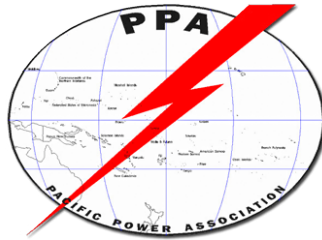




# GRID CONNECTED PV SYSTEMS WITH BATTERY ENERGY STORAGE SYSTEMS INSTALLATION GUIDELINES

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

They represent latest industry BEST PRACTICE for Installation of Grid Connected PV Systems with Battery Energy Storage Systems

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# 1. Introduction

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This guideline provides the minimum requirements when installing a Grid Connected PV System with a Battery Energy Storage System (BESS).

The array requirements are based on the requirements of: IEC 62458: Photovoltaic (PV Arrays- Design Requirements. These are similar to the requirements of AS/NZS5033: Installation and Safety Requirements of PV Arrays. The National Electrical Code (NEC) specifies maximum currents for strings, sub-arrays and arrays of 1.25 times the short circuit currents of the strings, sub-arrays and arrays. For protection and isolation devices the NEC has a required safety margin of 1.25 (125%), thereby having an effective overall oversizing of 156% (1.56 times) the relevant short circuit currents. The NEC requirements are provided as notes where appropriate.

Notes:

1. The new standard AS/NZS5139 introduces the terms battery system and Battery Energy Storage System (BESS). Traditionally the term batteries were used to describe energy storage devices that produced dc power/energy. However, in recent years some of the energy storage devices available on the market include other integral components which are required for the energy storage device to operate.

The term battery system replaces the term battery to allow for the fact that the battery system could include The energy storage plus other associated components. For example, some lithium ion batteries are provided with integral battery management systems while flow type batteries are provided with pumping systems.

The term battery energy storage system (BESS) comprises both the battery system, the battery inverter and the associated equipment such as protection devices and switchgear.

However, the main two types of battery systems discussed in this guideline are lead acid batteries and lithium ion batteries and hence these are described in those terms.

Since the two main battery systems used in this guideline are lead acid batteries and li ion batteries the inverter connected to the battery systems within this guideline is simply described as the battery inverter.

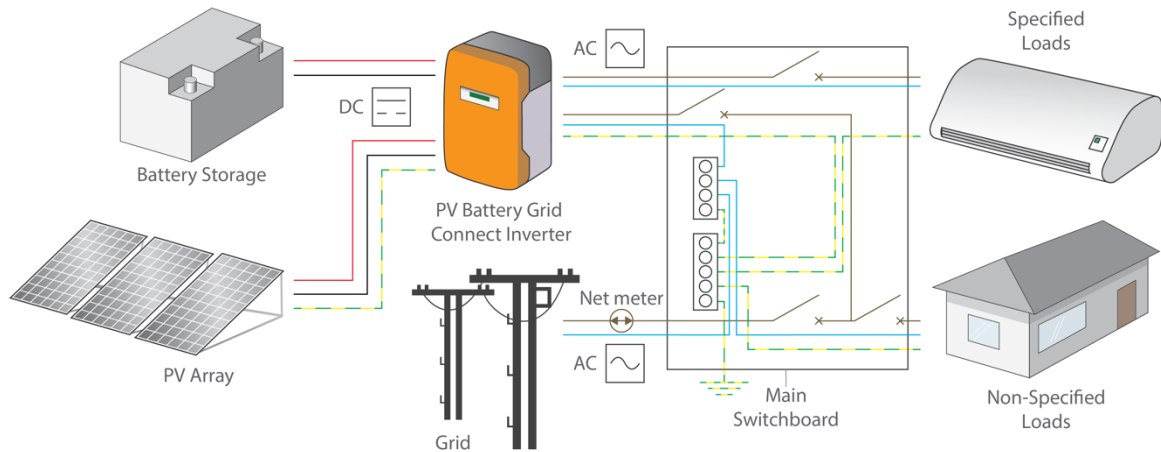
2. IEC standards use a.c. and d.c. for abbreviating alternating and direct current while the NEC uses ac and dc. This guideline uses ac and dc.
3. In this document there are calculations based on temperatures in degrees centigrade (°C). The formulas used are based on figures provided from solar module manufactures where the temperature coefficients are generally expressed in °C while there are some from the USA that have used degrees kelvin (K). A one-degree change in °C is equal to a one-degree change in K. So, if the module manufacturer provides the temperature coefficient in K, just change the K to a °C and use the formulas shown in this guideline.

If your local temperatures are given in Fahrenheit degrees, to use the formulas shown in this guideline, you must convert °F to °C. For your convenience in making that conversion, Annex 1 is a table to convert from °F to °C from 32°F to 127 °F (0 °C to 53 °C).

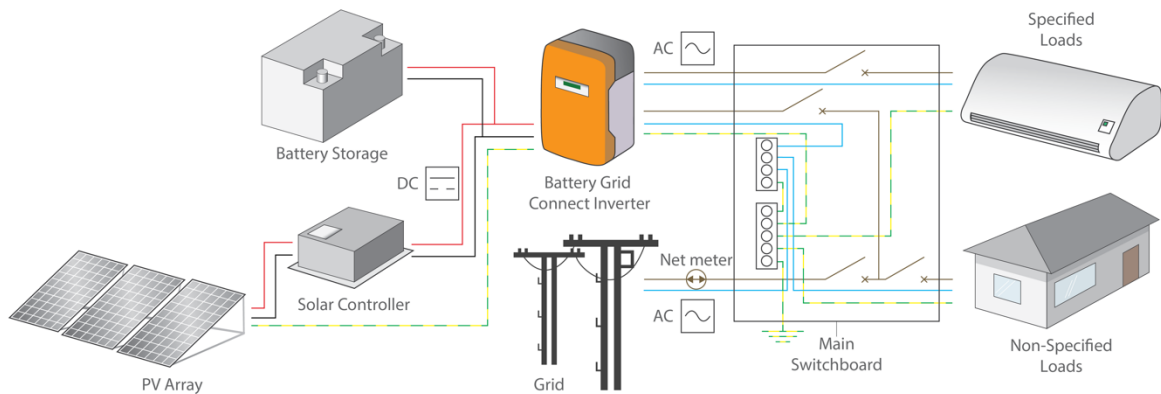
Use the appropriate Fahrenheit number in a °F column and use the number in the adjacent °C column in the formulas given in this guideline.

## 2. Typical Battery Energy Storage Systems Connected to Grid-Connected PV Systems

At a minimum, a BESS and the associated PV system will consist of a battery system, a multiple mode inverter (for more information on inverters see Section 13) and a PV array. Some systems have additional power conditioning equipment (PCE) to add functionality to the system. Below are examples of typical system configurations, note that this is not an exhaustive list.

