

OFF GRID PV POWER SYSTEMS SYSTEM INSTALLATION GUIDELINES

Includes Solar only PV Systems and Hybrid Systems
Comprising PV and Engine Driven Generator Sets.



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These guidelines have been developed for the Pacific off-grid power sector
These guidelines represent latest industry BEST PRACTICE for the installation of Off grid PV Power Systems.
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While all care has been taken to ensure this guideline is free from omission and error, no responsibility can be taken for the use of this information in the installation of any Off-grid PV Power System.

These guidelines are to be read in conjunction with:

- AS/NZS 5033 Installation and Safety Requirements of PV Arrays
- AS/NZS 5139 Electrical Installations - Safety of battery systems for use with power conversion equipment

The installation of the off- grid PV power systems shall be in accordance with all the requirements of these two standards and other standards listed in this guideline.

Cover Photos: Vision Energy

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List of Abbreviations

AC	Alternating Current
Ah	Amp hour
AS	Australian Standards
CCC	Current carrying capacity
CSA	Cross section area
DC	Direct Current
DVC	Decisive Voltage Classification
ELV	Extra low voltage
GFPD	Ground fault protective device
IEC	International Electrotechnical Commission
LV	Low voltage
MPPT	Maximum Power Point Tracker
NZS	New Zealand Standards
PCE	Power conversion equipment
PSH	Peak Sun Hours
PV	Photovoltaic
PWM	Pulse with Modulation
STC	Standard Test Conditions
VA	Voltage amperes
W_p	Watts Peak (also known as Peak-Watt)
Wh	Watt-hour

1 Introduction

This guideline provides a minimum set of installation requirements for electricians/technicians who are installing off-grid solar PV power systems in the Pacific region). Engineers and electricians/technicians designing the off-grid systems shall also follow the relevant technical requirements in this guideline within their designs.

The array requirements are generally based on the requirements of: AS/NZS 5033: Installation and Safety Requirements of PV Arrays. The battery system installation requirements are based on: AS/NZS 5139: Electrical installations - Safety of battery systems for use with power conversion equipment. The general principles from AS/NZS 4509 Stand-alone power systems and AS/NZS 3000 Wiring Rules for the relevant electrical installation work have been applied. Other international and regional best practices have been applied to provide clarity on installation practices. (Note: AS/NZS 4509 is currently undertaking a major review and should be released in early 2026. This guideline will be updated when that standard is released.)

Figure 1 shows the configuration of a system that provides dc power only. These systems typically range from 100W_p to 1 kW_p of solar modules but may be smaller or larger. For all sizes, the principles of design are the same. Many solar installations installed on rural residences use this basic design.

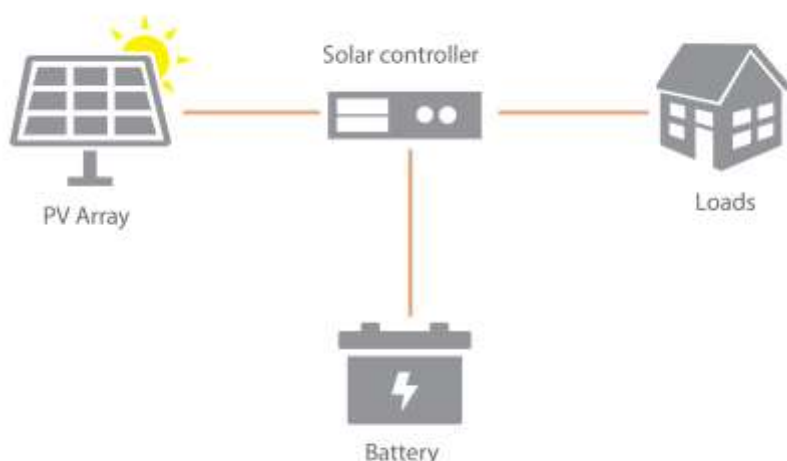


Figure 1: System Providing dc loads only (also known as a simple dc coupled system)

Note: Solar controller could be a switching type non-MPPT controller or a maximum Power Point Tracking (MPPT) Controller

Systems that include an inverter providing ac power to end-user can be provided as either:

- dc coupled systems (refer to Figure 2); or
- ac coupled systems (refer to Figure 3).

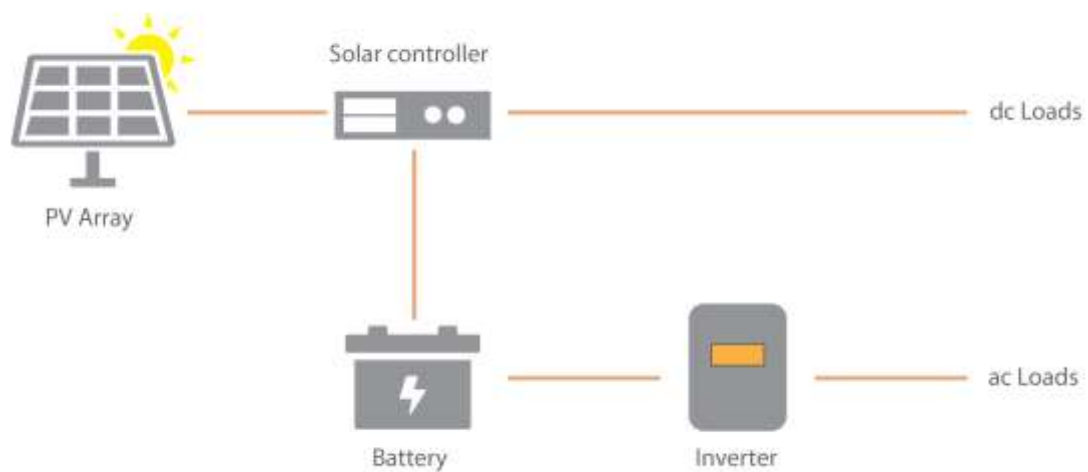


Figure 2: dc coupled system

Note: Solar controller could be a non-MPPT controller or a maximum Power Point Tracking (MPPT) Controller

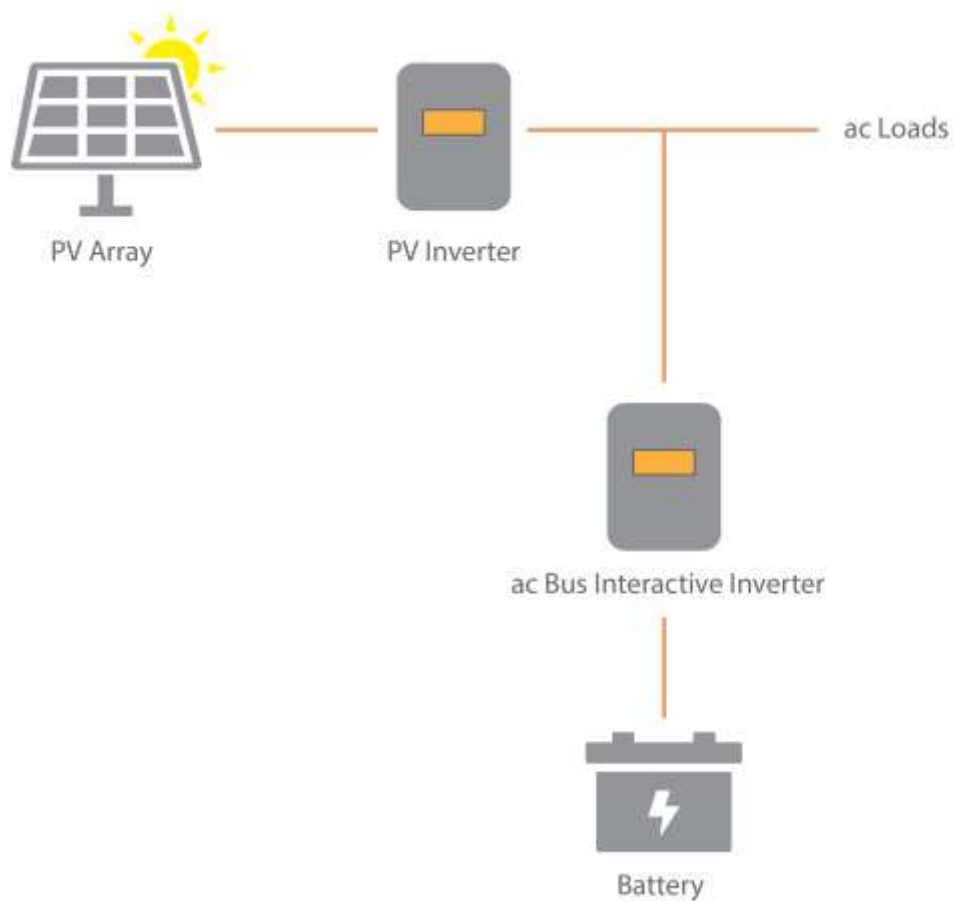


Figure 3: ac coupled system

Some systems can be a combination of ac coupled and dc coupled systems where part of the array is connected by dc through a solar controller to the battery and part of the array is connected directly to the ac load side via a PV inverter.

PART 1-PV ONLY SYSTEMS

2 Standards for Installation

System installation should comply with Australian/New Zealand Standards (AS/NZS) and International Electrotechnical Commission (IEC) standards. In addition, Lithium Ion based pre-assembled lithium-ion battery systems (if used) should comply with the Australian Best practice guideline listed below. These standards and guidelines are often updated and amended so the latest version should always be applied.

The relevant standards are listed in Table 1.

Table 1: Relevant Standards

Equipment Standards			
Modules			
IEC 61215	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.	
Recommended additional standards for Solar Modules installed in PNG			
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		
Inverters			
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.	
PV Inverters			
Note: PV inverters must comply with the inverter standards as listed above- However AS/NZS4777.2 ; Inverter Requirements is referenced in this guideline. In PV inverter the DC switch connector can be incorporated into the inverter if the isolator is in accordance with the requirements of AS/NZS4777.2			
Solar Controllers			
IEC 62109	Safety of power converter for use in photovoltaic power systems.		
	IEC 62109-1	Part 1: General requirements	
IEC 62509	Battery charge controllers for photovoltaic systems - Performance and functioning		
Battery Systems			
AS 60896.11	Stationary lead-acid batteries, Part 11: Vented types - General requirements and methods of tests		
AS 60896.21	Stationary lead-acid batteries, Part 21: Valve regulated types - Methods of test		
AS 60896.22	Stationary lead-acid batteries, Part 22: Valve regulated types - Requirements		
Note: the above 3 are direct adoptions from the IEC 60896 Stationary lead-acid batteries (series)			

AS/NZS IEC 60622	Secondary cells and batteries containing alkaline and other non-acid electrolytes - Sealed nickel-cadmium prismatic rechargeable single cells	
IEC 62619	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications.	
IEC 62932	Flow battery energy storage systems for stationary applications	
	IEC 62932-1	Part 1 Terminology and general aspects.
	IEC 62932-2	Part 2 Performance general requirements and test methods
	IEC 62932-3	Part 3 Safety requirements
PV Cables		
IEC 62930	Electric cables for photovoltaic systems with a voltage rating of 1.5 kV dc.	
Switch disconnectors		
AS 60947.3	Low-voltage switchgear and controlgear Switches, disconnectors, switch disconnectors and fuse combination units	
Plugs and Sockets		
AS/NZS 62852	Connectors for d.c. application in photovoltaic systems - Safety requirements and tests.	
Plug and play solar home systems		
IEC TS 62257-9	Recommendations for renewable energy and hybrid systems for rural electrification -	
	IEC TS 62257-9-5	Part 9-5: Integrated systems - Laboratory evaluation of stand-alone renewable energy products for rural electrification
	IEC TS 62257-9-8	Part 9-8: Integrated systems - Requirements for stand-alone renewable energy products with power ratings less than or equal to 350 W
Installation Standards		
AS/NZS 3000	Wiring Rules.	
AS/NZS 3008	Electrical Installations - Selection of Cables.	
AS/NZS 5033	Installation and safety requirements for PV Arrays.	
AS/NZS 4509	Stand-alone power systems	
AS/NZS 5139	Electrical installations - Safety of battery systems for use with power conversion equipment.	
AS 1768	Lightning Protection.	
AS/NZS 1170	Structural Design Actions	
	AS/NZS 1170.0	Structural design actions; Part 0: General principles
	AS/NZS 1170 .1	Structural design actions; Part 1: Permanent, imposed and other
	AS/NZS 1170 .2	Structural design actions; Part 2: Wind actions
	AS/NZS 1170 .4	Structural design actions; Part 4: Earthquake actions in Australia

Note: For the plug & play solar home systems, products that meet this standard are tested and approved by Verasol (<https://verasol.org>) (formerly known as Lighting Global Quality Standards. They shall have a Verasol Standardized Specifications Sheet and Verification letter.

Relevant Australian Guideline:

- Best Practice Guideline: Battery Storage equipment - Electrical safety requirements

3 Voltage Limits and Work Restrictions

System voltage classification in this guideline follows the Decisive Voltage Classification (DVC) as defined in IEC 62109 Safety of power converter for use in photovoltaic power systems and as shown in Table 2.

Table 2: Decisive Voltage Classification (DVC)

Decisive voltage classification (DVC)	Limits of working voltage (V)		
	ac voltage (rms)	ac voltage (peak)	dc voltage (mean)
DVC-A	$V \leq 25$	$V \leq 35.4$	$V \leq 60$
DVC-B	$25 < V \leq 50$	$35.4 < V \leq 71$	$60 < V \leq 120$
DVC-C	$V > 50$	$V > 71$	$V > 120$

AS/NZS 3000 defines the following:

- Extra Low Voltage (ELV) is $<120\text{V dc}$ or $<50\text{V ac}$
- Low Voltage (LV) is $>120\text{V dc}$ and $<1500\text{V dc}$ or $>50\text{V ac}$ and $<1000\text{ ac}$

In following this, some countries impose the following requirements on licensed or registered electricians:

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: $>120\text{V DC}$ or $>50\text{V AC}$ should be performed by a trained electrician.
- If the system contains ELV wiring installed by a person not by a trained electrician, then a minimum level of inspection by the electrician prior to closing the isolators between the battery system and battery inverter would include:
 - Testing the voltage and polarity of the battery system.
 - A visual inspection of the battery system wiring.

DVC is also used to classify ports on power conditioning equipment (PCE) such as inverters and solar controllers. If multiple pieces of equipment are connected directly to a circuit, the port with the highest DVC determines the DVC of the entire circuit. e.g., a battery system may be within DVC-A voltage range, but if it is connected to a DVC-C port, then that entire circuit is considered DVC-C.

Note: Prior to any installation work, a thorough risk assessment needs to be undertaken based on the relevant hazards present and battery technology used. Appropriate control measures need to be in place prior to any commencement of work. A sample risk assessment is shown in Appendix 3 that could be typically used as a guide for off grid PV system installations. Depending upon the arc flash energy rating present for the battery system, appropriate PPEs need to be worn while working on battery systems as specified in Table 3.3 of AS/NZS 5139. Table 3.3 has been reproduced in Appendix 3.

4 PV Array Installation

4.1 General

The PV array installation shall be compliant to AS/NZS 5033 requirements, in particular, Clauses 4.1 and 4.2 (2021 edition or equivalent updates). Additionally, the following important consideration should be made for the installation of PV array for off grid 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.

4.2 Selecting PV Modules

Solar modules shall comply with 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

The modules 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>

Appendix 2 has further information regarding the CEC approved products list and how to check that the products are listed.

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

4.3 Maximum PV Array Voltage (or PV dc circuit maximum voltage)

The switch disconnectors (isolators), MPPT solar controller inputs, non-MPPT solar controller inputs, PV inverter dc inputs (used in AC coupled systems) and associated wiring (cables) used in the PV array installation shall have minimum voltage rating as the PV dc 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 voltage/temperature coefficient of the modules installed.

The maximum V_{oc} of a module is determined by calculating the increase in V_{oc} due to the effective cell temperature being less than 25°C (77°C).

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°C).

If 15°C (59°C) is used as an example, then the increase in V_{mp} is $(15^{\circ}\text{C} - 25^{\circ}\text{C}) = -10$ times the voltage temperature coefficient ($\text{V}/^{\circ}\text{C}$). (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 together 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 Off Grid PV Power Systems – Design Guideline)

Assume the minimum effective cell temperature is 15°C (59°C), and that the array is for an ac coupled system or for a dc coupled system with a MPPT controller.

The module data sheet provides the following information:

- $V_{oc} = 41.02$
- V_{oc} temperature coefficient = $-0.28\%/^{\circ}\text{C}$

Therefore, in $\text{V}/^{\circ}\text{C}$ the V_{oc} temperature coefficient = $-0.28/100$ per degree C $\times 41.02\text{V} = -0.115\text{V}/^{\circ}\text{C}$

Based on the minimum temperature of 15°C (59°C) then the:

Increase in V_{oc} due to temperature $(15 - 25^{\circ}\text{C}) = -10^{\circ}\text{C}$ times the voltage temperature coefficient ($\text{V}/^{\circ}\text{C}$).

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

$$= 1.15\text{V}$$

So, the effective maximum V_{oc} of the module due to temperature = $41.02\text{V} + 1.15 = 42.17\text{V}$ dc 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 10 modules in a string, the maximum V_{oc} of the string will be $10 \times 42.17\text{V} = 421.7\text{V}$ dc

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 Table 3 that contains the temperature ranges and multiplication factors to correct the voltage (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 3: 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

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.

As an example, the year-round minimum temperature for a country is around 23 °C (73.4 °F). 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.

For example, a string of 10 modules ($V_{oc} = 41.02V$), will have PV dc maximum voltage of 418.4V (i.e. $1.02 \times 10 \times 41.02V$). However, sites in the highlands would experience a lower minimum day-time. If the minimum day time temperature was between 15 to 19 °C could use correction factors of 1.04 to be conservative (i.e. $1.04 \times 10 \times 41.02V = 426.6V$).

4.4 Orientation and Tilt

In off-grid PV systems the solar array is generally mounted:

- on an array frame that is tilted to fix the array at a preferred angle (usually used for flat roofs or for ground mounting) or
- “flat” on the roof so it is parallel to the slope of the roof but raised off the roof, or
- on a pole mounted system separate from the house, or
- ground mounted.

Although the maximum output would be obtained using an array frame that is tilted to fix the array at the optimum angle, because of concerns about wind loadings due to cyclones, the arrays can be mounted parallel to the roof.

In the design guideline, a design month was selected based on the relationship between the energy usage and the available solar irradiation. Ideally the array should be tilted at an angle that is best for this design month, but this might not always be possible.

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 other environmental factors. In the tropics this may vary due to the sun being in the north half of the sky part of the year and in the south half part 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.

In the design guideline, a design month was selected based on the relationship between the energy usage and the available solar irradiation. Ideally the array should be tilted at an angle that is best for this design month but this might not always be possible.

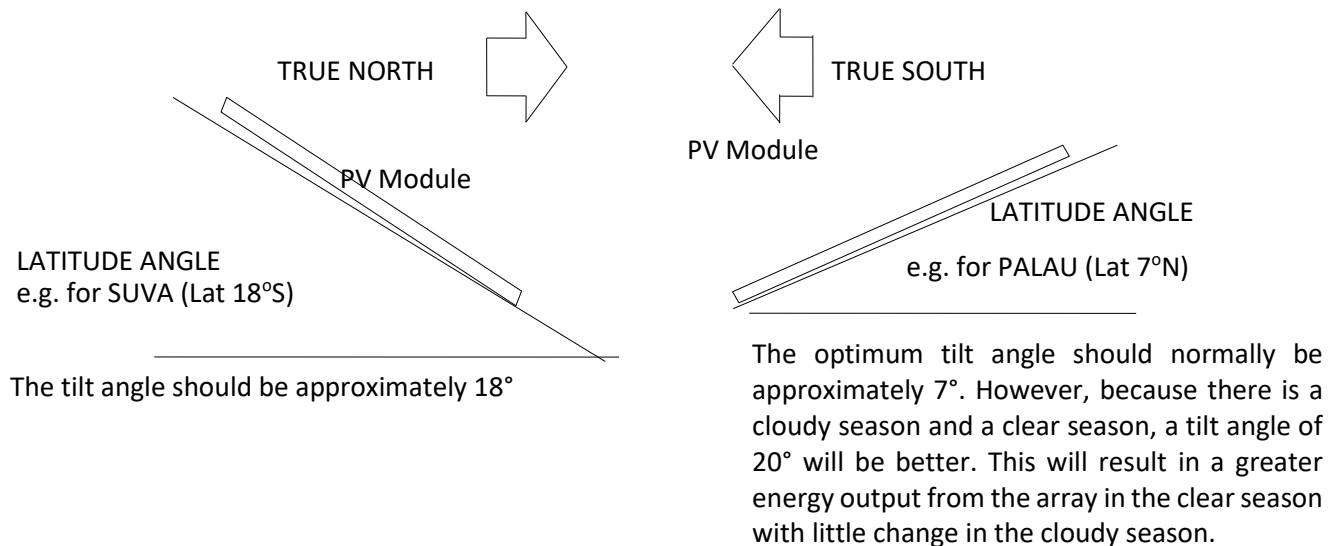


Figure 4 Examples of Tilt Angles

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 measured by satellite for each month of the year for: a horizontal surface, a surface tilted at the latitude angle and facing the equator and 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 be less than the maximum possible though local conditions may cause some variations in that rule.

