SEIAPI Sustainable Energy

GRID-CONNECTED PV SYSTEMS
SYSTEM INSTALLATION GUIDELINES

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DOCUMENT CONTROL

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1	2012/2014	Geoff Stapleton	1st version updated in 2014 to recognise PPA as partner
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3	December 2025	Geoff Stapleton	Revised based on updated standards and equipment advancements. It references clauses from Australia and New Zealand Standards

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These guidelines have been developed for The Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI).

They represent latest industry BEST PRACTICE for the installation of Grid Connected PV Systems

Cover Photos: CBS Power Solutions

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Abbreviations

A summary of the main acronyms and terms used in this document is listed below:

a.c.	Alternating current
AS/NZS	Australian / New Zealand Standards
CCC	Current carrying Capacity
CSA	Cross section area
d.c.	Direct current
DCU	d.c. conditioning units
DVC	Decisive Voltage Classification
ELV	Extra low voltage
EN	European Standards (European Norms)
IEC	International Electrotechnical Commission.
kW_p	Kilowatt Peak
kWh	Kilowatt hour
LV	Low voltage
MPPT	Maximum power point tracker
PCE	Power conversion equipment
PV	Photovoltaic
STC	Standard Test Conditions

1 Introduction

This document provides the minimum requirements when installing a grid connected PV system.

The array requirements are generally based on the requirements of AS/NZS 5033: Installation and Safety Requirements of PV Arrays.

Figure 1 shows a typical interconnection of a grid connected PV system while Figures 2 is typical wiring schematic.

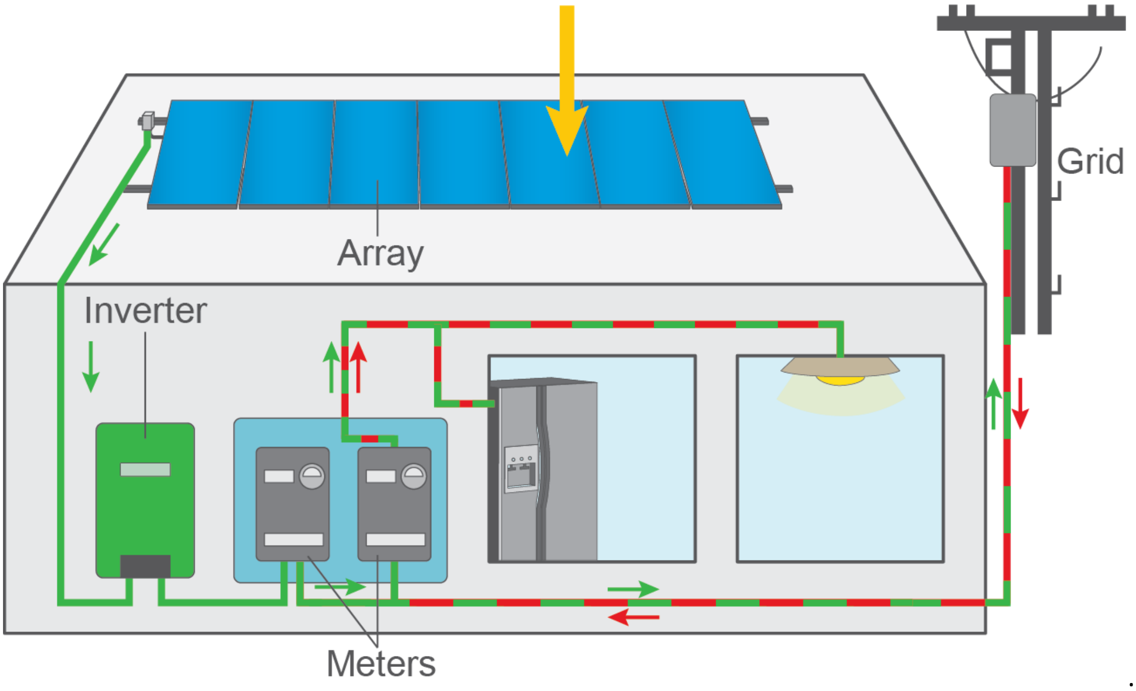

Figure 1: Grid Connected PV Systems

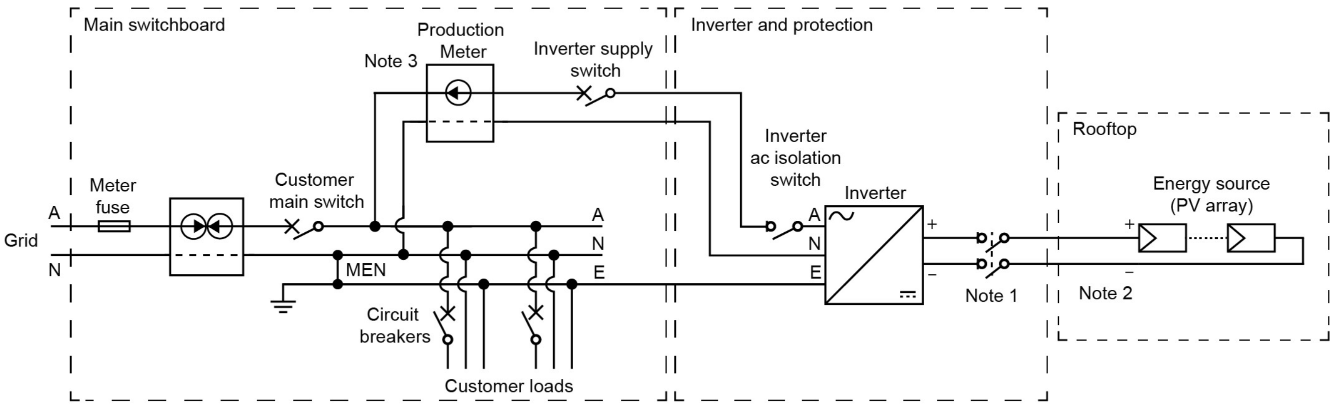

Figure 2: Wiring Schematic (AS/NZS)

Note 1: The load breaking dc. disconnection device near inverter could be integrated within the PCE. If the integrated disconnector complies with AS/NZS 5033 standard requirements, an external d.c switch disconnection device will not be required. For more details, refer to AS/NZS 5033:2021 Clause 4.5.3.1.
Note 2: The PV array disconnection could be in the form of a ''disconnection point'' or a separate switch disconnector which is not shown in the diagram
Note 3: Production Meter is a recommendation.

2 Standards for Installation

System installation should follow any standards that are typically applied in the country or region where the solar installation will occur. The following are the relevant standards in Australia, New Zealand and USA. Some Pacific Island countries and territories do follow those standards. These standards are often updated and amended so the latest version should always be applied.

Some Pacific Islands Utilities are also introducing their own interconnection guidelines and requirements that must be followed when installing grid connected PV systems in those countries.

In Australia and New Zealand, the relevant standards include:

- AS/NZS 3000 Wiring Rules.
- AS/NZS 3008 Electrical Installations-Selection of Cables.
- AS/NZS 4777 Grid Connection of energy systems by Inverters (series)
- AS/NZS 5033 Installation and Safety Requirements of PV Arrays.
- AS/NZS 1170 Structural design actions
- AS/NZS 1170.2 Structural design actions – Wind actions
- AS 1768 Lightning Protection.
- IEC 61215 Crystalline Silicon Terrestrial photovoltaic (PV) modules – Design qualification and type approval
- IEC 61215-1 Part 1: Test requirements
  - IEC 61215-1-1 Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules
  - IEC 61215-1-2 Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules
  - IEC 61215-1-3 Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules
  - IEC 61215-1-4 Part 1-4: Special requirements for testing of thin-film Cu(In,GA) $(S,Se)_2$ based photovoltaic (PV) modules

- IEC 61215-2 Part 2: Test Procedures
- IEC 61730 Photovoltaic (PV) module safety qualification.
- IEC 61730-1 Part 1: Requirements for construction.
- IEC 61730-2 Part 2: Requirements for testing.
- IEC 61701 Photovoltaic (PV) modules - Salt mist corrosion testing
- IEC 62804 Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation (PID) - Part 1-1: Crystalline silicon – Delamination
- IEC 62109 Safety of power converter for use in photovoltaic power systems.
- IEC 62109-1 Part 1: General requirements.
- IEC 62109-2 Part 2: Particular requirements for inverters.
- IEC 62930 Electric cables for photovoltaic systems with a voltage rating of 1.5 kV d.c. Solar Plugs and Connectors
- AS/NZS 62852 Connectors for d.c. application in photovoltaic systems - Safety requirements and tests.
- AS/NZS 60947.3 Low-voltage switchgear and control gear switches, disconnectors, switch-disconnectors and fuse-combination units. The switch disconnectors shall conform with utilization category d.c. PV2.
- IEC 62446 Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection.

Note: AS/NZS 3000, AS/NZS 5033 and AS/NZS 4777 do reference other balance of systems equipment standards.

3 Voltage Limits and Work Restrictions

System voltage classification in this guideline follow the Decisive Voltage Classification (DVC) as defined in the standard: IEC 62109 Safety of power converter for use in photovoltaic power systems as shown in Table 1.

Table 1: Decisive Voltage Classification

Decisive voltage classification (DVC)	Limits of working voltage (V)		
	a.c. voltage (rms)	a.c. voltage (peak)	d.c. voltage (mean)
DVC-A	V ≤ 25	V ≤ 35.4	V ≤ 60
DVC-B	25 <V ≤ 50	35.4 <V ≤ 50	60 <V ≤ 120
DVC-C	V > 50	V > 71	V > 120

Some countries in the Pacific follow the voltage limits as defined in the Australian/New Zealand standard (AS/NZS3000) where:

- Extra Low Voltage (ELV) is <120V d.c. or <50V a.c.
- Low Voltage (LV) is >120V d.c. and <1500V d.c. or >50V a.c. and <1000 a.c.

In following this some countries do have licensed or registered electricians impose the following requirements::

Extra Low Voltage Work:

- All extra low voltage wiring should be performed by a ‘competent’ person, which is defined in various standards: “a person who has acquired through training, qualifications, experience or a combination of these, knowledge and skill enabling that person to correctly perform the task required.”

Low Voltage Work

- All low voltage work: >120V d.c. or >50V a.c. should be performed by a trained electrician or similar (e.g. licensed or certified electrician).
- A trained electrician should be responsible for the safety of the system wiring prior to connection of the system to the grid.
- If the system contains ELV wiring installed by a person not by a certified electrician, then a minimum level of inspection by the electrician prior to closing the PV array isolators would include:
    - an open circuit voltage test on each PV string and on the total array.
    - A visual inspection of an open PV junction box (randomly selected) and the master array junction box.

These inspections/checks shall confirm as a minimum:

- the array voltages are as designed and specified.
- the appropriate cables (Cross Sectional Area and insulation), junction fittings and enclosures have been used

Both the non-electrician ELV installer, as well as the licensed electrician, are expected to carry out the checks on the ELV wiring.

Except when module inverters are used, grid connect PV arrays have open circuit voltage typically above 120V d.c. and hence considered LV. LV is dangerous and can kill a person if they touch live terminals.

4 Design and Drawings

The installer should have a copy of the system design and drawings for the installation as described in the design guideline. The system design should specify each component, including the make and model. The drawings should identify the location for each piece of equipment, as determined in the design process through consultation with the system owner.

5 Selecting a PV Module

All solar modules shall comply with either:
The following IEC standards:

- IEC 61215 Terrestrial photovoltaic (PV) modules - Design qualification and type approval
    - IEC 61215-1 Part 1: Test Requirements
    - One of IEC 61215 Part 1.1, Part 1.2 Part 1.3, part 1.4 which all relate to specific types of modules e.g. crystalline, thin film amorphous etc (See Section 2)
    - IEC 61215-2 Part 2: Test Procedures
- IEC 61730 Photovoltaic (PV) module safety qualification
    - IEC 61730-1 Part 1: Requirements for construction
    - IEC 61730-2 Part 2: Requirements for testing

For modules with IEC certification, they must be certified as Application Class II per IEC 61730.

It is recommended that the modules have the following enhancements:

- IEC 61701 Photovoltaic (PV) modules - Salt mist corrosion testing
- IEC 62804 – (2020) Photovoltaic (PV) modules - Test methods for the detection of potential-induced degradation (PID) - Part 1-1: Crystalline silicon – Delamination

A range of modules that comply with the above standards can be found on the Australian Clean Energy Council's (CEC) approved product list:

https://www.cleanenergycouncil.org.au/industry/products/modules/approved-modules

The solar module should have the following warranties:
- 10-year limited product warranty
- Limited Power Warranty with 25 years at 80% of the minimal output power

6 PV Array Installation

6.1 General

The PV array installation shall be compliant to AS/NZS 5033 requirements, in particular, Clauses 4.1 and 4.2 (or equivalent updates). Additionally, the following important consideration should be made for the installation of PV array for a grid connected PV system:
- Modules that are electrically in the same string and connected to the same MPPT shall be all in the same orientation.
- A minimum tilt of 10° is recommended to take advantage of self-cleaning during rain events. Horizontally mounted arrays will require additional maintenance [cleaning] and this should be included in the recommended maintenance schedule.

In grid connected PV systems the solar array could be mounted:
- "Flat" on the roof, that is parallel to the slope of the roof but raised off the roof or
- Integrated into the building or
- On an array frame that is tilted to fix the array at a preferred angle (usually for flat roofs or ground mounted).

6.2 Maximum PV Array Voltage (or PV d.c. circuit maximum voltage)

The switch disconnectors (isolators), inverter dc inputs and associated wiring (cables) used in the PV array installation shall have minimum voltage rating as the PV d.c. circuit maximum voltage as stated in AS/NZS 5033 (Clause 4.1). The PV array maximum voltage can be calculated in accordance with Clause 4.2.1.3 in AS/NZS 5033.

The PV Array Maximum voltage can be calculated using the minimum expected temperature at a site and the temperature coefficient of a module.

The maximum V_{oc} of a module is determined by calculating the increase in V_{oc} due to the effective cell temperature.

The increase in V_{oc} is calculated by multiplying the voltage temperature coefficient (V/°C) by the difference between the effective cell temperature and the STC temperature of 25°C (77°F).

If the temperature is 15°C, then the increase in V_{mp} is (15°C − 25°C) = −10 times the voltage temperature coefficient (V/°C). *(Note it is an increase because the co-efficient is a negative number and the difference in temperatures is also a negative number, so the two multiplied becomes a positive number)*

The effective V_{oc} of the module at the minimum module temperature = V_{oc} plus any change in V_{oc} due to the temperature of the module not being 25°C.

Worked example 1
(Refer to SEIAPI-PPA Grid Connected PV Systems - Design Guideline)
Assume the minimum effective cell temperature is 15°C.
The module data sheet provides the following information:

- V_{oc} = 41.02
- V_{oc} temperature coefficient = – 0.28%/°C

Therefore, in V/°C the V_{oc} temperature coefficient = − 0.28/100 per degree C x 41.02V = − 0.115V/°C

Based on the minimum temperature of 15°C then the:
Increase in V_{oc} due to temperature (15 – 25 °C) = −10°C times the voltage temperature coefficient (V/°C).

$$= -10^{\circ}C \times -0.115V/^{\circ}C$$
$$= 1.15V$$

So, the effective maximum V_{oc} of the module due to temperature = 41.02V+ 1.15 = 42.17V d.c. for each module in the string.