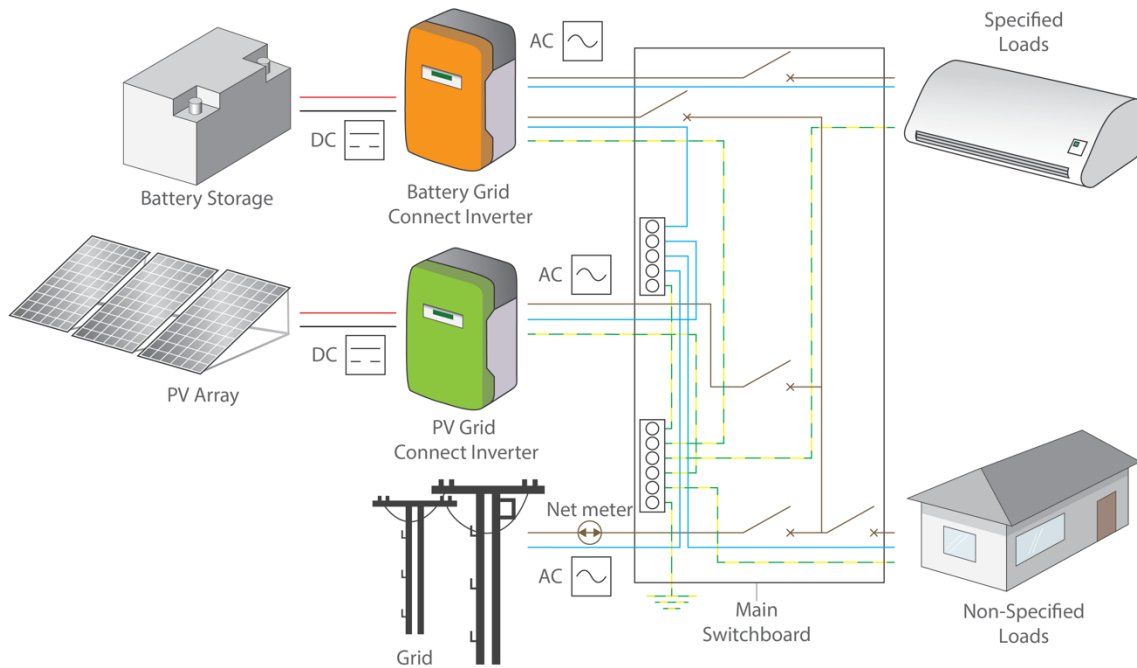


**Figure 1: Single PV Battery Grid Connect inverter layout(hybrid)**



**Figure 2: Single battery grid connect inverter with separate solar controller (dc coupled)**





**Figure 3: Two inverters, including PV inverter connected directly to specified loads (ac coupled)**

Some inverters can have both battery system and PV inputs which results in a system with a single PV battery grid connect inverter (as shown in Figure 1. These systems will be referred to as “hybrid” throughout the guideline. It requires replacing the existing PV inverter with a multimode inverter if retrofitted to an existing grid-connected PV system.

Figure 2 shows a system with a single battery grid connect inverter and a solar controller. These systems will be referred to as “dc coupled” throughout the guideline. The solar controller can be either a PWM type or MPPT type. It requires replacing the existing PV inverter with a battery grid connect inverter if retrofitted to an existing grid-connected PV system.

Figure 3 shows a system with two inverters, one battery grid connect inverter and one PV grid-connect inverter. These systems will be referred to as “ac coupled” throughout the guideline. The two inverters can be connected in a number of different ways to provide different functionality to the system. This system can be easily retrofitted to an existing PV system.

**Note:** For convenience any inverter that interconnects with a battery system will be referred to as the “battery inverter” and any inverter that interconnects with the PV array will be called the “PV inverter” however it must be appreciated that in some systems the battery inverter and PV inverter will just be one inverter , that is the PV battery grid connect inverter.

### 3. Standards Relevant to the Installation of Grid Connect PV System with BESS

---

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

In Australia and New Zealand, the relevant standards include:

- AS/NZS 1768 Lightning Protection.
- AS/NZS 3000 Wiring Rules.
- AS/NZS 3008 Electrical Installations-Selection of Cables.
- AS/NZS 4509 Stand-alone power systems
- AS/NZS 5033 Installation and safety requirements for PV Arrays.
- AS/NZS 5139 Electrical installations—Safety of battery systems for use with power conversion equipment
  
- AS 3011 Electrical Installations- Secondary batteries installed in buildings.
- AS 2676 Guide to the installation, maintenance, testing and replacement of secondary batteries in building
  
- 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)<sub>2</sub> based photovoltaic (PV) modules
  - IEC 61215-2 Part 2: Test Procedures
- IEC 61730 Photovoltaic (PV) module safety qualification.
  - IEC 61730-1 Part 1: Requirements for construction.
  - IEC 61730-2 Part 2: Requirements for testing.
- IEC 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.

In USA the relevant codes and standards include:

- Electrical Codes - National Electrical Code and NFPA 70:
  - Article 690: Solar Photovoltaic Systems.
  - Article 705: Interconnected Electric Power Production.
- Building Codes - ICC, ASCE 7
- UL Standard 1703 Flat Plate Photovoltaic Modules and Panels.
- UL Standard 1741 Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources.
  
- UL 62109 Standard for Safety of Power Converters for Use in Photovoltaic Power Systems.
  
- UL 2703 Standard for Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels.
  
- UL(IEC) 61215 Crystalline silicon terrestrial photovoltaic (PV) modules—Design qualification and type approval.

## 4. Voltage Limits and Work Restrictions

System voltage classification in this guideline follow the Decisive Voltage Classification as defined in the standard: IEC 62109 Safety of power converter for use in photovoltaic power systems as shown in Table 1. The Decisive Voltage Classification has not been adopted by the NEC at this stage.

**Table 1: 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	$25 < V \leq 50$	$35.4 < V \leq 50$	$60 < V \leq 120$
DVC-C	$V > 50$	$V > 71$	$V > 120$

DVC 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.

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

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

Note: In NEC they class ELV as less than 60V dc

In following these voltage limits, some countries require licensed or registered electricians to work on all but ELV systems and often impose the following requirements:

### Extra Low Voltage Work:

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

### Low Voltage Work:

- All low voltage work:  $>120V$  dc or  $>50V$  ac shall be performed by a trained electrician or similarly qualified worker (e.g. licensed or registered).

In the NEC standard anything above 60V dc is considered dangerous. Except when module inverters are used, grid connect PV arrays have open circuit voltage typically above 120V dc and hence considered LV. LV is dangerous and can kill a person if they come into contact with live terminals.

## 5. Selecting PV Modules

When selecting a solar module to be used in a PV power system the solar modules shall meet either:

- One of the following design qualification and type approval standards:
  - IEC 61215 Terrestrial photovoltaic (PV) modules - Design qualification and type approval
    - o IEC 61215-1 Part 1: Test Requirements
    - o IEC 61215-2 Part 2: Test Procedures

and

- IEC 61730 Photovoltaic (PV) module safety qualification
  - IEC 61730-1 Part 1: Requirements for construction
  - IEC 61730-2 Part 2: Requirements for testing

or the UL Standard

- UL Standard 1703: Flat Plate Photovoltaic Modules and Panels
- For modules with IEC certification must be certified as Class II per IEC 61730 (or Application Class A per IEC 61730:2004).

Note: IEC61215 are also available as European Standards (EN) and Underwriters Limited Standards (UL).