Off-grid PV System Design Guideline Appendix 3 provides tables that show 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. 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 in the northern hemisphere) or at an inclination not equal to the latitude angle. The designer can then use the 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 the kWh from each individual roof can be added together to get the total from all the modules in the installation.

4.5 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.

4.6 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:

- Modules attached to enclosed buildings with aspect ratios $h/b \leq 0.5$ and $h/d \leq 0.5$.
- Modules be attached parallel to the roof plane.
- Modules with a gap of between 50 mm and 300 mm between the underside of the panel, and
- 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 8.9 (in AS 1170.2) (roof edge includes ridges with pitch $\geq 10^\circ$).

Figure 5 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.

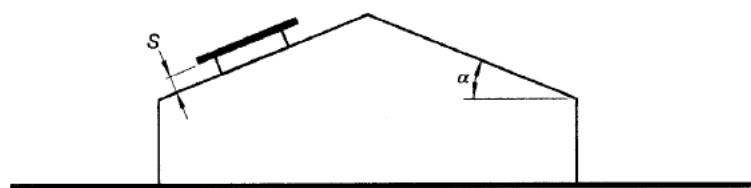


Figure B.9 — Panel mounted parallel to roof plane

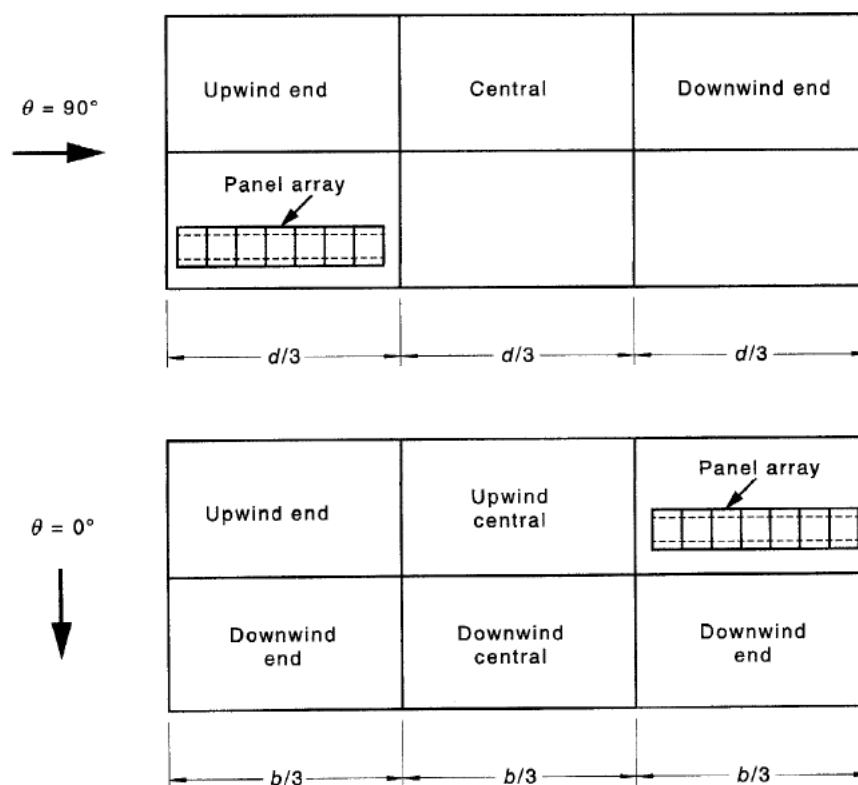


Figure 5: Roof Zones for Panel Array

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:

- a) 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.
- b) It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris.
- c) If fauna (e.g. rats) is 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).
- d) The array structures shall be designed to withstand the aggressively salty atmosphere.
- e) 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.
- f) 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.
- g) 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.
- h) 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.
- i) 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.
- j) 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.
- k) The installer must follow the array frame supplier's/manufacture'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:
 - i) Area of roof applicable for modules to be installed.
 - ii) Type, length and diameter/gauge of screws to be used.
 - iii) Number of screws required per attachment.
 - iv) Size of batten/purlin required for attachment.
- l) 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.

4.7 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 $2 \leq d/h \leq 5$ and $b/d \geq 2$.
- b) Modules attached to the frame at an inclination to ground, $\alpha \leq 30^\circ$.
- c) Panel arrays with a spacing of $3.5 \leq s/h \leq 10$.
- d) Modules with a minimum gap between the underside of the panel and the ground surface $c/h \geq 0.2$.

Figure 6 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.

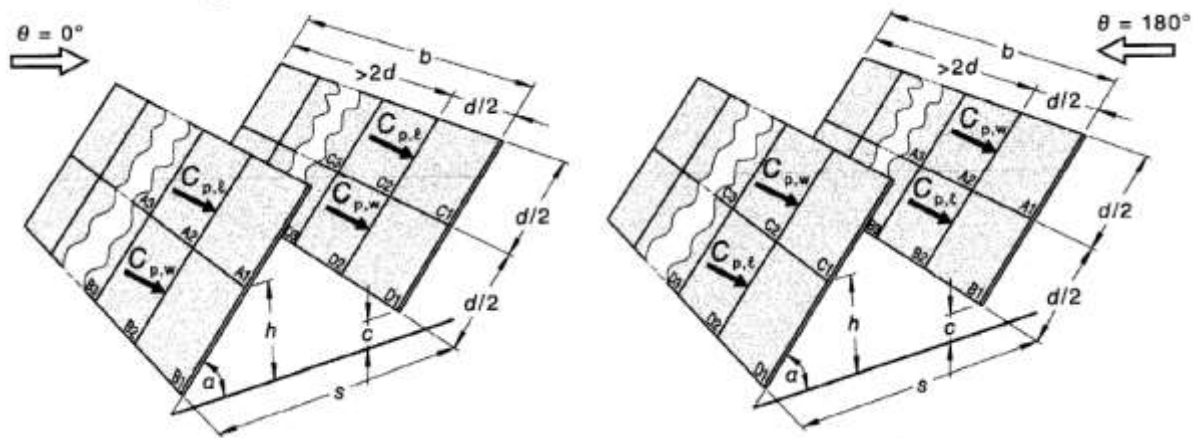


Figure 6: Wind Pressures on Ground Mounted Solar Panel Arrays as Shown in AS1170.2

- 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. If using posts or screws then a geotechnical study shall be undertaken to determine the suitability of the ground.

4.8 Attaching Modules to Array Frames

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.

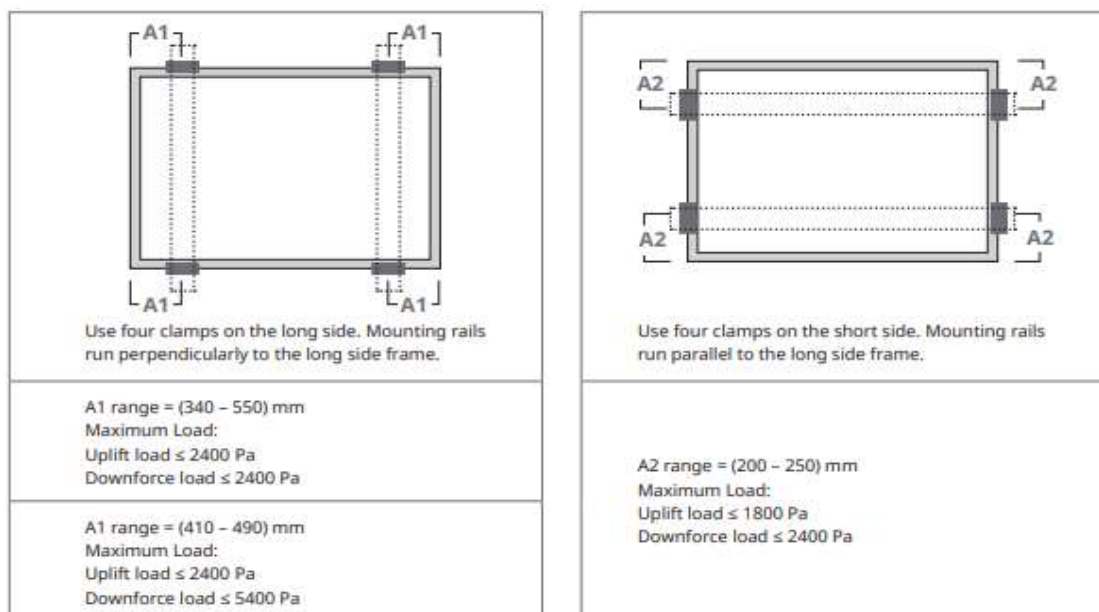


Figure 7: Example of Array Clamps (Source: Canadian Solar)

- ④ Ensure the clamps overlap the module frame by at least 5 mm (0.2 in)
- ⑤ Ensure the clamps overlap length is at least 40 mm (1.57 in)
- ⑥ Ensure the clamp's thickness is at least 3 mm (0.12 in).

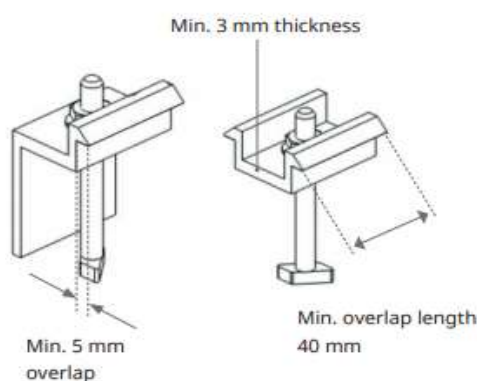


Figure 8: Module Clamps (Source: Canadian Solar)

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 whereby 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 withstand 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.

5 Battery System Installation

AS/NZS 5139 identifies three types of battery systems: pre-assembled BESS, pre-assembled battery systems and battery systems that do not meet the requirements of the Australian Best practice Guide: battery storage equipment – Electrical Safety Requirements. The preassembled BESS and pre-assembled battery systems are only relevant for lithium-ion type battery systems.

AS/NZS 5139 has separate sections for the installation of the three types of battery systems. Therefore, an installer only has to read and comply with the section relevant to the type of battery being installed. Hence, this guideline follows the same format however, it only includes sections on the installation of pre-assembled battery systems and battery systems. The pre-assembled BESSs are designed for grid connected systems only, hence not covered in this guideline.

Historically, battery system installation guidelines and standards were written just covering lead acid and nickel cadmium battery systems. Currently, there are many different battery technologies on the market and AS/NZS 5139 identifies the different types of hazards and installation requirements based on the relevant battery technology. Electrical and energy hazards are relevant for all battery technologies.

The battery systems installation section has a sub-section on battery systems hazards followed by separate sub-sections for the installation of preassembled battery systems and installation of battery systems (two sections relevant to the installation).

5.1 Battery System (or BESS) Hazards

Section 3 of AS/NZS 5139 elaborates on the BESS hazards. Clause 3.2 outlines seven main hazard types associated with BESS as follows:

- a. Electrical hazard.
- b. Energy hazard.
- c. Mechanical hazard.
- d. Fire hazard.
- e. Explosive gas hazard.
- f. Chemical hazard.
- g. Toxic fume hazard.

It is recommended that battery system installers facilitate a brief battery safety training to system owners emphasizing on the applicable hazards for the battery system and hazard mitigation measures. As a minimum, the battery safety training shall include:

- Introduction of battery technology
- Explanation of applicable battery hazards for the battery system e.g. chemical and/or fire and/or toxic fume etc
- Mitigation measures that have been undertaken during installation for the relevant hazards
- Dos and don'ts
- PPEs required to be worn during checks and maintenance
- Actions to take during emergency

Table 5 below is a reproduced version of Table 3.1 in AS/NZS 5139 which sets out classifications of the specified battery type (lead acid and lithium-ion batteries) for a range of identified hazards.

Table 4: Hazard classification by battery types

Battery Chemistry	Electrical Hazard	Energy Hazard	Mechanical Hazard	Fire hazard: level 1 or 2	Explosive gas hazard	Chemical Hazard	Toxic fume hazard
Lead acid	✓	✓	✓	Level 2 (Note 2)	✓	✓	✓
Lithium ion	✓	✓	✓	Level 1 (Note 1)	✓ (Note 3)	N/A	✓

Notes

1: Lithium-ion pre-assembled battery system or pre-assembled integrated BESS equipment conforming to the Best Practice Guide: Battery Storage Equipment – Electrical Safety requirements are N/A for this hazard classification.

2: Lead acid and nickel alkaline based batteries with cases that conform to V0 specifications in accordance with relevant product standards are N/A for this hazard classification.

3: Lithium chemistries that release hydrogen under fault conditions should be considered an explosive gas hazard e.g. lithium manganese.

5.1.1 Electrical Hazard

The electrical risks associated with a battery system are strongly dependent on the voltage of the battery bank, the characteristics of any other equipment that is connected to the battery system (e.g., PCE and/or energy source), the earthing, the protection systems, all interconnections, cable types, method of protection and siting of protection devices.

The decisive voltage classification (DVC) as defined in IEC 62109-1, shall be applied. Refer to section 3 of this guideline.

5.1.1.1 Battery system prospective fault current / short circuit current

The prospective short circuit current at the battery terminals of the battery system shall be based on the fault current able to be supplied by the battery cell, module or bank prior to the interaction of any battery management system.

The battery manufacturer should be consulted to determine the sizing of the battery prospective fault current protection. If information on cell prospective fault current is not available, the battery system should not be installed.

The internal resistance of a cell (lead acid) may be determined by the method shown in Clause 3.2.3.3 of AS/NZS 5139.

The cell short circuit current may be calculated as follows:

$$I_{sc} = \frac{V_{oc}}{R_i}$$

Where:

I_{sc} = cell short circuit current (A)

V_{oc} = cell open circuit voltage (V)

R_i = cell internal resistance at full charge (Ω)

5.1.2 Energy Hazard

According to clause 3.2.4.1 of AS/NZS 5139, arc flash occurs when electrical current passes through the air between electrified conductors when there is insufficient isolation or insulation to withstand the applied voltage.

Arc flash incident energy is dependent on the voltage, current and the length of time that the arc occurs. The energy dissipates out from the arc flash incident so it is at its greatest at the incident and diminishes further away from the incident.

The arc flash incident energy for battery systems having system voltages equal or less than 1000V d.c. is calculated using the following equation:

$$IE_m = 0.01 \times V_{sys} \times I_{arc} \times \left(\frac{T_{arc}}{D^2}\right) \times MF$$

Where:

IE_m = estimated d.c. arc flash incident energy at the maximum power point (cal/cm²)

V_{sys} = system voltage (V)

I_{arc} = arcing current (A)

T_{arc} = arcing time (s)

D = working distance (cm)

MF = multiplying factor

While

$$I_{arc} = 0.5 \times I_{bf}$$

Where;

I_{bf} = battery prospective fault current (A)

When calculating the arc flash energy, a maximum working distance of 45cm shall be applied.

In accordance with AS/NZS 5139 clause 3.2.4.2.3 when working on the PCE (inverter/solar controller) side of the protection device, the arcing time shall be based on the operating time of the protective device based on the prospective fault current.

If time is not known or working on battery system side of protection device then the arcing time shall be 2 seconds.

In accordance with AS/NZS 5139 clause 3.2.4.3, a multiplying factor of 3 should be applied when battery system is installed in battery enclosure and 1.5 could be applied in larger battery rooms. The required personal protective equipment (PPE) shall be determined having calculated the arc flash energy and applying Table 3.3 of AS/NZS 5139 (also refer Appendix 3). Also refer to examples on arc flash calculations in Appendix F of AS/NZS 5139.

Clauses 4.3.2 and 5.3.2 refer to arc flash hazard for pre-assembled BESS and pre-assembled battery system. These clauses say to refer to manufacturer's instructions when undertaking installation and maintenance.

There is a greater risk of arc flash when the individual batteries or battery modules are being installed as in the case of the battery systems being installed in accordance with Section 6 of AS/NZS 5139. For this reason, clause 6.3.2 contains many sub-clauses. Some key points in clause 6.3.2 include:

- Battery system installed in a domestic electrical installation shall have an Arc Flash value of less than 40cal/cm²

- Any battery system with an arc flash value greater than 4.0 cal/cm² cannot be installed within a building containing habitable rooms or in an enclosure attached to a building with habitable rooms
- When the arc flash value is above 8 cal/cm², the battery system must be able to be broken down into segments that will have an arc flash value less than 4 cal/cm².

If the arc flash value is above 4 cal/cm² then AS/NZS 5139 recommends that inter-string fusing is installed to reduce the arc flash value below 4 cal/cm². (Refer Figure 6.15 in AS/NZS5139).

For battery systems (section 6 of AS/NZS 5139), the designer/installer shall also calculate the Arc Flash Boundary (AFB). This is defined as the boundary marked by the distance from electrical equipment at which the arc flash incident energy would be 1.2 cal/cm². Anyone working within this boundary needs to wear the correct selection of PPE (refer Table 3.3 in AS/NZS 5139) to protect them from burns based on the calculated arc flash energy for the battery system. In accordance with table 6.1 in AS/NZS 5139, Arc Flash Energy of 1.2 cal/cm² has a consequence level of insignificant when undertaking risk assessments.

The AFB is calculated using the following formula:

$$AFB = \sqrt{(0.01 \times V_{sys} \times I_{arc} \times T_{arc} \times MF)/1.2}$$

where:

AFB = Arc flash boundary, in cm

V_{sys} = system voltage, in volts

I_{arc} = arcing current, in amps

T_{arc} = arcing time, in seconds

MF = multiplying factor

while

$$I_{arc} = 0.5 \times I_{bf}$$

where:

I_{bf} = battery system short circuit fault current in amps

5.1.3 Mechanical Hazards

The following are classified as the mechanical hazards:

- a. Weight.
- b. Sharp edges and corners.
- c. Moving parts.
- d. Falling over/tripping/seismic.
- e. Lack of lifting or securing accessories on batteries.

When installing a battery system, mechanical hazards applicable to the type, quantity, profile and size of the battery shall be taken into account.

5.1.4 Fire hazard

Depending on the type of battery system used, the risk of fire may result from any of the following:

- a. Excessively high or low temperatures.
- b. Over and under voltage.
- c. Overcharged or over-discharged.
- d. Puncturing or failure of the battery case.

Battery system shall be installed in such a manner that in the event of a fire, the spread of fire is kept to a minimum.

The risk of fire from lead acid or nickel alkaline battery systems with similar chemistries may result from the combination of ignition sources and hydrogen gases that are emitted when the battery is overcharged and the flammable materials of the battery or battery system.

Refer to Clause 6.3.5.2 of AS/NZS 5139 and section 5.3.2.9 of this guideline regarding the ventilation requirements (lead acid) to reduce the concentration of the hydrogen gas to a safe level and regarding removing the risk of spark hazards where the explosive gases are present.

The cause of fire in a lithium-ion battery may arise from the following:

- a. Thermal run-away of the batteries.
- b. A short circuit event of the internal electrodes that causes thermal runaway.
- c. Overvoltage/overcharge, which build internal pressure.

5.1.5 Explosive gas hazard

This relates to batteries that generate explosive gases such as hydrogen when being charged and hence deemed an explosive gas hazard (generally lead acid and alkaline based batteries). The manufacturer's charging regimes shall be followed for requirements on temperature compensation for battery charging voltages.

5.1.6 Chemical hazard

Safety data sheets provide information for all chemicals that are part of the battery system. This information contained within the safety data sheets need to be understood by installers of the battery system. Information in the safety datasheets includes important handling information, what to do in the event of a spill, first aid information and the hazards of the chemical including health, physical and environmental hazards.

5.1.7 Toxic fume hazard

Batteries that generate toxic fumes under normal operation or fault conditions are a toxic fume hazard. When installing a battery system, the toxic fume hazards depending on the type, quantity, profile and size of the battery system to be installed should be taken into account.

5.2 Pre-Assembled Battery Systems

5.2.1 Selecting a Pre-Assembled Battery System

A pre-assembled battery system is a system comprising one or more cells, modules or battery systems, and/or auxiliary equipment. E.g. lithium-ion battery system with its own battery management system (BMS). Pre-assembled battery systems may come in a dedicated battery system enclosure.

A pre-assembled lithium-ion battery system comprising lithium-ion batteries shall comply with:

- Australian Best Practice Guide- Battery Storage equipment- Electrical safety Requirements.

If installing a pre-assembled lithium-ion battery system in accordance with this section (section 5.2) of the guideline then, the pre-assembled battery system shall be selected from those on the Australian Clean Energy Council's approved product list:

<https://www.cleanenergycouncil.org.au/industry/products/batteries/approved-batteries>

Appendix 2 has further information regarding the CEC approved products list.

