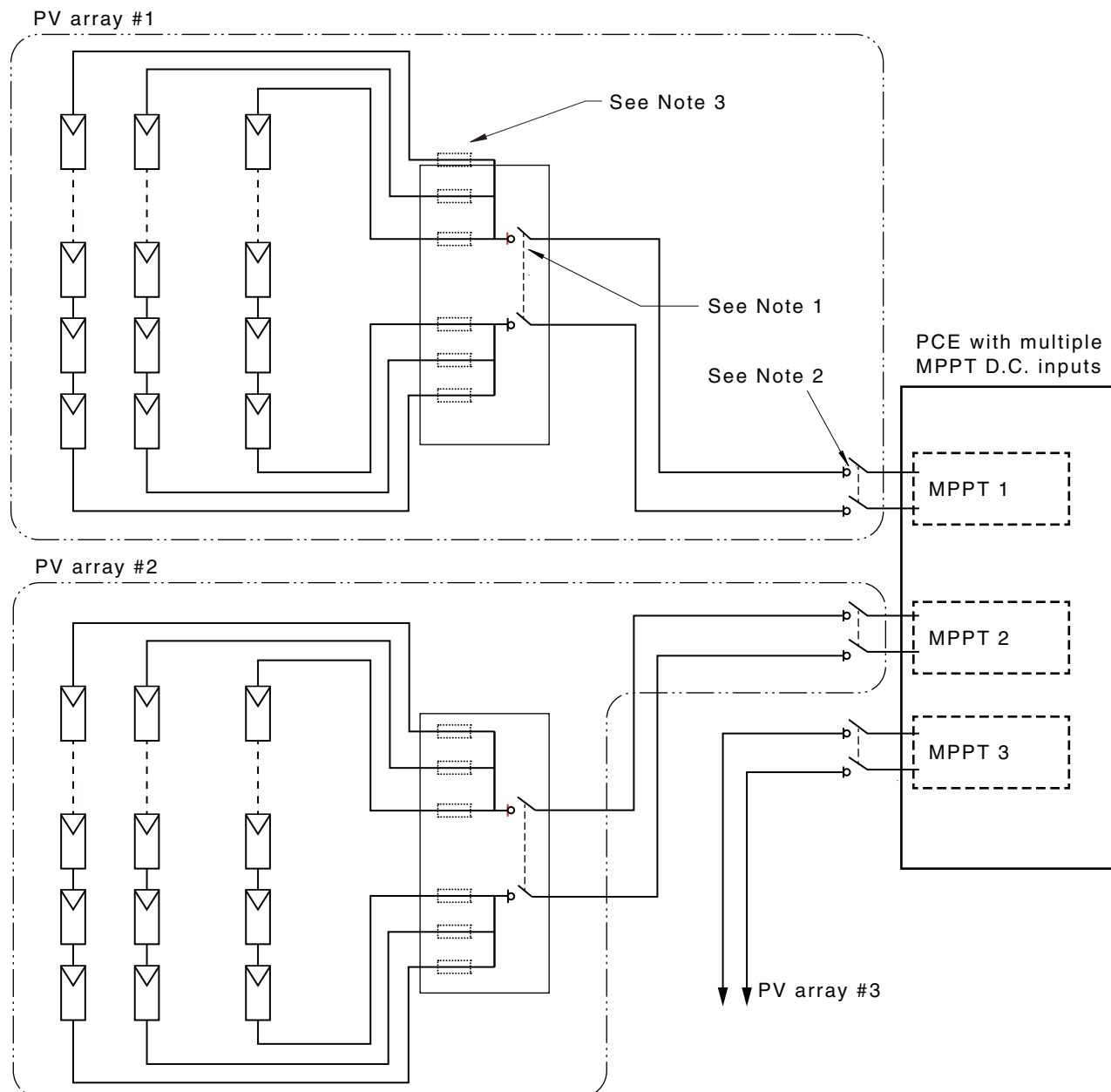
PV modules that are electrically in the same series string shall be within ± 5 degrees azimuth and ± 5 degrees tilt angle.

NOTE 3 Each parallel PV string may have a different orientation.

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 4 DCUs can contain MPPT units and so enable the connection of modules in different orientations as per [Clause 2.1.5](#).