## 6. PV Array Installation

### 6.1 General

- PV arrays for installation on domestic dwellings shall not have PV array maximum voltages greater than 600 V.
- Modules that are electrically in the same string shall be all in the same orientation.
- Even for latitudes less than 10°, a minimum tilt of 10° is recommended to take advantage of self-cleaning when it rains. Arrays mounted with a tilt less than 10° may require additional maintenance (cleaning) and this should be included in the recommended maintenance schedule.

### 6.2 Maximum PV Array Voltage

The PV Array Maximum voltage is the open circuit voltage ( $V_{oc}$ ) of the array when it experiences the lowest effective cell temperature. It can be calculated using the minimum expected temperature at site and the temperature coefficient of the selected module.

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

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

If we use 15°C (59°F) as the minimum cell temperature, then the increase in  $V_{mp}$  is  $(15°C - 25°C) = -10°C$  multiplied by the voltage temperature coefficient ( $V/°C$ ).

**Note:** it is an increase because the co-efficient is a negative number and the difference in temperatures is also a negative number, so the two multiplied together becomes a positive number.

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 2 containing the temperature

### Worked Example 1

Assume the minimum effective cell temperature is 15°C (59°F),

The module data sheet provides the following information:

- $V_{oc} = 37.7V$
- $V_{oc}$  temperature coefficient = 0.32%/°C

Therefore, in V/°C the  $V_{oc}$  temperature coefficient =  $-0.32/100$  per °C  $\times 37.7V = -0.121V/^\circ$

Based on the minimum temperature of 15°C then the cell temperature is 10°C below STC:

The Increase in  $V_{oc}$  due to temperature =  $-10^\circ\text{C}$  times the voltage temperature coefficient (V/°C).  
=  $-10^\circ\text{C} \times -0.121V/^\circ\text{C}$   
= 1.21V

So, the effective maximum  $V_{oc}$  of the module due to temperature =  $37.7V + 1.21V = 38.91V$  for each module in the string.

(For countries that use °F, use the supplied conversion table (Annex 1) to convert the minimum temperature in °F to °C then proceed as in the above example)

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 this example, if there are 4 modules in a string, the maximum  $V_{oc}$  of the string will be  $4 \times 38.91V = 155.64 V$  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 2 containing the temperature ranges and multiplication factors.

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

Lowest expected operating temperature (degrees Celsius)	Correction factor (Multiply this times $V_{oc}$ )	Lowest expected operating temperature (degrees Fahrenheit)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to 0	1.10	40 to 32
-1 to -5	1.12	31 to 23
-6 to -10	1.14	22 to 14
-11 to -15	1.16	13 to 5
-16 to -20	1.18	4 to -4
-21 to -25	1.20	-5 to -13
-26 to -30	1.21	-14 to -22
-31 to -35	1.23	-23 to -31
-36 to -40	1.25	-32 to -40

**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.

## 6.3 Orientation and Tilt

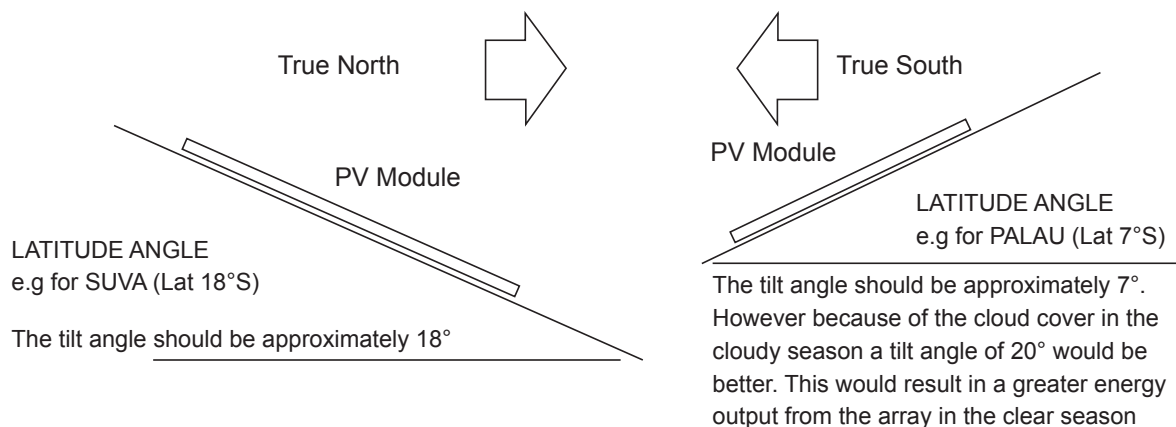
In grid-connected PV systems the solar array is generally mounted:

- On an array frame that is tilted to fix the array at a preferred angle (usually used for flat roofs or ground mounting), or
- “Flat” on the roof so that is parallel to the slope of the roof but raised off the roof for ventilaton, or
- On a pole mounted system separate from the house, or
- Ground mounted if the roof area or pole capacity is not sufficient.

Though the maximum output for a roof mounted system would be obtained using an array frame that it tilted to fix the array at the optimum angle, because of concerns about added cost as well as wind loadings due to tropical storms, the arrays usually are mounted parallel to the roof.

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

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



**Figure 4: Example of tilt angles**

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

- Alofi, Niue (Latitude 19°04'S, Longitude 169°55'W)
- Apia, Samoa (Latitude 13°50'S, Longitude 171°46'W)
- Hagåtña, Guam (Latitude 13°28'N, Longitude 144°45'E)
- Honiara, Solomon Islands (Latitude 09°27'S, Longitude 159°57'E)
- Koror, Palau (Latitude 7°20'N, Longitude 134°28'E)
- Lae, Papua New Guinea (Latitude 6°44'S, Longitude 147°00'E)
- Majuro, Marshall Islands (Latitude 7°12'N, Longitude 171°06'E)
- Nauru (Latitude 0°32'S, Longitude 166°56'E)
- Nouméa, New Caledonia (Latitude 22°16'S, Longitude 166°27'E)
- Nuku'alofa, Tonga (Latitude 21°08'S, Longitude 175°12'W)
- Pago Pago, American Samoa (Latitude 14°16'S, Longitude: 170°42'W)
- Palikir, Pohnpei FSM (Latitude 6°54'N, Longitude 158°13'E)
- Port Moresby, Papua New Guinea (Latitude 9°29'S, Longitude 147°9'E)
- Port Vila, Vanuatu (Latitude 17°44'S, Longitude 168°19'E)
- Rarotonga, Cook Islands (Latitude 21°12'S, Longitude 159°47'W)
- Suva, Fiji (Latitude 18°08'S, Longitude 178°25'E)
- Tarawa, Kiribati (Latitude 1°28'N, Longitude 173°2'E)
- Vaiaku, Tuvalu (Latitude 8°31'S, Longitude 179°13'E)

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

In general, 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 to that rule.

Annex 3 of the PV Grid Connect with BESS Design Guidelines provides tables that show the variation in irradiation due to different tilts and azimuths from those measured and recorded at the tilt angle equivalent to the latitude angle for the locations shown 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<sup>1</sup>. If the location for the system you are designing is not shown it is recommended that you use the site with the nearest latitude.