The lithium-ion batteries should have a minimum 10-year manufacturing warranty or a minimum cycle life of 5000 cycles of usable energy.

5.2.2 Pre-Assembled Battery Systems Installation

The pre-assembled battery system shall be installed in accordance with section 5 of AS/NZS 5139. This section of the guideline provides a brief overview of the requirements in section 5.

Installers shall carry out a risk assessment for each installation and include any other hazards identified and comply with AS/NZS 3000 and other relevant Australian standards.

In accordance with section 5 of AS/NZS 5139, the following important considerations shall be made with regards to installation of pre-assembled battery systems:

- a. Preassembled battery systems shall be installed by competent persons as highlighted in section 3 of this guideline.
- b. Any damaged equipment shall not be installed.
- c. A risk assessment shall be performed prior to planning any installation of pre-assembled battery system.
- d. All pre-assembled battery systems shall be installed in accordance with section 5 of AS/NZS 5139 and the additional requirements as specified by the manufacturer's documentation.
- e. Extra enclosure and housing will only be required based on the risk assessment considering the surrounding environment, location, venting and other site-specific issues.
- f. The pre-assembled battery system shall not be installed in locations where they will be exposed to temperatures lower than the minimum or greater than the maximum temperature specified by the pre-assembled battery system manufacturer.
- g. The pre-assembled battery system shall be selected and installed such that there is protection from presence of water, dust, high humidity, vermin and direct sunlight.
- h. Locations should be chosen that avoid heat sources such as direct sunlight, generators, steam pipes, hot water systems, air conditioners, space heaters and uninsulated walls affected by direct sunlight.
- i. Pre-assembled battery system should not be located near combustible materials.
- j. To protect from spread of fire to habitable rooms, if the wall/structure on which or near which the pre-assembled battery system will be mounted has a habitable room on the other side then the wall or structure shall be made of suitably non-combustible barrier.
- k. Pre-assembled battery system shall have a minimum protection of IP2X.
- l. Pre-assembled battery systems installed outdoors shall have IP rating appropriate for the location and be at least IP23.

5.2.2.1 Pre-assembled Battery System Location

AS/NZS5139 has a requirement that within domestic or residential electrical installations, pre-assembled battery systems **shall not be located in habitable rooms**. Though this is recommended it is very likely that this could not be achieved in dwellings in the Pacific countries. The definition of a habitable room is provided in AS/NZS 5139 clause 1.3.42. This states:

room associated with a domestic or residential electrical installation used for normal living activities
Note 1 to entry: For example, a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom

Looking at this list so in a typical Australian dwelling the only locations that might be suitable would be bathroom, laundry and garage. However, it is not ideal to have battery systems located in bathrooms or laundries because of the nearby presence of water.

Within the context of the above definition of habitable rooms, many dwellings in the Pacific countries only have habitable rooms. When this is the case then the installer shall take into consideration where is the location within the dwelling where inhabitants would not spend a lot of time and hence will not regularly be located near the battery system.

If the dwelling does have non-habitable rooms, e.g. garage, the diagrams in Appendix A of CEC Advice on AS/NZS 5139:2019 (available from the SEI API website: www.seiapi.com/guidelines/) also highlight several examples and provide more clarity on minimum clearances. In addition, pre-assembled battery systems shall not be installed in hazardous areas defined in AS/NZS 3000:2018 Section 7.

Pre-assembled battery system shall be protected from mechanical damage, environmental and other external influences. The location of the pre-assembled battery system shall provide access to connections and maintenance and servicing of serviceable equipment and doors and panels that are required for installation and maintenance.

Furthermore, the installation of pre-assembled battery system shall conform to the requirements for damp situations as required by AS/NZS 3000:2018 Section 6. The location of the pre-assembled battery system shall be determined by the outcome of the risk assessment.

Suitable locations include garages, storage rooms, dedicated battery system room and verandas, etc. If installed in corridors, hallway or lobby, there should be sufficient clearance from battery system for safe exit greater than 1 m.

The desired location of the battery system should be reviewed by an experienced structural engineer (for larger off grid PV systems). The mass of the battery system and cable trays, extra wind loading and seismic (earthquake) effects on the existing structure, whether it be a floor or wall, needs to be reviewed and approved.

The engineer may also need to assess the existing structure for any penetrations that may be required due to extra cabling and/or trenches underneath larger battery system systems installed on pavements on ground.

5.2.2.2 Restricted Locations

This is covered in Clause 5.2.2.2 of AS/NZS 5139. The preassembled battery system installation must not be installed in a location which may inhibit evacuation from a premise, including:

- a. as for switchboards (AS/NZS 3000).
- b. within 600mm of any exit.
- c. within 600mm of any vertical side of a window, or any building ventilation, opening into a habitable room. (This requirement could not be met in some Pacific dwellings)
- d. within 600mm of any appliance.
- e. within 900mm below b, c and d
- f. in ceiling spaces.
- g. in wall cavities.
- h. on roofs (except where specifically deemed suitable).
- i. under floors of habitable rooms.
- j. under stairways.
- k. under access walkways.
- l. in an evacuation route or escape route.

The rule stating that a battery shall not be installed within 600mm of any exit includes any exit to a building envelope, including garage doors.

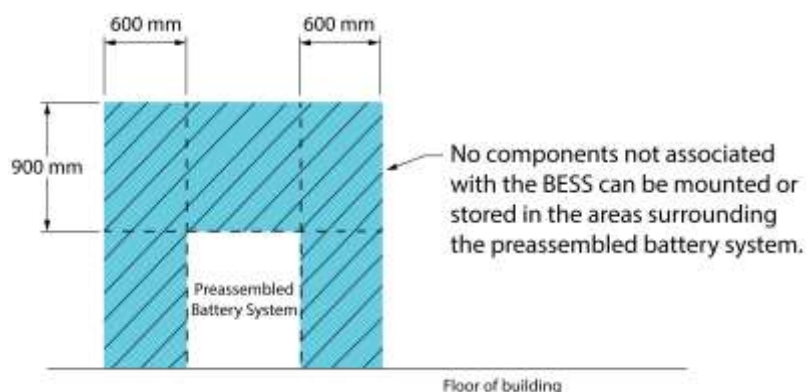


Figure 9: Restricted zones for appliances not associated with the pre-assembled battery system/battery system.

The rule stating that a battery shall not be installed within 600mm of any exit includes any exit to a building envelope, including garage doors.

5.2.2.3 Protection Against the Spread of Fire

Where the pre-assembled battery system is mounted within 300mm (of a wall with a habitable room on the other side of that wall then a non-combustible barrier with similar dimensions of the exclusion zone as shown in Figure 8 shall be installed. Refer to clause 5.2.4 of AS/NZS 5139 for further information.

5.2.2.4 Other Installation Considerations

The pre-assembled battery system needs to be installed appropriately to withstand seismic (earthquake) forces for the location.

For other important considerations on environmental requirements, IP rating, pre-assembled battery room requirements, installation hazards, disconnection, protection, earthing system documentation, refer to clauses 5.2 to 5.4 of AS/NZS 5139.

5.3 Battery System

5.3.1 Selecting a Battery System

Lead acid battery systems shall comply with one of the following standards:

- AS 60896.11 Stationary lead-acid batteries, Part 11: Vented types - General requirements and methods of tests
- AS 60896.21 Stationary lead-acid batteries, Part 21: Valve regulated types - Methods of test
- AS 60896.22 Stationary lead-acid batteries, Part 22: Valve regulated types - Requirements.
- IEC 60896 Stationary lead-acid batteries (series).

The lead acid batteries should have a minimum 5-year warranty or a minimum cycle life of 2500 cycles down to 50% depth of discharge.

The individual cells and for lithium-ion batteries shall comply with the following standard:

- IEC 62619 Secondary cells and batteries containing alkaline or other non-acid electrolytes— Safety requirements for secondary lithium cells and batteries, for use in industrial applications.

While a Pre-Assembled Battery System comprising lithium-ion batteries can comply with:

- Australian Best Practice Guide - Battery Storage equipment - Electrical safety Requirements

The lithium-ion batteries should have a minimum 10-year manufacturing warranty or a minimum cycle life of 5000 cycles of usable energy.

Nickel cadmium batteries shall conform to the following standard:

- AS IEC 60622 Secondary cells and batteries containing alkaline and other non-acid electrolytes - Sealed nickel-cadmium prismatic rechargeable single cells

The Nickel Cadmium batteries should have a minimum 10-year manufacturing warranty or a minimum cycle life of 5000 cycles down to 50% depth of discharge.

Flow battery systems shall conform to the following standards:

- IEC 62932-1 Flow battery energy storage systems for stationary applications- Part 1 Terminology and general aspects.
- IEC 62932-2 Flow battery energy storage systems for stationary applications- Part 2 Performance general requirements and test methods
- IEC 62932-3 Flow battery energy storage systems for stationary applications- Part 3 Safety requirements.

The flow batteries should have a minimum 5-year manufacturing warranty or a minimum of 2500 cycles of its total energy.

5.3.2 Battery System Installation

Section 6 of AS/NZS 5139 relates to the installation of all battery systems that do not conform to the Australian Best Practice Guide- Battery Storage equipment - Electrical safety Requirements. The battery systems shall be installed in accordance with section 6 of AS/NZS 5139. This section of the guideline provides a brief overview of the requirements in section 6.

Installers shall carry out a risk assessment for each installation and include any other hazards identified and comply with AS/NZS 3000 and other relevant Australian standards.

In accordance with section 6 of AS/NZS 5139, the following important considerations shall be made with regards to installation of battery systems:

- a. Battery systems shall be installed by competent persons as highlighted in section 3 of this guideline.
- b. Any damaged equipment shall not be installed.
- c. A risk assessment shall be performed prior to planning any installation of battery system.
- d. The battery systems shall be installed in accordance with section 6 of AS/NZS 5139 and the additional requirements as specified by the manufacturer's documentation.
- e. The battery system shall not be installed in locations where they will be exposed to temperatures lower than the minimum or greater than the maximum temperature specified by the pre-assembled battery system manufacturer.
- f. The battery system shall be selected and installed such that there is protection from presence of water, dust, high humidity, vermin and direct sunlight.

- g. Locations should be chosen that avoid heat sources such as direct sunlight, generators, steam pipes, hot water systems, air conditioners, space heaters and uninsulated walls affected by direct sunlight.
- h. The battery system should not be located near combustible materials.
- i. The battery system, the terminals and other connected live parts shall have a minimum protection of IP2X.
- j. Battery systems installed outdoors shall have IP rating appropriate for the location and be at least IP23. Higher IP rating protection may be required depending on the installation location and battery system type.

5.3.2.1 Battery System location

AS/NZS 5139 has a requirement that within domestic or residential electrical installations, pre-assembled battery systems **shall not be located in habitable rooms**. Though this is recommended it is very likely that this could not be achieved in dwellings in the Pacific Island countries. The definition of a habitable room is provided in AS/NZS 5139 clause 1.3.42. This states:

room associated with a domestic or residential electrical installation used for normal living activities

Note 1 to entry: For example, a bedroom, living room, lounge room, music room, television room, kitchen, dining room, sewing room, study, playroom, family room, home theatre and sunroom

Looking at this list so in a typical Australian dwelling the only locations that might be suitable would be bathroom, laundry and garage. However, it is not ideal to have battery systems located in bathrooms or laundries because of the nearby water.

Within the context of the above definition of habitable rooms, many dwellings in the Pacific Island Countries only have habitable rooms. When this is the case then the installer shall take into consideration where is the location within the dwelling where inhabitants would not spend a lot of time and hence will not regularly be located near the battery system.

If the dwelling does have non-habitable rooms, e.g. garage, the diagrams in Appendix A of CEC Advice on AS/NZS 5139:2019 (available from the SEI API website: www.seiapi.com/guidelines/) also highlight several examples and provide more clarity on minimum clearances. In addition, pre-assembled battery systems shall not be installed in hazardous areas defined in AS/NZS 3000:2018 Section 7.

Battery system shall be protected from mechanical damage, environmental and other external influences.

The battery system shall be installed in one of the following:

- A dedicated enclosure: An enclosed area that is not sufficiently large to allow a person to stand and move around inside (refer to Clause 6.2.5 of AS/NZS 5139)
- A dedicated room: An enclosed area that is accessible only by a door/door of sufficient size to allow to enter and walk within the area.

Note: The dedicated enclosure or dedicated room shall contain only the battery system and the battery system's associated equipment.

The location of the battery system shall provide access to connections and maintenance and servicing of serviceable equipment and doors and panels that are required for installation and maintenance.

Furthermore, the installation of battery system shall conform to the requirements for damp situations as required by AS/NZS 3000:2018 Section 6. The location of the battery system shall be determined by the outcome of the risk assessment.

Suitable locations include garages, storage rooms, dedicated battery system room, verandas, etc. If installed in corridors, hallway or lobby, there should be sufficient clearance from battery system for safe exit greater than 1 m.

The desired location of the battery system should be reviewed by an experienced structural engineer. The mass of the battery system and cable trays, extra wind loading and seismic (earthquake) effects on the existing structure, whether it be a floor or wall, needs to be reviewed and approved.

The engineer may also need to assess the existing structure for any penetrations that may be required due to extra cabling and/or trenches underneath larger battery system systems installed on pavements on ground.

5.3.2.2 Restricted locations

This is covered in Clause 6.2.2.2 of AS/NZS 5139 however, it has the same requirements as the pre-assembled battery system as shown in section 5.2.2.2 and Figure 9 of this guideline.

One extra restriction is that no equipment shall be mounted above explosive and/or corrosive gas emitting battery systems (e.g. lead acid batteries).

The rule stating that a battery shall not be installed within 600mm of any exit includes any exit to a building envelope, including garage doors.

5.3.2.3 Energy Hazard

Installation of battery systems that do not conform to the Australian Best Practice Guide- Battery Storage Equipment have the greater potential for an arc flash hazard. Please refer to section 5.1.2 of this guideline for more information and battery systems shall be installed in accordance with the requirements of clause 6.3.2 of AS/NZS 5139.

5.3.2.4 Fire Hazard

In accordance with AS/NZS 5139, battery systems can be deemed to have no fire hazard level, fire hazard level 1 or fire hazard level 2.

The level is determined when undertaking the risk assessment.

Those that are deemed to fire hazard level 1 shall only be installed in a dedicated enclosure detached from a building containing habitable rooms or in a detached non-habitable building.

Lead acid batteries that are not in a battery case with a V0 rating (refer table 3.1 in AS/NZS5139) are deemed to fire hazard level 2.

Lithium-Ion batteries being installed in accordance with section 6 of AS/NZS 5139 are deemed to fire hazard level 1.

The battery system shall be installed in accordance with clause 6.3.4 based on the battery system's fire hazard level.

5.3.2.5 Battery system enclosure

The battery system enclosure shall prevent unauthorised access to the battery system and the components. The design, layout and construction shall be in accordance with Clause 6.2.5.2.2 of AS/NZS 5139. The area inside the battery system enclosure shall allow for the following clearances:

- a. The space between cells shall be at least 3mm unless, otherwise stated by the manufacturer.

- b. There shall be a minimum of 25mm clearance between a cell/battery and any wall or enclosure unless otherwise stated by the manufacturer.
- c. The minimum distance between a vertically mounted battery and top of the battery system enclosure shall be half the distance from the front of the battery and rear most terminal of the battery or 75mm, whichever is the greater. However, the vertical clearance need not exceed 200mm between the highest point of the battery and lowest point of the structure (300mm for flooded lead acid batteries). Refer to appendix C of AS/NZS 5139 for illustrations.
- d. For a tiered, vertically mounted cell or battery, the minimum distance between a vertically mounted battery and top of the battery system enclosure shall be half the distance from the front of the battery and rear most terminal of the battery or 75mm, whichever is the greater. However, the vertical clearance need not exceed 200mm between the highest point of the battery and lowest point of the structure (300mm for flooded lead acid batteries). Refer to appendix C of AS/NZS 5139 for illustrations.
- e. A racked horizontally mounted cell/battery shall have a minimum 25mm clearance between the cell/battery and the above rack unless otherwise stated by the manufacturer.
- f. The batteries shall be mounted with the highest point no greater than 2.2m above the floor level.

In addition, the battery system enclosure should be designed such that it limits the installation to no more than two rows and two tiers of battery cells or modules to facilitate safe installation and maintenance. There should be unobstructed access provided by the door and panels for system installation and maintenance purposes. The design and construction of the battery system enclosure should be insect or vermin resistant.

Furthermore, Clause 6.3.5.3(c) of AS/NZS 5139 requires that no equipment which could cause a spark or arc shall be installed above the battery or battery modules (categorized with explosive gas hazard) inside the enclosure. This should be followed. For other important considerations on environmental requirements, IP rating, protection against fire, battery room requirements, installation hazards, disconnection, protection, earthing and system documentation, refer to clauses 6.2 to 6.4 of AS/NZS 5139.

5.3.2.6 Battery system room requirements

The battery room shall meet the requirements stated in Clause 6.2.6 of AS/NZS 5139. Anything not related to the battery system, shall be located outside the battery system room. The size of the room shall allow for sufficient clearance around the battery system to allow for safe installation and maintenance. The battery room shall prevent unauthorised access, it should be kept clean and dry and sufficiently ventilated.

The overcurrent protection devices, isolating switches and all socket-outlets that are mounted in the battery system room shall be mounted a minimum of 100mm below the battery terminals or a minimum of 600mm horizontally from the batteries (categorized with explosive gas hazard).

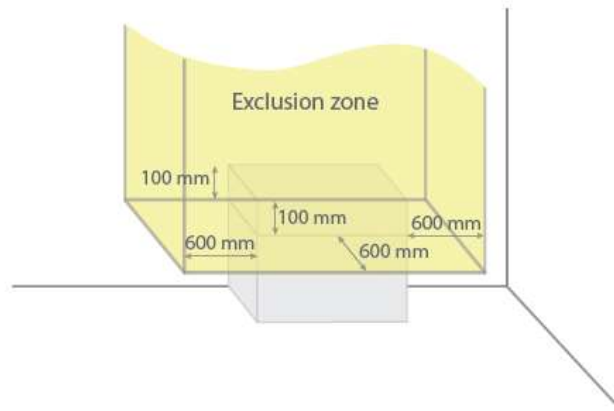


Figure 10: Exclusion zone for equipment located near a battery system (assuming battery terminals are on top surface) as stipulated by AS/NZS 5139:2019

5.3.2.7 Battery System Stand

For battery system stands, the requirements of AS/NZS 1170.1, AS/NZS 1170.2 and AS/NZS 1170.4 (in countries where there is a risk of earthquakes) shall apply. The following provisions apply for battery stands either within a battery system room or part of an enclosure:

- When the battery system stands are mounted vertically, stands should be designed so that the installation per stand is limited to a depth of two rows of batteries.
- If the height of the battery system is its longest dimension, horizontal restraining bars should be installed at the front and at the back of the stands.

Refer to Appendix C of AS/NZS 5139 for diagrams on battery system stands.

5.3.2.8 Ability to Withstand Seismic Forces

The battery system enclosure/battery stands shall be designed and installed to withstand seismic (earthquake) forces for the location taking into account the weight of the battery system, etc.

5.3.2.9 Ventilation Requirements for Lead-Acid Battery Systems

Refer to Clause 6.3.5.2 of AS/NZS 5139 for the ventilation requirements.

Battery system types that can emit explosive gases shall be installed in enclosures (or rooms) with sufficient ventilation to prevent the build-up of excessive explosive gases generated when the battery system is being charged.

- Best practice is to provide input ventilation vents below the level of battery system and the output vents on the opposite side of the battery system or, if practical, through the roof. Because hydrogen is lighter than air, outlet vents need to be as high as possible in the enclosure to prevent hydrogen build up (as shown in Figures 11 and 12).

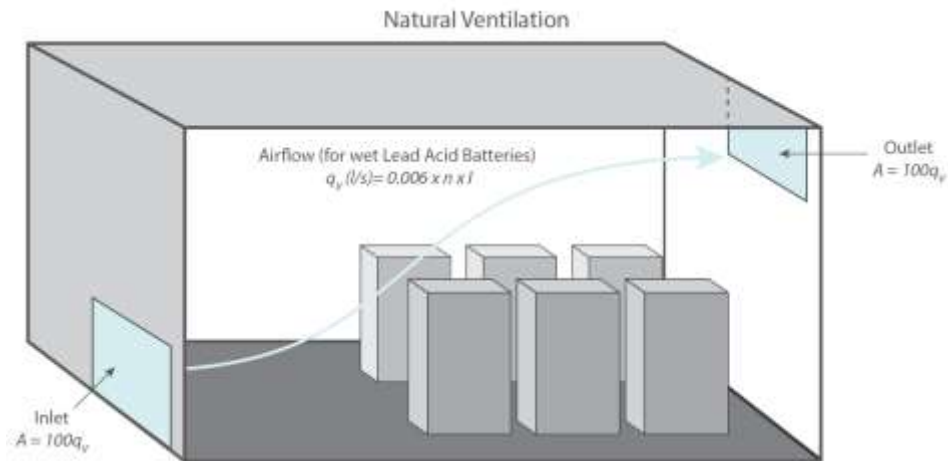


Figure 11: Natural ventilation arrangement for battery systems.