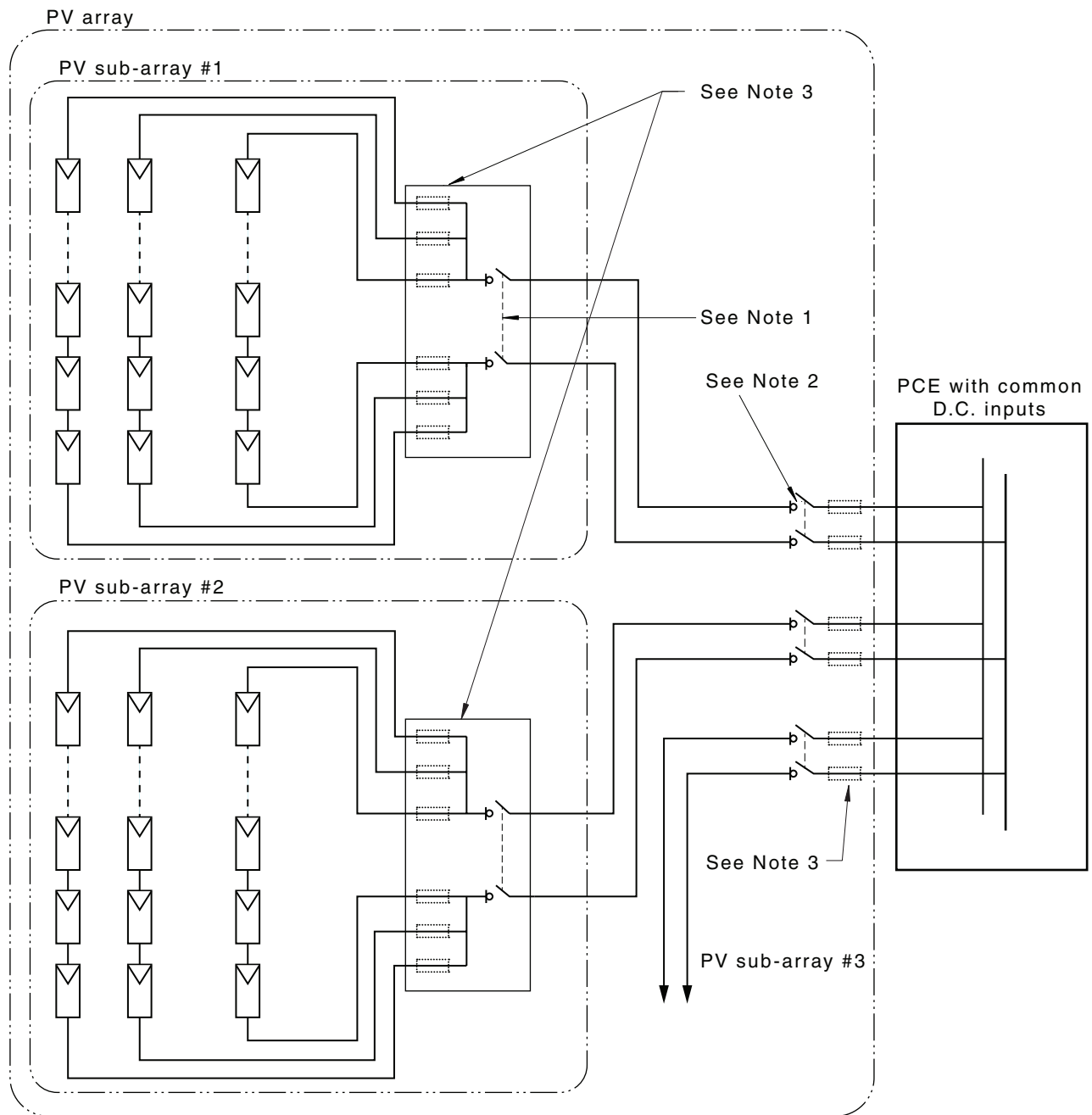


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

NOTE 3 Overcurrent protection devices where required, see [Clause 3.3](#).

Figure 2.5 — Typical configuration for PV array using a PCE with multiple MPPT PV inputs

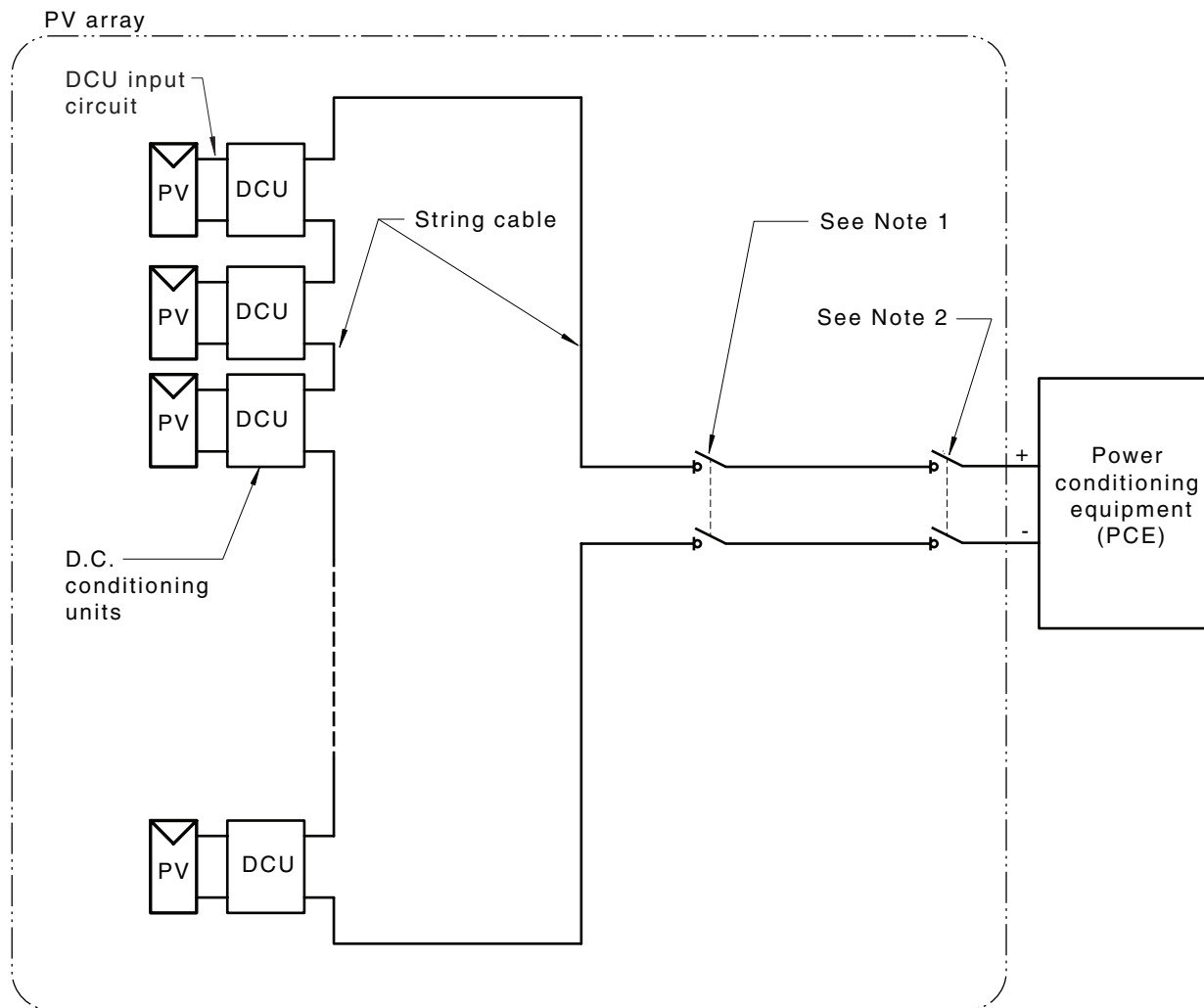


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

NOTE 3 Overcurrent protection devices where required, see [Clause 3.3](#).