The maximum V_{oc} of the string is then calculated by multiplying the maximum V_{oc} of one module by the number of the modules in the string. Thus, in the example above, if there are 11 panels in a string, the maximum V_{oc} of the string will be 11 x 42.17 = 463.87 V d.c.

If the temperature coefficients are not available and the array uses monocrystalline or polycrystalline modules, the PV array maximum voltage can be estimated by using the below table containing the temperature ranges and multiplication factors (Note: this table does not apply if the modules are thin-film types, the voltage/temperature coefficient for the specific thin-film modules in use should be obtained from the module manufacturer).

Table 2: Voltage correction factors for monocrystalline and polycrystalline silicon PV modules

Lowest expected operating temperature (degrees Celsius)	Correction factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23

-36 to -40	1.25

As an example, the year-round minimum temperature for a country is around 23°C). The temperature correction factors for the lowest expected operating temperature of 24 to 20°C is 1.02 for crystalline or polycrystalline modules in the table above. For thin-film module types, the voltage/temperature coefficient for the specific thin-film modules in use should be obtained from the module manufacturer.   In the highlands, it will be a lower temperature and a different correction factor will apply.

Hence, for a string of 11 modules (V_{oc} = 41.02V), it will have PV d.c. maximum voltage of 460.2V (i.e. 1.02 x 11 x 41.02V).

6.3 Orientation and Tilt

For best year-round performance a fixed PV array typically should be mounted facing true north (± 10°) in the South Pacific and true south (±10°) in the North Pacific at an inclination equal to the latitude angle or at an angle that will produce the best annual average performance taking into consideration: seasonal cloud patterns, local shading and environmental factors. In the tropics this could vary due to the sun being in both north and south at different times of the year.

Between latitudes 10° South and 10° North the array should be tilted at a minimum of 10 degrees. If the array is "flat" on the roof (that is parallel to the slope of the roof) or integrated into the building, the array will often not be at the preferred (optimum) tilt angle and in many situations will not be facing due north or due south however the effect on energy output due to installations not being at the optimum tilt and orientation is usually small for installations in the tropics.

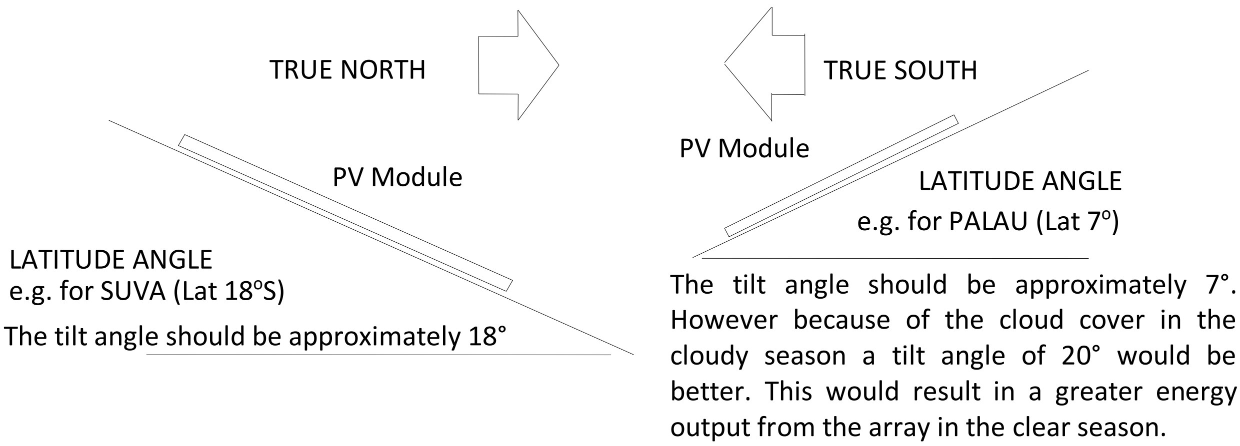

Figure 3 Examples of Tilt angles

Included with the design guideline (Appendix 2) is a set of tables for the following locations:

- Alofi, Niue (Latitude 19°04'S, Longitude 169°55'W)
- Apia, Samoa (Latitude 13°50'S, Longitude 171°46'W)
- Hagåtña, Guam (Latitude 13°28'N, Longitude 144°45'E)

- Honiara, Solomon Islands (Latitude 09°27’S, Longitude 159°57’E)
- Koror, Palau (Latitude 7°20’N, Longitude 134°28’E)
- Lae, Papua New Guinea (Latitude 6°44’S, Longitude 147°00’E)
- Majuro, Marshall Islands (Latitude 7°12’N, Longitude 171°06’E)
- Nauru (Latitude 0°32’S, Longitude 166°56’E)
- Nouméa, New Caledonia (Latitude 22°16’S, Longitude 166°27’E)
- Nuku’alofa, Tonga (Latitude 21°08’S, Longitude 175°12’W)
- Pago Pago, American Samoa (Latitude 14°16’S, Longitude: 170°42’W)
- Palikir, Pohnpei FSM (Latitude 6°54’N, Longitude 158°13’E)
- Port Moresby, Papua New Guinea (Latitude 9°29’S, Longitude 147°9’E)
- Port Vila, Vanuatu (Latitude 17°44’S, Longitude 168°19’E)
- Rarotonga, Cook Islands (Latitude 21°12’S, Longitude 159°47’W)
- Suva, Fiji (Latitude 18°08’S, Longitude 178°25’E)
- Tarawa, Kiribati (Latitude 1°28’N, Longitude 173°2’E)
- Vaiaku, Tuvalu (Latitude 8°31’S, Longitude 179°13’E)

These tables show the average daily total irradiation for each month of the year for: surface at horizontal, a surface tilted at latitude and for a surface tilted at latitude plus 15 degrees.

When the roof is not oriented true north (southern hemisphere) or true south (northern hemisphere) and/or not at the optimum inclination, the output from the array will generally be less than the maximum possible though local conditions may cause some variations in that rule.

Appendix 3 of the design guideline provides tables that the variation in irradiation due to different tilts and azimuths from the optimums as shown for the locations listed in Table 3. The tables show the average daily total irradiation represented as a percentage of the maximum value i.e. PV orientation is true North (azimuth = 0°) in the Southern Hemisphere or true South in the Northern Hemisphere (azimuth = 180°) with an array tilt angle equal to the latitude angle or 10° whichever is greater[1]. If the location for the system you are designing is not shown it is recommended that you use the site with the latitude closest to your location.

Table 3: Sites for Orientation and Tilt tables in Appendix 3 of Design Guideline

No	Site	Latitude	Longitude
1	Nauru	*0°32' South*	*166°56' East*
2	Vaiaku, Tuvalu	*8°31' South*	*179°13' East*
3	Apia, Samoa	*13°50' South*	*171°46' West*
4	Suva, Fiji	*18°08' South*	*178°25' East*
5	Tongatapu, Tonga	*21°08' South*	*175°12' West*
6	Palikir, Pohnpei FSM	*6°54' North*	*158°13' East*
7	Hagåtña, Guam	*13°28' North*	*144°45' East*

The tables in Appendix 3 (Design guideline) provide values for an array mounted in 36 orientations (azimuths) and 10 inclination (tilt) angles in increments of 10˚.
Using these tables will provide the system installer with information on the expected output of a system (with respect to the maximum possible output) when it is located on a surface that is not facing true north (or south) or at an inclination not equal to the latitude angle. The designer can then use the

[1] It is not advisable to mount panels at a tilt angle less than 10° since panels need to be self-cleaned by the rapid run-off of rain.

peak sun hour data for the site to determine the expected peak sun hours of sun falling on the array at the actual orientation and tilt angle for the system to be installed. Note that in the case of arrays that are mounted on several roofs at different orientations and tilts, each roof must have the solar input calculated separately as the kWh per individual roof then all the kWh that result can be added together to get the total from all the modules in the installation.

6.4 Selecting an Array Structure

The array structure should have been selected by the designer and the details provided to the installer however the installer should also understand why a specific array structure is selected.

The array structure and module attachment system selected for the PV modules shall be designed to resist the ultimate wind actions for the site where the array will be located and be constructed of material suitable for the location.

The mounting of the system including brackets and clamps must be robust to be able to withstand movement either from wind or seismic activity.

The mounting system structure shall comply with the requirements set in AS1170.2 Structural design actions – Part 2: Wind actions.

6.5 Modules Mounted on Roofs (Not Building integrated)

Section B.6.1 in AS1170.2 provides design guidelines for wind pressures for structures that meet the following conditions:

a) Modules attached to enclosed buildings with aspect ratios $h/b \leq 0.5$ and $h/d \leq 0.5$.
b) Modules be attached parallel to the roof plane.
c) Modules with a gap of between 50 mm and 300 mm between the underside of the panel, and
d) Modules with a minimum distance between panel and roof edge of 2s where s is the gap between the underside of the panel and the roof surface, as shown in Figure B.9 (in AS 1170.2) (roof edge includes ridges with pitch ≥ 10°).

Figure 4 below shows an excerpt from Section B.6.1 in AS1170.2 with wind pressure zones shown upwind end, central, downwind end, upwind central and downwind central. Table B.12 in AS 1170.2 provides the wind pressure coefficients to each zone that relate to the array arrangement.

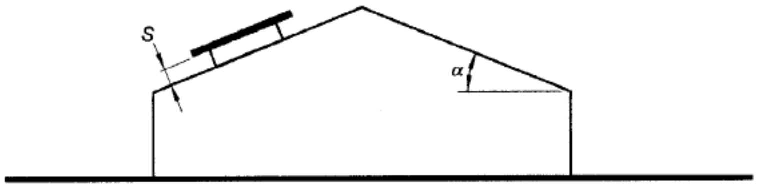

Figure B.9 — Panel mounted parallel to roof plane

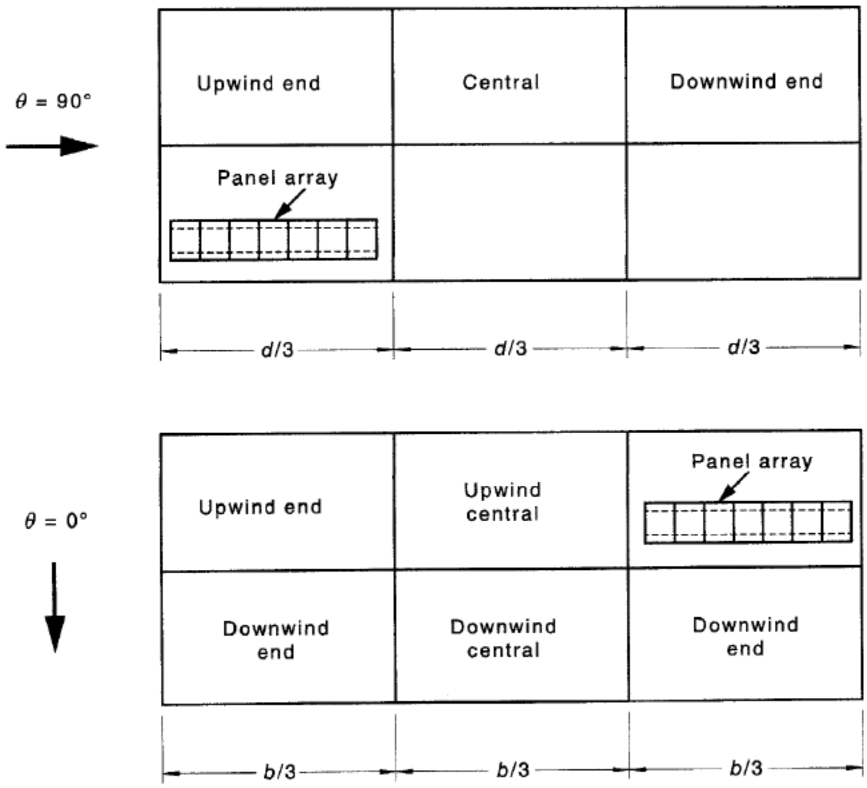

Figure 4: Roof Zones for Panel Array

The PV array roof mounting shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.2 (or equivalent updates).

Generally, the following major aspects shall be considered:

- If the modules use crystalline cells, then it is preferable to allow sufficient space below the array (> 50mm or 2 inches) for cooling by natural ventilation. Insufficient cooling will result in high module operating temperatures and lower outputs from the panels.
- It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris.
- If fauna (e.g. rats) are a problem in the vicinity of the installation, then consideration should be given as to how to prevent them gaining access under the array (see cable protection).
- The array structures shall be designed to withstand the aggressively salty atmosphere.
- All array supports, brackets, screws and other metal parts shall be of suitable low-corrosion materials suitable for the lifetime and duty of the system, that do not increase their rates of corrosion when mounted together in an array, and when mounted on the surface of the underlying structure. This may include techniques to minimise corrosion rates appropriate to the local environment, including but not restricted to methods such as: non-reactive separators between metal surfaces and under screw and bolt heads; and selection of materials with an appropriate type and thickness of anti-corrosive coating.

- Where timber is used it must be suitable for long-term external use and fixed so that trapped moisture cannot cause corrosion of the roof and/or rotting of the timber. The expected replacement time should be stated in the system documentation.
- Any roof penetrations must be suitably sealed and remain waterproof for the expected life of the system. If this is not possible then this must be detailed in the Maintenance Schedule.
- If the roof is using tiles, tiles shall sit flat after the installation of tile mounting brackets to ensure the tiles maintain their original ingress protection. There may be a requirement to grind some of the underside of the tile to enable it to sit correctly.
- For metal roofs the array frame structure should be attached to the roof using brackets that are screwed through the ridges of the roof into a purlin or rafter below.
- All fixings must ensure structural security when subject to the highest wind speeds likely in the region and local terrain - This may require specific tests of the fixing/substrate combination on that roof. The installer shall ensure that the array frame that they install has applicable engineering certificates verifying that the frame meets wind loadings appropriate for that particular location. For those countries which have experienced Category 5 cyclones/typhoons in the past shall have the frames and module attachments designed to meet the wind speeds expected in a Category 5 cyclone/typhoon.
- The installer must follow the array frame supplier's/manufacturer's recommendations when mounting the array to the roof support structure to ensure that the array structure still meets wind loading certification. The installer shall also consider the following:
    - Area of roof applicable for modules to be installed.
    - Type, length and diameter/gauge of screws to be used.
    - Number of screws required per attachment.
    - Size of batten/purlin required for attachment.
- If necessary, refer to the roof manufacturer's guidelines (or installation guide) to ensure that the materials introduced by the installation of PV array frames are compatible with the roofing material.

6.6 Ground Mounted Array

Section B.6.2 in AS1170.2 provides design guidelines for wind pressures for structures that meet the following conditions:

a) Modules attached to a ground mounted frame with aspect ratios $2 \le d/h \le 5$ and $b/d \ge 2$.
b) Modules attached to the frame at an inclination to ground, $\alpha \le 30°$.
c) Panel arrays with a spacing of $3.5 \le s/h \le 10$.
d) Modules with a minimum gap between the underside of the panel and the ground surface $c/h \ge 0.2$.