If the ventilation vents are all on one side, increased airflow can be achieved if the internal ceiling slopes up to the outlet vent as shown in Figure 12.

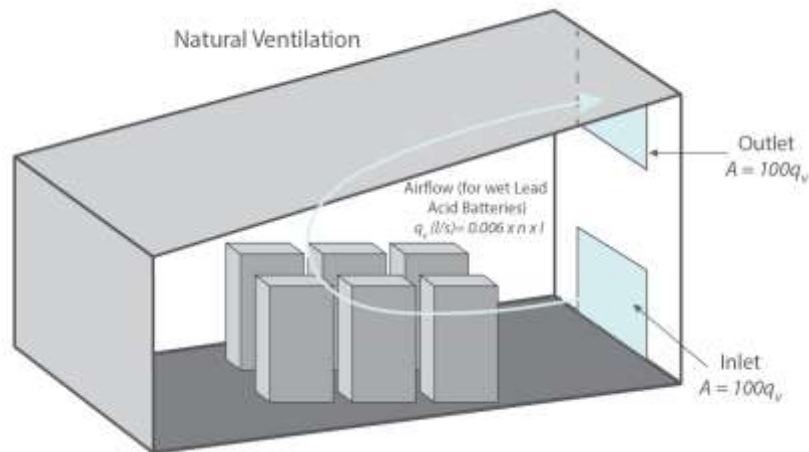


Figure 12: Natural ventilation arrangement for battery systems with vents on one side.

Determining the size of the vents

The minimum area in cm^2 required for natural ventilation for both inlet and outlet apertures (for lead acid battery systems) are given by:

$$A = 100 \times q_v \text{ cm}^2$$

Where q_v is the minimum exhaust ventilation rate in litres per second ($q_v = 0.006 \times n \times I$)

and n = the number of 2V battery cells

I = the charging rate in amperes

Since lead acid battery systems consist of the number of 2V cells needed to provide the required voltage and Ah capacity of the battery system and hence that is the number of cells that is referred to in the formulas.

Charging rate for flooded lead acid battery systems

In accordance with the standards, for flooded lead acid battery systems, the charging rate in amperes is the maximum combined output rating of the charger(s) or the rating of its output fuse or circuit breaker, whichever is lesser.

Charging rate for sealed lead acid battery system

For valve regulated lead acid battery systems the charging rate is either:

- Condition I - The combined maximum charge current possible from all sources if the PCE (solar controller/battery inverter) controlling the charging does not have automatic over voltage cut-off; or
- Condition II - 0.5 A per 100 Ah of battery capacity at the 3-hour rate of discharge if the PCE (solar controller/battery inverter) controlling the charging does have automatic over voltage cut-off.

e.g. battery cell has C₃ rating of 500Ah therefore the charge current used in ventilation formula is = (500Ah/100Ah) x 0.5A = 2.5A

This is the current that is then applied in the formula above for valve regulated (sealed) battery systems. The full available charging current is not required to be applied.

6 Solar Controller Installation

6.1 Selecting the Solar controller

The solar controller(s) shall comply with one of the following standards:

- IEC 62509 Battery charge controllers for photovoltaic systems - Performance and functioning
- IEC 62109 Safety of power converters for use in photovoltaic power systems
 - IEC 62109-1 Part 1: General requirements
- UL Standard 1741: Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources

Notes:

1. IEC 62509 has not been updated for many years, so it is outdated with respect to some of the modern battery technologies e.g. lithium-Ion batteries are not covered by this standard.
2. Australia does require the solar controller to comply with IEC 62109-1 Part 1: General requirements. However, there are many good controllers on the market that do not meet this standard.

A small range of solar controllers that comply with the above standards can be found within the Australian Clean Energy Council's approved product list for inverters:

<https://www.cleanenergycouncil.org.au/industry/products/inverters>

6.2 Installation Requirements

The following minimum requirements shall be followed with regards to solar controller installation:

- a. The solar controller shall be installed as to the manufacturer's instructions
- b. Installation of solar controllers (either non-MPPT or MPPT) should be near batteries or at a convenient monitoring location as close as practical to the batteries.
- c. For a solar controller not located near batteries, it will be necessary to use a model that has a separate battery voltage sensor connected at the battery terminals to allow for voltage drop in the cables that could cause improper charging if the voltage is measured at the controller instead of at the battery system.
- d. Never install the solar controllers on top or above the enclosure of battery systems that emit explosive gases, or near the ventilation vents.
- e. Solar controllers dissipate heat, there must be sufficient ventilation for these sensitive pieces of equipment. Always follow the manufacturer's recommendations for installation, ventilation and clearances around the solar controller heat sinks.

- f. MPPT Earth Fault Indication If a solar controller is installed outside, the controller should have an IP rating of at least IP56. Due to the humidity and high salt environment in the Pacific region it is recommended that all controllers should have this IP rating or higher.
- g. Solar controllers are not to be installed in direct sunlight.

6.3 Earth Fault Alarm

According to Clause 3.5.3 of AS/NZS 5033, where the calculated PV dc circuit maximum voltage is above 120 V or the PV array is connected to a non-separated MPPT Solar controller, 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.

7 PV Inverter Installation

7.1 Selecting the PV Inverter

The inverter(s) shall comply with the following standards:

- IEC 62109 Safety of power converters for use in photovoltaic power systems
 - IEC 62109-1 Part 1: General requirements
 - IEC 62109-2 Part 2: Particular requirements for inverters

Though the inverter is not connected to the electrical grid, the PV inverter is the same product as that connected to the grid. Some PV inverters do have frequency and voltage protections settings suitable to off grid systems which is generally broader range in under and over frequency settings.

A range of PV inverters that comply with the above standards can be found on the Australian Clean Energy Council's approved product list:

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

If the PV inverter is selected from the Australia approved products list, then the PV inverter should be programmed for Australia C.

It is important that the PV inverter and battery inverter are compatible because the battery inverter will need to control the operation of the PV inverter when the battery system is being charged from the PV array via the PV inverter.

7.2 Installation Requirements

The following minimum requirements shall be followed with regards to PV inverter installation:

- a) The PV inverter shall be installed as to the manufacturer's instructions.
- b) The PV inverter shall be installed in a location that is appropriate for the IP rating of the PV inverter. Where this is not possible then the PV inverter/s should be in an appropriate weatherproof enclosure that has adequate ventilation.
- c) If a PV inverter is installed outside, the PV inverter should have an IP rating of at least IP56. Due to the humidity and potentially high salt environment in some parts of the Pacific region, it is recommended that all PV inverter should have this IP rating or higher.
- d) PV inverters are not to be installed in direct sunlight.

- e) The PV inverter shall be installed with recommended clearances around the PV inverter as specified by the manufacturer.
- f) PV inverters should be installed in dust free locations;
- g) PV inverters can be heavy; it is important that the surface on which the PV inverters will be mounted is appropriately weight-bearing.
- h) The PV inverter heat sink shall be clear of any obstacles that may interfere with cooling of the PV inverter.
- i) The PV inverter shall be installed so as to provide accessibility for operation, testing, inspection, maintenance and repair.
- j) arranged to prevent ingress of vermin, insects, water and dust, so as to prevent deterioration of the operational functions of the inverter.
- k) All cables shall be installed and sized in accordance with AS/NZS 3000, the AS/NZS 3008.1.1 series
- l) Cables connected to the PV inverter shall be mechanically secured in such a manner that they cannot be inadvertently unplugged from the inverter. This can be achieved by:
 - i) Having the PV inverter housed in an enclosure (with cables suitably supported).
 - ii) The use of a PV 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.
 - iii) The use of conduit and secure wall fixings:
 - Where the inverter requires dc connectors to be used, a maximum allowable distance of no more than 200mm of unprotected dc 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.

7.3 PV Inverter Earth Fault Indication

According to Clause 3.5.3 of AS/NZS 5033, where the calculated PV dc 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.

8 Battery Inverter Installation

8.1 Selecting the Battery Inverter

When selecting an inverter to be used, the inverter shall comply with:

- IEC 62109 Safety of power converters for use in photovoltaic power systems
 - IEC62109-1 Part 1: General requirements.
 - IEC62109-2 Part 2: Particular requirements for inverters.

A range of PV inverters that comply with the above standards can be found on the Australian Clean Energy Council's approved product list and hence can be selected from the following list:

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

However, there are battery inverters available internationally that do comply with one of the standards listed above and are possibly not used in Australia and therefore not on the list.

It is important that the battery inverter and PV inverter are compatible because the battery inverter will need to control the operation of the PV inverter when the battery system is being charged from the PV array via the PV inverter.

8.2 Installation Requirements

Where the battery system voltage is DVC-A, non-separated (i.e. transformer-less) battery inverters should not be used. Refer clause 5.3.1.1 and 6.3.1.1 of AS/NZS 5139 stating where these shall not be installed with pre-assembled battery systems or battery systems.

Some general installation requirements are:

- a. Non-separated (i.e. transformer-less) battery inverters shall not be used if the output of the inverter is going to be hard wired to a switchboard.
- b. Non-separated inverters should have loads directly connected via a plug to the ac output via the power outlet located on the inverter.
- c. The battery inverter should be installed as close as possible to the battery system to minimise voltage drop.
- d. If the battery inverter is installed outside, the battery inverter should have an IP rating of at least IP56. Due to the humidity and high salt environment in the Pacific region, it is recommended that all battery inverters should have this or higher IP rating.
- e. Battery inverters are not to be installed in direct sunlight.
- f. The battery inverter shall be installed with recommended clearances around the battery inverter as specified by the manufacturer.
- g. Battery inverters should be installed in dust free locations.
- h. Battery inverters can be heavy; it is important that the surface on which the battery inverters will be mounted is appropriately weight-bearing.
- i. The Battery inverter heat sink shall be clear of any obstacles to facilitate cooling of the battery inverter.

9 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 DVC-C (that is greater than 120V dc). This could occur with dc coupled systems using MPPT solar controllers or with ac coupled systems using PV inverters.

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

For ac coupled systems or dc coupled systems using MPPT solar controllers, a dangerous situation is only likely to occur at:

- the PV Array switch-disconnector (isolator) before the PV inverter or MPPT solar controller;
- 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 13) 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 interconnecting cable of the array be connected.

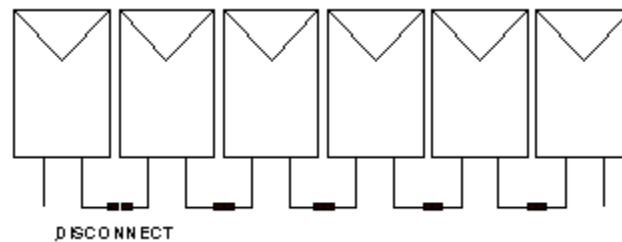


Figure 13: Disconnected interconnect cable

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.

10 PV Array Wiring

10.1 Selection of dc Cable for PV Array



Figure 14: Double insulated solar dc cable

The PV dc cables (i.e. string/array cable) used in the system shall conform to IEC 62930: Electric cables for photovoltaic systems with a voltage rating of 1.5 kV d.c.

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

- Be suitable for dc applications.
- Have a voltage rating greater than or equal to the calculated PV dc circuit maximum voltage (determined using section 4.3) 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.
- 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,

Notes:

- Clause 4.4.2.1 also provides recommendations for other types of cables when installed in buildings
- According to Clause 4.4.2.3, the nominal cross-sectional area of PV dc conductors shall not be less than 4 mm².

10.2 Installation of the PV Array Wiring

The installation of PV dc 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:

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

In addition, cables shall 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).

10.3 Selection of Current Carrying Capacity of PV String Cables

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.

For clarity, figure 15 depicts string and array cable within a PV system.

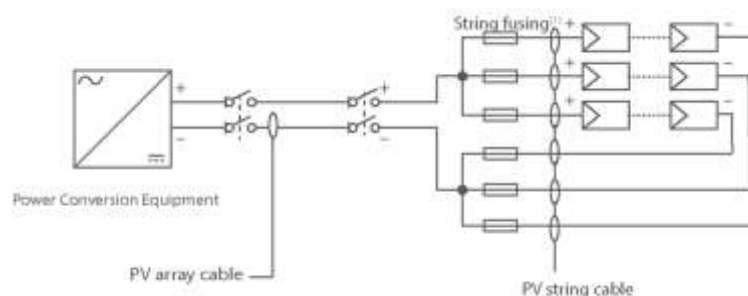


Figure 15 PV string and array cable illustration

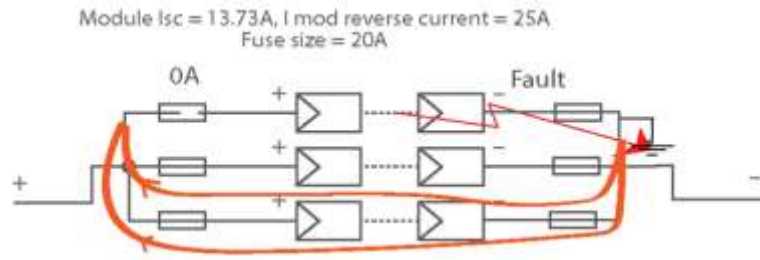


Figure 16 Diagram showing how currents flow from other strings into the string that has a fault

Figure 16 depicts how the current flows from other strings to the string with the fault and showing that the string fuse would potentially blow.

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:

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

$$CCC \geq 1.25 \times I_{SC \text{ MOD}} \times K_1 \text{ (if no DCUs present)}$$

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.

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

$$CCC \geq I_n + 1.25 \times K_1 \times I_{SC \text{ MOD}} \times (S_A - 1) \text{ (if no DCUs present)}$$

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.

10.4 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 off grid PV system could potentially carry current from external sources, such as a battery bank. Note for dc coupled off-grid PV systems array protection will be required.

Refer to figure 15 for array cable illustration.

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:

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

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

In a large off grid PV systems, 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.

10.5.1 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 PV inverter or solar controller backfeed current:

$$CCC \geq \text{PV inverter or solar controller backfeed current}$$

10.5.2 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. Refer to figure 17 for sub-array cable illustration.

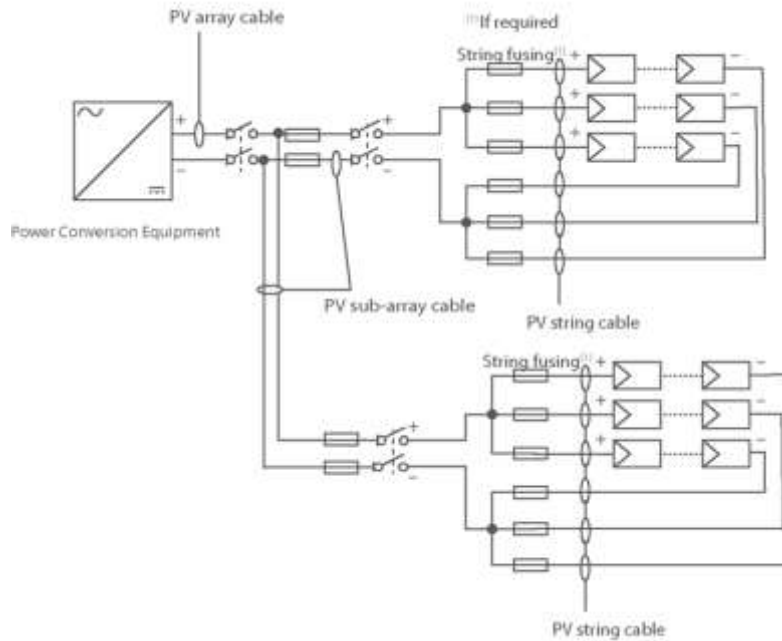


Figure 17 Sub-array cable illustration

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:

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

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

Figures 18 and 19 denote the flow of fault currents in sub-array systems. Figure 18 shows fault currents in sub-arrays with no sub-array protection (2 sub-arrays) whilst figure 19 shows fault currents in sub-arrays with sub-array protection (3 sub-arrays).

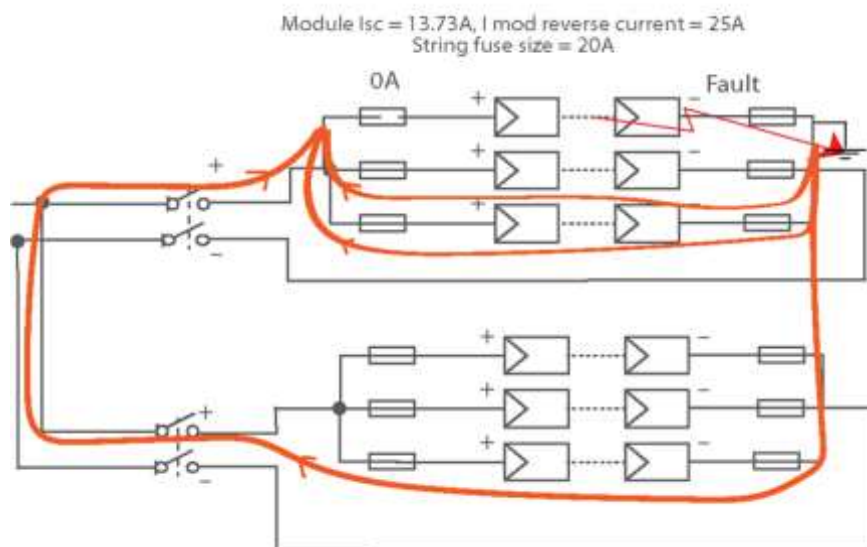


Figure 18 Diagram showing fault currents in sub-arrays with no sub-array protection (2 sub-arrays)

Fault current will flow from the two strings in the same sub-array and also from the other sub-array until the string fuse in the faulty string blows. Then, the current from the other two strings and the sub-array with no fault will continue to the load.

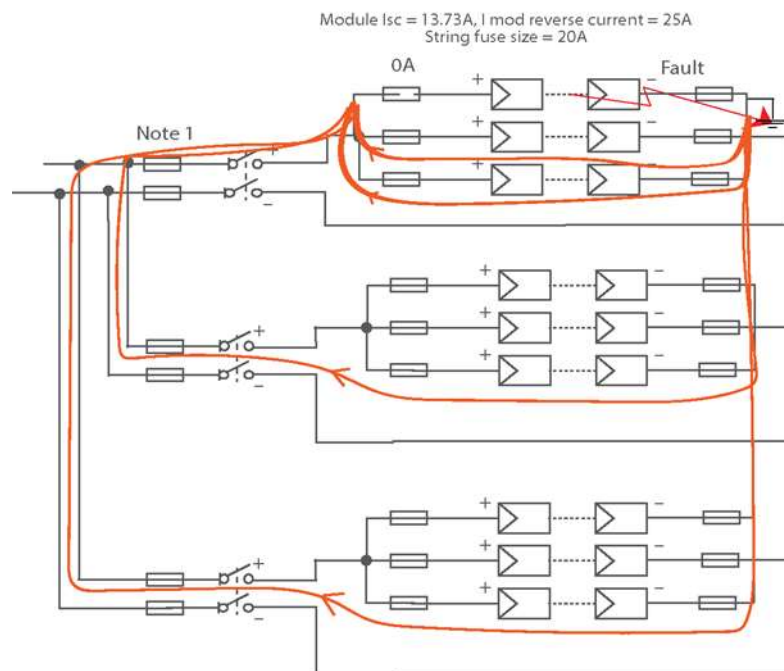


Figure 19 Diagram showing fault currents in sub-array with sub-array protection (3 sub-arrays)

Note 1: When a fault occurs on one string, fault current will flow from both the parallel strings within that sub-array and also from the other two sub-arrays. Though there is sub-array string fusing to protect the sub-array cable, it is unlikely that that will blow before the string fuse because the string fusing will have a lower current rating than that of the sub-array fuse.

10.5.3 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.

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

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:

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

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

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.

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

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

Note: Refer to SEIAPI/PPA Grid Connected PV System Installation Guidelines for some worked examples in determining the current carrying capacity in arrays.

10.6 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 20, 21 and 22 give examples on how the conductive wiring loop can be avoided. Figure 23 shows what should not be done.