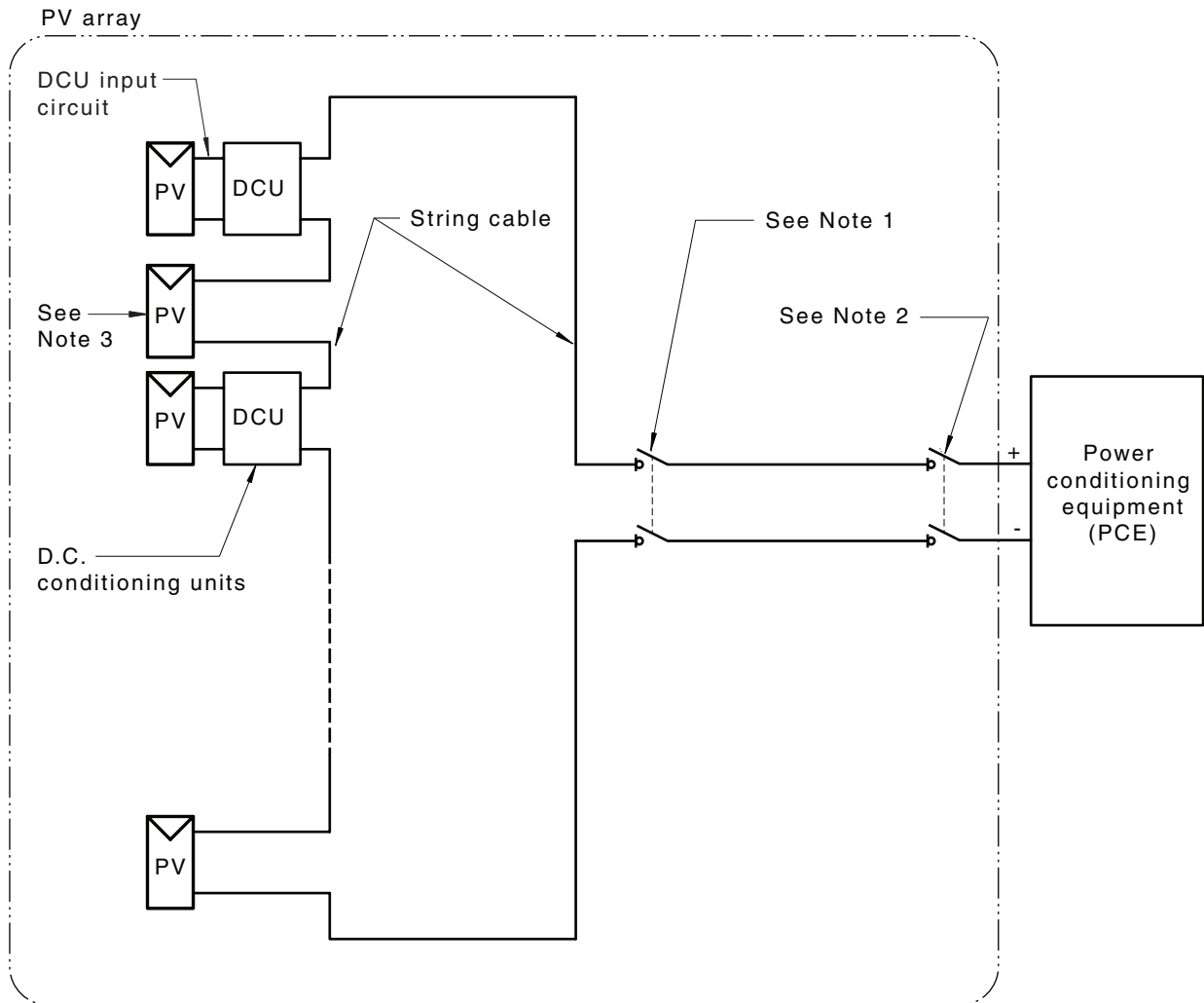
Figure 2.6 — Typical configuration for PV array using a PCE with multiple d.c. inputs internally connected to a common d.c. BUS



NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

Figure 2.7 — Typical configuration for PV string constructed using d.c. conditioning units



NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See [Clause 4.3.3](#) for alternative PV isolation methods.

NOTE 2 This Figure shows the method of isolation at the PCE as an adjacent and physically separate load break disconnection device. See [Clause 4.5.3](#) for load break disconnection requirements at the PCE.

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

Figure 2.8 — Typical configuration for PV strings constructed using partial DCU strings

2.2 Other considerations

2.2.1 Considerations due to fault conditions within a PV array

The source of fault currents shall be identified in any installation.

Systems connected to PCE and/or external sources such as batteries, may have high prospective fault currents due to the equipment's characteristics, see [Clause 3.3.2](#).

PV modules (and consequently PV arrays) behave like current sources under low impedance faults. Consequently, fault currents may not be much greater than normal full load currents, even under short circuit conditions.

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

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

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

NOTE 1 In conventional electrical installations the large inherent fault current capability of the system will generally operate a fuse, circuit-breaker or other protection system under fault conditions.

- (b) Earth fault detection, alarm, shutdown, or both, could be required as part of the system protection functions to reduce the risk of fire.

NOTE 2 See [Clause 3.3](#) for overcurrent protection requirements and [Clause 3.5](#) for earth fault protection requirements.

2.2.2 Considerations due to operating temperature

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

The manufacturer's specified temperature derating/rerating shall be applied to the nominal values of components such as fuses, switches, and circuit breakers according to the maximum temperature to which the component is subjected when installed.

PV module ratings provided by manufacturers are stated at STC.

PV modules operate at elevated temperatures when installed. PV modules can be expected to operate at approximately 25 °C above the ambient temperature in a typical installation with very good ventilation under full sun (1 000 W/m²). The temperature rise can be considerably higher when irradiance levels are greater than 1 000 W/m² and when PV modules have poor ventilation (40 °C to 50 °C rises are possible).

The following recommendations on the PV array design are made based on the operating characteristic of PV modules:

- (a) For most 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 PV modules and associated components.

NOTE 1 For crystalline silicon PV cells the maximum power decrease may be between 0.3 % and 0.5 % per each degree Celsius rise in operating temperature above STC.

- (b) All the components and equipment that are in direct contact or near the PV array (conductors, PCEs, connectors, etc.) should be capable of withstanding the expected maximum operating temperature of the PV array.

NOTE 2 PV modules have voltage increases under cold conditions (see [Clause 4.2](#) for further considerations).

2.2.3 Performance issues

The performance of a PV array is affected by many factors, including but not limited to the following:

- (a) Shading — Care should be taken in selecting a site for the PV array. Nearby trees, buildings and adjacent PV array rows may cause shadows to fall on the PV array during some part of the day.

It is important that any shadowing be almost eliminated or at least reduced to a very small time period, as even the smallest shadow on the array can severely limit its performance (e.g. TV aerials, chimneys, overhead cables and inter-row shading). Where shadowing cannot

be eliminated, a design using suitable products that reduce the effects of shadowing on performance should be considered.

- (b) Temperature rise — Issues of performance degradation due to temperature rise and the need for good ventilation are described in [Clause 2.2.2](#). Care should be taken to keep PV modules as cool as practicable.
- (c) Voltage drop in cables — In the design process the sizing of cables within the array and in cable connections from the array to the application circuit affect the voltage drop in those cables under load. This can be particularly significant in systems with low output voltage and high output current. It is recommended that under maximum load conditions the voltage drop from the most remote PV module in the array to the input of the PCE be not be greater than 3 % of the V_{mp} voltage (at STC).
- (d) Soiling — Soiling of the surface of PV modules caused by dust, dirt, bird droppings, snow, industrial pollution, etc., can significantly reduce the output of the array. Arrangements should be made to clean the PV modules regularly in situations where significant soiling may be a problem.

NOTE See [Clause D.2](#) for details on periodic maintenance.
- (e) Orientation — The tilt of the PV modules to the horizontal, and the direction the PV modules are facing with respect to true north will affect the performance of the system, see [Clause 2.1.6](#).
- (f) PV module degradation — Ageing of PV modules may affect the output characteristics of the PV modules. Degradation may not be uniform across the array.

3 Safety issues

3.1 Maximum voltage limits

The calculated PV maximum voltage of PV d.c. circuits shall not be greater than 1 000 V d.c. for domestic electrical installations.

The calculated PV maximum voltage of PV d.c. circuits shall not be greater than 1 500 V d.c. for other electrical installations.

NOTE See [Clause 4.2.1.3](#) for PV d.c. circuit maximum voltage calculation.

3.2 Protection against electric shock

For protection against electric shock, the requirements of [Section 4](#) shall apply.

PV module exposed metal earthing and equipotential bonding shall be according to [Clause 4.6.2](#).