Figure 4 below shows an excerpt from Section B.6.2 in AS1170.2 with wind pressure zones shown by A1 to A3, B1 to B3, C1 to C3 and D1 to D3. Tables B.13 and B.14 in AS1170.2 provide the wind pressure coefficients to each zone that relate to the array arrangement.

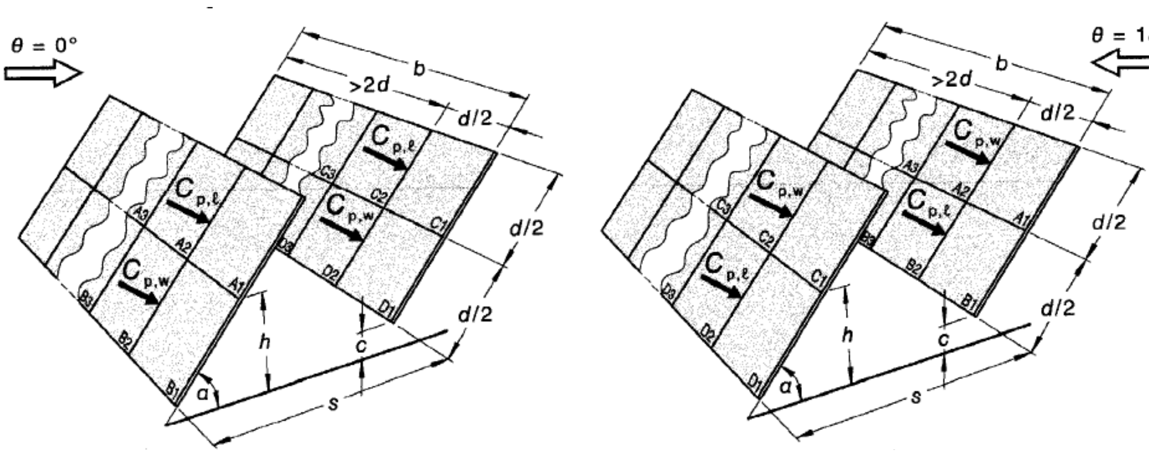

Figure 5: Wind Pressures on Ground Mounted Solar Panel Arrays as Shown in AS1170.2

- The array structures shall be designed to withstand the aggressively salty atmosphere that would occur in the coastal regions of the Pacific region.
- Installation of footings, posts, screws and/or in-ground fasteners shall follow manufacturer's instructions and installation manuals.

For smaller ground mount systems (generally **<100kW**), the modules could be attached to a pre-engineered frame, often designed to house up to 10 kW of PV modules per frame. Several of these fixed frames could be used for large capacity arrays. Either the modules could be clamped or bolted to the frame or the framing structure may use a U-shaped channel into which the modules slide; in both cases, the framing structure is fixed to concrete foundations. In areas where the soil is suitable and wind conditions sufficiently mild, earth screws may be suitable replacements for a concrete foundation.

For large ground-mounted installations, a pile-driven installation may be suitable. A geotechnical survey should be conducted to survey the ground and check for soil compactness, site classification, shrink swell index (in accordance with AS2870 - Residential slabs and footings), soil type, soil moisture content, aggressivity assessment (in accordance with AS2159 - Piling - Design and installation), rock or rubble size and depth and thermal and electrical resistivity (for the design of the cabling). Note, looser soils will require posts to be driven deeper. Site pull out and lateral load testing of the piles can be performed to predict the load carrying capacity of the soil used in the design.

6.7 Free Standing PV Arrays

The array mounting frames must be wind rated in accordance with relevant wind loading standards. For those countries which have experienced Category 5 cyclones/typhoons then the frames shall be designed to remain intact in the wind speeds expected in a Category 5 cyclone/typhoon
Installation of footings, posts, screws and/or in-ground fasteners shall follow manufacturer's instructions and installation manuals.

6.8 Building Integrated PV (BIPV)

The installation of modules that are being used as building materials (e.g. tiles, building walls windows, and sun-screens that have integrated solar generation elements) should only be installed by a person qualified to install that particular type of building element.

6.9 Attaching Module to the Array Frame

This work shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.2.2.6 (or equivalent updates).

The following shall be strictly practiced when attaching the module to the mounting structure:

- Solar 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.
- The mounting of the PV modules should allow for the expansion and contraction of the PV modules under expected operating conditions.
- Where modules are installed in such way that a junction box is to the side or at the bottom, care must be taken to ensure this is permitted by the manufacturer.
- When using clamps, solar panel manufacturer's installation instructions shall be followed. The installer shall consider the following:
    - amount of overhang allowed from clamp to end of module.
    - size of clamp required.

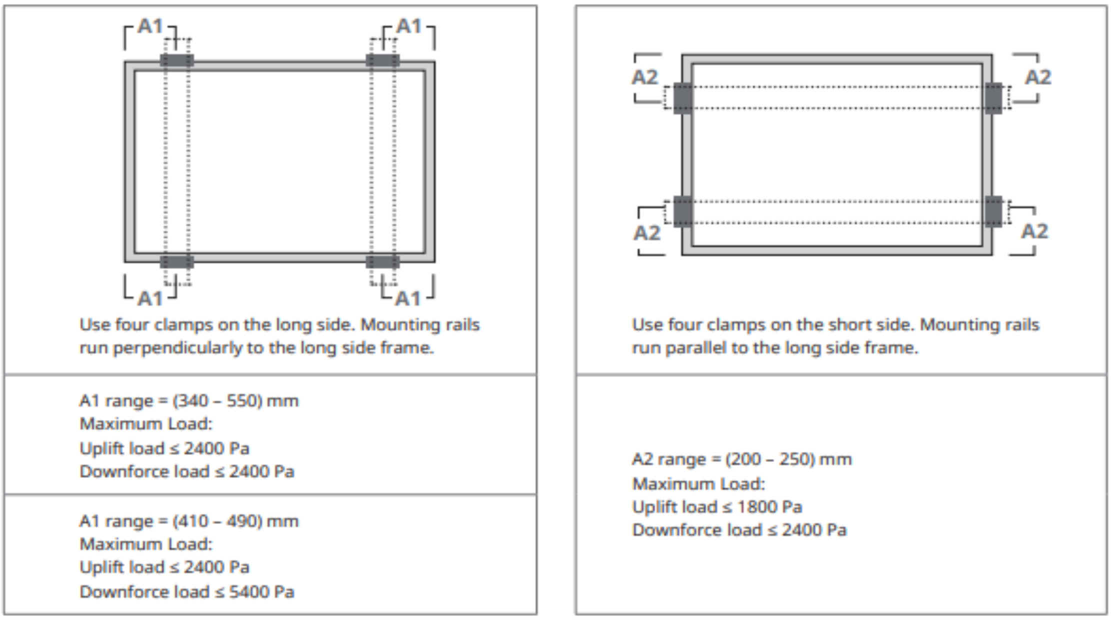

Figure 6: Example of Array Clamps (Source: Canadian Solar)

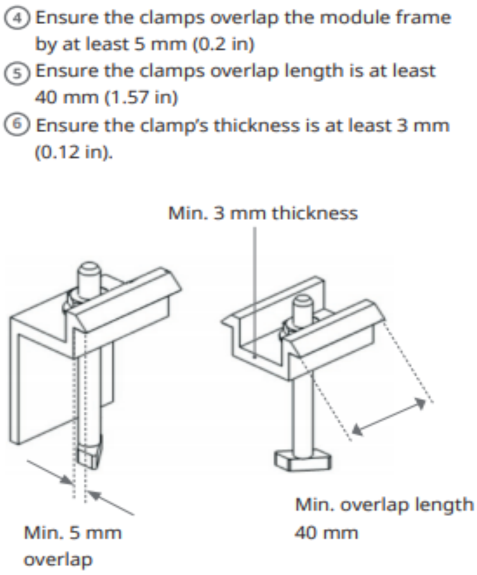

Figure 7: Module Clamps (Source: Canadian Solar)

NOTE: Attaching a solar module in such a manner (e.g., drilling, pop riveting) that causes a hole in the anodised aluminium frame of the solar module typically voids the manufacturer's product warranty with respect to defects in material and workmanship. If the installer intends to undertake an installation in this manner, they shall obtain written verification from the manufacturer that it does not affect the warranty. This shall be included in the system documentation supplied to the customer.

What clamps should be used in countries that experience Cyclones?
Experience in the last few years has shown that in countries that experience category 3 plus cyclones should have single module clamps on each module instead of dual module clamps. There have been a number of failures of dual module clamps due to cyclones which have resulted in a "zipper" effect where by one clamped module comes loose then the rest of the panels in that string are also loose.
Therefore, it is important that the array frame selected has been designed to be suitable for installation to with stand Category 5 cyclones. Array frames that are designed for winds experienced in Category 5 cyclones typically have mid-clamps longer than 50 mm (2 inches) in length and there can be as many as 3 railings per module. In a large system, consideration shall be given to using an end clamp for every fourth module so if one does become loose then only a few other modules would be affected, not necessarily the whole array.

7 PV Array Wiring

7.1 Selection of d.c. Cables

7.1.1 d.c.string/array cables

Figure 8: Double insulated solar D.C. cable

The PV d.c cables (i.e. string/array cable) used in the system shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.4.2.1 (or equivalent updates)

Generally, the installer shall consider the following for cables used within the PV array wiring:

- Be suitable for d.c. applications.
- Have a voltage rating greater than or equal to the calculated PV d.c. circuit maximum voltage (determined using Table 2 in section 6.2) in accordance with Clause 4.2.1.3.
- Conform to IEC 62930 Electric cables for photovoltaic systems with a voltage rating of 1.5 kV d.c. where not installed underground.
- Note: For cable that is installed underground, see Clause 4.4 2.5 of AS/NZS 5033.
- Have each conductor double insulated for where the calculated PV d.c. circuit maximum. voltage is above 35 V.
- Have a temperature rating according to the application.
- Be water resistant.
- If exposed to the environment, cables should be UV-resistant, be protected from UV light by appropriate protection, or installed in UV-opaque conduit that is itself UV-resistant,
- Cables directly terminated to plugs, socket and connectors as specified in Clause 4.3.8 of AS/NZS 5033, shall be class 5 (flexible) in accordance with IEC 60228 (Conductors of insulated cables).

Notes:

1. Clause 4.4.2.1 also provides recommendations for other types of cables when installed in buildings
2. According to Clause 4.4.2.3 (AS/NZS 5033), the nominal cross-sectional area of PV d.c. conductors shall not be less than 4 mm^2.

7.2 Installation of the PV Array Wiring

The installation of PV d.c. cables (i.e., string/array cable) shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.4.3 & 4.4.3.1 (or equivalent updates). Mainly, the following shall be complied to in regards to installation of the PV array wiring:

- meet the requirements of Clause 4.3.2.3 (AS/NZS 5033), mainly:
    - Insulated and sheathed UV resistant cables shall be used.
    - Cables shall be protected from mechanical damage.
    - Cables shall be clamped to prevent undue strain on the connections/terminations.
    - Cables shall not lie on roofs without an enclosure.
    - Cables shall not obstruct the natural water drain paths or promote accumulation of debris.
    - Plastic cable ties shall not be used as a primary means of support.
    - 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.
- meet the wiring enclosure requirements of Clause 4.4.5 (AS/NZS 5033), mainly:
    - where conduit systems are used, all parts shall be sealed appropriately (by using methods such as glue) unless otherwise stated by the manufacturer.
    - they shall be marked in accordance with Clause 5.3.1 (AS/NZS 5033).
    - documented in accordance with Clause 5.6 (AS/NZS 5033).
- are supported so they do not suffer fatigue due to wind affects.

In addition:

- Cables should meet both the current carrying capacity (CCC) requirements (refer to Clause 4.4.2.2 of AS/NZS 5033) and the voltage drop requirements (refer to Clause 4.4.2.4 of AS/NZS 5033).

7.3 Calculating Voltage Drop (Metric)

The voltage drop in a PV cable shall be calculated as follows:

1. Resistivity Formula

Voltage drop is calculated using Ohm's law:

$$V = I \times R$$

Combining this with the formula for calculating resistance, the voltage drop along a cable is given by:

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times \rho}}{\mathbf{A_{CABLE}}}$$

Voltage drop (in percentage) = $\frac{V_d}{V_{MP}} \times 100$

Where:

L_{CABLE} = route length of cable in metres (multiplying it by two adjusts for total circuit wire length since a complete circuit requires a wire out and another wire back along the route).

I = current in amperes.

ρ = resistivity of the wire in $\Omega/m/mm^2$

A_{CABLE} = cross sectional area (CSA) of cable in mm^2.

V_{MP} = Maximum Power Point voltage in Volts.

For PV arrays the current is the short circuit current (I_{sc})of the string, sub-array or array. The Maximum line voltage in volts is the maximum power point voltage of the string, sub-array or array (V_{mp}).

The three types of cables that are commonly used within PV systems and their typical maximum temperature ratings include:

- Polyvinyl Chloride (PVC) - maximum temperature 75°C
- Cross Linked Polyethylene (XLPE) - maximum temperature 90°C
- Cross Linked Polyethylene (XLPE) - maximum temperature 110°C

Table 4 shows typical resistivities for the different types of cables at their maximum temperature.

Table 4: Resistivity for different cables ($\Omega/m/mm^2$).

Cable Type	Copper	Aluminium
PVC-75°C	0.0209	0.0328
XLPE 90°C	0.0219	0.0345
XLPE 110°C	0.0233	0.0367

Worked Example 2:

A solar array has been installed and the distance between the output of the array and the inverter is 10 metres. The short circuit current of the array is 13.73A.
The cable used is of copper and insulation type is XLPE rated for 90°C.
The cables have a cross sectional area of 4 mm^2
The cable has a resistivity of 0.0219 ohms/metre/mm^2
The array has maximum power point voltage of 472V.

$V_d = 2 \times L_{CABLE} \times I \times \rho / A_{CABLE}$

$= (2 \times 10 \times 13.73 \times 0.0219)/4$
$= 1.50V$

Voltage Drop in percentage) = $\frac{V_d}{V_{MP}} \times 100$
$= 1.50/472 \times 100\%$
$= 0.32\%$

Alternatively, the method stated in section 4 of AS/NZS 3008.1 could also be used.

2. AS/NZS 3008 Formula

$$V_d = \frac{(V_c \times L \times I)}{1000}$$

Where:

V_d = Actual voltage drop (in V)

L = Route length (in m)

I = Current flow (in A). For PV DC cables, the I_{SC} current (at STC) should be used.

V_C = Millivolt drop per amp-metre route length (in mV/Am)

Tables of V_C values may be provided by the cable manufacturer, or otherwise can be found in the relevant Australian standards. Typical values for single-core flexible cable in touching formation is given in Table 5. The voltage drop values are typically for three-phase AC circuits, which can then be converted to single phase AC or DC values by multiplying by 1.155.