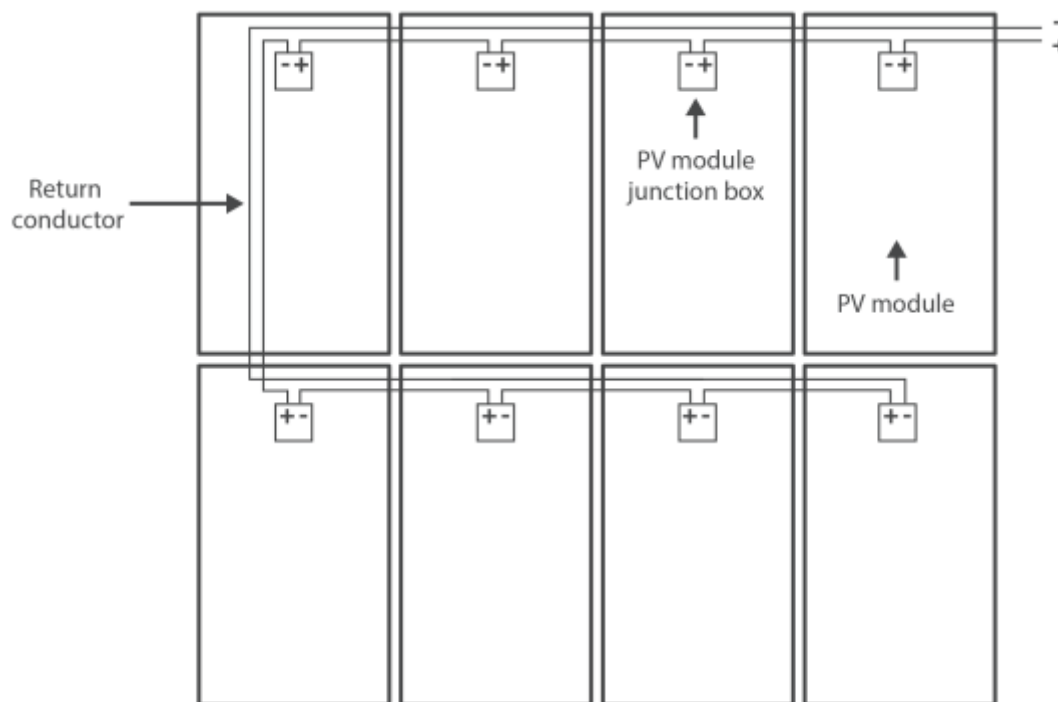


Figure 20: Example of Wiring to avoid Conductive Loops

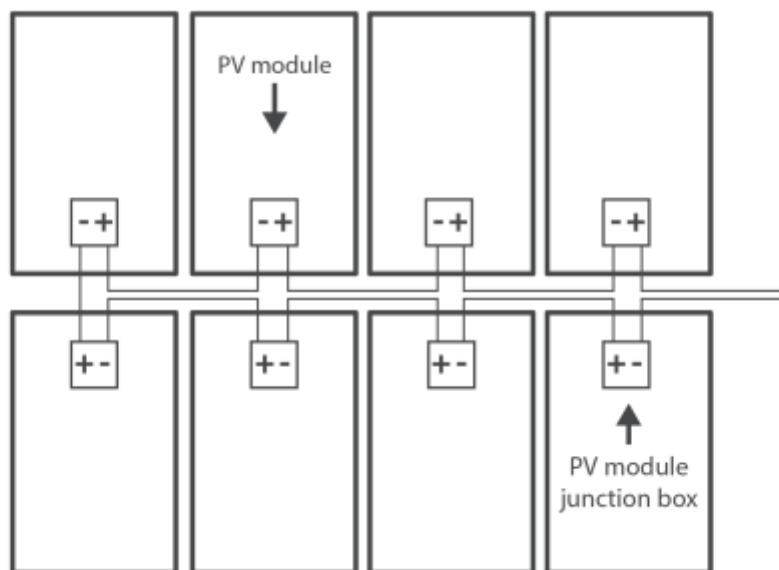


Figure 21: Example of Wiring to avoid Conductive Loops

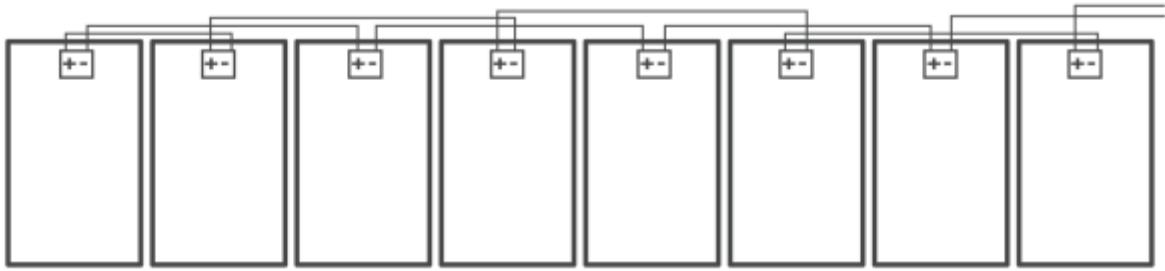


Figure 22: Example of Wiring to avoid Conductive Loops

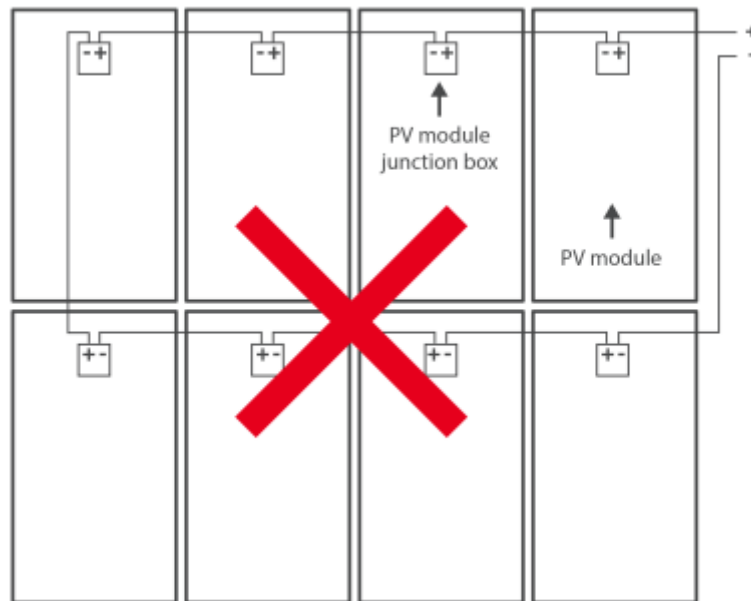


Figure 23: Example of Wiring that will cause Conductive Loops and not to be done.

11 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.

12 Segregation of dc and ac circuits

The segregation of PV dc 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 dc and ac circuits within enclosures by insulation barriers.
- Where switches for dc and ac circuits are mounted on a common mounting rail the mounting rail shall not be conductive (e.g. metal).
- dc and ac circuits should be clearly marked.

13 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 -

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

Key installation requirements that shall apply include:

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

14 Installation of PV Array Cable between Array and Solar Controller (dc coupled System) or PV Inverter (ac coupled System)

The following minimum requirements shall apply:

- a. If the PV array has a rated output voltage greater than 120V dc (DVC-C) the PV array cables within buildings installed in: ceiling spaces, wall cavities, under floors and other hidden locations shall be enclosed in heavy-duty (HD) insulating conduit so that the risk of short-circuit is reduced. In all other locations, it shall be installed in medium-duty conduit as a minimum.
- b. PV array cables shall be installed in UV-resistant conduits if exposed to the outdoor environment.
- c. Conduits shall be installed so that they are adequately supported.
- d. Double insulation of each conductor shall be maintained within wiring enclosures (e.g. conduit).
- e. The wiring enclosure shall be labelled 'SOLAR' on the exterior surface of the enclosure at an interval not exceeding 2 metres.
- f. Where the PV array cable and conduit passes through a tile or steel roof, an appropriate collar flashing (e.g. Dektite®) shall be installed. Refer figure 24 that shows the collar flashing.
- g. Installing a conduit just through a hole in a metal roof and sealing with silicone is prohibited.



Figure 24: A Dectite® with a metal roof flashing

15 Installation of Cable Between non-MPPT Solar Controller and Battery System.

The following minimum requirements shall apply:

- a. The cables between the non-MPPT solar controller and the battery system shall have a voltage rating greater than the maximum voltage rating of the battery when being charged.
- b. The current carrying capacity of the cable between the non-MPPT solar controller and battery system shall be capable of carrying the maximum charge current from the array.
- c. The current-carrying capacity of the cable between the battery and non-MPPT solar controller shall be based on the dc current rating of the associated over-current protection.
- d. Any battery cable forming the connection between a battery system terminal and the non-MPPT solar controller, shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the associated over-current protective device
- e. The dc cables between the non-MPPT solar controller and the battery system can be single insulated if the battery system is DVC-A (that is $\leq 60V$).
- f. Cables and conduits shall be installed so that they are adequately supported.
- g. When using non-MPPT controllers, it is recommended that the voltage drop from the most remote module in the array to the battery system should be no more than 2% based on rated input current of non-MPPT solar controller and should not exceed 5% under any circumstance (refer AS/NZS 5139 clause 6.3.1.5.4).

16 Installation of Cable Between PCE and Battery System.

16.1 Installation of Cable Between MPPT Solar Controller and Battery System.

The following minimum requirements shall apply:

- a. If the PV array has a rated output voltage greater than 60V ($>DVC-A$) and the MPPT solar controller is not electrically separated between the input and output, the dc cables between the MPPT solar controller and the battery system shall be double insulated and should be in medium duty conduit.
- b. The cables between a non-separated MPPT solar controller and the battery system shall have a voltage rating greater than the maximum voltage of the array.
- c. The cables between a separated MPPT solar controller and the battery system shall have a voltage rating greater than the maximum voltage of the battery.
- d. The current carrying capacity of the cable between the MPPT solar controller and battery system shall be capable of carrying the maximum charge current from the MPPT solar controller.
- e. The current-carrying capacity of the cable between the battery system and MPPT solar controller shall be based on the dc current rating of the associated over-current protection.

- f. Any battery cable forming the connection between a battery system terminal and the MPPT solar controller, shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the associated over-current protective device.

16.2 Installation of Cable Between Battery Inverter and Battery System

This shall be in accordance with either:

- Clause 5.3.1.4 of AS/NZS 5139 for pre-assembled battery systems or
- Clause 6.3.1.5 of AS/NZS 5139 for battery systems.

The battery cable shall be flexible cable in accordance with clause 5.3.1.4.2 (or 6.3.1.5.2) of AS/NZS 5139.

The current carrying capacity of the cable shall be in accordance with clause 5.3.1.4.5 (or 6.3.1.5.5) of AS/NZS 5139, however, some general cable requirements include:

- Any battery system cable forming the connection between a battery system terminal and the respective battery system over-current protection device for the battery inverter cable, shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the associated over-current protective device.
- The current carrying capacity of the cable between the battery system and the battery inverter shall be capable of carrying the maximum current based on either the 30-minute power rating of the battery inverter (if provided) or the continuous power rating of the battery inverter.
- The current-carrying capacity of the cable between the battery system and battery inverter shall be based on the dc current rating of the associated over-current protection.

The cables shall be mechanically protected as required in clause 5.3.1.4.3 (or 6.3.1.5.3) of AS/NZS 5139.

Wiring between the battery system and the battery inverter shall meet the requirements of AS/NZS 3000 for selection and installation of wiring systems.

The cable between the battery system, the overcurrent protection device and the battery inverter should be double insulated for all battery systems operating greater than DVC-A (>60V).

16.3 Battery System Cable Sizing

Cable sizing for fault current conditions in the battery system is particularly important due to the huge currents that can be generated by modern batteries in the event of a short circuit.

Battery system manufacturers are required to provide the short circuit current (or fault current) of their battery systems as per **AS/NZS 5139:2019** Clause 3.2.3.3. If no information is available, the battery system should not be installed.

The minimum cable size (CSA) of the cable can be calculated, using the following formula.

$$A = \frac{\sqrt{I_{sc}^2 \times t}}{K}$$

where

A = Cross-sectional area of the cable (in mm²)

I_{sc} = Maximum short circuit current (in A)

t = Duration of short circuit current (in s): this is determined by the tripping operation of the

overcurrent device

K = Constant from AS/NZS 3008.1.1:2017 clause 5.3

Refer to figure 25 for the battery system cable terminologies and potential locations of overcurrent protection device/disconnection device.

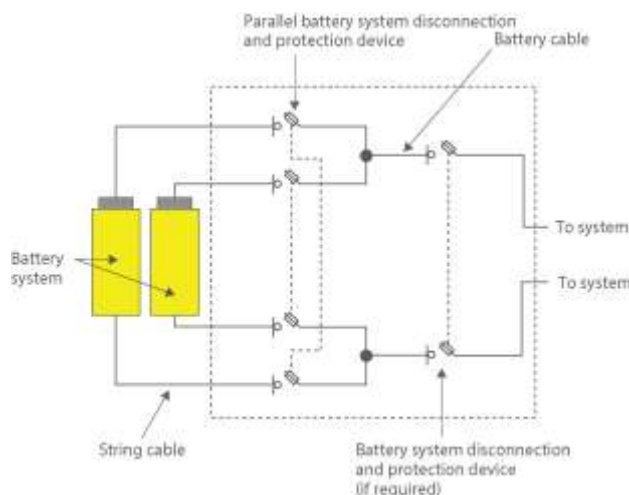


Figure 25: Battery system protection and cable sizing.

Worked Example 2

A battery system comprises a single battery system with a maximum fault current of 3,450 A. The battery cabling is copper wire sheathed in V-75 PVC insulation, with a maximum expected operating temperature of 70 °C (158 °F). The protection devices will operate within 1 second of a fault current.

Using an initial temperature of 70 °C (158 °F) and a final temperature of 160 °C (320 °F) (from the relevant standards, 160 °C (320 °F) is the maximum temperature able to be withstood by both copper and PVC V-75), K = 115. AS/NZS 3008.1.1:2017 Clause 5.3.

$$A = \frac{\sqrt{3450^2 \times 1}}{115}$$
$$A = 30 \text{ mm}^2$$

The calculated cross-sectional area of the battery cables is 30 mm², hence a minimum 35mm² battery cable could be used. However, it is also advisable to confirm with the manufacturer's installation manual on any battery system cable recommendations.

16.4 Installation of Cables to Parallel Battery Systems

- Battery systems that comprise individual battery systems connected in parallel shall not have the wiring of the battery systems in a daisy-chain, as shown in Figure 26, that is from battery system to another such that only one battery system is directly connected to the equipment e.g. solar controller or battery inverter.

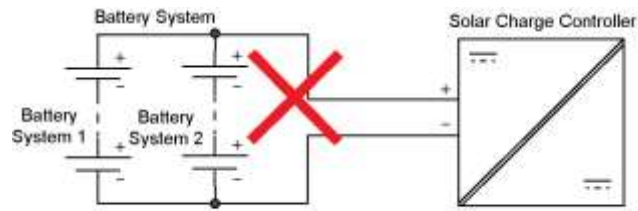


Figure 26: Daisy chained battery systems

- Within a battery system comprising battery systems in parallel, the cables from each individual battery system to a charging source (solar controller) and load source (inverter and solar controller) shall be the same resistance. This is achieved by having the same cable lengths between the battery system terminals of each battery system and the charging and load sources. Examples of how to achieve this are shown in Figures 27, 28 and 29. The cross-sectional area of the cables must also be the same and though only the solar controller is shown in the drawings this shall be repeated for the battery inverter.

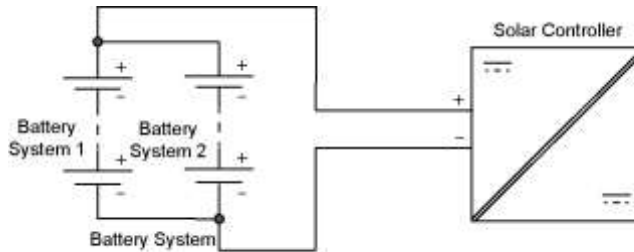


Figure 27: Example of correct cabling of parallel battery systems

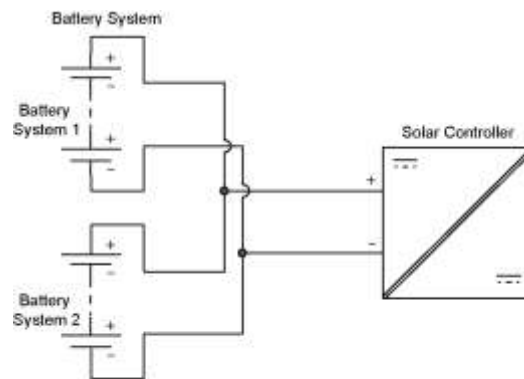


Figure 28: Example of correct cabling of parallel battery systems

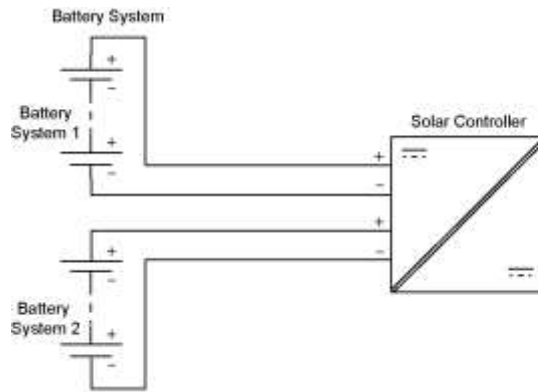


Figure 29: Example of correct cabling of parallel battery systems

17 Cable Joints and Termination

- A faulty cable joint and termination causes loose connection or short circuit.
- Unnecessary cable joints to be avoided by carrying out pre-installation site survey and measurement of cable route.
- All wire connections, switches, receptacles and breakers should be mounted in electrical boxes. If box is mounted outdoor, minimum ingress protection rating should be IP56 (Refer AS/NZS 5033 Clause 4.4.6).
- Male and female part of the connectors must be of same type/ model and from the same manufacturer.
- Use appropriate size and type of cable lugs in all cable terminals.
- Do not terminate cable without cable lug.
- Use heavy duty industrial type crimping tool or as recommended by the connector manufacturer.

18 Voltage Drop

- The voltage drop between the PV array and the battery system should never exceed 5%
- The voltage drop between the battery system and any DC load should never exceed 5%

18.1 Calculating Voltage Drop for Systems that Include non-MPPT Solar Controllers

This section is for systems that are using non-MPPT solar controllers.

Resistivity Method

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:

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

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

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 $\Omega/\text{m}/\text{mm}^2$

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

V_{batt} = the nominal voltage of the battery system which is the dc system voltage.

For PV arrays connected to a non-MPPT controller, the current is the short circuit current (I_{sc}) of the string, sub-array or array. The battery system's voltage is the nominal battery system voltage of the battery system.

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

Table 5: Resistivity for different cables ($\Omega/\text{m}/\text{mm}^2$)

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 3

A solar array has been installed and the distance between the output of the array and the non-MPPT solar controller is 10 metres. The short circuit current of the array is 9.6A.

The cable has a cross-sectional area of 10 mm^2

The cable is copper, insulation type is XLPE rated for 90°C (194°F) with a resistivity of 0.0219 ohms/metres/ mm^2

The battery system voltage of the system is 24V.

$$\begin{aligned} V_d &= \frac{2 \times L_{\text{CABLE}} \times I \times \rho}{A_{\text{CABLE}}} \\ &= 2 \times 10 \times 9.6 \times 0.0219 / 10 \text{ V} \\ &= 0.42 \text{ V} \end{aligned}$$

$$\begin{aligned} \text{Voltage Drop in percentage} &= \frac{V_d}{V_{\text{Batt}}} \times 100 \\ &= 0.42 / 24 \times 100 \\ &= 1.75\% \end{aligned}$$

18.2 Calculating Voltage Drop for Systems that Include a MPPT

This section is for systems that are using Maximum Power Point Trackers (MPPT) type solar controllers (dc coupled) or a PV inverter that includes an MPPT controller (ac coupled).

Resistivity Method

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:

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

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

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 $\Omega/\text{m}/\text{mm}^2$
- A_{CABLE} = cross sectional area (CSA) of cable in mm^2 .
- V_{MP} = Maximum Power Point voltage in Volts.

For PV arrays connected to a MPPT type solar controller (dc coupled) or PV inverter (ac coupled) 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}).

Worked Example 4:

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.

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

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

$$= 1.50\text{V}$$

$$\text{Voltage Drop in percentage} = \frac{V_d}{V_{\text{MP}}} \times 100$$

$$= 1.50/472 \times 100\%$$

$$= 0.32\%$$

18.3 Alternative AS/NZS 3008 method

Alternatively, the method stated in section 4 of AS/NZS 3008.1 could also be used for ac and dc cables of the off-grid PV system. This method is commonly used for ac cables.

AS/NZS 3008 Method

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

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 7. 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 6: Three-phase V_c for single-core flexible cable (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

The percentage voltage drop and cable sizes could be verified using online tools based on AS/NZS 3008 method from the following link:

<https://www.jcalc.net/cable-sizing-calculator-as3008>

Worked Example 5:

Using Table 7, determine the voltage drop and percentage voltage drop for the array cable where:
Selected cable size is 4mm². (From Table 7, the three-phase V_c value is 10.9 mV/Am)

Route length = 10 m,

Maximum current (I_{sc}) = 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 6:

10.9 x 1.155 = 12.59 mV/Am (single phase)

$V_d = (10 \text{ m} \times 13.73 \text{ A} \times 12.59 \text{ mV/Am}) / 1000 = 1.73\text{V}$

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

19 Protection Requirements

All cables shall be electrically protected from fault currents that could occur.