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

**Table 3: Sites for Orientation and Tilt Tables in Annex 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 Annex 3 of the *PV Grid Connect with BESS Design Guidelines* provide values for a plane in 36 orientations (azimuths) and 10 inclination (tilt) angles in increments of 10°.

Using these tables will provide the system installer with information on the expected output of a system (with respect to the maximum possible output) when it is located on a surface that is not facing true north (or south) or at an inclination 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 orientation and tilt angle for the system to be installed assuming that there is no seasonal cloudiness. 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 kWh per individual roof then all the kWh that result can be added together to get the total from all the modules in the installation.

## 6.4 Roof Mounted not Building Integrated

- 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 output.
- It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris under the modules.
- If fauna (e.g. rats) are a problem in the vicinity of the installation, then consideration should be given to how to prevent them gaining access under the array (see cable protection).
- 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, do not increase their rates of corrosion when mounted together in an array (e.g. aluminium in contact with steel), 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 differing metal surfaces and under screw and bolt heads; and selection of materials with the appropriate type and thickness of anti-corrosive coating.
- Where timber is used it must be suitable for long-term external use and fixed so that trapped moisture cannot cause corrosion of the roof and/or rotting of the timber. The expected replacement time should be stated in the system documentation.
- Any roof penetrations must be suitably sealed and be waterproof for the expected life of the system. If this is not possible then this must be detailed in the Maintenance Timetable.
- If the roof uses tiles, all tiles shall sit flat after the installation of tile mounting brackets to ensure the tiles maintain their original water ingress protection. There may be a requirement to grind some of the underside of the tile to enable it to sit correctly.
- For metal roofs the array frame structure should be attached to the roof using brackets that are screwed through the ridges of the roofing into a purlin or rafter below.
- All fixings must ensure structural security when subject to the highest wind speeds for the region and local terrain - This may require specific tests of the fixing/substrate combination on that roof. For those countries which have experienced Category 5 cyclones/typhoons then the frames shall be designed to meet the wind speeds expected in a Category 5 cyclone/typhoon.
- The installer shall ensure that the array frame that they install has applicable engineering certificates



verifying that the frame meets maximum wind loadings experienced for that particular location.

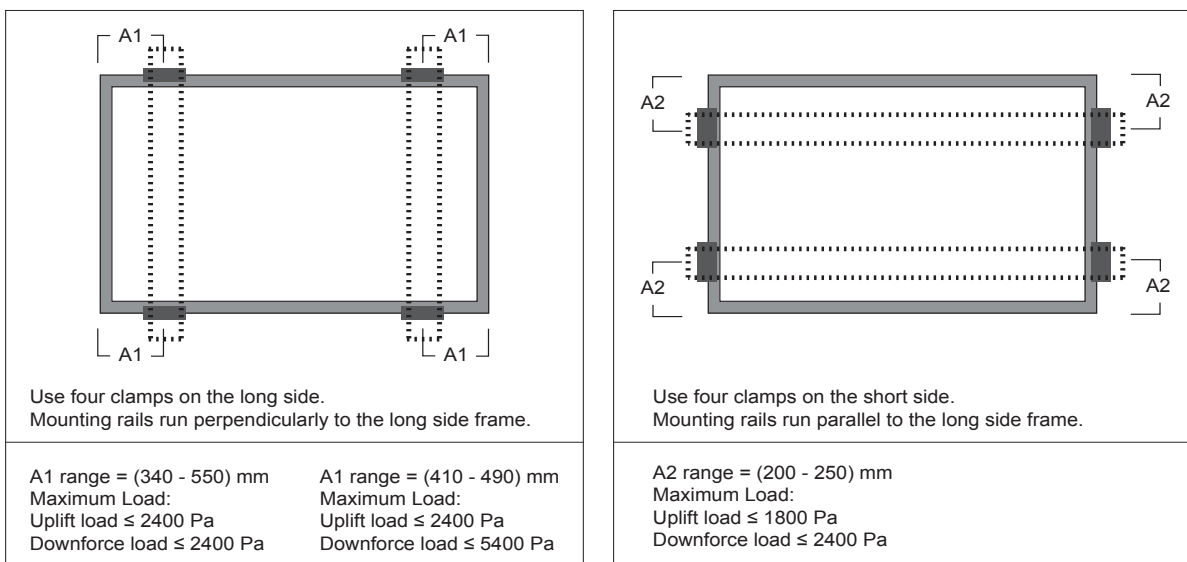
- The installer must follow the array frame suppliers/manufacturers recommendations when mounting the array to the roof support structure to ensure that the array structure still meets wind loading certification. The installer shall also consider the following:
  - Area of roof applicable for modules to be installed
  - Type, length and gauge of screws to be used
  - Number of screws required per fixing
  - Size of batten/purlin required for fixing
- If necessary, refer to the roof manufacturer's guidelines to ensure that the materials introduced by the installation of PV array frame are compatible with the roofing material.

## 6.5 Free Standing Array Mounting Structure

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

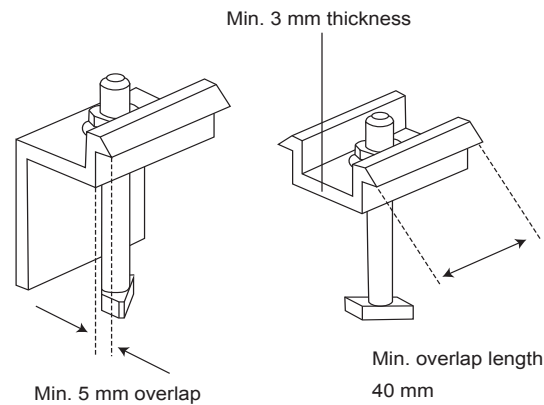
## 6.6 Attaching Modules to Array Mounting Structure

- Solar modules should be attached to the array structure either using the mounting holes provided by the manufacturer or via clamps.
- 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 the 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 5: 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 6: 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/Typhoons?

In the last few years, in countries that experience category 3 plus cyclones/typhoons, there have been a number of failures of dual module clamps due to cyclone wind which have resulted in a “zipper” effect whereby one clamped module comes loose due to wind causing the clamp to vibrate and undergo stress. Then the rest of the modules in that string also come loose since the loss of the module on one side of the dual clamp loosens the clamping force on the module on the other side of the clamp and so on down the string.

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 at least every fourth module so if one does become loose then only a few other modules would be affected, not necessarily the whole array.

## 7. Selecting a Battery System

Lead acid battery systems shall meet one of the following standards:

- IEC 61427-1 Secondary Cells and Batteries for Renewable Energy Storage – General Requirements and Methods of Test – Part 1: Photovoltaic Off-grid Application
- IEC 60896 Stationary lead-acid batteries (series)
- UL 1973 Standard for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications
- UL 1989 Standby Batteries

- Battery systems that meet one of the above UL standards shall also meet:
  - UL-2054 Safety Standard for household and commercial batteries

The individual cells and the assembled battery pack for lithium-ion batteries shall meet either:

- 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.
- or
- UL 1642 Standard for Lithium Batteries; and
  - UL 2054 Safety standard for household and commercial batteries.