Table 5: Three-phase V_C for single-core flexible cable in touching formation (mV/Am)
Extracted from AS/NZS 3008.1 Table 47

Conductor CSA (mm^2)	Conductor temperature (°C)				
	45	60	75	90	110
0.5	74.2	78.2	82.2	86.1	91.4
1.0	37.1	39.1	41.1	43.1	45.7
1.5	25.3	26.7	28.0	29.4	31.2
2.5	15.2	16.0	16.8	17.6	18.7
4	9.42	9.92	10.4	10.9	11.6
6	6.28	6.62	6.96	7.29	7.74
10	3.64	3.84	4.03	4.22	4.48
16	2.31	2.43	2.56	2.68	2.85

25	1.50	1.58	1.66	1.74	1.84
35	1.07	1.13	1.18	1.24	1.31
50	0.760	0.798	0.837	0.875	0.926
70	0.551	0.577	0.603	0.630	0.665

Worked Example 3:
Using Table 4, determine the voltage drop and percentage voltage drop for the array cable where:
Selected cable size is $4mm^2$. (From Table 4, the three-phase V_c value is 10.9 mV/Am)
Route length = 10 m,
Maximum current (Isc) = 13.73 A,
The array has maximum power point voltage of 472V.

$$V_d = \frac{(V_c \times L \times I)}{1000}$$

Converting three-phase values to single-phase from Table 4:

10.9 x 1.155= 12.59 mV/Am (single phase)
V_d = (10 m × 13.73 A x 12.59 mV/Am) / 1000 = 1.73V

$\%V_d$=1.73/472 x 100% = 0.37%

7.4 Selection of Current Carrying Capacity of PV String Cables

PV string and array cables should meet the current carrying capacity (CCC) requirements according to Clause 4.4.2.2/ 4.2.2.2 of AS/NZS 5033) which is summarised as follows:

Each string cable should be capable of carrying all possible current sources in the system. As overcurrent protection limits the amount of current able to safely pass through different parts of the system, the CCC rating of a string cable should take any overcurrent protection in the system into account.
The string cables may also carry current being fed from a number of strings to a single string if that single string is not operating at the same voltage level as the other strings.

If string overcurrent protection will be installed:
The string cable should be able to carry any current able to pass through the string overcurrent protection.

$$CCC \geq I_n \text{ (rating of string overcurrent protection)}$$

For example, if the fault current protection device is rated at 10A, the string will need to be rated with a current carrying capacity (CCC) of a minimum of 10A.

If string overcurrent protection will not be installed:
If there is only one string in the whole array, the string cable should be rated to carry the short circuit current of the string, with a safety margin:

$$CCC \geq I_{STRING\ MAX}$$

$$CCC \geq 1.25 \times I_{SC\ MOD} \times K_I \text{ (if no DCUs present) (mono-facial modules)}$$

Note: See Appendix J of AS/NZS 5033 for the determination of K_1. The K_1 factor used in AS/NZS 5033 for determining cable and fuse ratings in Clause 3.3 and Clause 4.2.2 is affected by the use of bifacial modules. For mono-facial modules, use K_1 factor as 1.

If there is more than one string in the array, the string cable should be able to carry the combined short-circuit currents from the other strings (with safety margin) as well as any current able to pass through downstream overcurrent protection.

$$\mathbf{CCC \geq I_n + I_{STRING\ MAX} \times (S_A - 1)}$$

$$\mathbf{CCC \geq I_n + 1.25 \times K_I \times I_{SC\ MOD} \times (S_A - 1) \text{ (if no DCUs present)}}$$

Where:

- ***CCC*** = Current carrying capacity rating of the cable (in A);
- I_n = Downstream overcurrent protection (in A)
- S_A = Total number of parallel connected PV strings in the PV array
- I_{SC} = Short circuit current of the module (in A)
- 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.

If there is no downstream overcurrent protection, I_n is replaced by the inverter ***back-feed current*** and the number of strings is equal to the number of strings in the whole array.

Worked Example 4:

A PV system is made up of two strings with the following characteristics:
$I_{SC\ MOD}$ = 5.1 A.
Module reverse current rating = 20 A.
$I_{BF\ TOTAL}$ = 0 (no other current sources).
K_I= 1

To determine if overcurrent protection is required, the following calculation is used:
$I_{F\ STRING} + I_{BF\ TOTAL} > I_{MOD\ MAX\ OCPR}$
Where:
$I_{F\ STRING} = (S_A - 1) \times I_{STRING\ MAX}$
$I_{STRING\ MAX} = 1.25 \times K_I \times I_{SC\ MOD}$
Therefore:
$I_{STRING\ MAX} = 1.25 \times 1 \times 5.1 = 6.375$ A
$I_{F\ STRING} = (2 - 1) \times 6.375 = 6.375$ A
6.375 + 0 is not greater than 20 A so overcurrent protection is not required.
The string cable CCC is thus:
$CCC \geq I_n + 1.25 \times K_I \times I_{SC\ MOD} \times (S_A - 1)$
$CCC \geq 0 + 1.25 \times 1 \times 5.1 \times (2 - 1)$
$CCC \geq 6.375$ A

7.5 Selection of Current Carrying Capacity of PV Array Cables

The array cable should be capable of carrying all currents from the PV array as well as any possible back-feed current from the inverter. The array cable for a standard grid-connected PV system will not carry any current from external sources, such as a battery bank. Therefore, it is expected that there will be no array overcurrent protection installed.

The array cable should be sized to carry whichever is the greater of:

1. The array short circuit current (with safety margin):

$$CCC \geq 1.25 \times \textit{array short circuit current}$$

   OR

2. The inverter back-feed current:

$$CCC \geq \textit{inverter backfeed current}$$

Worked Example 5:

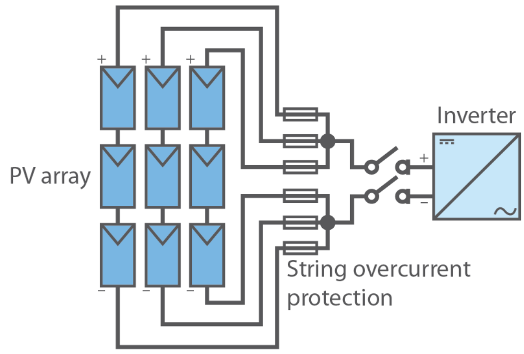

Figure 9: Current carry Capacity of Cables with string fusing

Assuming:
Modules are mono-facial
Inverter backfeed current = 0A
No DCUs present
In Figure 8:

- The CCC of the String Cable is rated minimum of the string fuse rating
- The CCC of the Array cable is rated: 1.25 x 3 x $\mathbf{I_{SC\ MOD}}$

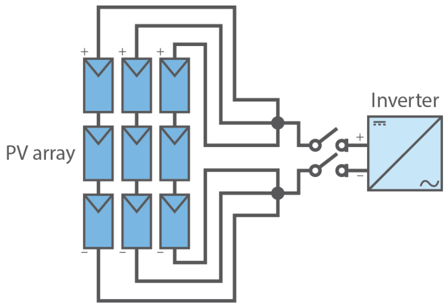

Figure 10: Current carry Capacity of Cables with no string fusing

Assuming:
Modules are mono-facial
Inverter backfeed current = 0A
No DCUs present
In Figure 9

The CCC string cable is rated:
$= In + 1.25 \times K_I \times I_{SC\ MOD} \times (S_A - 1)$
$= 0 + 1.25 \text{ x } 1 \text{ x } (S_A - 1)$
$= 1.25 \times I_{SC\ MOD} \times (3 - 1)$
$= 1.25 \times I_{SC\ MOD} \times 2$

The CCC of the Array cable is rated: 1.25 x 3 x $\mathbf{I_{SC\ MOD}}$

7.6 Selection of Cables when Array Comprises Sub-Array PV Systems

In a large grid connected PV system the array could consist of a number of sub-arrays. A sub-array comprises a number of parallel strings of PV modules. The sub-array is installed in parallel with other sub-arrays to form the full array. The effect of this is to decrease the potential fault current through different parts of the system.

7.6.1 PV Array Cables

The current carrying capacity (CCC) of the PV array cable will be rated as follows:
The array cable should be sized to carry whichever is the greater of:

1. The array short circuit current (with safety margin):

$$CCC \geq 1.25 \times \text{array short circuit current}$$

OR

2. The inverter back-feed current:

$$CCC \geq \text{inverter backfeed current}$$

7.6.2 PV Sub-Array Cables

The sub-array cable should be able to carry its short-circuit current, and it may also need to account for when the sub-array is fed currents from the other sub-arrays because the sub-array is not operating at the same level as the other sub-arrays.

If sub-array overcurrent protection will be installed:
The sub-array cable should carry any current that can pass through the sub-array overcurrent protection.

$$CCC \geq I_n \text{ (rating of string overcurrent protection)}$$

If sub-array overcurrent protection will not be installed:

$$CCC \geq In + (S_A - S_{SA}) \times I_{STRING\ MAX}$$
$$CCC \geq In + (S_A - S_{SA}) \times 1.25 \times K_I \times I_{SC\ MOD} \text{ (if no DCUs)}$$

7.6.3 PV String Cables

If string overcurrent protection will be installed:
The string cable should be able to carry any current able to pass through the string overcurrent protection.

$CCC \geq I_n$ (rating of string overcurrent protection)
If string overcurrent protection will not be installed:
If there is only one string in the sub-array, the string cable should be rated to carry the short circuit current of the string, with a safety margin:

$$CCC \geq I_{STRING\ MAX}$$
$$CCC \geq 1.25 \times I_{SC\ MOD} \times K_I \text{ (if no DCUs present)}$$

If there is more than one string in the sub-array, the string cable should be able to carry the combined short-circuit currents from the other strings (with safety margin) as well as any current able to pass through downstream overcurrent protection.

$$CCC \geq I_n + I_{STRING\ MAX} \times (S_{SA} - 1)$$

$$CCC \geq I_n + 1.25 \times K_I \times I_{SC\ MOD} \times (S_{SA} - 1) \text{ (if no DCUs present)}$$

Worked Example 6:

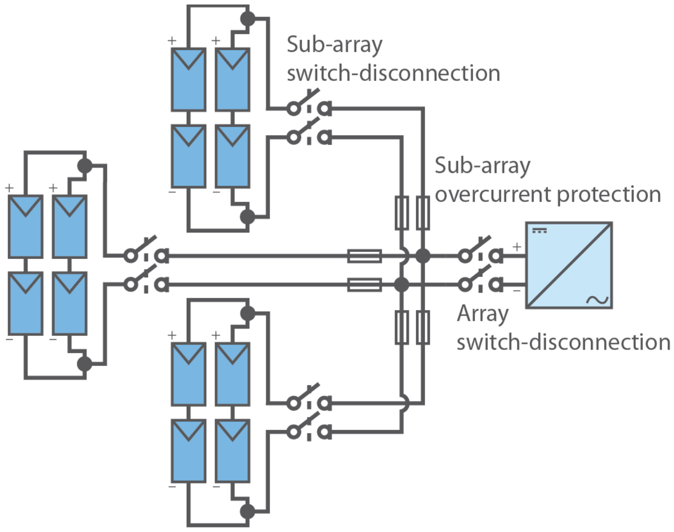

Figure 11: Array with sub-array fusing

Assuming:
Modules are mono-facial, Inverter backfeed current = 0A and No DCUs present

In Figure 11:

- The CCC of the String Cable is rated:
- CCC $\geq$ $I_n + 1.25 \times K_I \times I_{SC\ MOD} \times (S_{SA} - 1)$ (if no DCUs present)
- The CCC of the subarray shall be a minimum of:
- CCC $\geq I_n$ (rating of string overcurrent protection)
- The CCC of the Array cable is rated: 1.25 x 6 strings x $\mathbf{I_{SC\ MOD}}$

7.7 Wiring Layout

The wiring layout shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.2.3.3 (or equivalent updates).
Cables need to be laid in parallel close together to avoid wiring loops which could induce high voltages due to nearby lightning strikes.

Figures 12, 13 and 14 give examples on how the conductive wiring loop can be avoided. Figure 15 shows what should not be done.