Figures 30, 31, 32 and 33 show the typical protection and isolation (switch-disconnection) requirements in dc and ac coupled systems.

Note: Historically the battery system protection devices were a fuse switch-disconnector however the price of dc rated circuit breakers has reduced sufficiently that they are now the preferred disconnection and protection device.

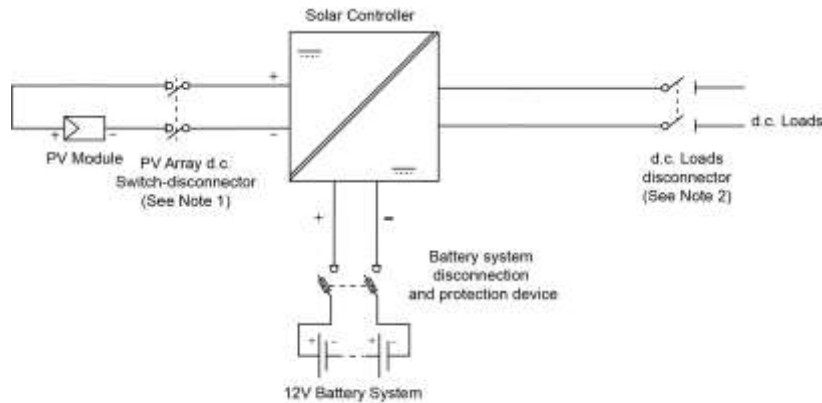


Figure 30: dc coupled - simple dc only system (typical for rural residences)

Notes:

1. A PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting. However, many standards allow the battery system switch fuse to meet the isolation requirement. If a PV array switch disconnector is installed it will be required to be a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery system.
2. A loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting. However, the battery system disconnection device can meet the isolation requirement. If a load switch disconnector is installed it will be required to be a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the load cables.

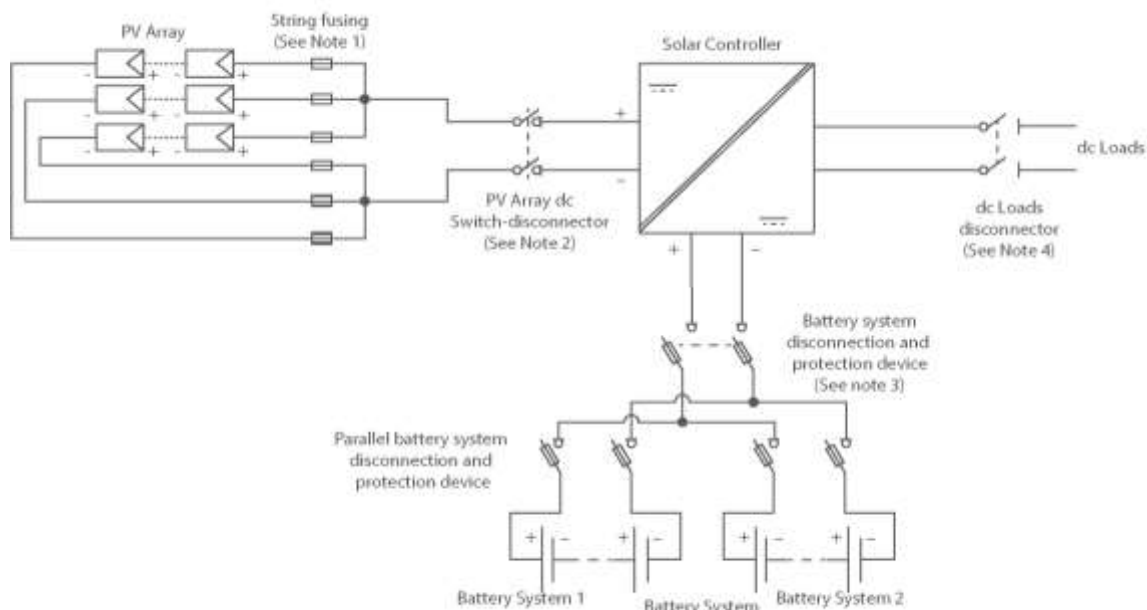


Figure 31: dc coupled - larger dc only system

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 19.2.).
2. The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery system switch fuse to meet the isolation requirement. If the PV switch disconnector is installed it will be required to be a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery system.
3. Battery systems in parallel each require their own isolation and protection devices. Over-current protection is required for the battery system cable when the current-carrying capacity of the battery system cable is less than the sum of all individual battery over-current protection devices. A battery system switch disconnecting device is recommended because it allows the disconnection of the complete battery system via the one switch disconnector.
4. The loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery system switch-fuse to meet the isolation requirement. If the loads switch disconnector is installed it will be required to be a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the load cables.

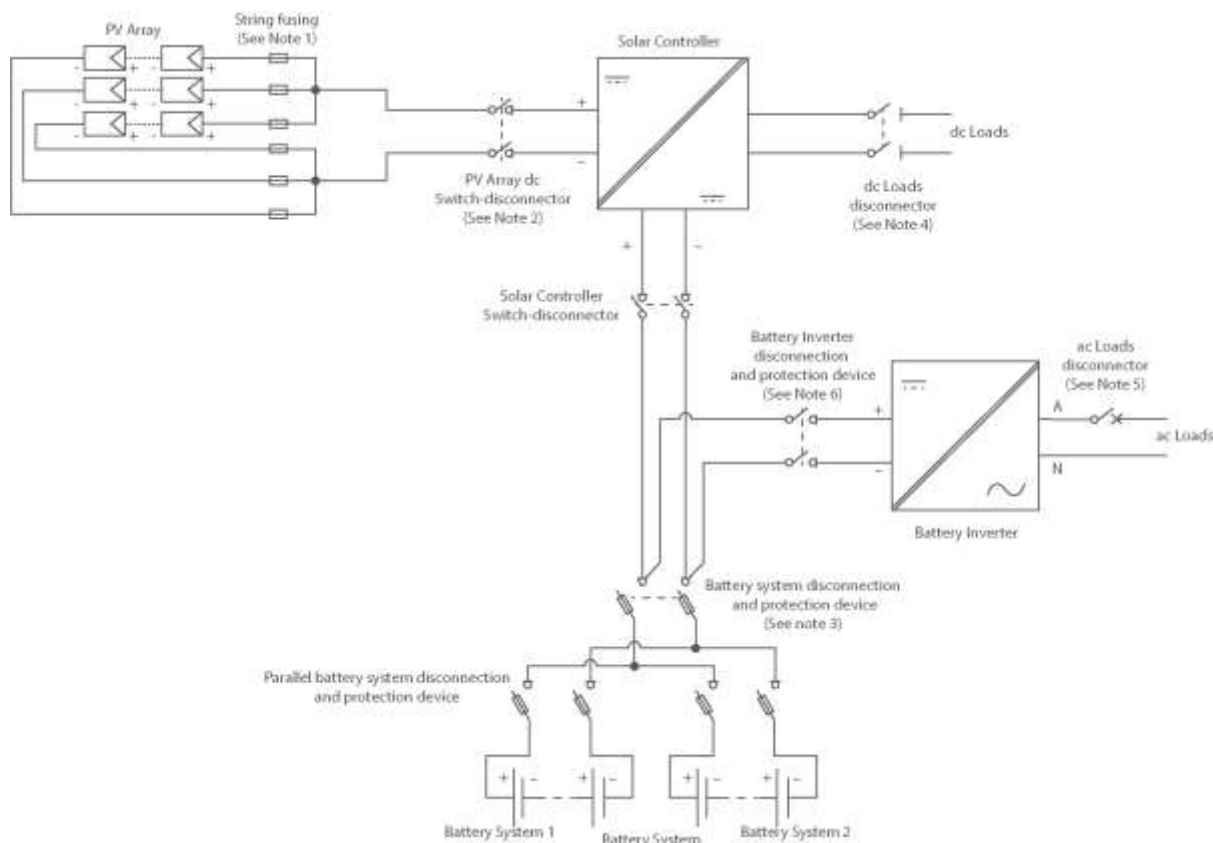


Figure 32: dc coupled with dc and ac Loads

Notes:

- 1.** String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 19.2.).
- 2.** The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery system switch fuse to meet the isolation requirement. If the PV switch disconnector is installed it will be required as a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the PV array cables and the solar controller allows backfeed from the battery system.
- 3.** Battery systems with parallel battery systems each require their own isolation and protection devices. Over-current protection is required for the battery system cable when the current-carrying capacity of the battery system cable is less than the sum of all individual over-current protection devices. A battery system switch disconnection device is recommended because it allows the disconnection of the complete battery system via the one switch disconnector. Sometimes this might be a four (4) pole device to allow different size fuses to protect the inverter cable and the solar controller cable which will be generally be different cross-sectional areas (or gauges)
- 4.** The loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery system disconnection device to meet the isolation requirement. If the loads switch disconnector is installed it will be required to be a protection device (e.g. a non-polarised dc circuit breaker) if the battery system protection ratings are greater than the current carrying capability of the load cables.
- 5.** A separate ac load disconnect is required if the battery inverter does not have a switch disconnector on the ac output. This will be required as a protection device (e.g. an ac circuit breaker) for protecting the ac load cable.
- 6.** Battery inverter switch disconnector – Note that overcurrent protection is required to be installed at the battery system port of the inverter if

- a. the inverters charging (or load) current under fault current is greater than the current carrying capacity of the cable between the battery system and inverter and
- b. the length of cable to the inverter is greater than 3 metres from the battery systems overcurrent protection device.

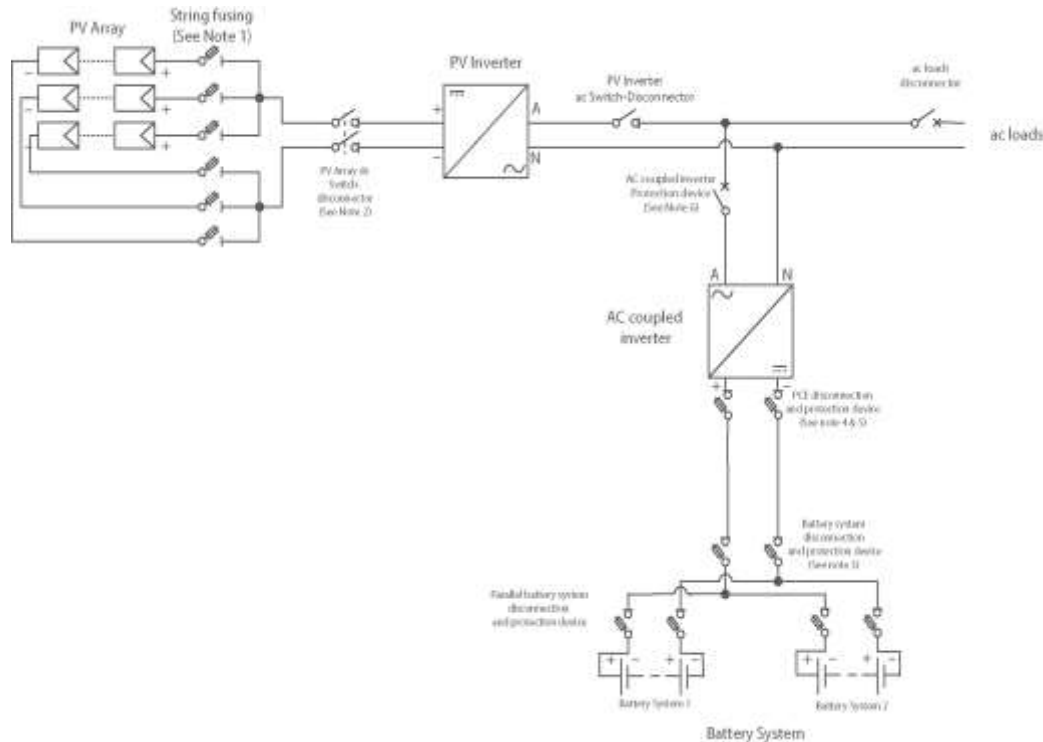


Figure 33: ac coupled with ac loads

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 19.2).
2. A PV array dc switch disconnector is required but it can be part of the PV inverter (refer to Section 20.2).
3. Battery systems with parallel battery systems each require their own isolation and protection devices. Over-current protection is required for the battery system cable when the current-carrying capacity of the battery system cable is less than the sum of all individual battery systems over-current protection devices. A battery system switch disconnecting device is recommended because it allows the disconnection of the complete battery systems using only one switch disconnector.
4. Overcurrent protection is required to be installed at the battery system port of the inverter if
 - c. the inverters charging (or load) current under fault current is greater than the current carrying capacity of the cable between the battery system and inverter and
 - d. the length of cable to the inverter is greater than 3 metres from the battery systems overcurrent protection device.
5. If the cable between the battery system and battery inverter is greater than 2 metres then an isolating device is required at the inverter.
6. A separate ac coupled inverter disconnect device is required if the battery inverter does not have a switch disconnector on the ac output. This will be required to be a protection device (e.g. ac circuit breaker) for protecting the ac load cable.

19.1 PV 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.

19.2 Solar Array dc Cable Protection

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

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 off-grid PV systems shall comply with these requirements.

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:

$$\begin{aligned} I_{F \text{ STRING}} + I_{BF \text{ TOTAL}} &> I_{MOD \text{ MAX OCPR}} \\ \text{(When simplified)} \\ (S_A - 1) \times I_{STRING \text{ MAX}} + I_{BF_TOTAL} &> I_{MOD_MAX_OCPR} \\ (S_A - 1) \times 1.25 \times K_I \times I_{SC_MOD} + I_{BF_TOTAL} &> I_{MOD_MAX_OCPR} \end{aligned}$$

Where:

- $I_{BF \text{ TOTAL}}$ = 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.
- $I_{MOD \text{ MAX OCPR}}$ = 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:

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

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

2. Where all PV modules have DCUs attached:

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

3. Where only some PV modules have DCUs attached:

Comply with both of the previous formulas

Where:

- $I_{\text{STRING MAX}}$ (if no DCUs) = $1.25 \times K_I \times I_{\text{SC MOD}}$
- $I_{\text{MOD MAX OCPR}}$ = 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.
- $I_{\text{DCU OCPR}}$ = DCU maximum overcurrent protection rating as determined by the DCU manufacturer

Worked Example 6

A PV system has 3 strings of PV modules, and no DCUs. The modules have a I_{SC} of 9.8 A and an $I_{\text{MAX OCPR}}$ 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:

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

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

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

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

24.5 A + 3 A > 20 A → TRUE, so string overcurrent protection is required.

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

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

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

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

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.

Sub-array protection

Where no sub-array and array protection are required, cable size should be calculated using Clause 4.4.2 (AS/NZS 5033).

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:

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

Where:

S_{SA} = strings in parallel in the sub-array.

$I_{STRING\ MAX}$ (if no DCUs) = $1.25 \times K_I \times I_{SC\ MOD}$

Array protection

Array overcurrent protection is designed to protect the entire PV array from external fault currents. For off grid systems this can only occur in dc coupled systems when the solar controller (non-MPPT solar controller or MPPT) allows fault current from the battery system to back-feed through the controller.

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) = $1.25 \times K_I \times I_{SC\ MOD}$

19.3 Battery System Cable Protection – dc coupled – dc loads only

For dc coupled systems with dc loads only, as shown in Figures 30 and 31, the only battery system cables are those between the battery system and the solar controller. The protection devices will be rated to allow the maximum charge current provided by the solar controller and the maximum dc load current that is to be provided by the solar controller.

19.4 Battery System Cable Protection - dc coupled – ac and dc loads

dc coupled systems with ac and dc loads as shown in Figure 32 can potentially have two different sized battery cables:

1. The battery cable between the battery system and the solar controller.
2. The battery cable between the battery system and the battery inverter.

The protection devices for the cable connected to the solar controller from the battery system will be rated to allow the maximum charge current provided by the solar controller to the battery system and the maximum dc load current that is to be provided at the output of the solar controller, whichever is larger. This protection device will need to be suited for motors if there are any dc motors connected to the system. These fuses are a specific type to allow for the motor surge capability.

The protection device for the battery cable to an inverter will be determined via the process defined in section 19.6.

19.5 Battery Cable Protection – ac coupled

ac coupled systems as shown in Figure 33 only have one set of cables from the battery system and that is to the battery inverter.

The protection device for the battery inverter will be determined via the process defined in section 19.6.

19.6 Battery System Cable Protection - Battery Inverter

Usually, the dc coupled/ac coupled inverter/battery inverter manufacturers recommend cable overcurrent protection rating for the battery system cable for the correct/reliable operation of the system, hence the recommendations shall be applied.

If this has not been provided, refer to the following to select the appropriate system protection for the cable to the battery inverter:

To select the appropriate battery protection for the cable to the battery inverter:

1. Obtain the battery inverter manufacturer's data of:

- Continuous power rating (Watts)
- 3 to 10 second surge rating (Watts)
- Average inverter efficiency (%)

2. Obtain Time-Current characteristics for the overload protection to be used.

[All manufacturers publish time-current information for their circuit breaker and HRC fuse ranges]

3. For each inverter power rating determine the current drawn from the battery system using:

$$I = \frac{\text{Inverter Power Rating (W)}}{(\text{inverter efficiency} \times \text{nominal system voltage})}$$

4. Consult the Time-Current characteristic of available overload protection devices to determine the device with an appropriate rating that matches the maximum load and maximum load surge characteristics.

The inverter protection device (if a switch fuse or suitably rated dc circuit breaker) will typically be used as the main battery disconnection device and smaller protection devices will be needed for the protection of the solar controller (in the case of a dc coupled system). These smaller would be placed on the output side of the main battery disconnection device and in the circuit for dc cable to the solar controller.

For dc coupled systems where the inverter protection is being used for the main battery system protection and there are dc loads (connected to the solar controller) then the sizing of the inverter cable protection device shall be sized to meet the current requirements of the inverter (as above) plus any significant dc loads being supplied by the solar controller.

For both dc and ac coupled systems often the battery inverter can also act as a battery charger (such as when an ac generator has been connected). In that case, the battery inverter fuse is being used as a main battery fuse during charging, so the maximum charge current could be greater than the maximum load current. In this situation the larger of the load current or the charging current will be the determining factor for the protection device rating.

20 Disconnection (Isolation) Requirements

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

- A battery system switch disconnector between the battery system and the solar controller (if installed).
- A battery system switch disconnector between the battery system and the battery inverter (if installed).
- A PV array dc switch disconnector located near the MPPT solar controller when the array maximum voltage is greater than 60V (>DVC A),
- A PV array dc switch disconnector (this could be part of the PV inverter) located near the PV inverter (AC coupled).

Note: these dc switch disconnectors *must be designed for the dc voltage being seen by the switch*. Switches, relays or circuit breakers intended for ac use or for lower dc voltages must not be used as arcing and possible fire damage may result. Refer to section 20.5 for the specific requirements for the battery system switch disconnectors.

It is recommended that a PV array dc switch disconnector be installed near a non-MPPT solar controller— although the battery system isolator is accepted by most standards as meeting this function. This switch disconnector is invaluable when fault finding a system.

There should be a switch disconnector for the dc loads being supplied directly by the system.

Battery inverters generally have a built-in switch disconnector at the ac output. If the unit(s) that are installed do not, it is recommended to install one on the ac output of each battery inverter.

Note: Though the disconnection devices are switch disconnectors the signs shall use the word “isolators” for simplicity and consistency with most published standards.

20.1 Disconnection Requirements Within an Array

- Every string within a PV array shall be capable of being individually disconnected (isolated) from the rest of the system. This disconnection does not have to be one rated for load breaking. The module connectors can perform this function. However, if the module connectors are used it is critical that they do say on them “Do Not Break Under Load”. They can only be disconnected after the main PV array switch disconnector is opened and there is no load on the module connectors.
- Sub-arrays shall be capable of being individually disconnected (isolated) from the rest of the system. It is recommended that this uses a load-break switch disconnector.

20.2 PV Array DC Switch Disconnector near PV Inverter and MPPT (if array is LV)

- According to clause 4.5.3 of AS/NZS 5033, there shall be a load break disconnection device at the solar controller/PV inverter to break the current on PV dc circuits. This could be achieved by either:
 - An adjacent and physically separate load break disconnection device in accordance with Clause 4.3.4.2 (AS/NZS 5033) or
 - A load break disconnection device that is part of and within the PV inverter, where the device and the PV inverter conform to AS/NZS 4777.2.
- Where multiple disconnection devices are required to isolate the array(s) from the PV inverter(s) or MPPT'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 all the multiple supplies in order to isolate the equipment.
 - Where there is more than one isolator, they shall be individually labelled e.g. “PV Array DC isolator inverter 1” and “MPPT A” or “MPPT 1”
- Where strings are paralleled at the PV inverter or MPPT, it is recommended that this occurs on the PV inverter or MPPT side of the disconnection device or in the PV inverter/MPPT itself as shown in Figure 34.