3.3 Protection against overcurrent

3.3.1 General

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

PV modules may be connected in parallel and directly connected to external sources (e.g. batteries). These parallel circuits and additional sources increase the available current under fault conditions.

The overcurrents in a PV system can be caused by the sum of currents—

- (a) originating at the PV modules (multiple parallel strings); and

(b) not originating at the PV modules (e.g. from external sources such as BESS, backfeed from PCEs)

Overcurrent protection shall be provided and applied in accordance with this document and with PV module manufacturer's requirements.

NOTE See [Figure 3.1](#) for a typical example of overcurrent protection for PV modules, external sources and backfeed from the PCE.

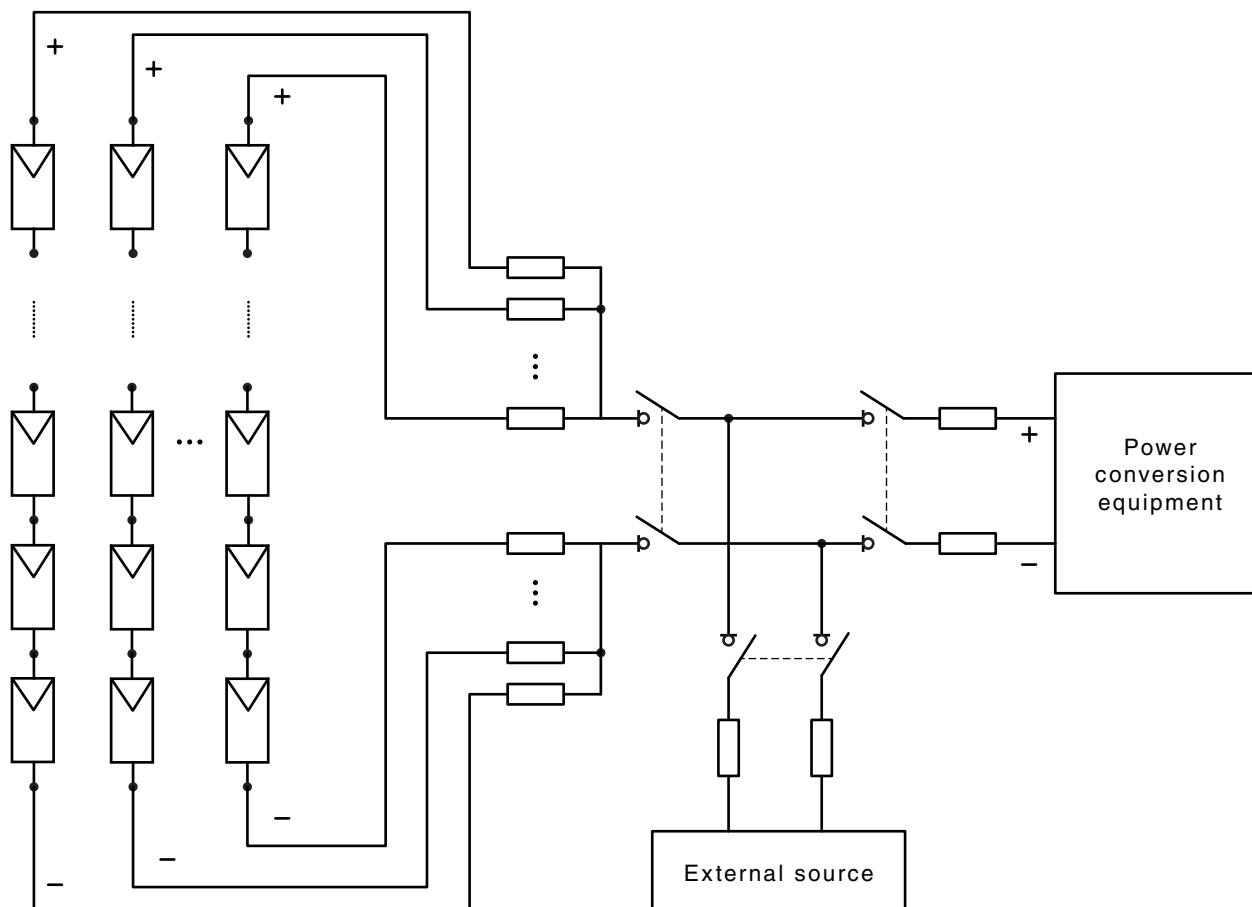


Figure 3.1 — A typical example of overcurrent protection for PV modules, external sources and backfeed from the PCE

3.3.2 Potential fault currents not originating at PV modules

All cables and components (including, but not limited to, array cables, sub-array cables, string cables and PV modules) in a PV system shall be protected from currents not originating at the PV modules.

$I_{BF\ TOTAL}$ is the sum of all backfeed sources of current not originating at the PV modules, such as from PCE/s or other external sources that are directly connected to the array.

NOTE The value of backfeed short-circuit current available from the PCE should be documented in installation information.

3.3.3 Calculation of potential fault currents originating at PV modules

3.3.3.1 Calculation of maximum string current

The value of $I_{STRING\ MAX}$ depends on the PV system configuration, and is calculated as follows:

(a) String containing no DCUs:

$$I_{\text{STRING MAX}} = 1.25 \times K_I \times I_{\text{SC MOD}}$$

NOTE 1 See [Appendix J](#) for the determination of K_I .

- (b) Strings containing partial DCUs:

The greater of the following:

$$I_{\text{STRING MAX}} = I_{\text{DCU string max}}$$

or

$$I_{\text{STRING MAX}} = 1.25 \times K_I \times I_{\text{SC MOD}}$$

- (c) Strings with DCUs on all modules:

$$I_{\text{STRING MAX}} = I_{\text{DCU string max}}$$

NOTE 2: See [Clause 1.4](#) for notations.

3.3.3.2 Calculation of potential string fault current

$I_{\text{F STRING}}$ is the fault current that may flow in a string due to other parallel connected strings in the array.

$$I_{\text{F STRING}} = (S_A - 1) \times I_{\text{STRING MAX}}$$

NOTE 1 Where there is only one string, $I_{\text{F STRING}} = I_{\text{STRING MAX}}$ i.e. the minimum current rating of a string is the string current itself.

NOTE 2 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.

NOTE 3 See [Clause 1.4](#) for notations.

3.3.3.3 Calculation of potential sub-array fault current

$I_{\text{F S-ARRAY}}$ is the fault current that may flow in a sub-array due to other parallel connected strings in the array.

$$I_{\text{F S-ARRAY}} = (S_A - S_{SA}) \times I_{\text{STRING MAX}}$$

NOTE 1 See [Clause 1.4](#) for notations.

3.3.4 Requirements for overcurrent protection

3.3.4.1 Strings

For strings connected in parallel, overcurrent protection shall be provided when—

$$I_{\text{F STRING}} + I_{\text{BF TOTAL}} > I_{\text{MOD MAX OCPR}}$$

Where overcurrent protection is required, see [Clause 3.3.5](#) for rating of the overcurrent protection devices.

NOTE 1 See [Clause 1.4](#) for notations.