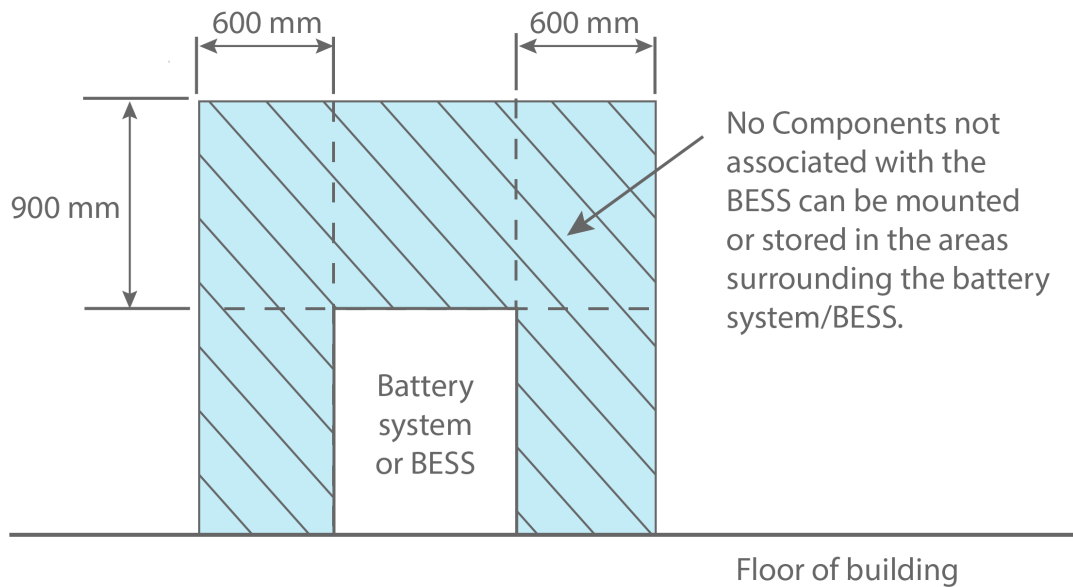
## 8. Battery System Installation

This installation guideline is only written for lead-acid batteries and lithium-ion batteries which are provided as individual components. If the battery system is being provided within a pre-assembled BESS then follow the relevant installations requirements for the technology of the battery system within the BESS.

(Note: The following requirements do not need to be applied to small 12V systems comprising up to 2 monoblock 12V batteries)

- The battery system must be installed in a dedicated battery system room or enclosure.
- The location and/or enclosure selected must ensure that mechanical protection is guaranteed and access to the battery system is restricted to those people who are authorised to have that access.
- Sufficient space should be available within the enclosure to allow for ease of battery system installation and maintenance, and no metal objects should be in the vicinity such that one could fall across battery cell terminals and cause a short circuit.
- For a large battery system containing multiple individual cells or units it is recommended that, if possible, the battery system enclosure should not be located within the main building and the ideal location is within a building (e.g. shed) that is separate and preferably not put to other use.
- If the battery system enclosure is mounted in a separate building, then those battery systems that emit explosive fumes, such as lead acid battery systems, should be vented only to the outside.
- If it is a dedicated room and part of an occupied building, then there should be access from the outside and for battery systems that emit explosive fumes (lead acid type b) the internal walls should not have any vents/penetrations to the inside of the associated building.
- The battery system shall not be installed in restricted locations including:
  - A habitable room
  - Within 600mm of any exit, window, hot water unit, air conditioning unit or any other major appliance
  - Within 900mm below any of the previous items;
  - In ceiling spaces;
  - In wall cavities;
  - On roofs except where specifically deemed suitable;
  - Under floors, stairways or access walkways, or;
  - In an evacuation or escape route.
- No metal devices shall be installed above a battery system that could fall onto the terminals on the battery system.
- The location that the battery system is installed should be dry.
- Battery systems should be raised off the ground or concrete floor. If left on the ground, the lower sections of the battery cells will adopt the temperature of the ground, which is generally lower than the ambient temperature adopted by the upper sections of the battery systems. With certain chemical-based battery systems, this can lead to stratification of the electrolyte and premature failure.
- Luminaires should not be installed directly above or within 200 mm of any battery system.
- The enclosure should not be located in direct sunlight and should be in a location that keeps the battery system system as cool as possible.
- Adequate ventilation should be available to assist in temperature control and if necessary, to avoid the build-up of hydrogen or other gases associated with charging. The outlet ventilation must be to the outside of the building in which the battery system is located.
- Battery systems are typically heavy and the area under the battery system shall be capable of safely bearing the weight of the battery system.

- Guard against electrolyte spillage for those battery system types containing liquid chemicals. The material used for the construction of the enclosure should resist the specific corrosive effects of the battery liquid or be painted with a corrosion resistant paint that does resist those specific effects.
- Ideally any electrolyte spillage should be contained within the enclosure or room.
- No components not associated with the battery system or BESS shall be installed/mounted in the area surrounding the battery system/BESS as shown in Figure 7.



**Figure 7: Restricted zones for appliances not associated with the battery system**

Note: If it is a lead-acid battery or Lithium-ion battery, the associated inverter is also not allowed within the area shown in Figure 7.

## 9. Ventilation Requirements for Lead-Acid battery systems

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

Battery system types that can emit explosive gases shall be installed in enclosures (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 Figure 8 and 9).

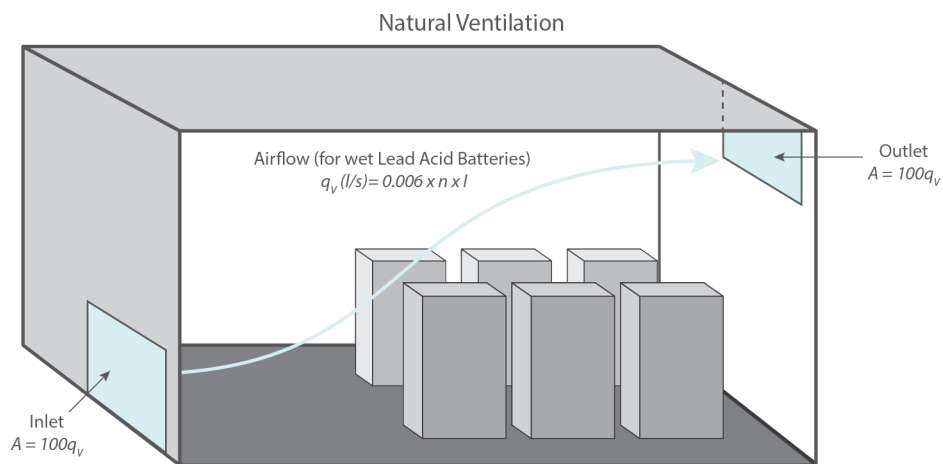


Figure 8: Natural ventilation arrangement for battery systems

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 6.