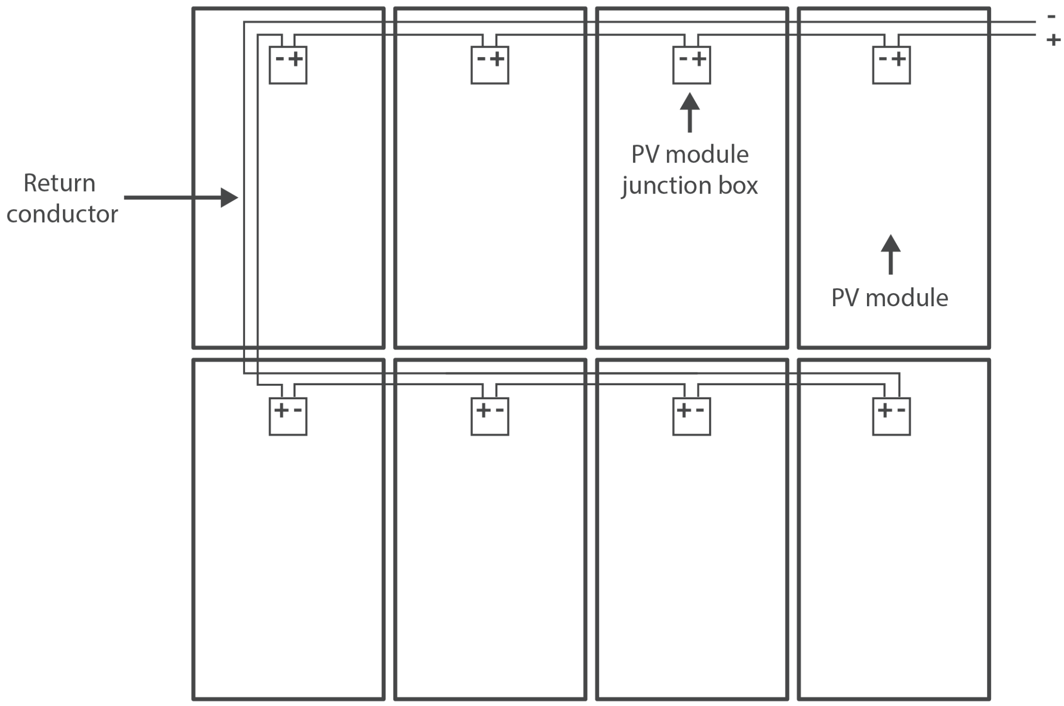

Figure 12: Example of Wiring to avoid Conductive Loops

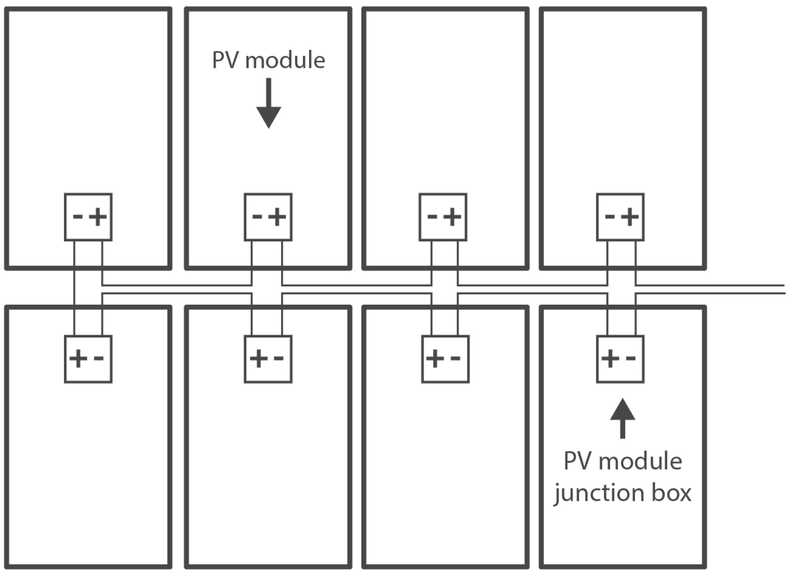

Figure 13: Example of Wiring to avoid Conductive Loops

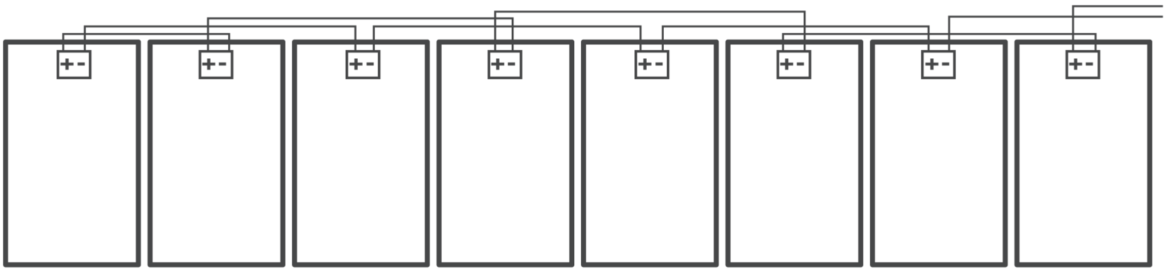

Figure 14: Example of Wiring to avoid Conductive Loops

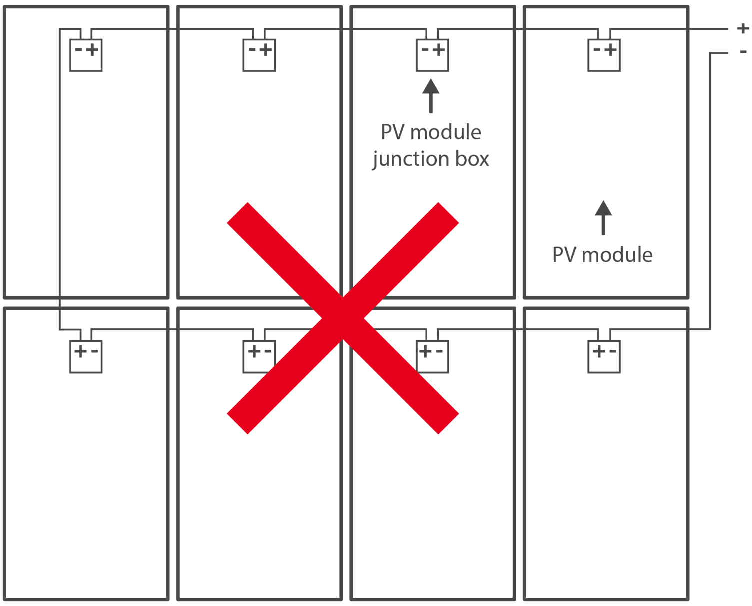

*Figure 15: Example of Wiring that will cause Conductive Loops and **not** to be done.*

8 Disconnection Requirement within an Array

The PV Isolation (disconnection) methods shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.3 (or equivalent updates).

For a system comprising a string inverter then, 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 AS/NZS 5033 Clause 4.3.5 2.1.

Figure 16 Example of a disconnection point

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

For systems that include optimisers or module inverters, the following shall apply:

- 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.

- 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 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 PV inverter (PCE), the requirements specified in Clause 4.3.3.1 shall be followed.

Refer to Clause 4.3.3 and 4.3.4 in AS/NZS 5033 for further details. In regards to d.c. Isolator sizing, refer to Clause 4.3.4 and guidance provided in Appendix H of AS/NZS 5003 (when required).

9 d.c Cable Protection

The d.c. overcurrent protection shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.6 (or equivalent updates).

9.1 String, sub-array and array protection

Clause 3.3.5 and Table 3.1 of AS/NZS 5033 gives the sizing requirements for string, sub-array and array overcurrent protection, using values calculated from the previous clauses. The grid connected PV systems shall comply with these requirements.

9.1.1 String protection

String overcurrent protection is required if the maximum string fault current, including any potential backfeed current from other sources, is greater than the module reverse fuse rating.

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

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

(When simplified)

$$(S_A - 1) \times I_{STRING\ MAX} + I_{BF\_TOTAL} > I_{MOD\_MAX\_OCPR}$$

$$(S_A - 1) \times 1.25 \times K_I \times I_{SC\_MOD} + I_{BF\_TOTAL} > I_{MOD\_MAX\_OCPR}$$

Where:

- $I_{BF\ TOTAL}$ = 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. The inverter backfeed short-circuit current, if present, can be obtained from the inverter manufacturer’s installation manual.
- $I_{MOD\ MAX\ OCPR}$ = PV module maximum overcurrent protection rating as determined by ***IEC 61730-2***. Also referred to as maximum series fuse rating, or maximum reverse current rating, and can be found on the PV module datasheet.
- S_A = Total number of parallel connected PV strings in the PV array.
- I_{SC} = Short circuit current of the module (in A).
- 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.

String protection if required can be calculated using Clause 3.3.5 and Table 3.1 of AS/NZS 5033.

1. Where there are no DCUs:

$$1.2 \times I_{STRING\ MAX} < I_n < I_{MOD\ MAX\ OCPR}$$

$$\text{(when simplified) } 1.5 \times K_1 \times I_{sc\,MOD} < I_n < I_{MOD\,MAX\,OCPR}$$

2.Where all PV modules have DCUs attached:

$$I_{STRING\,MAX} < I_n < I_{DCU\,OCPR}$$

3.Where only some PV modules have DCUs attached:
Comply with both of the previous formulas
Where:

- $I_{STRING\,MAX}$ (if no DCUs) = $1.25 \times K_I \times I_{SCMOD}$
- $I_{MOD\,MAX\,OCPR}$ = PV module maximum overcurrent protection rating as determined by ***IEC 61730-2***. Also referred to as maximum series fuse rating, or maximum reverse current rating, and can be found on the PV module datasheet.
- $I_{DCU\,OCPR}$ = DCU maximum overcurrent protection rating as determined by the DCU manufacturer

Worked Example 7
A PV system has 3 strings of PV modules, and no DCUs. The modules have a I_{SC} of 9.8 A and an $I_{MAX\,OCPR}$ of 20 A. The K_I factor has been determined to be 1 (mono-facial), and the inverter has a potential backfeed current of 3 A.

According to AS/NZS 5033:2021, string overcurrent protection is required if:

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

$$\text{Which when simplified becomes: } (S_A - 1) \times I_{STRING\,MAX} + I_{BF\,TOTAL} > I_{MOD\,MAX\,OCPR}$$

$$(S_A - 1) \times 1.25 \times K_I \times I_{SC\,MOD} + I_{BF\,TOTAL} > I_{MOD\,MAX\,OCPR}$$

$$((3 - 1) \times 1.25 \times 1 \times 9.8\text{ A}) + 3\text{ A} > 20\text{ A}$$

$$24.5\text{ A} + 3\text{ A} > 20\text{ A} \rightarrow \text{TRUE, so string overcurrent protection is required.}$$

According to AS/NZS 5033:2021, string overcurrent protection sizing I_n must comply with:

$$1.2 \times I_{STRING\,MAX} < I_n \leq I_{MOD\,MAX\,OCPR}$$

$$\text{Which becomes: } 1.2 \times 1.25 \times K_I \times I_{SC\,MOD} < I_n \leq I_{MOD\,MAX\,OCPR}$$

$$1.5 \times 1 \times 9.8\text{ A} = 14.7\text{A}$$

Therefore, I_n must be more than 14.7 A and less than or equal to 20 A. We would probably choose a 20 A fuse.

9.1.2 Sub-array protection

Where no sub-array and array protection are required, cable size should be calculated using Clause 4.4.2.
Sub-array overcurrent protection is not explicitly required by the relevant standards, but if it is not used then the sub-array cables must be sized to carry the fault current from all sub-arrays except itself, so sub-array protection is recommended if there are more than two sub-arrays.

However, if sub-array and array protection are required, then it can be calculated using Table 3.1 of AS/NZS 5033.

If sub-array overcurrent protection is required for a system, the nominal rated current for the overcurrent protection device will be as follows:

$$I_n \geq S_{SA} \times I_{STRING\ MAX}$$

Where:

S_{SA} = strings in parallel in the sub-array.
$I_{STRING\ MAX}$ (if no DCUs) = 1.25 × K_I × $I_{SC\ MOD}$

9.1.3 Array protection

The requirements for array overcurrent protection are limited: it is to be installed only in the event that another current source is present that may cause damage to the PV array under fault conditions. Examples of such current sources are battery banks or other generator sets.

If array protection is required, the rated current of the overcurrent protection device will be the following:

$$I_n \geq S_A \times I_{STRING\ MAX}$$

Where:

S_A = strings in parallel.
$I_{STRING\ MAX}$ (if no DCUs) = 1.25 × K_I × $I_{SC\ MOD}$

9.2 Fuses

Fuses or circuit breakers can be used for string overcurrent protection. Any fuses used in PV systems should be DC rated. Circuit breakers may be used for string protection as long as they are:

- Rated for DC voltages of at least the PV array maximum voltage.
- Bi-directional (non-polarised.)
- Within the current rating range, as calculated above.
- Compliant with all other specifications, as per the appropriate standards.

Fuses used for string overcurrent protection shall comply with Clause 4.3.6.3 of AS/NZS 5033.

10 Earthing of Array Frames

The earthing requirements of PV Array exposed conductive parts shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.6.2 (or equivalent updates).
Essentially:

- 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:
  - All conductive PV module frames.
  - Array mounting frames that are directly in contact with the PV d.c. cables.
  - Conductive cable support systems or conductive wiring enclosures that are directly in contact with the PV d.c. cables.
- 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.

Other important considerations and best practice for earthing or bonding include (with reference to Clause 4.6.2, 4.6.3, 4.6.4 and 4.6.5 of AS/NZS 5033):

- Earth connection shall be:
    - o by a purpose-made fitting providing earthing or bonding connections for dissimilar metals and fitted to the manufacturer's instructions, or
    - o by purpose-made washers with serrations or teeth for the connection between the PV module and mounting frame fitted to the manufacturer's instructions, and
    - o Tinned cable lugs of earthing and bonding cables fixed by stainless steel bolts washers and
  - star washers to aluminium frames.
    - o arranged so that the removal of a single module earth connection will not affect the continuity of the earthing or bonding connections to any other module.
- Self-tapping screws and rivets shall not be used.
- Many of the commercial array frames come supplied suitable washers for bonding the modules to the array and also special washers for connecting sections of the array frame. If the array frame being used does not than the aluminium module frame can be bonded to the mounting frame by the use of suitable products, such as Wiley Electronics' WEEB (washer, electrical equipment bond), Unirac's bonding clip and other suitable clamps. A WEEB is a stainless-steel washer with sharp teeth that penetrate the non-conductive protective coating of the module frame, creating an electrical connection between the module frame and the mounting frame. A WEEB lug also prevents galvanic corrosion between the aluminium mounting structure and the copper earthing cable.

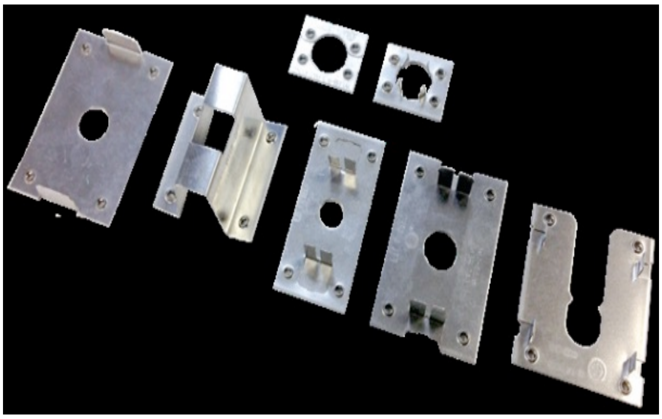

Figure 17 Various WEEB washers for earthing the module frame.

- Earthing or bonding connections to PV array frames shall be protected against corrosion. All earth connections to the mounting rail should be sprayed with corrosion resistant paint to protect the connection from corrosion from the weather.
- Ensure that rail joiners (splices) provide earth continuity. Some rail manufacturers state that the use of a rail joiner (splice) provides earth continuity between rails. If the manufacturer does not provide this information, an earth strap shall be installed across the joint.
- The earthing cable can be insulated unsheathed cable. If exposed to direct sunlight the cable shall have a physical barrier to prevent exposure to direct sunlight.
- The earthing cable should be installed in parallel with and in close proximity to the PV array cable (both positive and negative), the inverter and the inverter a.c. cables going to the switchboard or distribution board.
- 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.

- The earthing conductor from the PV array can connect to inverter's main earth conductor in the a.c. output cable provided the following conditions are met:
    - Installation is not subject to lightning
    - Inverter a.c. earth is of an appropriate size
- Earth cable cannot pass through a tile or steel roof without additional mechanical protection (conduit) and an appropriate collar flashing (e.g., Dektite®). The same conduit used for PV array cable can also be used for the earth cable.
  All earthing/bonding cables should be connected to the same earth grounding point. If multiple grounding points are used, all ground points should be connected together with a earthing cable.
- The minimum earthing or bonding conductor size shall be determined using Clause 4.6.5 of AS/NZS 5033 and in particular Figure 4.13 and Table 4.6. The bonding conductor shall have a resistance no more than 0.5 Ω between exposed conductive parts and the installation earthing system. Generally, a minimum cable size of 4 mm^2 shall be used (with separated inverters), however, if the array structure is to be earthed (for lightning protection then it should be minimum 16 mm^2. The actual size could be confirmed using Figure 4.13 and Table 4.6.
- For non-separated PCEs, the earth cable size is dependent upon whether there is d.c. overcurrent protection or not, the size of string, sub-array or array cable and as per the earthing requirements of AS/NZS 3000 (see Table 4.6 of AS/NZS 5033).

11 Safe Installation Practice

A dangerous situation occurs when the person installing the system is able to come in contact with the positive and negative outputs of the solar array or sub-array when the output voltage is rated greater than DVC-A (that is greater than 60V d.c.)

Most grid-connected systems use solar modules which are connected using double insulated leads with polarised shrouded plug and socket connections.

Therefore, the dangerous situation is only likely to occur at:

- the PV Array switch-disconnector (isolator) before the inverter;

and

- the sub-array and array combiner boxes (if used).

To prevent the possibility of an installer coming in contact with live wires it is recommended practice that one of the interconnect cables of each string (as shown in Figure 18) is left disconnected until all the wiring is complete between the array and the inverter. Only after all switch-disconnectors and other hard-wired connections are completed should the interconnect of the array be connected.

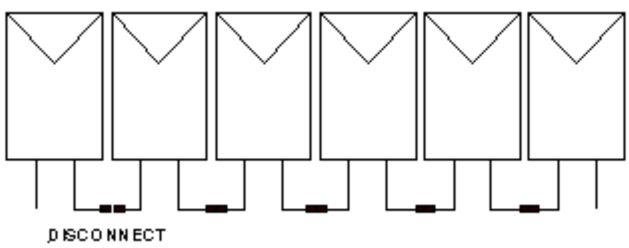

Figure 18: Disconnected interconnect cable

The installer shall ensure that all connectors used are waterproof and connected securely to avoid the possibility of a loose connection. Only connectors of the same type from the same manufacturer are allowed to be mated at a connection point.