3.3.4.2 Sub array

Where no overcurrent protection is provided, the cable size shall be as specified in [Clause 4.4.2](#) depending on the relevant circuit.

Where overcurrent protection is provided, the following apply:

- (a) The nominal overcurrent protection rating shall be calculated as specified in [Table 3.1](#).
- (b) The cable size shall be as specified in [Clause 4.4.2](#) depending on the relevant circuit.

3.3.4.3 Array

Where no overcurrent protection is provided, the cable size shall be as specified in [Clause 4.4.2](#) depending on the relevant circuit.

Where overcurrent protection is provided, the following apply:

- (a) The nominal overcurrent protection rating shall be calculated as specified in [Table 3.1](#).
- (b) The cable size shall be as specified in [Clause 4.4.2](#) depending on the relevant circuit.

3.3.5 Nominal overcurrent protection rating calculations

The nominal overcurrent protection current to which the PV system is rated shall be calculated in accordance with the [Table 3.1](#).

NOTE This Clause determines the nominal ratings of overcurrent protection. The actual rating of the overcurrent protection device may be de-rated/re-rated depending on the environment where they are installed, see [Clause 4.3.6.1](#).

Table 3.1 — Nominal overcurrent protection rating calculations

Relevant circuit	No DCUs	Partial DCUs	Containing DCUs on all modules
String	For single PV string (see Figures 2.3 and 2.4) $1.2^a \times I_{\text{STRING MAX}} < I_n \leq I_{\text{MOD MAX OCPR}}$	$1.2^a \times I_{\text{STRING MAX}} < I_n \leq I_{\text{MOD MAX OCPR}}$ and $I_n \leq I_{\text{DCU OCPR}}$	$I_{\text{STRING MAX}} < I_n \leq I_{\text{DCU OCPR}}$
Sub-Array	$I_n \geq S_{\text{SA}} \times I_{\text{STRING MAX}}^b$		
Array	$I_n \geq S_{\text{A}} \times I_{\text{STRING MAX}}^b$		
^a The 1.2 multiplier is used for string fusing only. ^b The 1.2 multiplier is not used here to allow designer flexibility. Care should be taken when using a lower multiplier in areas where heightened irradiance occurs frequently, as this can cause nuisance overcurrent operation. NOTE 1 Circuit breakers are not recommended for string overcurrent protection. NOTE 2 In high irradiance areas considerations should be given to choosing a fuse in the higher range of ratings allowed to avoid the likelihood of early fuse failure. NOTE 3 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 overcurrent protection and cable ratings. NOTE 4 See Clause 1.4 for notations.			

3.4 Protection against fire caused by arcs

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

- (a) all connections are correctly tightened to avoid points of failure over time;
- (b) all connectors are properly locked into place;
- (c) all crimp connections are performed according to manufacturer's instructions; and

NOTE 1 Special care should be taken in the case where wire harnesses, plugs, sockets and connectors are assembled on site.

- (d) appropriate materials are used for contacts and connections (for example not using dissimilar metals)

NOTE 2 Failure of plugs, sockets and connectors (due to poor assembly or crimping) has been identified as a statistically significant failure mode.

NOTE 3 For installation requirements of plugs, sockets and connectors, see [Clause 4.3.9](#).

3.5 Protection against earth faults

3.5.1 General

Where the calculated PV d.c. circuit maximum voltage is above 35 V, the PV array shall be protected against earth faults.

Requirements for detection of faults, actions required, and alarms depend on the type of system earthing, and the status of the separation/isolation of the PCE that is connected to the PV array.

PCE charge controllers used for all systems where the calculated PV d.c. circuit maximum voltage is above 120 V shall also provide fault detection and alarm functions.

NOTE 1 See [Appendix B](#) for examples of earthing systems and earth faults.

NOTE 2 IEC 62109-2 specifies inverter requirements based on inverter isolation and array earthing, and requirements for initiation of earth fault alarms either during operation or on start-up of the inverter, or both.

NOTE 3 Manufacturers should provide instructions for installation of different types of inverters dependent on the inverter's internal protection and system configuration in accordance with IEC 62109-2.

The external alarm function provided in the inverter (refer to IEC 62109-2) shall be used to activate an earth fault alarm as detailed in [Clause 3.5.3](#).

3.5.2 Systems with direct functional earthing of the PV array

3.5.2.1 General

All PV conductors in a direct functionally earthed array shall be treated as live parts with respect to protection against electric shock.

NOTE 1 See [Appendix B](#) for examples of functional earthing configurations.

NOTE 2 The intent of this requirement is to ensure that the functionally earthed conductor is not assumed to be at earth potential during evaluation of insulation coordination aspects such as clearance to earth etc. because its connection to earth does not conform to the requirements for protective earthing.

In systems with direct functional earthing, an earth fault interrupter (EFI) shall be installed such that, if an earth fault occurs, the functional earth of the array is interrupted to interrupt the fault current. The EFI shall sense an earth fault, interrupt the earth fault and provide an indication of the fault when earth fault currents exceed the limits shown in [Table 3.2](#).

When an EFI operates, the affected PV system shall be shut down until the fault is corrected and an earth fault alarm initiated according to [Clause 3.5.3](#).

Table 3.2 — Nominal overcurrent rating of earth fault interrupter

Total PV array power rating kW	Maximum earth fault detection setting A
0-25	1
25-50	2
50-100	3
100-250	4
> 250	5
NOTE Direct functional earthed systems are under review and may be precluded in future editions of this Standard. Systems that use resistive functional earthing should be used where possible, where the resistance limits possible fault current to less than 30 mA. It is important to check PV module manufacturer's requirements for bleeding charge from cells.	

3.5.2.2 Additional PCE detection required for functionally earthed PV arrays

In addition to the EFI, the PCE or an external device shall, before start-up of the system —

- (a) open circuit the functional earth connection to the PV array;
- (b) measure the resistance to earth of each conductor of the PV array; and
- (c) where the earth insulation resistance is—
 - (i) above the threshold of R_{ISO} limit shown in [Table 3.3](#) the system shall reconnect the functional earth and be allowed to start; and
 - (ii) equal to or less than the threshold R_{ISO} limit, the system shall shut down and initiate an earth fault alarm in accordance with [Clause 3.5.3](#).

NOTE Direct functional earthing of systems is not recommended. Functional earthing via a resistor is a safer option wherever it is possible.

Table 3.3 — PV array to earth insulation resistance (R_{ISO}) limits vs inverter rating

Total PV array power rating kW	R_{ISO} limit, k Ω
≤ 20	30
> 20 to ≤ 30	20
> 30 to ≤ 50	15
> 50 to ≤ 100	10
> 100 to ≤ 200	7
> 200 to ≤ 400	4
> 400 to ≤ 500	2
> 500	1

3.5.3 Earth fault alarm

Where the calculated PV d.c. circuit maximum voltage is above 120 V or the PV array is connected to a non-separated inverter conforming to IEC 62109-2, an earth fault alarm system shall be installed.

The alarm system shall continue repeating its operation at least at hourly intervals until the earth fault is corrected or until the fault is acknowledged.