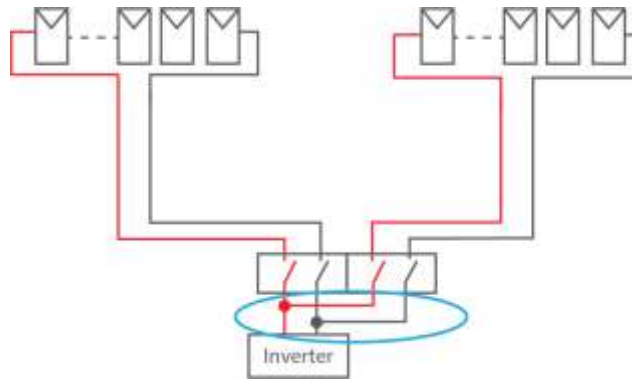


Figure 34: Paralleling strings on inverter/MPPT side of PV array disconnecter devices

Note: In Figure 34 the inverter could also be an MPPT.

- 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 cable entries into the switch-disconnector and cable drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 25.6.

20.3 PV Array DC Switch Disconnecter near Non-MPPT Solar Controller

For DVC-A systems ($\leq 60V$) this is optional since the battery system switch disconnector meets the requirements. However, if a switch disconnector is installed it should meet the following requirements:

- All PV array switch-disconnectors shall be capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like.
- Where multiple disconnection devices are required to isolate the array(s) from the solar controller(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 all the multiple supplies to isolate the equipment.
 - Where there are more than one isolator, they shall be individually labelled e.g. "PV Array DC isolator Solar Controller 1"
- 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 cable entries into the switch-disconnector and cable drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 20.6.

20.4 Load Disconnection Requirements

- All dc and ac load circuits shall be capable of being isolated.
- For dc loads this could be performed by the controller and for dc only systems this could be the battery system switch disconnector. However, it is recommended that a separate dc switch disconnector is located in the load output cables from the solar controller.
- For dc coupled systems with ac loads, ac switch disconnectors should be located in the output cables from battery inverter unless there is an ac switch disconnector included on the inverter.
- For ac coupled systems, ac switch disconnectors should be located in the output cables from
 - a battery inverter,
 - a PV inverter.
- dc load switch disconnectors shall meet the requirements of 20.6

- ac load switch disconnectors shall meet the standard requirements for ac switch disconnectors as required in AS/NZS 3000 and have minimum current ratings equivalent to the rated output current of the battery inverter and/or PV inverter.

20.5 Battery System Switch Disconnection Device Requirements

For battery system switch disconnectors, according to clause 5.3.1.3.3 and 6.3.1.3.3 of AS/NZS 5139, the disconnection device shall:

- Conform to AS 60947.3;
- Be of the non-polarized type;
- Be dc rated;
- Have a voltage rating greater than the battery system's maximum voltage under all operating conditions;
- Be rated to withstand the maximum short-circuit current;
- Have a current rating greater than the maximum d.c. current for the BESS;
- Be rated to interrupt for full load;
- Meet the requirements of AS/NZS 3000: 2018 Section 2 for isolating device selection;
- Be rated for independent manual operation;
- Have a minimum pollution degree 3 classification;
- Be able to be secured in the open position and only secured when the main contacts are in the open position.
- Conform to requirements for isolation including marking requirements for an isolation device; and
- Have a Utilisation category of at least DC21B.

20.6 dc PV Switch-Disconnector Requirements

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

- be rated for dc use.
- Be 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.

21 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 dc 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 dc cables.

- Conductive cable support systems or conductive wiring enclosures that are directly in contact with the PV dc cables.
- Where the calculated PV dc 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:
 - by a purpose-made fitting providing earthing or bonding connections for dissimilar metals and fitted to the manufacturer's instructions, or
 - 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
 - Tinned cable lugs of earthing and bonding cables fixed by stainless steel bolts washers and star washers to aluminium frames.
 - 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 (figure 35) also prevents galvanic corrosion between the aluminium mounting structure and the copper earthing cable.



Figure 35 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 ac cables going to the switchboard or distribution board (ac coupled).
- 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 ac output cable provided the following conditions are met:
 - Installation is not subject to lightning
 - Inverter ac 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 an 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 0.5Ω 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 dc 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).

22 Earthing of Battery System

Four different categories of earthing arrangements for battery systems are detailed in clauses 5.3.1.6 ad 6.3.1.7 of AS/NZS5139. If a battery system is to be earthed then the relevant arrangements shall be followed.

Inverter and battery system manufacturer's instructions shall be followed to determine the best earthing arrangement. If a battery system is to be earthed then the relevant arrangements as shown in AS/NZS 5139 shall be followed.

Pre-assembled battery systems and battery systems connected to battery inverter that do not have separation between the dc battery port and ac grid port shall not be earthed.

AS/NZS5139 Clauses 5.3.1.7 and 6.3.1.8 details when earthing or bonding of metallic enclosure is required for the different earthing arrangements when the battery system is operating at voltages greater than DVC-A.

Earth fault alarms might need to be installed for some systems operating at DVC-B or DVC-C as detailed in AS/NZS5139 clause 5.3.1.8 and 6.3.1.9.

23 Shutdown Procedure

- A shutdown procedure is required to ensure safe de-energisation of the system.
- 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 dc isolator 2”, “Battery System Isolator 3”.
- In general, the shutdown procedure shall require the system to be shut down in the following order:
 - Isolation of PV input. (locations should be specified)
 - Isolation of the ac loads and also dc loads
 - Isolation of the battery system by opening battery system switch-fuse or opening battery system circuit breakers.

24 Metering

As a minimum each system should have meters showing:

- battery system voltage.
- Battery system charge current from solar.
- PV array output current
- PV array output voltage
- load current from the battery system

25 Signage

The shutdown procedure sign as described in section 23 shall be located at the main switchboard and near the equipment that should be shutdown.

The signage requirements recommended in AS/NZS 5033 (Clause 5.3) shall be complied with in the installation of the off-grid PV power system. The following signage is required for the PV section of the off-grid PV Power system:

- If the PV inverter in an ac coupled systems connects to the main switchboard or a distribution board, a sign should be included in the main switchboard and distribution board 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 PV inverter.
- A sign with text ‘MAIN SWITCH (BATTERY INVERTER SUPPLY)’ shall be permanently fixed adjacent to the main switch for the battery inverter off-grid supply.
- Where the PV inverter in an ac coupled is connected to a distribution switchboard that is supplied with the battery inverter power from the off-grid system, a sign with text ‘MAIN ISOLATOR (BATTERY INVERTER SUPPLY)’ (could be called normal supply) shall be permanently fixed adjacent to the isolator for the normal supply to the distribution switchboard.
- If the PV inverter is connected to the main switchboard and not mounted near the main switchboard, then there should be a sign in the switchboard stating where the inverter is located.
- There should be a sign on the main switchboard stating the location of the PV array, the maximum dc array short circuit current and array open circuit voltage from the system.
- PV dc 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 dc VOLTAGE’ on the cover.
- A sign with text ‘PV ARRAY dc 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 DC SOURCES’ and ‘TURN OFF ALL DC 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.

The following signage is required for the battery system section of the off-grid PV Power system:

- A sign indicating that battery systems are installed shall present a circular green reflector sign with the letters “ES” on or immediately adjacent to the main switchboard. Under the “ES” lettering, United Nations number for the primary chemistry shall be included e.g. UN 3480.
- A sign for battery system location layout. An example is shown in figure 36.

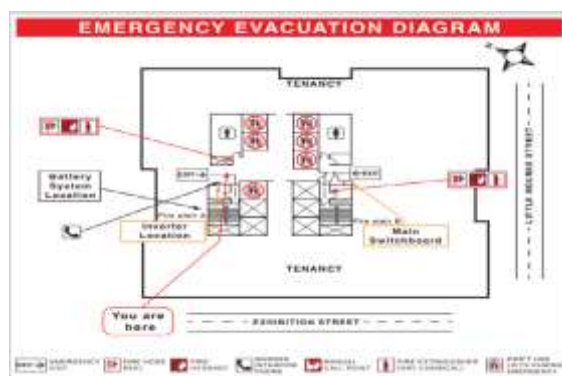


Figure 36: Battery system location layout.

- A sign pertaining to restricted access for battery systems that are accessible within an enclosure or room shall have a sign which designates “Danger”, “restricted access” mounted either adjacent to the enclosure/door.
- A sign stating voltage and current shall be mounted adjacent to the enclosure or on doors and shall include the following:
 - “Battery System”
 - Short circuit current (Amps)
 - Maximum d.c voltage (Volts)
- For all battery systems categorized as explosive gas hazards shall have a “Danger”, “Risk of Explosion” sign installed in a suitable position.



Figure 37: Example of risk and battery explosions warning sign.

- For all battery systems categorized as toxic fume hazard shall have a “Danger”, “Toxic fumes” sign installed.
- For all battery systems categorized as chemical hazards shall carry a sign specifying what to do if body parts (such as skin, eyes, etc) are exposed to the chemical.



Figure 38: Example of electrolyte burns signs.

- For battery systems categorized as having an arc flash hazard above “minor” shall carry a warning sign to indicate the dangers of arc flash.
- All disconnectors shall be labelled and where there is more than one, numbered. For example:
 - Battery system dc disconnector 1.
 - Battery system dc disconnector 2.
- A sign showing the proper Shutdown Procedure shall be located near the system.
- Battery system cables shall be labelled “BATTERY” at intervals less than 2 m.
- The battery safety datasheet (SDS) shall be included within a document holder at the main switchboard or meter box and where installed, at the fire control and indicator panel.

26 Commissioning

The commissioning sheets provided with these guidelines (Appendix 1) should be completed by the installer. A completed copy shall be provided to the customer as part of the system documentation and a copy retained by the installer that has been initialled by the customer showing it to be a true copy of the commissioning sheets provided to the customer.

26.1 PV Array Short Circuit Current Measurement for Arrays Greater than DVC-A

Where short circuit currents are required to be measured, undertake the following steps to measure the short circuit current safely as shown in Figure 39.

- Ensure each string fuse (where required) is not connected or that any LV array is disconnected somewhere in each string as shown in Figure 13 of these guidelines.
- Leave the 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 13) to complete the wiring of the string. Turn on PV array switch disconnector and using a dc. clamp meter,

measure the dc short circuit current for String 1. Turn off the PV array switch disconnecter. Disconnect the string fuse for string 1 or remove the disconnecter to break the string circuit.

- Repeat for each string

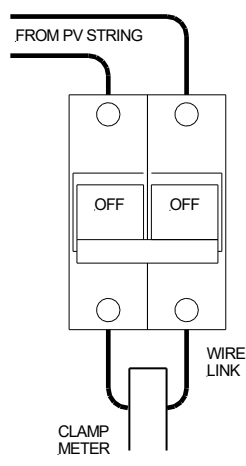


Figure 39: Measuring Short Circuit current

26.2 PV Array Insulation Resistance Measurement

Warning: PV array dc circuits are live during daylight and unlike conventional ac circuits cannot be isolated before performing this test.

This test is required for all arrays where the maximum array voltage is LV, that is, greater than DVC-C. 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 8 shows the minimum values that should be achieved for different array voltages.

Table 7: Minimum Insulation Resistance

ARRAY VOLTAGE (V X 1.25)	TEST VOLTAGE	MINIMUM INSULATION RESISTANCE, MΩ
< 120	250	0.5
120 – 500	500	1
> 500	1000	1

27 Documentation

All complex systems require a user manual for the customer, off Grid PV power systems are no exception.

The documentation for system installation that shall be provided includes:

- List of equipment supplied with each item's model, description and serial number
- List of action to be taken in the event of an earth fault alarm
- Battery system information including total storage capacity, address and contact details for the manufacturer's representative, UN Number for the battery cell or battery system, commissioning date, system provider contact details, etc.

- Start-up procedure and verification checks.
- Operating instructions and a description of the function and operation of all installed equipment.
- Shutdown and isolation procedures for emergencies and for maintenance. Instructions on how to identify when the system is not operating correctly and what to do in case of a system failure.
- Commissioning sheet and installation checklist
- Warranty information
- A basic connection diagram that includes electrical ratings of the PV array, the battery system, the solar controllers, battery inverters, PV inverters and the ratings of all overcurrent devices and switches as installed
- System performance estimate including completed load assessment forms.
- Recommended maintenance procedures and timetable for the installed system
- Equipment manufacturer's documentation, datasheets, safety data sheets for batteries and handbooks for all equipment supplied
- Array frame engineering certificate for wind and mechanical loading
- Installer/designer's declaration of compliance
- A copy of risk assessment undertaken including information on specific requirements to address all risks (for example, the action to take when toxic fumes are present).
- Decommissioning information for battery system replacement or battery system removal including safe handling procedures for the battery system and recommendations for recycling.

PART 2-HYBRID SYSTEMS

28 Installation of Hybrid Systems

The installation requirements of the PV array, battery system, battery inverter and balance of system components are contained in Part 1. The relevant sections are referred to below and this section only highlights the specific installation requirements of the generator and any additional requirements needed to integrate the generator into a hybrid off-grid system installation.

How the generator interconnects within the hybrid system depends on the type of battery inverter, the load characteristics and the size of the system. Figure 40 to Figure 43 show typical configurations for PV/generator hybrid systems.

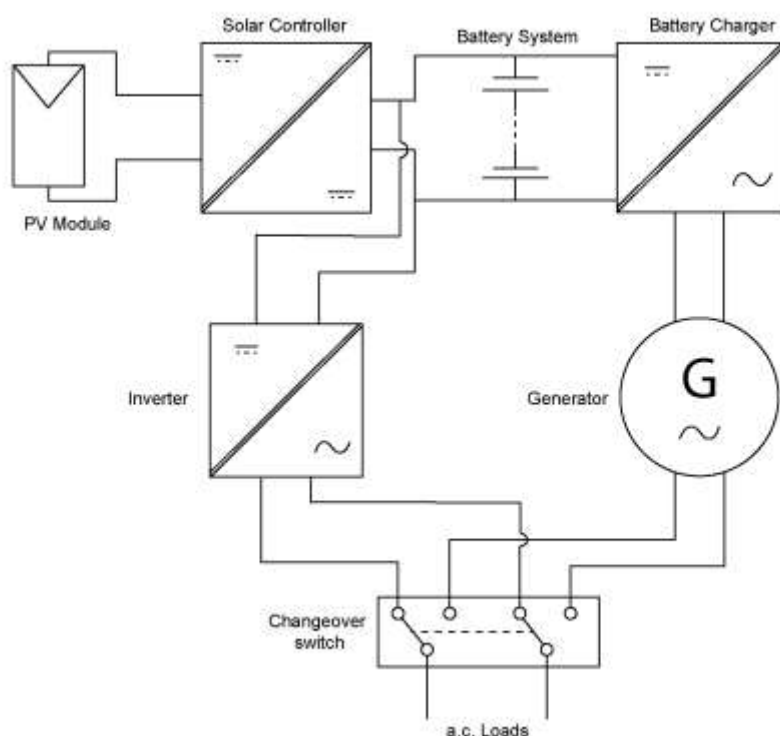


Figure 40: Generator connected to both the battery system (via a battery charger) and the loads (via a changeover switch)

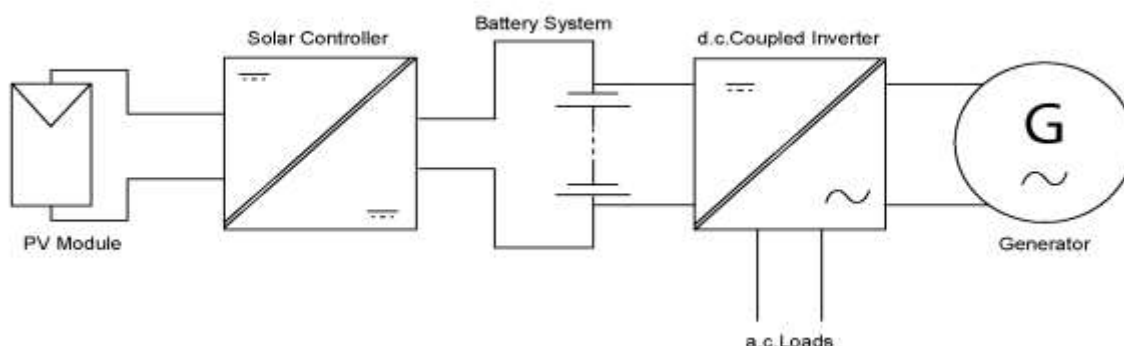


Figure 41: Generator connected to an inverter/charger or an interactive dc coupled inverter connecting as a dc coupled system.

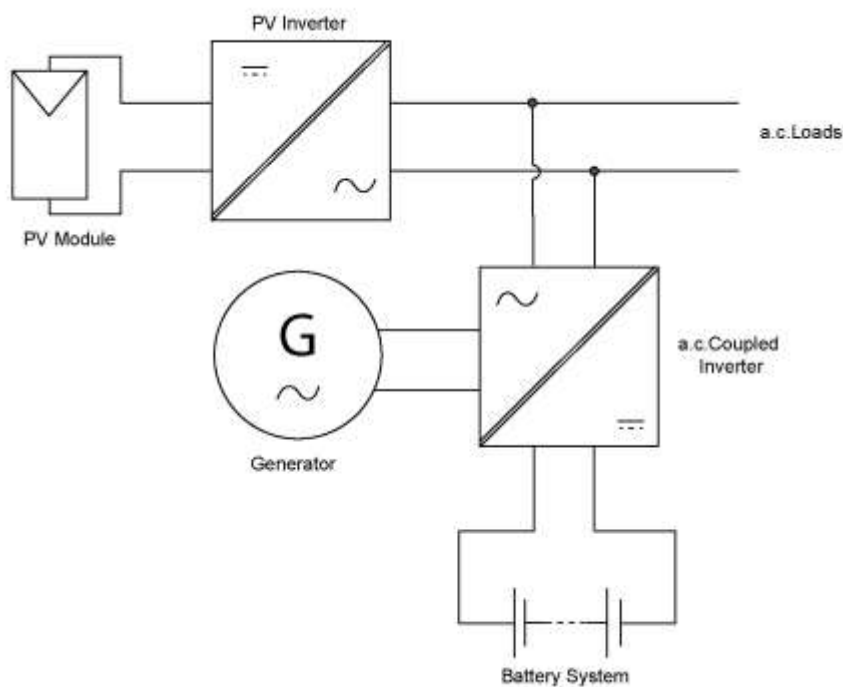


Figure 42: Generator connected to an ac coupled inverter connecting as an ac coupled system

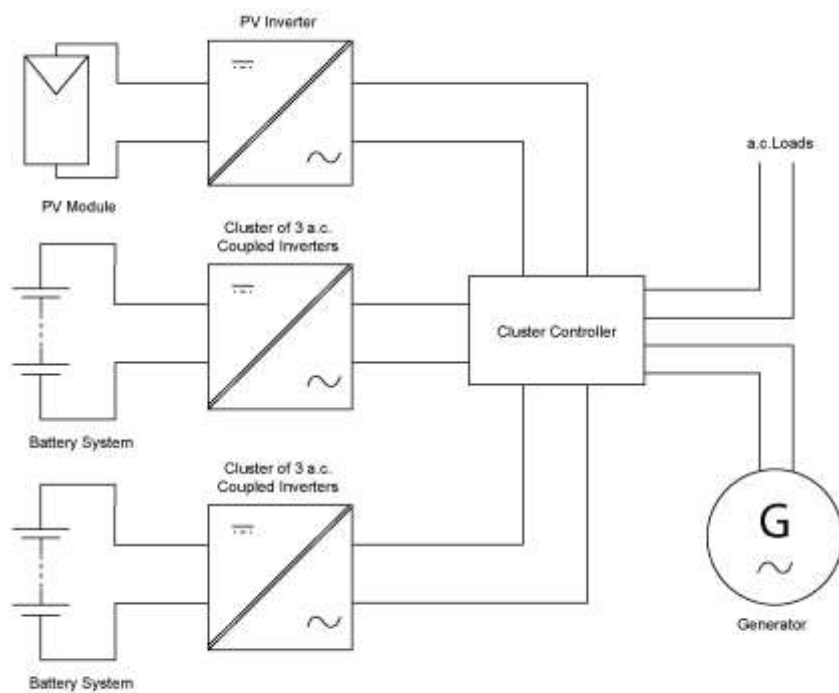


Figure 43: ac coupled system with multiple inverters connected to a cluster controller with the generator connected to it.

Certain models of ac coupled inverters require a cluster controller or cluster box for interconnecting the multiple ac generating devices. These are generally required when there are numerous clusters of ac coupled inverters in parallel. Each cluster comprise 3 single phase inverters providing 3 phases.