When mounted on a roof, the solar module interconnect cables must be supported clear of the roof surface to prevent debris build up or damage to insulation.

12 Installation of PV Array cable between Array and Inverter

For the PV d.c. cables that are installed within buildings, additional mechanical protection shall be provided in accordance with Clause 4.4.5.2.2 of AS/NZS 5033 (or equivalent updates):

- enclosed in metal or heavy-duty insulating conduit where installed within a ceiling space, in wall cavities or under a floor; or
- installed in medium duty insulating wiring enclosure in other locations within buildings.

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.
- and in a restricted access location, there are no additional mechanical protection requirements for the wiring system.

Also see relevant requirements in Clause 4.4.5.2 of AS/NZS 5033.

Additionally, the following best practices shall be adopted:

- PV array cables shall be installed in UV-resistant conduits if exposed to the outdoor environment.
- Conduits shall be installed so that they are adequately supported.
- Double insulation of each conductor shall be maintained within wiring enclosures (e.g. conduit).
- The wiring enclosure shall be labelled 'SOLAR' on the exterior surface of the enclosure at an interval not exceeding 2 metres.
- Where the PV array cable and conduit passes through a tile or steel roof, an appropriate collar flashing (e.g. Dektite®) shall be installed.
- Installing a conduit just through a hole in a metal roof and sealing it with silicone is prohibited.

Figure 19: A Dektite® flashing on a metal roof.

13 Installation of Combiner Boxes

- Combiner boxes (PV string or PV array) installed outside shall be at least IP65 and shall be UV resistant.
- PV array and PV string combiner boxes which contain fuses or switch disconnectors shall be located where they can be reached without having to dismantle any structure such as cupboards, structural framing etc.
- Any cable entries into combiner boxes via cable glands or conduit glands should maintain the IP rating of the combiner box.

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

The segregation of PV d.c cables and other non-PV cables shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.4.3.2 (or equivalent updates). Effective segregation can be achieved by separation of 50 mm or greater.

Specifically,

- Segregation shall be provided between d.c. and a.c. circuits within enclosures by insulation barriers.
- Where switches for d.c. and a.c. circuits are mounted on a common mounting rail the mounting rail shall not be conductive (e.g. metal).
- d.c. and a.c. circuits should be clearly marked.

15 Selection and Installation of Plugs, Sockets and Connectors

The selection and installation of plugs, sockets and connectors shall be compliant to AS/NZS 5033 requirements, in particular, Clause 4.3.8 and 4.3.9 (or equivalent updates).

The key requirements are the Plugs, sockets and connectors shall -

- conform to AS/NZS 62852;
- be protected from contact with live parts in connected and disconnected states (e.g., shrouded);

Key installation requirements that shall apply include:

- be installed to minimize strain on the connectors (e.g. supporting the cable on either side of the connector);
- be installed to maintain the IP rating;
- be installed on PV d.c. cables conforming to plug, sockets and connector manufacturers' requirements;
- only be mated with those from the same manufacturer and designed to be mated together; and
- be terminated using a tool (where required) designed for the purpose and technique specified by the plugs, socket or connector manufacturer's instructions.

16 Inverter Selection

When selecting an inverter to be used in a Grid Connected PV system the inverter(s) shall meet:

- IEC62109 Safety of power converters for use in photovoltaic power systems
  - IEC62109-1 Part 1: General requirements.
  - IEC62109-2 Part 2: Particular requirements for inverters.

Australia requires inverters that connect to the grid to comply with: AS/NZS 4777.2 Grid connection of energy systems via inverter: Inverter requirements. This standard has requirements that are required by the numerous power utilities and the Australian Energy Market Operator for the operation of the Australian grid.

If inverter is sourced from Australia then:,

1. the inverters should also comply with AS/NZS4777.2 Grid Connection of energy systems by Inverters- Part 2: Inverter requirements; and
2. the inverters are recommended to be selected from those on the Australian Clean Energy Council's approved product list:

https://www.cleanenergycouncil.org.au/industry/products/inverters/approved-inverters

For those following Australia and New Zealand standards and hence, AS/NZS 4777, the following will be useful:
AS/NZS 4777.2 has three settings for Australia and the settings are dependent on your location. The three settings are:

- Australia A – applies to the configuration of inverter settings in Victoria, South Australia, New South Wales, ACT and Queensland.
- Australia B – applies to the configuration of inverter settings in Western Australia (Western Power).
- Australia C – applies to the configuration of inverter settings in North-western Australia (Horizon Power) and Tasmania.

Inverters in the relevant country should be set to the applicable settings. It is recommended that the PICTs select Australia C.

17 Inverter Installation Requirements

The inverter installation shall be compliant to AS/NZS 4777.1 requirements, in particular, Clause 5.3.1 (or equivalent updates), mainly:

- the inverter shall be installed in a suitable, well-ventilated place.
- installed in accordance with the IP rating and the manufacturer's specific requirements.
- arranged so as to provide accessibility for operation, testing, inspection, maintenance and repair.
- arranged to prevent ingress of vermin, insects, water and dust, so as to prevent deterioration of the operational functions of the inverter.

All cables shall be installed and sized in accordance with AS/NZS 3000, the AS/NZS 3008.1.1 series and the specific requirements of AS/NZS 4777.1.

Additionally, the following important points shall be considered:

  - Ensure the location is appropriate for the IP rating of the inverter. Where this is not possible then the inverter/s should be in an appropriate weatherproof enclosure.
  - Comply with specific environmental requirements e.g., not in direct sunlight, direct rain, etc.
  - Ensure mounting structure is able to support inverter weight.
  - Ensure mounting structure material is appropriate for the inverter.
  - Recommended clearances shall be followed.
- The inverter heat sink shall be clear of any obstacles that may interfere with cooling of the inverter.

- Cables connected to the inverter shall be mechanically secured in such a manner that they cannot be inadvertently unplugged from the inverter. This can be achieved by:
    - Having the inverter housed in an enclosure (with cables suitably supported).
    - The use of an inverter which has the cable connection area of inverter covered by a removable enclosure/cover which protects the supported cables so that there are no exposed, unsupported cable loops.
    - The use of conduit and secure wall fixings.

      NOTE: Where the inverter requires d.c. connectors to be used, a maximum allowable distance of no more than 200 mm of unprotected d.c. cable shall be permitted between connectors and conduit provided the location is not subject to mechanical damage.
    - Where the inverter is exposed to the weather there shall be no open ends of conduit. If a cable is required to exit from a conduit, an appropriate cable gland shall be installed on the end of the conduit to ensure the IP rating is maintained.
- The installer shall ensure that the grid parameters of the inverter are set to the utility's requirements.

17.1 Inverter Earth Fault Indication

According to Clause 3.5.3 of AS/NZS 5033, 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 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.

Micro inverter and a.c. module systems typically operate at a PV array maximum voltage less then 120V d.c. and therefore are not required to have an earth (ground fault) indication, although it is recommended that if the system has that capability, it should be installed.

Where the system utility uses remote monitoring to inform the customer of an earth fault, the configuration of the remote monitoring shall be provided in the customer's manual.

17.2 Additional Requirements for Module Inverters

The following is in addition to the above requirements for all inverters.

- d.c. cable length is less than 1.5m (5 feet) (including any adaptor cables)
- The method of cable support for the interconnecting a.c. cable and d.c. panel cables shall have a life as long as the system. Plastic cable ties should not be used as the primary means of wiring support.
- Cable support shall ensure that there is no stress placed on connectors.
- Plugs, sockets and connectors shall only be mated with those of the same type from the same manufacturer.
- A PV array disconnection device is not required for PV modules connected to micro inverters (or module inverters).

18 Switch Disconnectors

Switch disconnectors are load breaking devices and sometimes called isolators. Within the grid connected PV system switch disconnectors are required as follows:

- PV array d.c. switch disconnector located near inverter[2];
- a.c. switch disconnector located near inverter[3];
- a.c. main switch located within the switchboard or distribution board that is interconnected to the inverter.

For micro-inverter installations an a.c. switch-disconnector is required at the point where the inverter interconnecting cables connect to the cable that is then interconnected to the switch board or distribution board.

Note: Though the disconnection devices are switch-disconnectors the signs shall use the word isolators for simplicity.

18.1 PV Array d.c. Switch Disconnector near inverter

According to clause 4.5.3 of AS/NZS 5033, there shall be a load break disconnection device at the PCE to break the current on PV d.c. circuits. This could be achieved by one of the following:

- Either an adjacent and physically separate load break disconnection device in accordance with Clause 4.3.4.2
  Or
- 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.

Also see exceptions on the d.c switch disconnector requirements. A load breaking disconnection device is not required for a.c. module inverters and where the PV array maximum voltage is less than 120V and when the PV modules are within 1.5m of the inverter.

<u>Requirements for multiple disconnection devices</u>

- Where multiple disconnection devices are required to isolate the array(s) from the inverter(s) they shall be grouped so that they all operate simultaneously, or they shall all be grouped in a common location and have warning signs indicating the need to isolate multiple supplies to isolate the equipment.
  - Where there are multiple isolators, they shall be individually labelled e.g. “PV Array d.c. isolator inverter 1 MPPT A”
- Where strings are paralleled at the inverter, it is recommended that this occurs on the inverter side of the disconnection device or in the inverter itself.

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[2] The load breaking d.c. disconnection device near inverter could be integrated within the inverter. If the integrated disconnector complies with AS/NZS requirements, an external d.c disconnection device will not be required.

[3] An a.c switch disconnector will only be required when the distance from the switchboard is more than 3m and the inverter is not in clear line of site.

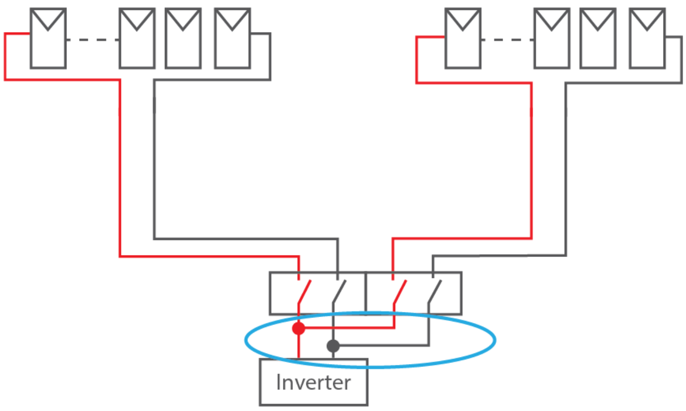


Figure 20: Connection for Parallel Switches

- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP 56.
- It is recommended that there are no top entries into the switch-disconnector and drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet all the requirements of section 19.2.

18.2 d.c Switch-Disconnector Requirements

According to Clause 4.3.4.2 .2 of AS/NZS 5033, the switch-disconnectors shall:

- be rated for d.c. use.
- Readily available
- be rated to interrupt full load and prospective fault currents.
- not be polarity sensitive.
- interrupt all live conductors simultaneously.
- be capable of being secured in the open position.
- not have exposed live parts in either the connected or disconnected state.
  conform with switch disconnector requirements of AS 60947.3 with utilization category d.c.-PV2.

Current and voltage ratings for switch disconnectors shall be in accordance with Clause 4.3.4.2.3. Also see Appendix H of AS/NZS 5033 for more information on the voltage and current ratings and examples. In accordance with AS/NZS5033 clause 4.6 when installed outside the d.c. switch disconnector shall have an IP56.

To check whether switch-disconnector is suitable for a system, perform the three steps below while referring to the isolator's datasheet. For these calculations, the maximum current is defined as 1.25 × I_{SC_ARRAY}.

Step 1: Thermal effects

The maximum current must be less than or equal to I_{the} for the installation conditions:

- Indoors at 40°C ambient for isolators installed indoors.
- Outdoors at 40°C ambient for isolators installed outdoors in a location fully shaded all day (e.g. carport, verandah).
- Outdoors at 60°C ambient with solar effects for rooftop isolators or isolators
- Installed externally where the enclosure or shroud will receive direct sunlight.

Step 2: Operational conditions

Consider the isolator configuration when the positive and negative conductors are operating in series. Looking at the first row where U_e is higher than the PV array max voltage, check that I_e is higher than the maximum current.

Step 3: Fault conditions

This step is for non-separated (transformerless) inverters only. Considering the isolator configuration when the positive and negative conductors are not working in series (e.g. due to an earth fault on one of the conductors), check that $I_{(make)}$ and $I_{c\ (break)}$ are higher than your maximum current for the maximum voltage U_e.

When in fault conditions, the isolator must be able to withstand the maximum current using half of the poles (either the negative or the positive side only). The $I_{(make)}$ and $I_{c\ (break)}$ is the current that one pole can withstand for very short periods of time. The isolator should be replaced after breaking this current.

Worked Example 8

The switch-disconnector with specifications given in figure below will be used as the rooftop PV array isolator for an array with a **transformerless** inverter. The system has a PV array maximum voltage of 540 V and an array short circuit current of 14 A. The following example checks whether the isolator selected is suitable for this purpose.

Identification			Rating Data
I_{th} rated thermal current, unenclosed, at 40°C shade ambient air temperature			32 A
I_{the} rated thermal current, indoors, at 40°C shade ambient air temperature, in a specific dedicated enclosure			32 A
I_{the} rated thermal current outdoors at 40°C shade ambient air temperature without solar effects in a specific dedicated enclosure rated IP 56NW			32 A
I_{the} *solar* current value, outdoors at 60°C shade ambient air temperature, with solar effects in a specific dedicated enclosure rated IP 56NW			28 A
	U_e rated operational voltage (V)	**I_e DC-PV2 rated operational current (A)**	**$I_{(make)}$ and $I_{c(break)}$ DC-PV2 $4 \times I_e$ (A)**
2 pole	≤500	32	128
	600	32	128
	800	27	108
	1000	13	52
4 pole	≤500	32	128
	600	32	128
	800	32	128
	1000	32	128

Step 1. $1.25 \times I_{SC\_ARRAY} = 1.25 \times 14$ A =17.5 A. This isolator will be installed outdoors in direct sunlight. I_{the} under these conditions (60°C) is 28 A according to data sheet, which is higher than 17.5 A, so the rating is acceptable.

Step 2. The isolator has four poles and there is only one string to be switched, so the positive and negative conductors will each go through 2 poles. During normal operation, these operate in series, so there are 4 poles total operating in series. Looking at the 4 pole configuration, the next highest U_e above 540 V is 600 V, and the corresponding I_e is 32 A. This is higher than 17.5 A, so the rating is acceptable.

Step 3. The positive and negative conductors each go through 2 poles. This is a transformerless inverter, so under earth fault conditions, either conductor may switch the full array current and voltage. Therefore, looking at the 2 poles in series configuration, at the 600 V row, the $I_{(make)}$ and $I_{c(break)}$ for the chosen configuration is 128 A. This is higher than 17.5 A, so is acceptable.
The d.c. isolator meets all three sizing requirements from AS/NZS 5033. Therefore, the chosen isolator and the PV array configuration are compatible.