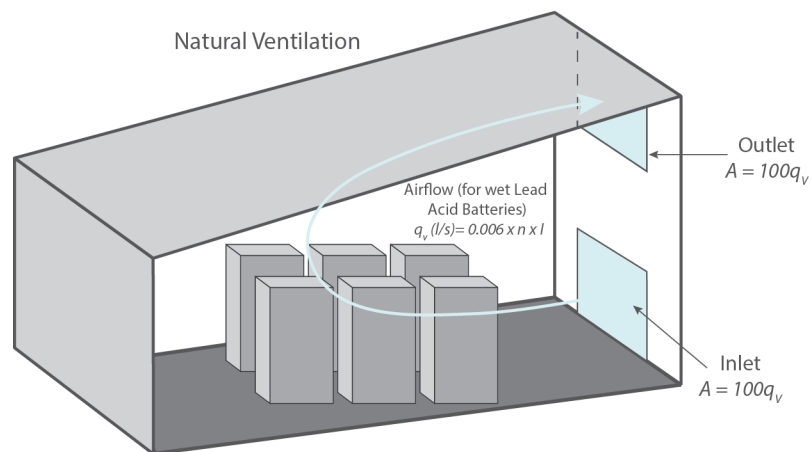


Figure 9: Natural ventilation arrangement for battery systems with vents on one side

## 9.1 Determining the Size of Vents (Metric)

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

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

Where  $q_v$  is the minimum exhaust ventilation rate in litres per section =  $0.006 \times n \times I$   
and  $n$  = the number of battery system 2V cells  
 $I$  = the charging rate in amperes

Note: The charging rate in amperes is the maximum charging current available from the system. However, in accordance with standards the charging rate in amperes is the maximum output rating of the largest charging source or the rating of its output fuse or circuit breaker. Consideration should always be given to the fact that two sources could be charging the battery system at the same time. Where the battery system comprises series strings of cells connected in parallel the maximum charging rate is divided by the number of parallel strings.

## 9.2 Determining the Size of Vents (Imperial)

The minimum area in  $\text{in}^2$  required for natural ventilation for both inlet and outlet apertures (for wet lead acid battery systems) are given by:

$$A = 15.5 \times q_v \times \text{in}^2$$

Where  $q_v$  is the minimum exhaust ventilation rate in litres per second =  $0.006 \times n \times I$  (Note : The area formula has been converted from centre-metres to inches-the ventilation formula is still metric)  
and  $n$  = the number of battery system cells  
 $I$  = the charging rate in amperes

Note: The charging rate in amperes is the maximum charging current available from the system. However, in accordance with standards the charging rate in amperes is the maximum output rating of the largest charging source or the rating of its output fuse or circuit breaker. Consideration should always be given to the fact that two sources could be charging the battery system at the same time. Where the battery system comprises series strings of cells connected in parallel the maximum charging rate is divided by the number of parallel strings.

## 9.3 Ventilation of Valve Regulated (Sealed) Lead-Acid Batteries

The charging rate  $I$  in the ventilation formula is 0.5A per 100Ah at the 3h rate ( $C_3$ ) of discharge of battery capacity for lead acid batteries.

e.g. battery cell has  $C_3$  rating of 500Ah therefore the charge current used in ventilation formula is  
=  $(500\text{Ah}/100\text{Ah}) \times 0.5\text{A} = 2.5\text{A}$

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

## 10. Selecting a Solar Controller

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When selecting a solar controller to be used in a PV system the controller should meet 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

## 11. Solar Controller Installation

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- The solar controller shall be installed as to the manufacturer's instructions
- Installation of solar controllers (either PWM or MPPTs) should occur near battery systems or at a convenient monitoring location.
- If the solar controller is not located near the battery system, it will be necessary to use a model that has a separate battery system voltage sensing capability to allow for voltage drop in the cables.
- Never install controllers within the forbidden zone shown in figure 7.
- 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 clearance around controller heat sinks.
- 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.
- Solar controllers are not to be installed in direct sunlight.

### 11.1 MPPT Earth Fault Indication

- Where the PV array maximum voltage is greater than ELV (DVC-C) an earth fault system shall be installed.
- The alarm system may be an audible signal, indicator light or another form of fault communication, e.g. fax, email, SMS. The fault indication shall be installed in a way that it will make the system owner aware of the fault and cause the initiation of an action to correct the earth fault.

## 12. Selecting an Inverter

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When selecting an inverter to be used, the inverter shall meet either:

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

or

- UL Standard 1741 Standard for Inverter, converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources.

## 13. Types of Inverters

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Within AS/NZS4777 there are two definitions:

**Inverter:** A device that uses semiconductor devices to transfer power between a dc source(s) or load and an ac source(s) or load.

**Multiple mode inverter (MMI):** An inverter that operates in more than one mode, for example having grid-interactive functionality when grid voltage is present, and stand-alone functionality when the grid is de-energized or disconnected.

The problem is that though there are two definitions there are still many types of inverter based on the differences in the operating functions of the inverter. For clarity, in this guideline we are more definitive through naming the inverter by its function.

There are four main types of inverters on the market that could be used in a grid connected PV system with BESS. These are: PV grid connect, stand alone, battery grid connect and PV battery grid connect. A minimum of 1 inverter is required for a BESS system to operate since battery systems typically produce dc electricity, and typical loads use ac electricity.

Note: The term battery inverter is used here because that is noting that the inverter is directly connected to the battery system as its power source.

### 13.1 PV Grid Connect Inverter

A PV grid connect inverter is capable of producing an ac output that can interact with the grid. It cannot independently produce ac output as it requires a reference to ac power (typically the grid or another ac source). Therefore, a PV array cannot power loads via a PV grid connect inverter without additional equipment. They typically contain an MPPT for controlling the PV array output.

Note: Considering the two definitions above, the PV Grid Connect Inverter would be defined as an “Inverter”.

### 13.2 PV Battery Grid Inverter

A PV Battery grid connect inverter (hybrid) has both a PV inlet port and a battery system inlet port. It will also have a port for interconnecting with the grid and an outlet port for dedicated (specified) loads. Hence it is capable of operating with or without the grid. The multimode ability is required for the system to operate during certain conditions such as blackouts, or for PV system operating in zero export mode. When it operates during blackouts, the inverter isolates from the grid, and is often configured so it can still supply specified loads.

Note: Considering the two definitions above the PV Battery Grid Connect Inverter would be defined as a “Multimode Inverter”.

### 13.3 Battery Grid Connect Inverter

A battery grid connect inverter is capable of producing an ac signal compatible with the grid. It is able to synchronise with the grid and it can independently produce ac output if there is no grid.

Note: Considering the two definitions above the Battery Grid Connect Inverter would be defined as a “Multimode Inverter”.



## 13.4 Stand-Alone Inverter

Stand-alone inverters are designed to provide ac power from battery systems which are typically charged by renewable energy sources. These inverters are not designed to connect to or to inject power into the electricity grid so they can only be used in a grid connected PV system with a BESS when the inverter is connected to dedicated loads either permanently or via a change-over switch when the grid is not available. (Note: Considering the two definitions above the Stand-Alone Inverter would be defined as an “Inverter”)

Note: For convenience any inverter connected to the battery system will be referred to as the “battery inverter” however it must be appreciated that in some systems the battery inverter will be a PV battery grid connect inverter and hence that inverter must be sized as the battery inverter and also sized to suit the PV array. Any inverter connected to the PV array will be referred to as the PV inverter.