The cluster controller (or box) is provided by the manufacturer of the ac coupled inverter and the installer shall follow the installation requirements of the manufacturer. Note that Figure 43 shows the PV inverter connected to the cluster controller. The PV inverter can also be connected directly onto the ac load line and the PV system does not need to be located in the same location as the rest of the system (battery system, ac coupled inverters, cluster control and generator)

28.1 Array Installation

Refer to Section 4 for the installation of PV arrays. Depending on the size of the PV array with the hybrid system, the PV array may be broken into many sections each with their own separate solar controller and/or PV inverter.

28.2 Battery System Installation

Refer to Sections 5.1 to 5.3 on battery system hazards, selecting a pre-assembled battery system, selecting a battery system, installation of preassembled battery system and installation of battery system. Refer to Section 5.3.2.9 on the ventilation requirements (for lead acid battery systems).

In larger hybrid systems comprising multi cluster inverters, the system may be made up of a number of individual battery banks each connected to their own cluster of battery inverters and PV arrays.

28.3 Solar Controller and/or PV Inverter Installation

Refer to Section 6 for the installation of solar controllers and Section 7 for the installation of PV inverters.

If the PV array installation does include multiple solar controllers, then the number of controllers in parallel shall not be greater than that recommended by the manufacturer and the relevant intercommunications wiring shall be installed such that the controllers operate together.

28.4 Battery Inverter Installation

Refer to Section 8 for the installation of the battery inverters.

In small hybrid systems made up of inverter/chargers and dc or ac coupled inverters the generator will be electrically connected to the inverter along with communication/control cables to allow the inverter to stop/start the generator.

With larger systems the inverters may have multiple inverters interconnected in parallel clusters. The number of clusters shall not be greater than that recommended by the manufacturer and the relevant intercommunications wiring shall be installed such that one inverter (or cluster) acts as the “master” and the others the slaves.

Some system configurations may require the inverters’ electrical outputs to interconnect through a cluster control box (Refer Figure 43), this is where the generator will also be electrically connected.

28.5 Battery Charger Installation

If the hybrid system includes a separate battery charger:

- The battery charger shall be installed as to the manufacturer’s instructions.
- Installation of the battery charger should be near the batteries
- Never install the battery charger on top or above the enclosure of batteries that emit explosive gases or near the ventilation vents.
- Battery chargers dissipate heat so there must be sufficient ventilation for removing heat from these sensitive pieces of equipment. Always follow the manufacturer’s recommendations for installation, ventilation and clearances around heat sinks.
- If a battery charger is installed outside, the charger should have an IP (Ingress Protection) rating of at least IP56.

- Battery chargers should be installed in dust free locations;
- Battery chargers can be heavy, it is important that the surface on which they will be mounted is appropriately weight-bearing
- Battery chargers are not to be installed in direct sunlight.

28.6 Generator Installation

Generators shall be installed in accordance with AS/NZS 3010 Electrical installations - Generating sets.

Other considerations when installing a generator:

- The generator should be installed in a separate room or shed that only contains the generator and ancillary equipment such as its controller, fuel tank, etc.
- The generator enclosure should be lockable to provide security against tampering, theft or accidental contact by unauthorised persons.
- The foundation supporting the generator is generally a concrete slab that is reinforced and capable of supporting 125% of the pressure exerted by the generator, including fuel, and typically between one and two times the mass of the overall genset.
- The location must be easy to access and cable distances to other components is minimised, while still being far enough away from dwellings to avoid annoyance to residents due to noise and exhaust fumes.
- **Combustion and Cooling Air Supply:** Air is essential both for the combustion of fuel in the engine and the cooling of the equipment. As a rule of thumb, cooling requires six to eight times as much air as combustion. Air intake and exhaust vents should be located to permit smooth air flow over the set. The air should be as cool as possible at the time it reaches the air cleaner. In excessively dusty conditions, additional intake filtration may be required. In order to minimise the ingress of dust and dirt, cooling fans/vents should not face the predominant wind directions.
- **Fuel Supply:** Depending on the size of the generator, the fuel tank may be a small gravity feed unit, a base mounted unit, an external day tank or an underground tank. Fuel storage may be subject to local regulations or standards so installers must check with the relevant government department. Generally, this will mean storage is kept away from potential sources of ignition (including the generator and its associated electrical equipment), provision of bunding or other means of containing a spill from the primary storage vessel is usually required. Warning signs and access control provisions will almost certainly be required with their content depending on the quantity of fuel stored and the type of storage installed.
- **Exhaust:** If the flow of exhaust gases is restricted, back pressure will reduce the power output of the engine. The exhaust pipe should be of adequate diameter for its length, and if bends are to be included, they should be of long radius. If the exhaust pipe is mounted to a fixed structure, a flexible fitting must be included to isolate it from engine vibration and to provide for dimensional changes due to temperature changes. Because heat reduces an engine's efficiency, exhaust components adjacent to the generator should be lagged with heat resistant insulating material to reduce heating engine components.
- **Mechanical and Exhaust Noise:** Noise from the generator includes both general mechanical noise and noise from the exhaust. To attenuate mechanical noise, it will be necessary to insulate the interior of the generator room with a sound retardant material. It is common to fit noise attenuating louvres to the air intakes and outlets. Exhaust noise can be lessened by fitting a silencer or muffler. The degree of attenuation depends on the quality (and cost) of the silencer. The direction at which exhaust is discharged will also affect noise levels.
- **Generator Starting Battery System:** The starting battery system must have sufficient capacity to crank the engine under cold start conditions, and to attempt multiple starts if required. An auxiliary battery charger must be installed if the generator is not guaranteed to run for 4 to 6 hours at least once every week.

- **Ancillary Electrical Equipment:** Electrical installation work must be carried out by a licensed electrician. A circuit breaker will be required for the ac outputs and appropriate instruments should be fitted.
- **Cabling:** Cabling should be supported, protected from damage of all types (including vermin, temperature, fuel and lubricants, external influences etc.) and installed in accordance with AS/NZS 3000.

Noise prevention and mitigation measures should be applied where predicted or measured noise impacts from generator running exceed the applicable noise level guideline at the most sensitive point of reception. Noise level at the point of reception (within buildings) should not exceed the levels presented in Table 9, otherwise, generators having lower dB shall be utilised so that it does not exceed the permissible noise level in Table 9.

Installers/contractors shall ensure that noise protection must be worn when working around generators with rating 65 dB or greater.

Table 8 Noise level Guidelines

Noise level Guidelines ¹		
	One Hour L _{Aeq} (dBA)	
Receptor	Daytime 07:00-22:00	Nighttime 22:00-07:00
Residential; institutional; educational	55	45
Industrial; commercial	70	70

Source: International Finance Corporation (IFC) General Health, and Safety (EHS) Guidelines

Note:

1.Guidelines values are for noise levels measured out of doors i.e. the noise heard from the generator in the residential/commercial building and it is not necessarily the noise present at the generator itself.

28.7 PV Array Wiring

Refer to Sections 9, 10 and 11 for the safe wiring installation practices (Section 9), the wiring of the PV array (Section 10) and the installation of combiner boxes (Section 11). Also refer to Section 12 on segregation of ac and dc circuits and Section 13 on selection and installation of plugs, sockets and connectors. Section 14 covers installation of PV array wiring between the PV array and the solar controller (dc coupled)/PV inverter (ac coupled).

28.8 Battery System Cabling

Refer to Sections 15, 16 and 17 for the installation of cables between the battery system and solar controllers (Sections 15 and 16) and battery inverters (Section 16.2). Refer to Section 16.4 for the installation of wiring in battery systems with parallel battery strings and Section 17 on cable joints and termination.

28.9 Voltage Drop

The voltage drop between the generator and the furthest AC load shall not exceed 5%.

Refer to Section 18 for the formulas for determining voltage drop and also the recommended voltage drops for the rest of the hybrid system.

The AS/NZS 3008 Method stated in section 4 of AS/NZS 3008.1 could be used for the generator AC cable.

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

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/A m)

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 6 of AS/NZS3008.1. 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.

28.10 Protection Requirements

The cable between the generator and the hybrid system shall be protected by a suitably rated circuit breaker complying with AS/NZS 3000 requirements.

Refer to Section 19 for the protection requirements for the rest of the hybrid system.

28.11 Disconnection (isolation) Requirements

The generator shall be capable of being isolated from the rest of the hybrid system by a load breaking disconnection device. The circuit breaker mentioned in Section 28.10 can meet this requirement.

The generator control system shall include a disconnection device to isolate the remote-control wires to the inverter and other control equipment (e.g. a remote starting switch) that can send a signal to start the generator.

Refer to Section 20 for the disconnection (isolation) requirements for the rest of the hybrid system.

28.12 Earthing

The conductive metal casing of the generator shall be bonded to earth (ground).

Refer to Section 21-22 for the earthing requirements for the rest of the hybrid system.

28.13 Shutdown Procedure

The process for shutting down of the generator should be included in the system shutdown procedure.

Refer to Section 23 for the shutdown procedure for the rest of the hybrid system.

28.14 Signage

A warning sign indicating that the generator can start automatically at any time should be positioned in a prominent location near the generator.

Refer to Section 25 for the signage requirements for the rest of the hybrid system.

28.15 Commissioning

Commissioning of the system shall include:

- Starting the generator to determine that it operates properly including measuring its operating voltage and frequency;
- Testing that the generator can start and stop through being remotely controlled by the inverter and any other starting control devices; and
- Testing to show that the ac and dc coupled inverters synchronise with the generator and can also operate in charging mode when generator is operating.

Refer to section 26 for the commissioning requirements for the rest of the hybrid system

28.16 Documentation

All manuals related to the generator and a service book for maintenance should be included with the system documentation provided to the client.

Refer to Section 27 for the documentation requirements for the rest of the hybrid system.

29 Appendix 1 Installation and commissioning sample

This is just a sample for an off-grid PV Power system but could be expanded for larger systems.

Installers name:	
Installers signature:	
Testing and Commissioning date:	
System Location	
Equipment Data	
PV module manufacturer:	
PV module model number:	
PV module peak power rating:	W _p
PV Module rated short circuit current (I _{sc})	A
PV Module rated maximum power current (I _{mp})	A
PV Module rated open circuit voltage (V _{oc})	V
PV Module rated maximum power voltage (V _{mp})	V
Number of Modules:	
PV Array Rating	KW _p
Battery system manufacturer:	
Battery system model:	
Battery system voltage	V
Battery system storage capacity	Ah/Wh
Number of Battery Systems	
Total Battery System Storage capacity	
Solar controller manufacturer	
Solar controller manufacturer	
Solar controller model	
Solar controller input and output current rating.	A
Solar controller voltage ratings	V
Number of Solar controllers	
PV Inverter manufacturer	
PV inverter KW/KVA rating	
PV Inverter 3 phase or 1 phase	
Number of PV Inverters	
a.c. systems 3 phase or 1 phase	
Battery Inverter manufacturer	
Battery Inverter model	
Battery Inverter Input current ratings	A
Battery Inverter Input d.c. voltage rating	V
Battery Inverter Power Rating	W or VA
Number of Battery inverters	
Generator Manufacturer	
Generator Model	
Generator Power Rating	W or VA
PV array Switch disconnecter manufacturer	
PV Array Switch disconnecter model	
PV Array Switch disconnecter current rating	A

PV Array Switch disconnecter voltage rating	V
Solar controller to Battery system protection current rating	A
Solar controller to battery system protection voltage rating	V
Battery Inverter to battery system protection current rating (if there are separate fuses for battery inverter and solar controller)	A
Battery Inverter to battery system protection voltage Rating (if there are separate fuses for inverter and solar)	V
Generator AC Circuit Breaker Rating	
Testing of System (System Not On Yet)	
Solar Irradiance at same angle of solar module	W/m ²
Module No 1: I _{sc}	A
Module No 1: V _{oc}	V
Module No 2: I _{sc}	A
Module No 2: V _{oc}	V
Continuity between PV array, d.c. switch-disconnector and controller or PV inverter:	
Array Positive (Tick if correct)	
Array Negative (tick if correct)	
Correct polarity between PV array and solar controller/PV inverter	
Continuity between solar controller, protection device and battery system	
Battery Positive (Tick if correct)	
Battery Negative (tick if correct)	
Correct polarity between solar controller and battery system	
Continuity between battery system, protection device and battery inverter	
Battery Positive (Tick if correct)	
Battery Negative (tick if correct)	
Correct polarity between inverter and battery	
If DC loads from solar controller:	
Continuity between solar controller, light switch and lights	
Positive (Tick if correct)	
Negative (tick if correct)	
Correct polarity between controller and d.c. loads (This could be expanded if testing d.c. circuits if they have been installed as part of system installation)	
PV Array String Cables	
Cross Sectional Area of string cables	mm ²
Current Carry Capacity of string cables	A
Maximum current from string	A
Maximum length of string cables	m
Maximum voltage drop in string cables	V
String V _{mp} (MPPT Solar controller or PV Inverter) or battery voltage (Non MPPT Solar Controller)	V
Maximum voltage drop (string cables) as %	%
Array String Cables	
Cross Sectional Area of array cable	mm ²
Current Carry Capacity of array cable	A
Maximum current on from array	A

Maximum length of array cable	m
Maximum voltage Drop in Array cable	V
Array V_{mp} (MPPT or PV Inverter) or Battery Voltage (PWM)	V
Maximum voltage drop (array cables) as %	%
Total maximum voltage drop- array to MPPT or PV Inverter as % array Note: not relevant for PWM controller-required % is from array to battery	%
Solar Controller to Battery Cable	
Cross Sectional Area of controller to battery cable	mm ²
Current Carry Capacity of controller to battery cable	A
Maximum current from the controller to/from battery	A
Maximum length of controller to battery cable	m
Maximum voltage drop in controller to battery Cable	V
Battery Voltage	V
Maximum voltage drop (controller to battery cable) as %	%
Total maximum voltage drop -array to battery (array cables) as % battery voltage (PWM controller)	%
Battery System to Battery Inverter Cable	
Cross Section Area of battery to inverter cable	mm ²
Current Carry Capacity of battery to inverter cable	A
Maximum Current on from/to battery to inverter	A
Maximum Length of battery to inverter cable	m
Battery Voltage	V
Maximum voltage drop as %	%
Note the above is just an example of voltage drop for the d.c. side of the system. a.c. side might also need to be undertaken if required	
Battery System Voltage at Terminals	V
If 2V cells than this would be expanded to record each cell voltage	
If battery systems are wet lead acid batteries than the specific gravities would be recorded	
Turn System On - including DC loads	
Array voltage at Controller input	V
Array current	A
Battery system voltage at controller	V
Voltage at furthest d.c. load (array turned off)	V
Battery Inverter a.c. voltage	V
Generator a.c. voltage	V
Solar charging the battery system (tick if correct)	
Solar Controller operating correctly (tick if correct)	
PV Inverter operating correctly (tick if correct)	
Battery Inverter operating correctly (tick if correct)	
d.c. loads operating correctly (tick if correct)	
Generator operating correctly (tick if correct)	
If Battery Inverter is interactive or inverter/Charger—Batteries being charged when generator on (tick if correct)	
If battery Inverter is interactive it synchronises with generator? (tick if yes)	
Battery Inverter controls stop/start of generator (if applicable) (tick if correct)	

30 Appendix 2 How to Verify that Products Meet Standards

It can be difficult and time consuming to verify that a product meets AS/NZ standards and/or IEC standards, plus there can be fake certificates available. Australia has overcome this through a publicly available 'approved products list' for modules and inverters and some preassembled Li Ion batteries.

Australian Approved Products List. The Australian government has funded the Clean Energy Council (CEC) to develop the approved products list. Manufacturers or importers submit the relevant paperwork to the CEC, who undertake due diligence to verify that the submitted products meet required standards. Products that comply are added to the approved products list, which include solar modules, inverters, solar controllers, pre-assembled battery systems (BS) and pre-assembled Battery Energy Storage Systems (BESS). The list is free to access at the following site: <https://www.cleanenergycouncil.org.au/industry/products>.

The direct link to approved solar modules is:

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

The direct link to approved inverters and solar controllers is:

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

Note: Australia require the solar controller to comply with IEC 62109-1 Part 1: General requirements. However, there are many good controllers on the market that are not listed because they are not sold in Australia. If the solar controller is not listed on the approved products list it should comply with one the three standards listed in this document. SEI-API will endeavour to develop a list of solar controllers not listed on the Australian approved products list that do comply with at least one of these three standards

The direct link for pre-assembled BS and BESS is:

<https://www.cleanenergycouncil.org.au/industry/products/batteries/approved-batteries>

Pre-assembled battery systems only include li Ion battery systems, so the list does not include lead acid battery systems or other technologies such as flow battery, vanadium redox etc.

31 Appendix 3 Sample risk assessment (or Job Safety Analysis) for Off grid PV system

(The following is just a sample and a more detailed risk assessment form specific to the site, system and hazards concerned could be formulated)

1. Responsibilities

Inductions for all workers (inclusive of employees and sub-contractors) need to be conducted prior to commencing site work. A record of inductions and toolbox meetings need to be kept at the office for any future reference.

2. Description of Work

This brief, step by step work summary is to be completed by the Site Supervisor or similar on site prior to work commencing to assist in the identification of possible hazards:

1. Arrival onsite, park in non-hazardous area and ensure equipment and tools are safe
2. Discuss solar system installation locations with client prior to commencing work
3. Assessment of all work areas completed and any potential risks identified and noted

3. Risk Assessment

	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

(Classify and assess the risks using the above table)

Activities to be performed: Site assessment, installation of PV array, installation of battery system, installation of PCE and balance of system component, commissioning of systems, etc.

(More activities could be added where relevant, note that the consequence likelihood and hazard rating could potentially vary from one site to another)

Hazard	Consequence of Hazard	Likelihood of Hazard	Hazard Rating	Control	New Consequence of Hazard	New Likelihood of Hazard	New Hazard Rating After Control	Who is Responsible?
Workplace/worksite hazards/untrained workers				Do a risk assessment prior to commencing work Make sure workers have received prior training or are qualified to carry out the specified tasks				
Uninformed workers				Conduct a site-specific induction				
Slips, trips and falls				Assess the condition and roof pitch before working and take actions to avoid slip and trips. Use appropriate PPEs e.g. hard				

				hat, safety boots (ensure it is not slippery), harness etc				
Cuts and abrasions to hands, Eyes, Feet				Wear appropriate PPE as required e.g. gloves, safety glasses and safety boots, etc.				
Sun burn and dehydration				Wear sunscreen, wide brim hats, long sleeve shirt, drink plenty of water				
Falls from height				Make sure appropriate fall protection is in place and secure where required. Wear harness				
Falling objects / Protruding Objects				Ensure tools are tethered and stay vigilant				
Manual Handling				Train workers in correct lifting techniques				
Injury upon using power tools				Ensure workers are trained in their use, use battery operated tools, wear appropriate PPEs (safety glasses, safety boots, etc), clear obstacles, etc				
Electrocution				Isolate supply, test and communicate with the team Wear electrical gloves when working on live wires. Wear insulated safety boots				
Environmental hazards, animals and snakes				Identify if there are any environmental hazards and mitigate. Visually inspect prior to any work and have a mitigation plan				
Battery installation hazards (Including chemical hazards, fire, arc flash, toxic fumes, etc)				Follow manufacturer's requirements for appropriate PPEs (e.g. safety glasses, aprons, gloves, safety boots, etc). Note: use appropriate PPEs depending upon the battery technology and hazards applicable, use safe working distances, avoid battery shorting, avoid smoking near batteries, equipment directly above batteries etc Note: Table 3.3 of AS/NZS 5139 presents the PPE that needs to be worn based on the arc flash energy rating of the battery system being installed. The arc flash hazards could be avoided when appropriate PPEs are worn. Refer to the table below.				

PPE level	Cal/cm ²	PPE description
0	0	No protection from arc flash
1	>0 and ≤ 4	Arc-rated long sleeve shirt Arc-rated pants or overalls Arc-rated face shield with hard hat Safety glasses (worn under shield) Hearing protection Leather and voltage rated gloves (as needed) Leather work shoes
2	>4 and ≤ 8	Arc-rated long sleeve shirt Arc rated pants or overalls Arc-rated face shield and balaclava or arc flash suit with hard hat Safety glasses (worn under hood or shield) Hearing protection Leather and voltage rated gloves (as needed) Leather work shoes
3	>8 and ≤ 25	Arc-rated long sleeve jacket Arc rated pants Arc-rated flash hood with hard hat Safety glasses (worn under hood) Hearing protection Leather and voltage rated gloves (as needed) Leather work shoes
4	>25 and ≤40	Arc-rated long sleeve jacket Arc rated pants Arc-rated flash hood with hard hat Safety glasses (worn under hood) Hearing protection Leather and voltage rated gloves (as needed) Leather work shoes HAZARD – Be aware of heat stress when wearing Cat 4 Clothing
5	>40	Measures shall be taken in installation to avoid this level as PPE is very specialised and limited

Source: Reproduced from AS/NZS 5139 Standard, originally extracted from “Electrical Arc Flash Hazard Management Guideline” published on March 2019.