18.3 d.c Switch Disconnector Installation Requirements

The d.c disconnection device (isolator) shall be installed in accordance with clause 4.5.4 of AS/NZS 5033.

Additionally, the following best practices shall be followed during installation:

- Strain relief provided for conductors (where conduit is not used to enter the enclosure)
- Maintaining IP56 Ratings of the d.c. isolator, only manufacturers entry points to be used.
- Cable glands, conduits and fittings shall not enter/exit the top face of the enclosure.
- Sealing or gluing of conduit glands and adapters.
- Where entry is via a cable gland, IP rated glands and multi-hole grommets to suit the number of conductors entering shall be used.
- Use of silicon to seal enclosures is not permitted, unless specified by the manufacturer.
- Only manufacturer mounting points shall be used.

- Where conduit systems have a section in an outdoor environment and terminates into an enclosure with a d.c. isolator, the conduit shall have a drain device fitted at the lowest point. (Please refer to Figures 4.10 and 4.11 of AS/NZS 5033).

Figure 21 An example of a drain tap

- Install a shroud over the d.c. isolator, of adequate size and compliant to clause 4.4.7.3, unless installed within the 30° protection of the soffit.

18.4 a.c. Switch-Disconnector near Inverter

The a.c. switch disconnector (isolator) shall be compliant to AS/NZS 4777.1 requirements, in particular, Clauses 3.4.3 and 1.3.2 (or equivalent updates). Mainly, the following shall apply.

- Where the inverter is not within 3 metres and in the line of sight of the switchboard to which it is connected, an isolator shall be provided at the inverter so that a person operating the switch has a clear view of any person working on the inverter. (Refer to figures 22, 23 and 24).

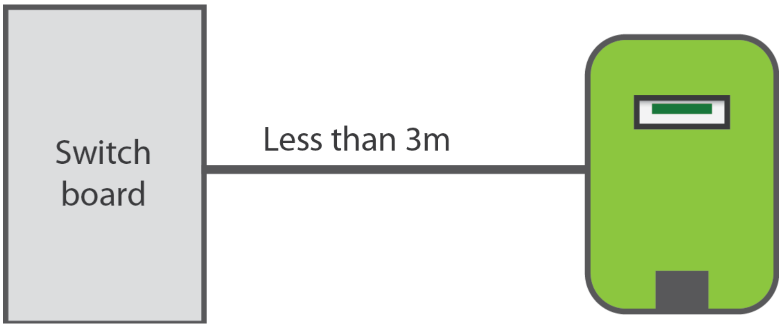


Figure 22: An a.c. switch-disconnector is not required when the distance between the switchboard and the inverter is less than 3m and the inverter is visible from the switchboard

Figure 23: a.c. switch-disconnector is required when distance is greater than 3m or the switchboard is not visible from the inverter

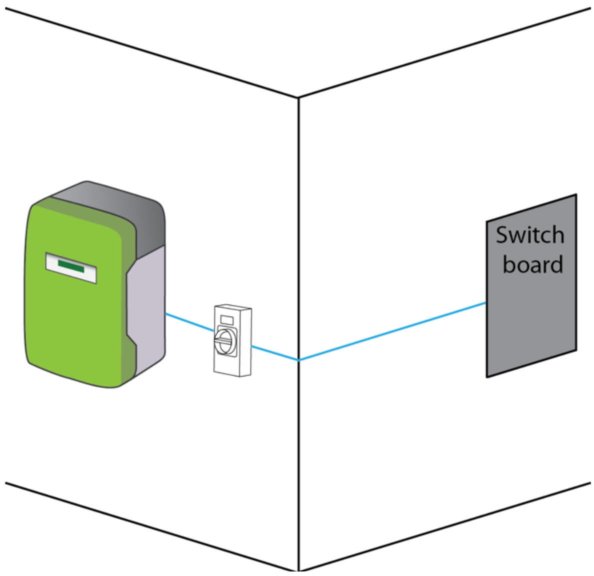


Figure 24: a.c. switch-disconnector required when the switchboard is away from the line of sight

- Where the disconnection device is exposed to the weather, it shall have an IP rating of at least IP 56.
- It is recommended that there are no top entries into the switch-disconnector and drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- The switch shall have a minimum current rating equal to the maximum a.c. rating of the inverter.

18.5 Main Switch (Inverter Supply) in Switchboard

The main switch (inverter supply) shall be compliant to AS/NZS 4777.1 requirements, in particular, Clause 3.4.1 (or equivalent updates). The following shall apply:

- The inverter should be connected directly to the main switchboard via a main switch.
- An isolation switch or circuit breaker with the characteristics in Clause 3.4.3 may be used.
- The labelling of all main switches shall be in accordance with Section 6 (AS/NZS 4777.1)
- The a.c. current rating of a grid connected solar system comprised of a single inverter shall be the rated current of the inverter.
- Where the solar system is comprised of multiple inverters, the solar system a.c current rating shall be the summation of the rated currents of all the inverters of that solar. The main switch (inverter supply) shall be sized to suit the total solar system a.c. rated current for those inverters connected to it.
- The main switch for the switchboard or the distribution board, to which the inverter is connected, shall be a lockable circuit breaker to provide protection for the cable to the inverter.

18.6 a.c. Isolator for Micro inverter Installation

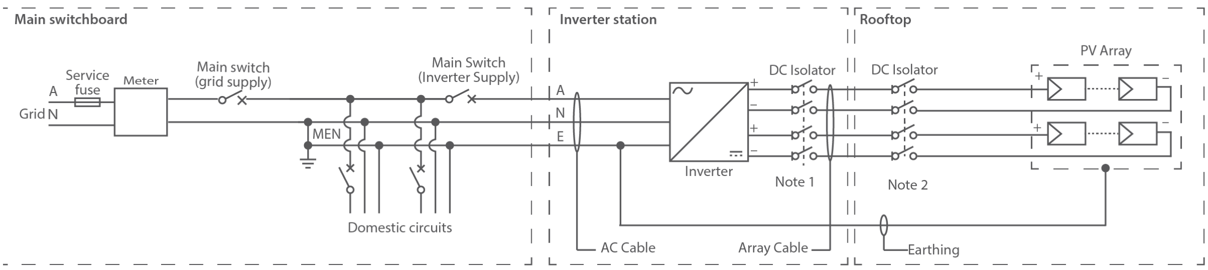
- A labelled, lockable, switch-disconnector (inverter a.c. isolator) shall be installed at the point of transition from the micro inverter interconnect cable to fixed wiring. The purpose of the a.c. isolator is to de-energise the a.c. from the micro inverter(s) for maintenance or fault rectification
- The isolator shall be installed adjacent to the inverter or inverter group. This switch-disconnector may be a single switch-disconnector and can be used to isolate multiple adjacent inverters.

- Where micro inverters are not installed adjacent to each other, additional switch-disconnectors shall be installed.
- Switch-disconnector enclosures shall be IP56 rated.
- All entry points (conduit and cable glands) to the switch-disconnector enclosure should be on the lower end of the enclosure either underneath or facing down the roof.
- If exposed to the weather a secondary shield is recommended to shelter the inverter a.c. switch-disconnector from direct exposure to rain and sun.

19 Installation of a.c. Cable between Inverter and the Grid

The a.c. cable between the inverter and the grid shall be compliant to AS/NZS 4777.1 requirements, in particular, Clauses 3.3.1, 3.3.2 and 3.3.3 (or equivalent updates). The following shall apply:

- All cables shall be installed and sized in accordance with AS/NZS 3000, the AS/NZS 3008.1.1 series and the requirements of ASNZS 4777.1.
- All a.c. cables between the inverter and any switchboard and all the cables between any distribution boards and a main switchboard which carry current from the inverter shall be rated for at least the full output current of the inverter energy system. Cables shall not lie on roofs or floors without an enclosure or conduit.
- The inverter shall be connected by fixed wiring to a dedicated circuit on a switchboard or distribution board.
- It shall be installed on the load side of the existing meter as shown in figure 24. Monitoring equipment as specified by the inverter manufacturer shall be installed to enable the inverter to operate in zero export mode.
- All existing and new cabling shall be designed and checked for the maximum voltage rise between the electricity distributor's point of supply and the inverter a.c. terminals (grid-interactive port) in accordance with the following requirements. The overall voltage rise from the point of supply to the inverter a.c. terminals (grid-interactive port) shall not exceed 2% of the nominal voltage at the point of supply.



Note 1: The load breaking d.c. disconnection device near inverter could be integrated within the inverter. If the integrated disconnector complies with AS/NZS 5033 requirements, an external d.c disconnection device will not be required. For more details, refer to AS/NZS 5033:2021 Clause 4.5.3.1.
Note 2: This could either be a ''disconnection point'' (non-load breaking) or a switch disconnector (for arrays greater than 120V). For more details, refer to AS/NZS 5033:2021 Clause 4.3.3.1

Figure 25 Example of electrical schematic of a grid connected PV system layout as per AS/NZS standards

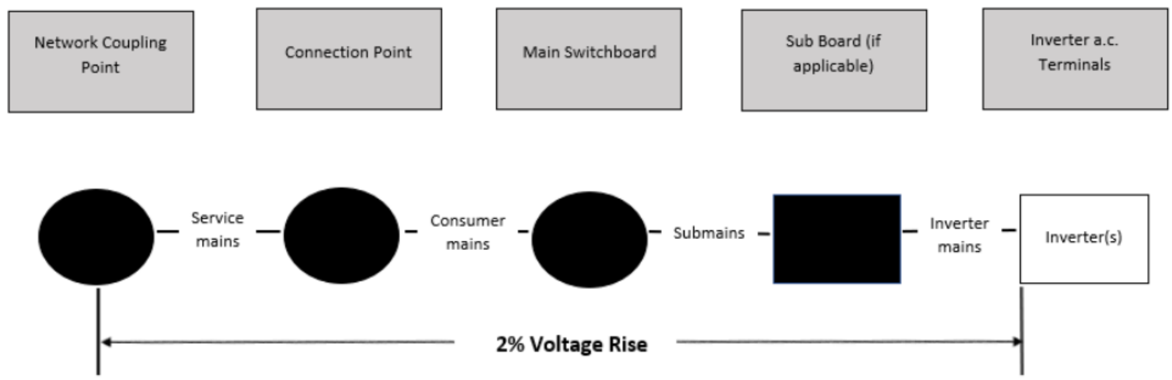


Figure 26 Depiction of the allowable 2% voltage rise

Source: Extracted from ''Standard for Small IES Connections'' by ENERGEX and Ergon Energy

19.1 Calculating Voltage Rise

Refer to Appendix C of AS/NZS 4777.1 for guidance and examples on the voltage rise calculations. The AS/NZS 3008.1 formula and method have been used:

$$V_d = \frac{(V_c \times L \times I)}{1000}$$

This method shall be used for voltage rise calculations.

or

Using formula:

$$\mathbf{V_d} = \frac{\mathbf{2 \times L_{CABLE} \times I \times} \cos \Phi \times \boldsymbol{\rho}}{\mathbf{A_{CABLE}}}$$

Where:

- L_{CABLE} = route length of cable in metres (multiplying it by two adjusts for total circuit wire length since a complete circuit requires a wire out and another wire back along the route).
- I = current in amperes.
- ρ = resistivity of the wire in Ω/m/mm^2
- A_{CABLE} = cross sectional area (CSA) of cable in mm^2.
- $\cos \Phi$ = power factor

20 Shutdown Procedure

A shutdown procedure is required to ensure safe de-energisation of the grid connected solar system. The shutdown procedure shall be compliant to AS/NZS 4777.1 requirements, in particular, Clause 6.7 (or equivalent updates).

- In addition, the shutdown procedure shall reflect the specific requirements of the individual system.
- All isolating switches (switch-disconnectors) referred to in the shutdown procedure shall correspond to individual switch-disconnector (isolator) labels (e.g "PV array d.c. isolator", "Solar Supply Main Switch").

- For central inverter systems, an engraved label showing the shutdown procedure shall be installed adjacent to the inverter. An example shutdown procedure would be:
    - Turn off the main switch solar supply at the a.c. switchboard and then the a.c. isolator at the inverter (where installed) then,
    - Turn off the PV array d.c. isolator at the inverter.

  WARNING: PV array d.c. isolators
  Do not de-energise the PV array and array cabling using the module interconnectors.
- Micro inverter systems and a.c. module system switching shall be installed at the switchboard to which the inverter is connected. An example shutdown procedure would be:
    - Turn off the main switch solar supply at the a.c. switchboard.

This will isolate the PV array.

- d.c. Conditioning Units - The shut-down procedure must reflect the specific requirements of the individual system.

21 Metering

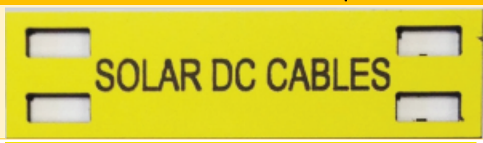
The following important considerations shall be made:

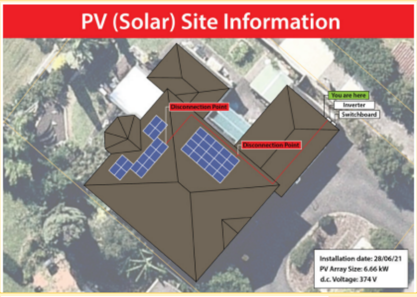
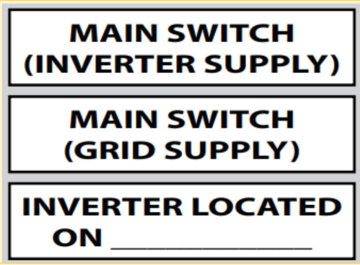
- The site shall comprise an existing meter. The PV inverter shall be connected on the load side of the existing meter as shown in Figure 25.
- Customers are advised to install another energy meter for recording output of the solar PV system.
- The installer shall notify the customer of the metering processes.

22 Signage

The signage requirements recommended in AS/NZS 5033 (Clause 5.3) and AS/NZS 4777.1 (Section 6) shall be complied with in the installation of the grid connected PV system. Essentially, the table below states the common signage required and their locations.

Table 6 Examples of signage

Signage	Example
PV d.c. cables Permanently and legibly marked with **'SOLAR'** every 2m	
When wiring system is installed in an accessible ceiling space or within an accessible floor space, a warning label shall be installed / Combiner boxes WARNING: HAZARDOUS d.c. VOLTAGE	
On or immediately adjacent to the main metering panel and main switchboard (See notations: AC, SW or DP in AS/NZS5033)	
PV array DC disconnecting devices Sign located in a prominent location on the disconnector with: "PV array D.C. isolator"	

Where there are multiple DC disconnection devices that are not ganged	
Disconnection point - A sign shall be attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point:	
Solar system layout shall be shown on a plan (map or drawing) located at the main switchboard and/or meter box	
“Multiple Supplies” – Isolate All Supplies before working on the switchboard. In a prominent position on the switchboard the inverter is connected to. Refer to Clause AS/NZS 4777.1:2016 Clause 6.2 a)	
Shutdown procedure The procedure shall be placed adjacent to and visible from the equipment to be operated in the event of a shutdown.	Refer to example in AS/NZS5033 
Inside Main Switchboard: A sign adjacent to inverter main switch with: ‘Main Switch (Inverter Supply)’ ‘Main Switch (Grid Supply)’ ‘Inverter Located at’ Refer to AS/NZS 4777.1 for more details.	
On the inverter-adjacent AC isolator (if present). Refer to AS/NZS 4777.1:2016 Clause 6.8	

Generally, the following mandatory signage shall be applied:

- A sign should be included in the switchboard stating:
    - ‘WARNING’, ‘MULTIPLE SUPPLIES’ and ‘ISOLATE ALL SUPPLIES BEFORE WORKING ON THIS SWITCHBOARD’.
- A sign with text ‘MAIN SWITCH (Inverter SUPPLY)’ shall be permanently fixed adjacent to the main switch for the inverter.