## 14. Installing a PV Inverter

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- The PV inverter shall be installed as to the manufacturer’s instructions.
  - 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.
  - If a PV inverter is installed outside, the PV 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 PV inverters should have this IP rating or greater.
  - PV inverters are not to be installed in direct sunlight.
  - The PV inverter shall be installed with recommended clearances around the PV inverter as specified by the manufacturer.
  - PV Inverters should be installed in dust free locations.
  - PV inverters can be heavy, it is important that the surface on which the PV inverters will be mounted is appropriately weight-bearing.
  - The PV inverter heat sink shall be clear of any obstacles that may interfere with cooling of the PV inverter.
  - Cables connected to the PV inverter shall be mechanically secured in such a manner that they cannot be inadvertently unplugged from the PV inverter. This can be achieved by:
    - Having the PV inverter housed in an enclosure (with cables suitably supported).
    - The use of an PV inverter which has the cable connection area of PV inverter covered by a removable enclosure/cover which protects the supported cables so that there are no exposed, unsupported cable loops.
    - The use of conduit and secure wall fixings
- Note:** Where the PV 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 PV 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.

### 14.1 PV Inverter Earth (Ground) Fault Alarm

- Where the PV array maximum voltage is greater than ELV (DVC-C) an earth fault system shall be installed.
- The alarm system may be an audible signal, indicator light or another form of fault communication, e.g. fax, email, SMS. The fault indication shall be installed in a way that it will make the system owner aware of the fault and initiate an action to correct an earth fault.

## 14.2 Ground Fault Protection (countries following NEC requirements)

NEC 2017 (690.41) introduced the requirement that PV array shall be with dc ground-fault protection meaning:

- The ground fault protective device (GFPD) or system shall detect ground fault(s) in the PV array dc current-carrying conductors and components.
- The circuit with the ground fault shall be interrupted by either:
  - The GFPD disconnecting the conductor with the fault, or
  - The Inverter connected to the conductor with the fault ceases providing any output power.

Exception: PV arrays with no more than two PV source circuits and with all PV system dc circuits not on or in buildings shall be permitted without ground-fault protection.

## 15. Installing a Battery Inverter

This section applies to any inverter that interconnects with a battery system. This includes PV battery grid connect inverters, battery grid connect inverters and stand-alone inverters.

- Where the battery system voltage is ELV, non-separated (i.e. transformerless) battery inverters should not be used unless they are installed in a pre-assembled BESS where access to the battery system is only available via a locked enclosure.
- The battery inverter should be installed as close as possible to the battery system to minimise voltage drop.
- 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 inverter should have this or higher IP rating.
- Battery inverters are not to be installed in direct sunlight.
- The battery inverter shall be installed with recommended clearances around the battery inverter as specified by the manufacturer.
- Battery inverters should be installed in dust free locations.
- Battery inverters can be heavy, it is important that the surface on which the PV inverters will be mounted is appropriately weight-bearing.
- The Battery inverter heat sink shall be clear of any obstacles to facilitate cooling of the PV inverter.

## 16. Safe Installation Practice

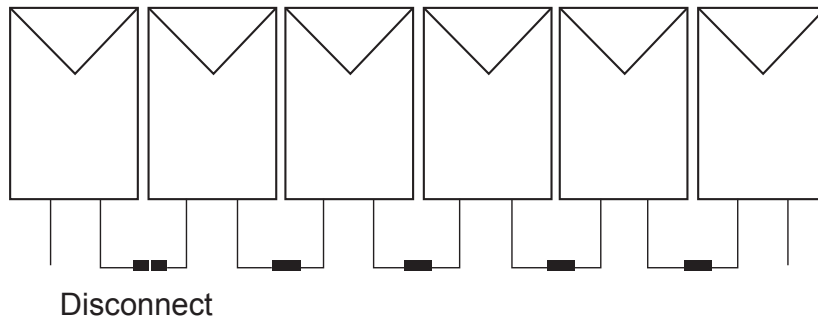
A dangerous situation occurs when the person installing the system is able to come in contact with the positive and negative outputs of the solar array or sub-array when the output voltage is rated DVC-C (that is greater than 120V dc). This could occur with a dc coupled system using MPPTs or an ac coupled system.

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

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

- The PV Array switch-disconnector (isolator) before the PV inverter or MPPT controller;  
AND
- The sub-array and array junction 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 10) is left disconnected until all the wiring is complete between the array and the PV inverter. Only after all switch-disconnectors and other hard-wired connections are completed should the interconnect of the array be connected.



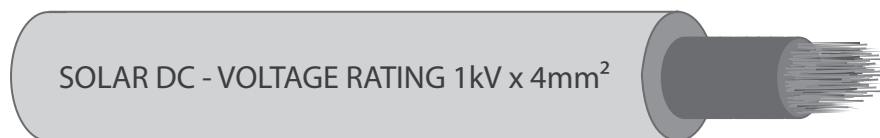
**Figure 10: Disconnected interconnect cable**

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.

## 17. PV Array Wiring

### 17.1 Selection of dc Cable for PV Array



**Figure 11: Double insulated solar dc cable**

Cables used within the PV array wiring shall:

- Be suitable for dc application,
- Have a voltage rating equal to or greater than the PV array maximum voltage determined in section 4.
- Have a temperature rating according to the application.
- If exposed to salt environments be tinned copper, multi stranded conductors to reduce degradation of the cable over time,
- Be water resistant.
- In all systems operating at voltages above DVC-A, cables shall be selected so as to minimise the risk of earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables, particularly for cables that are exposed or laid in metallic tray or conduit.
- It is recommended that string cables be flexible to allow for thermal/wind movement of arrays/module.
- For PV arrays that operating at voltages above DVC-A, Cables should comply with PV1-F requirements or UL 4703 or VDE-AR-E-2283-4.

Note: PV1-F cable requirements may be found in the document TUV 2 PfG 1169/08.2007.

Correctly sized cables in an installation will produce the following outcomes:

1. There is no excessive voltage drop (which equates to an equivalent power loss) in the cables.
2. The current in the cables will not exceed the safe current handling capability of the selected cables known as current carrying capacity (CCC).

## 17.2 Installation of PV Array Wiring

- Plastic cable ties are not to be used as the primary means of support.
- Cables shall not lie on roofs or the ground without an enclosure or conduit.
- Cables shall be protected from mechanical damage. Where the presence of fauna is expected to constitute a hazard, either the wiring system shall be selected accordingly, or special protective measures shall be adopted.
- All external wiring must be protected from UV either by using UV rated cables or installing the cables into enclosures/conduit.
- All conduits exposed to direct sunlight shall be suitably UV rated.
- The installer shall ensure that all cable connectors used are waterproof and connected securely to avoid the possibility of a loose connection.
- Only cable connectors which are the same type/model from the same manufacturer are allowed to be married at a connection point.
- It is recommended that under maximum solar current the voltage drop from the most remote module in the array to the input of the MPPT or PV inverter should not exceed 3% of the  $V_{mp}$  voltage (at STC) for PV arrays.