The earth fault alarm shall be at least one of the following types:

- (a) Remote communication (such as email, SMS or similar).
- (b) Local indication.

Where local indication is used for the earth fault alarm, it shall be either an audible or visual signal placed in an area that will be noticed.

A set of operational instructions shall be provided that includes the actions to take when the alarm operates.

NOTE Many inverters have earth fault detection and indication, in the form of indicator lights. This indication is generally not in an area that will be noticed. IEC 62109-2 requires that inverters have a local indication and a means of signalling an earth fault externally. The external alarm function should be used to cause an action to be initiated to correct the earth fault (i.e. by placing a light or audible signal where it will be noticed).

3.6 Protection against effects of lightning

This Clause provides information specific to PV systems.

NOTE 1 Refer to AS 1768 for all other lightning protection requirements.

The following shall apply to a PV system:

- (a) Where an LPS is installed, the PV system shall be bonded to the LPS in accordance with AS 1768.
- (b) Surge protection devices (SPDs) installed on the d.c. side of the PCE shall be designed for that purpose. SPDs for d.c. use shall conform to IEC 61643-31 or EN 50539-11. SPDs designed for a.c. application shall not be used.

See [Appendix G](#) for recommendations on lightning and surge protection for PV systems, and for maps showing the ground flash density of lightning in Australia and New Zealand.

4 Selection and installation of electrical equipment

4.1 General

PV array wiring and associated components are often exposed to UV, wind, water, snow and other severe environmental conditions. Wiring and components shall be fit for purpose and installed in a way to minimize exposure to detrimental environmental effects.

PV array equipment and associated components shall be installed in accordance with the requirements of this section, and the additional requirements as specified in the manufacturer's instructions where applicable.

NOTE 1 Attention is drawn to the need for prevention of water accumulation in cable/PV module support systems.

NOTE 2 All installed equipment should conform with the applicable EMC requirements as specified in AS CISPR 11 or IEC 62920.

Means of safe disconnection of the array shall be provided.

All components shall conform with the following requirements:

- (a) Be rated for d.c. use.

- (b) Have a voltage rating greater than or equal to the calculated PV d.c. circuit maximum voltage in accordance with [Clause 4.2.1.3](#).
- (c) Have a current rating greater than or equal to the calculated PV d.c. circuit current in accordance with [Clause 4.2.2](#).
- (d) Be UV resistant unless installed in a location protected against the effects of UV radiation.
- (e) Have a temperature rating appropriate to their location and application.

NOTE 3 PV arrays are installed in full sun. Ambient temperatures and temperatures inside enclosures can be very high. This is an important consideration when selecting components.

NOTE 4 All components used in salt mist conditions should be suitable for use in these conditions.

4.2 Voltage and current calculations

4.2.1 PV maximum voltage calculation

4.2.1.1 General

The PV maximum voltage is calculated to ensure that the components selected in the PV installation are rated for the expected voltages. The PV maximum voltage calculation depends on the system configuration.

4.2.1.2 PV module maximum voltage calculation

The PV module maximum voltage is equal to $V_{OC\ MOD}$ corrected for the lowest expected operating temperature, as follows:

$$V_{MOD\ MAX} = V_{OC\ MOD} + \gamma_v (T_{min} - T_{STC})$$

Correction of the voltage for the lowest expected operating temperature shall be carried out by any of the following:

- (a) Using the formula above.
- (b) Calculated according to the PV module manufacturer's instructions.
- (c) Where manufacturer's instructions are not available for crystalline and multi-crystalline silicon PV modules, multiplying $V_{OC\ MOD}$ by a correction factor according to [Table 4.1](#), using the lowest expected operating temperature as a reference.
- (d) Where the lowest expected operating temperature is below $-40\ ^\circ\text{C}$, or where technologies other than crystalline or multi-crystalline silicon are in use, voltage correction made in accordance with manufacturer's instructions.

Deviations from these methods that account for the coincidence of irradiance and lowest expected operating temperatures may be permitted with engineering justification.

NOTE The various methods above give either conservative or more specific maximum PV array voltage values depending on the method.

Table 4.1 — Voltage correction factors for crystalline and multi-crystalline silicon PV modules

Lowest expected operating temperature °C	Correction factors
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

4.2.1.3 PV d.c. circuit maximum voltage calculation**4.2.1.3.1 Systems containing no DCUs**

The PV array maximum voltage is calculated by using any of the following ways:

- (a) PV array maximum voltage = $V_{MOD\ MAX} \times M$; or
- (b) Calculated in accordance with IEC 62548.

4.2.1.3.2 Systems containing partial DCUs

PV array maximum voltage calculation applied to system containing partial DCUs ($V_{DCU\ string\ max}$) shall be calculated as follows:

$$V_{DCU\ string\ max} = (V_{DCU\ max} \times \text{number of DCUs in series}) + (V_{MOD\ MAX} \times m)$$

4.2.1.3.3 Systems containing DCUs on all modules

PV array maximum voltage calculation applied to system containing DCUs ($V_{DCU\ string\ max}$) on all modules shall be calculated by using any of the following ways:

- (a) $V_{DCU\ string\ max} = V_{DCU\ max} \times \text{number of DCUs in series}$.
- (b) Calculated in accordance with IEC 62548.

4.2.2 PV d.c. circuit current calculation**4.2.2.1 General**

The amount of current in electrical equipment associated with PV arrays depends on the configuration of the PV arrays.

Individual PV modules are current-limited sources. However, because they can be connected in parallel, and connected to external sources (see [Clause 3.3](#)), the maximum current in the circuits of the PV system may be much higher and shall be calculated in accordance with [Table 4.2](#).

Components and cables shall be rated to carry currents according to this Clause.

4.2.2.2 Current calculations

Table 4.2 — Current calculation of circuits

Relevant circuit	Protection	Current calculation of circuits
PV string	PV string overcurrent protection not provided	For a single string array, the greater of the following: $I_{\text{STRING}} = I_{\text{STRING MAX}}^a$ or $I_{\text{BF TOTAL}}$
		For all other cases: $I_{\text{STRING}} = I_n^b + I_{\text{F STRING}}$
	PV string overcurrent protection provided	$I_{\text{STRING}} = I_n^c$
PV sub-array	PV sub-array overcurrent protection not provided	$I_{\text{S-ARRAY}} = I_n^b + I_{\text{F S-ARRAY}}$
	PV sub-array overcurrent protection provided	$I_{\text{S-ARRAY}} = I_n^c$
PV array	PV array overcurrent protection not provided	The greater of the following: I_{ARRAY} or $I_{\text{BF TOTAL}}$
	PV array overcurrent protection provided	$I_{\text{ARRAY}} = I_n^c$
^a See Clause 3.3.3.1 for calculation of $I_{\text{STRING MAX}}$ in a single string array. ^b The nearest downstream (away from the array) overcurrent protection could be the sub-array protection, and if this is not present then it could be the array overcurrent protection, if present. When overcurrent protection is not used in either the sub-array or the array, then I_n shall be replaced by $I_{\text{BF TOTAL}}$ in the equation. ^c I_n is the current rating of the relevant overcurrent protection device. See Clause 3.3. NOTE See Clause 1.4 for notations.		