- Where the inverter is connected to the main switchboard, a sign with text 'MAIN SWITCH (GRID SUPPLY)' shall be permanently fixed adjacent to the main switch for the grid supply.
- Where the inverter is connected to the distribution switchboard, a sign with text 'MAIN ISOLATOR (NORMAL SUPPLY)' shall be permanently fixed adjacent to the isolator for the normal supply to the distribution switchboard.

NOTE: The terms 'grid supply', 'normal supply' and 'mains supply' can be used alternatively

- If the inverter is not mounted near the switchboard, then there should be a sign in the switchboard stating where the inverter is located.
- There should be a sign on the switchboard stating the location of the PV array, the maximum d.c. array short circuit current and array open circuit voltage from the system.
- PV d.c cables shall be permanently and legibly marked with 'SOLAR' every 2m.
- Any junction boxes used between the array and the inverter should have a sign 'WARNING: HAZARDOUS d.c. VOLTAGE' on the cover.
- A sign with text 'PV ARRAY d.c. ISOLATOR' shall be fixed permanently adjacent to the PV array d.c. switch disconnector.
- Where there are multiple disconnection devices, a sign with texts 'WARNING: MULTIPLE d.c. SOURCES' and 'TURN OFF ALL d.c. ISOLATORS TO ISOLATE EQUIPMENT' shall be fixed near the inverter.
- A green PV label indicating that there is a PV system at the site using the notations – (See notations: AC, SW or DP in AS/NZS 5033).
- Solar system layout shall be shown on a plan (map or drawing) located at the main switchboard and/or meter box.
- Where a disconnection point is used, an appropriate sign shall be attached to the PV module or structure within 300 mm of the disconnection point to identify the location of the disconnection point: "PV String Disconnection Point''.
- A sign with steps to safely shut down the system shall be fixed adjacent to and visible from the equipment to be operated in the event of shutdown. This sign may also include detailed steps of the start-up procedure.

23 Testing and Commissioning

The verification and testing of the system shall be compliant to AS/NZS 5033, in particular clauses 4.7.2 and 4.7.3. The following mandatory tests shall be applied in addition to the recommendations specified in AS/NZS 3000:

- Continuity of the earthing system
- Insulation Resistance test
- Polarity test
- Open circuit voltage (V_{0c})

After visual inspection and testing are completed, the system shall be commissioned, in the appropriate sequence according to the shutdown and reconnection instructions. The commissioning requirements listed in Clause 6.3 of AS/NZS5033 shall be followed. Refer to *'**Appendix 2** Installation and commissioning checklist sample'*. It is highly recommended that installers use this installation and commissioning checklist. A completed copy shall be provided to the customer as part of the system documentation and a copy retained by the installer.

In some systems (e.g. utility scale, large commercial systems) testing and commissioning shall be in accordance with IEC62446: Grid connected photovoltaic systems – Minimum requirements for system documentation, commissioning tests and inspection.

23.1 Short Circuit Current measurement

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.
Where short circuit currents are required, undertake the following steps to measure the short circuit current safely as shown in Figure 27.

- Ensure each string fuse (where required) is not connected or that LV array is disconnected somewhere in each string as shown in Figure 18 of these guidelines.
- Leave solar array cable connected to the PV array switch disconnector.
- Remove the cable from the PV array switch disconnector to the inverter.
- With the PV array switch disconnector off - put a link or small cable between the positive and negative outputs of the PV array switch disconnector.
- Install the string fuse for string 1 or connect the string disconnect (figure 18) to complete the wiring of the string. Turn on PV array switch disconnector - using a d.c. clamp meter, measure the d.c. short circuit current for String 1. Turn off the PV array switch disconnector. Disconnect string fuse for string 1 or remove the disconnector to break the string circuit.
- Repeat for each string

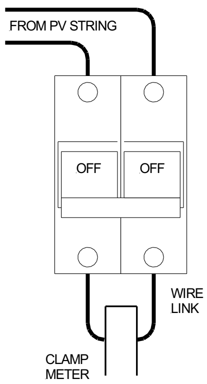


Figure 27: Measuring Short Circuit Current

23.2 Insulation Resistance Measurement

Warning: PV array d.c. circuits are always live during daylight and unlike conventional a.c. circuits cannot be isolated before performing this test.

The insulation resistance test should be undertaken when all the system wiring has been completed.

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. Table 7 shows the minimum values that should be achieved for different system voltages.

Table 7: Minimum Insulation Resistance

PV d.c circuit maximum voltage	TEST VOLTAGE	MINIMUM INSULATION RESISTANCE, MΩ
< 120	250	0.5
120 – 500	500	1
> 500	1000	1

24 Maintenance of Systems

A maintenance procedure and timetable shall be provided to the customer. AS/NZS 5033 Appendix D provides a list of the recommended maintenance for the PV array and includes suggested frequency.

In summary the maintenance includes

- module cleaning and removal of debris.
- system inspection and testing.
- electrical checks to ensure all components are operating as intended.
- reviewing the inverter display panel for recorded faults.
- checking that access to the isolator switches has not been impeded.
- making sure the emergency procedures for shutdown and isolation are clearly displayed.

25 Documentation

The documentation shall be compliant to AS/NZS 5033 requirements, in particular, Clause 6.2 (or equivalent updates). The designer and/or installer shall provide a system manual to the customer including the following:

- Basic system information including system rating and component ratings, and commissioning date.
- A list of electrical equipment supplied, with model description and serial numbers.
- A list of actions to be taken in the event of an earth fault alarm.
- Shutdown and isolation procedure for emergency and maintenance that shall ensure safe de-energization of the system.
- As built (installed) system wiring diagram that includes the electrical ratings of the PV array, and the ratings of all overcurrent devices and switches as installed.
- Disconnection device location and cable routing.
- System performance estimate.
- Maintenance procedure and timetable
- Installation and commissioning checklist (Appendix 2).
- Warranty information.
- Equipment manufacturer's documentation and handbooks for all equipment supplied.

26 Appendix 1 Sample Risk Assessment Matrix and Template

	Likelihood			
Consequence	Rare	Low	Occasional	Likely
Catastrophic (kill or permanently maim)	MEDIUM	HIGH	EXTREME	EXTREME
Major (long term injury or illness)	MEDIUM	MEDIUM	HIGH	EXTREME
Moderate (medical attention with several days off work)	LOW	MEDIUM	MEDIUM	HIGH
Minor (first aid needed)	LOW	LOW	MEDIUM	MEDIUM

Activities to be performed: Site assessment, installation of microinverter system, installation of string inverter system, commissioning of systems, fault finding exercises

Hazard	Consequence of Hazard	Likelihood of Hazard	Hazard Rating	Control	New Consequence of Hazard	New Likelihood of Hazard	New Hazard Rating After Control

27 Appendix 2: Installation and Commissioning Sample

<table>
<tr><td colspan="2">Installer name:</td></tr>
<tr><td colspan="2">Installer signature:</td></tr>
<tr><td colspan="2">Commissioning date:</td></tr>
<tr><td colspan="2">Installation address:
Customer name:
Customer contact details:</td></tr>
<tr><td>PV module manufacturer:</td><td>PV module model number:</td></tr>
<tr><td>Inverter No 1 Manufacturer</td><td>Inverter No 1 Model Number</td></tr>
<tr><td>Inverter No 2 Manufacturer</td><td>Inverter No 2 Model Number</td></tr>
<tr><td>Inverter No 3 Manufacturer</td><td>Inverter No 3 Model Number</td></tr>
<tr><td colspan="2">All PV modules connected to the same MPPT are of the same make and model or have similar rated electrical characteristics:
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">All PV modules connected to the same string have the same angle of tilt and azimuth:
YES ☐ NO ☐</td></tr>
<tr><td>Number of modules in series:
String 1:
String 2:
String 3:
String n: (add more as required)</td><td>Number of strings in parallel:
Sub-array 1:
Sub-array 2:
Sub-array 3:
Sub-array n: (add more as required)</td></tr>
<tr><td colspan="2">Array mounting system manufacturer:</td></tr>
<tr><td colspan="2">Array mounting system model:</td></tr>
<tr><td colspan="2">Array mounting system certified for installation site parameters with respect to wind speeds.
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">Array mounting system does not use or contact any galvanically dissimilar metals:
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">All penetrations and fixings are suitably sealed and weatherproofed:
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">PV array voltage complies with site regulations:
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">PV system wiring is suitably protected from mechanical action:
YES ☐ NO ☐</td></tr>
<tr><td colspan="2">PV array uses single-core double-insulated cabling compliant to relevant standards:
YES ☐ NO ☐</td></tr>
</table>

Overcurrent protection is provided where required: YES ☐ NO ☐ NOT REQUIRED ☐
All dc components (switch disconnectors, cables, fuses etc) and cables are rated correctly for dc usage and have voltage ratings greater than or equal to the PV array maximum voltage: YES ☐ NO ☐ All ac components are rated correctly for AC usage. YES ☐ NO ☐
All components are suitable for their environment and have the appropriate IP and UV ratings: YES ☐ NO ☐
Disconnection devices (or disconnection points) and protection devices (where installed) are readily accessible in the case of maintenance or emergency: YES ☐ NO ☐
Disconnecting devices comply with frequency-of-use requirements and are rated for the temperature-adjusted operational circuit current: YES ☐ NO ☐
PV Array switch-disconnectors are rated to switch full-load currents and are not polarity–sensitive: YES ☐ NO ☐
PV array switch-disconnectors interrupt all live conductors: YES ☐ NO ☐
PV conductor current-carrying capacity is equal to or greater than the potential system fault current or the overcurrent protection (where installed): YES ☐ NO ☐
PV cabling, where exposed to the elements, is UV-resistant or installed in UV-resistant enclosures: YES ☐ NO ☐
A method of securing cabling has been used that will last the lifetime of the system: YES ☐ NO ☐
DC cabling within buildings is enclosed in heavy-duty-rated protection: YES ☐ NO ☐ NOT REQUIRED ☐
Combiner boxes are installed according to manufacturer recommendations: YES ☐ NO ☐
Combiner boxes are suitably protected from the environment using appropriate bottom-entry cable glands: YES ☐ NO ☐
Double insulation between all conductors is maintained throughout the system: YES ☐ NO ☐
PV plugs, sockets and connectors comply with relevant standards, are rated for the installation environment and connected only with the same make and model: YES ☐ NO ☐
Blocking and bypass diodes, where installed external to the PV module are suitably protected and graded according to relevant standards and system

parameters: YES ☐ NO ☐
Overcurrent protection (where required) is installed at the end of the conductor that is most electrically remote from the PV modules: YES ☐ NO ☐ NOT REQUIRED ☐
A dc switch-disconnector is located adjacent to the inverter if the array is not in the line of sight with the inverter or integrated into PCE: YES ☐ NO ☐
Where multiple dc disconnection devices are installed, they are ganged together or grouped and labelled such that it is clear that all must be operated to isolate the system: YES ☐ NO ☐ NOT REQUIRED ☐
All exposed metal module frames and mounting equipment are earthed and equipotentially bonded in accordance with the relevant standards: YES ☐ NO ☐
Equipment used for PV module and mounting frame earth connections is fit for that purpose: YES ☐ NO ☐
Earthing has been arranged so that the removal of a single module earth connection will not disrupt the continuity of the bonding connections for the rest of the array: YES ☐ NO ☐
Earthing conductor type and size comply with the relevant standards: YES ☐ NO ☐
PV array functional earthing is done close to or within the inverter and is done according to the relevant standards: YES ☐ NO ☐ NOT REQUIRED ☐
The inverter complies with the relevant country standards: YES ☐ NO ☐
The inverter installation complies with the manufacturer's instructions, the distribution network service provider's rules and regulations and relevant legislation: YES ☐ NO ☐
Inverters connected to LV PV arrays have an internal or external earth fault alarm system: YES ☐ NO ☐
Signage and labelling conforms to the relevant standards and guidelines: YES ☐ NO ☐

Example test records

The following pages contain example test records that may be used as part of the system commissioning.

PV Array dc

Note

+ve = positive

–ve = negative

If array is LV (120–1,500 V), there is no voltage on input side of array (or string) combiner box (if one is installed)	☐

There is no voltage on output side of array combiner box (if one is installed)	☐
Continuity between strings and array combiner box:	
String 1 +ve	☐
String 1 –ve	☐
String 2 +ve	☐
String 2 –ve	☐
String 3 +ve	☐
String 3 –ve	☐
String 4 +ve	☐
String 4 –ve	☐
Correct polarity between strings and array combiner box:	
String 1	☐
String 2	☐
String 3	☐
String 4	☐
Open circuit voltages:	
String 1	V
String 2	V
String 3	V
String 4	V
Continuity between array combiner box and PV array DC switch-disconnector:	
Sub-array +ve	☐
Sub-array –ve	☐
Correct polarity between array junction box and PV array DC switch-disconnector	☐
Sub-array V_{OC}	V
Short circuit currents:	
String 1	....A
String 2	....A
String 3	....A
String 4	....A
Short circuit current array	....A
Reconnect the strings one at a time by reconnecting the string overcurrent protection (fuses) or reconnecting any module connectors.	
Open circuit voltage at input side of PV array dc switch-disconnector	V
Continuity between PV array dc switch-disconnector and inverter:	
Array +ve	☐
Array –ve	☐
Correct polarity between PV array dc switch-disconnector and inverter	☐

Inverter ac

Note: Following has been written for single phase based on 230V in south pacific.

Continuity between inverter and kWh meter:	
Active (Line)	☐
Neutral	☐
Continuity between kWh meter and PV inverter AC disconnector:	
Active (Line)	☐
Neutral	☐
Correct polarity between kWh meter and PV inverter AC disconnector	☐
Correct polarity at output of PV inverter AC switch-disconnector from grid	☐
Voltage at output of PV inverter AC switch-disconnector from grid	V
Initial reading of kWh meter	....

Insulation Resistance

Insulation Resistance	
Array Positive to Earth	MΩ
Array negative to Earth	MΩ

Start-up of system

Refer to system manual for the inverter and follow start-up procedure. This generally involves turning on the PV array dc switch-disconnector followed by the inverter ac switch-disconnector, but the procedures as recommended by the inverter manufacturer must be followed.	
System connects to grid	☐
When inverter ac switch-disconnector and PV array ac switch-disconnector are turned on and inverter start-up procedure followed:	
Voltage at dc input of inverter	V
Voltage within operating limits of inverter	☐
Voltage at ac output of inverter	V
Current at ac output to inverter	....A
@ Irradiance value of	....W/m^2
Input power of the inverter (if available)	....W
Output power of the inverter (if available)	....W
Output power is as expected	☐
System disconnects from grid when inverter ac switch-disconnector is turned off	☐