4.3 PV arrays

4.3.1 Selection of PV modules

4.3.1.1 General

PV modules shall be qualified to IEC 61215-1, IEC 61215-2, IEC 61730-1 and IEC 61730-2. In addition, the modules shall be qualified to IEC 61215-1-1, IEC 61215-1-2, IEC 61215-1-3 or IEC 61215-1-4 depending on the cell technology.

Modules shall be classified as Safety Class II as specified in IEC 61730.

PV modules only conforming to Class 0 requirements of the above documents shall not be used. If it has multiple classifications then it shall be installed in accordance with requirements of the classifications other than Class 0.

For building mounted applications, the fire test requirement of IEC 61730 shall be Fire Class C or higher based on the test procedure detailed in [Appendix I](#).

PV Modules for use in systems with calculated PV d.c. circuit maximum voltage above 50V d.c. shall include bypass diodes evaluated under the above Standards, unless the PV module manufacturer specifies not to use bypass diodes.

4.3.1.2 Additional Standards for PV modules

Additional information on PV module reliability is given in the following Standards:

- (a) IEC 61701, Resistance to salt mist corrosion (in coastal environments)
- (b) IEC 62716, Photovoltaic (PV) modules — Ammonia corrosion testing
- (c) IEC TS 62804-1, Photovoltaic (PV) modules — Test methods for detection of potential-induced degradation — Part 1: Crystalline silicon
- (d) IEC 62941, Terrestrial photovoltaic (PV) modules — Quality system for PV module manufacturing
- (e) IEC TS 63126, Guideline for qualifying PV modules, components and materials for operation at high temperatures
- (f) IEC TS 63209-1, Extended stress testing of PV modules for risk analysis (in development)

NOTE Current editions of IEC 61215 and IEC 61730 Standards have been demonstrated in field studies to be insufficient for evaluating the long term durability of PV modules under some installation conditions. Test protocols including those above are designed to address these issues. These should be considered where appropriate.

4.3.2 Installation of PV modules

4.3.2.1 General

The installation of PV modules shall be in accordance with all sections of this Standard.

4.3.2.2 Mechanical

4.3.2.2.1 General

Support structures and PV module mounting arrangements shall conform to applicable building codes, regulations, and Standards.

4.3.2.2.2 Thermal aspects

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

4.3.2.2.3 Mechanical loads on PV structures

The PV array support structures shall conform to national Standards and regulations with respect to loading characteristics.

NOTE The effect of wind and snow loads on PV arrays is particularly significant.

4.3.2.2.4 Mechanical loads (New Zealand only)

In New Zealand only, the PV array support structure shall be designed and constructed to withstand seismic (earthquake) forces, in accordance with NZS 4219.

4.3.2.2.5 Wind

PV modules, PV module mounting frames, PV array structures, and the methods used for attaching PV modules to frames and frames to buildings or to the ground shall be designed to resist the ultimate wind actions. Attachments shall be appropriate for the importance level, classification and location, calculated in accordance with AS/NZS 1170.2.

For applications beyond the limits of AS/NZS 1170.2, reference should be made to other publications or alternatively seek further advice, which may include wind tunnel testing or computer simulations.

NOTE 1 Key issues to be considered include but are not limited to the following:

- (a) Fixing spacings appropriate to roof type and location on roof.
- (b) Minimum embedment depth (into timber) and the minimum sheet thickness (into steel).
- (c) Fastener specification (e.g. type or gauge).
- (d) Exclusion zones.
- (e) The maximum wind speed expected (or known) on site should be used, with due consideration to regular wind events (cyclones, tornadoes, hurricanes, etc.).

The PV array structure shall be secured in accordance with applicable regulations and Standards.

NOTE 2 Applicable building codes may apply when securing the PV array structure.

Where a PV array is to be installed on a pre-existing building or structure, an assessment of the capability of the building to support the static and dynamic loads due to the array should be carried out.

Wind force applied to the PV array may generate a significant load for associated building structures. This load should be included in the assessment of the capability of the building to withstand the resulting forces.

4.3.2.2.6 Attaching PV modules to the array structure

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PV modules should be attached to the array structure either using the mounting holes provided by the manufacturer or via clamps that are suitable for the maximum wind at the site.

When using clamps, the mounting system and solar module manufacturer's installation instructions shall be followed. The following shall be considered:

- (a) The number of clamps required for a given wind load and mounting configuration.
- (b) The location of clamps (e.g. amount of overhang allowed from clamp to end of module).
- (c) The size of clamp required (length, width and minimum engagement of frame).
- (d) The quantity, location and dimensions of underlying support beams.
- (e) The clamp force specifications for the fasteners.

Where modules are installed in such way that a junction box is to the side or at the bottom, care should be taken to ensure that it is in accordance with manufacturer's requirements.

NOTE Attaching a PV module in such a manner that creates a hole in the anodised aluminium frame of the solar module (e.g. drilling, pop riveting) typically voids the manufacturer's product warranty with respect to defects in material and workmanship.

4.3.2.2.7 Snow/ice accumulation

Snow and/or ice build-up on the photovoltaic array shall be considered when selecting PV modules, designing the supporting structure for the PV modules and assessing the building capability to support the array, refer to AS/NZS 1170.3.

4.3.2.2.8 Corrosion

PV module mounting frames, and the methods used for attaching PV modules to frames and frames to buildings or to the ground, shall be made from corrosion resistant materials suitable for the lifetime and duty of the system (e.g. aluminium, galvanized steel or H3 treated timber).

If the associated roofing or building structure is metallic, then aluminium, stainless steel, hot dipped galvanized steel, wood or polymer materials shall be used.

All framing systems shall be suitable for the location and duty of the system.

NOTE Care should be taken in selecting materials and protection in marine and other corrosive environments.

In coastal areas, the fitting of PV modules to a roof that is exposed to salt laden air may prevent salt deposits from being washed off the roof by rain.

Maintenance instructions as well as roof mounting structure configuration should allow for regular wash down with fresh water.

All bolts, nuts and fasteners shall have appropriate durability for the installed locality. Bolts and nuts should typically be stainless steel.

Care shall be taken to prevent electrochemical corrosion between dissimilar metals. This may occur between structures and the building and between structures, fasteners and PV modules. Stand-off materials shall be used to reduce electrochemical corrosion between galvanically dissimilar metal surfaces (e.g. nylon washers or rubber insulators). Aluminium framing components and stainless fasteners are permitted to be in direct contact (without stand-off materials) as the two metals are sufficiently galvanically similar.

4.3.2.3 Electrical

4.3.2.3.1 General

Where wiring of strings between modules or DCUs is not protected by conduit or other enclosures, the following requirements apply:

- (a) Insulated and sheathed UV resistant cables shall be used.
- (b) Cables shall be selected as specified in [Clause 4.4.2](#).
- (c) Cables shall be protected from mechanical damage.
- (d) Cables shall be clamped to prevent undue strain on the connections/terminations.
- (e) Cables shall not lie on roofs.
- (f) Cables shall not obstruct the natural water drain paths or promote accumulation of debris.
- (g) The method of cable support and fixing shall have a lifetime greater than or equal to the life of the PV system. Plastic cable ties shall not be used as a primary means of support.
- (h) Cables shall be protected against abrasion, tension, compression and cutting forces that may arise from thermal cycles, wind and other forces during installation and throughout the life of the installation.

- (i) Cables shall be supported so they do not suffer fatigue due to wind/snow effects.

NOTE 1 Typically, plastic cable ties exposed to UV will degrade within 2 to 5 years.

NOTE 2 Plastic cable ties installed under an array are still exposed to reflected UV radiation.

Where wiring of strings between modules or DCUs is protected by conduit or other enclosures, the requirements of [Clause 4.4.5](#) shall be followed.

4.3.2.3.2 Restricted access for PV modules

Where PV modules are within 2.5m from the ground, floor or platform and are not installed on a roof, restricted access shall be provided to PV modules and wiring systems up to the disconnection point.

NOTE See [Clause 4.4.5](#) for information on installation requirements of wiring enclosures.

4.3.2.3.3 Wiring loops

To reduce the magnitude of lightning-induced overvoltages and radio interference, the PV array wiring should be laid in such a way that the area of conductive loops is minimized (e.g. by laying cables in parallel, as shown in [Figure 4.1](#)).

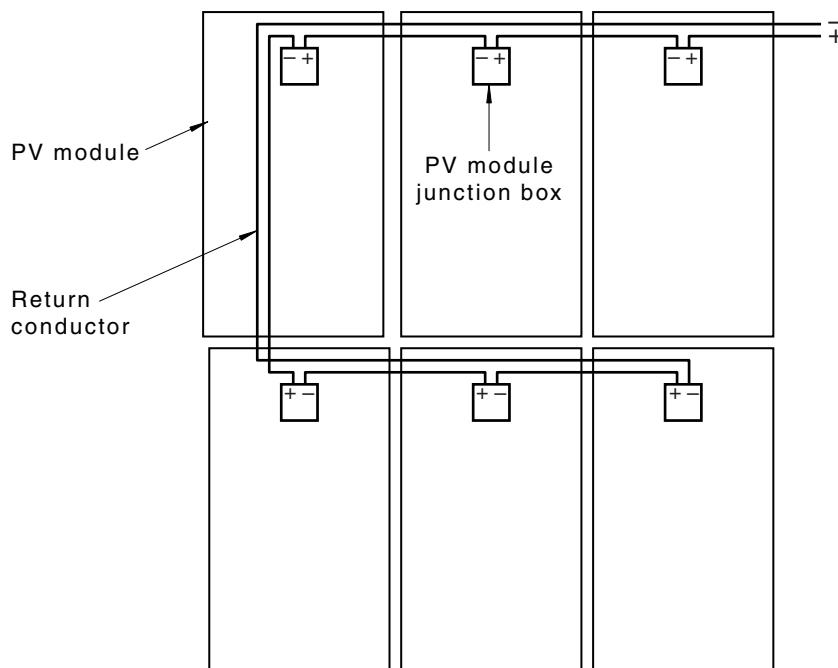


Figure 4.1(a) — PV string wiring examples to minimize area of conductive loop

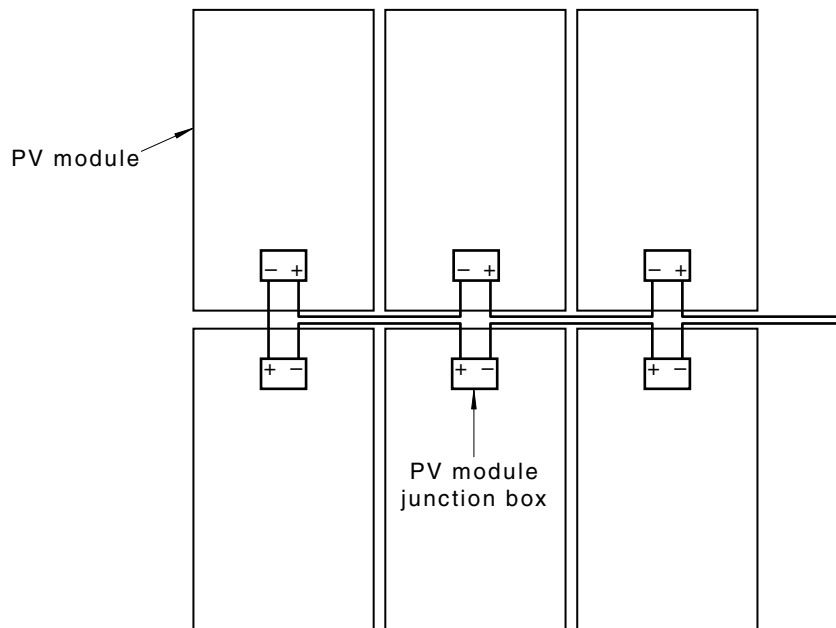


Figure 4.1(b) — PV string wiring examples to minimize area of conductive loop

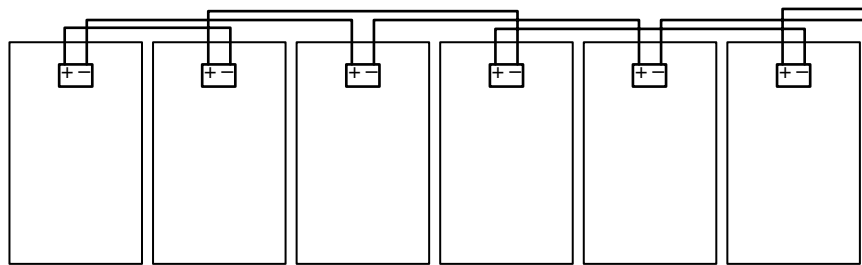


Figure 4.1(c) — PV string wiring examples to minimize area of conductive loop

4.3.2.3.4 In-line fusing

Where an in-line fuse is in a plug, socket and connector, see [Clause 4.3.9](#) for the installation requirements.

4.3.3 PV isolation methods

4.3.3.1 PV isolation methods for systems exceeding 120 V

Where the calculated PV d.c. circuit maximum voltage exceeds 120 V, a disconnection point shall be provided to isolate each PV string at the PV modules, see [Clause 4.3.5.2.1](#).

EXCEPTION — A disconnection point is not required to isolate each string, where a load break disconnection device is installed adjacent to the PV modules of the PV array that is being isolated.

NOTE 1 See [Clause 4.5.3.1](#) for requirements on load break disconnection devices at the PCE. An additional load break disconnection device may be required where there are more than two parallel strings in accordance with [Figure 4.2](#).

Where a load break disconnection device is required in addition to the disconnection point, it shall be selected in accordance with [Clause 4.3.4.2](#) and installed in accordance with [Clause 4.3.5.3](#).