Note: For systems using PWM controllers It is recommended that under maximum solar current the voltage drop from the most remote module in the array to the battery system should not exceed 5% of the battery system voltage.

## 17.3 Wiring Loops

Cables need to be laid in parallel close together to avoid wiring loops which could attract lightning surges. Figure 12, Figure 13 and Figure 14 give examples on how the conductive wiring loop can be avoided while Figure 15 shows a wiring arrangement that will cause a conductive loop and should not be used. For minimizing lightning generated voltage surges, the positive and the negative wires should always be run together.

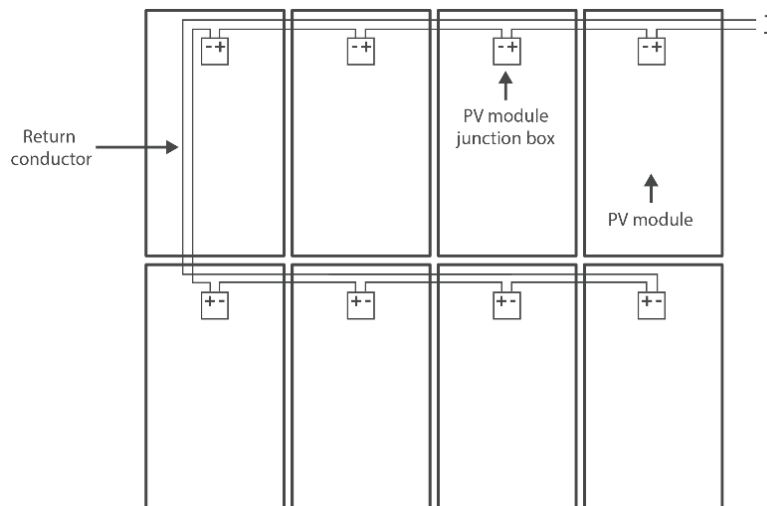
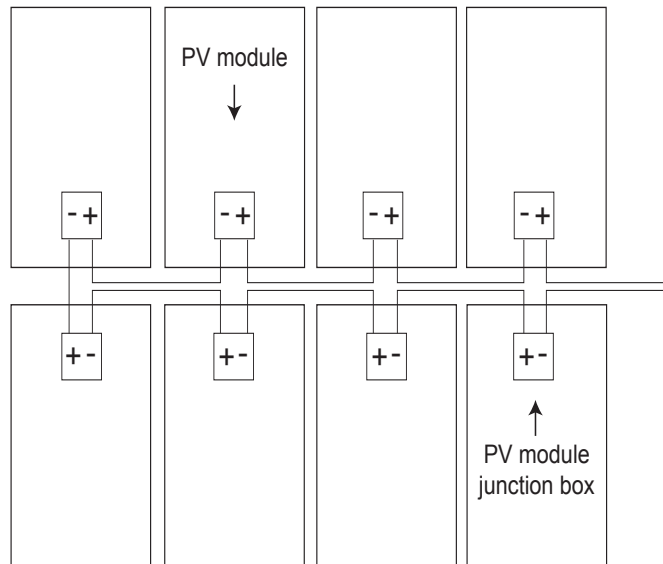
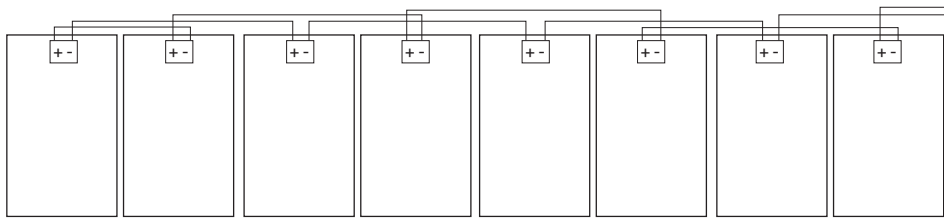


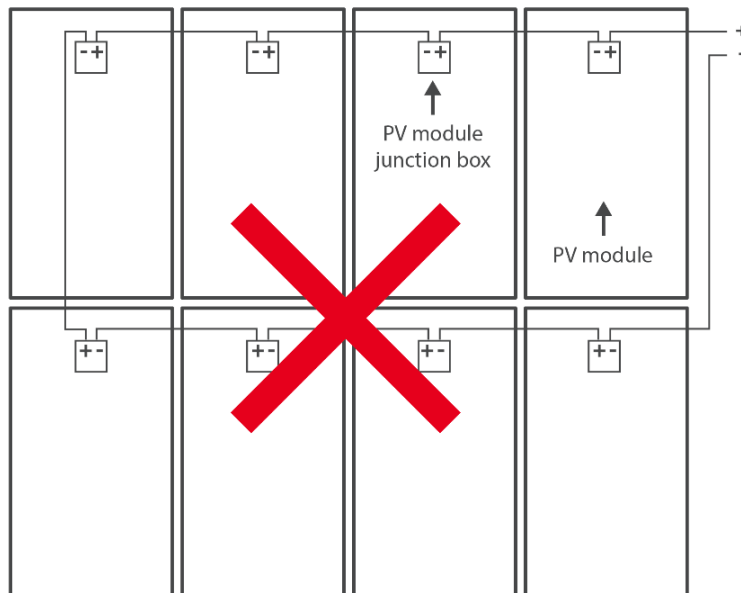
Figure 12: Example of wiring to avoid conductive loops



**Figure 13: Example of wiring to avoid conductive loops**



**Figure 14: Example of wiring to avoid conductive loops**



**Figure 15: Example of wiring to be avoided because it includes conductive loops**

## 17.4 Selection of Current Carrying Capacity of PV String Cables

- If a fault current protection device is located in the string cable, the string cable must have a rating equal to or greater than the current rating of the fault current protection device. For example, if the fault current protection device is rated at 8A, the string will need to be rated with a current carrying capacity (CCC) of a minimum of 8A.
- If no fault current protection is provided, the current carrying capacity (CCC) of the string cable will be rated according to:

$$CCC > 1.25 \times I_{SCMOD} \times (\text{Number of Strings} - 1) + I_n$$

Where:

$I_{SCMOD}$  = short circuit current of PV module

$I_n$  = current rating of nearest downstream protection device

## 17.5 Selection of Current Carrying Capacity of PV Array Cables

- If a fault current protection device is located in the sub-array cable, the sub-array cable must have a rating equal to or greater than the current rating of the fault current protection device.
- If no fault current protection device has been included, the current carrying capacity of the PV sub-array cable will be rated according to:

$$CCC > 1.25 \times I_{SCARRAY}$$

Where:

$I_{SCARRAY}$  = sum of short circuit currents of all the strings in the array

## 17.6 Selection of Current Carrying Capacity of Sub- Array Cables

### 17.6.1 PV Array Cables

- In a large grid connected PV system the array could consist of a number of sub-arrays. A sub-array comprises a number of parallel strings of PV modules. The sub-array is installed in parallel with other sub-arrays to form the full array. The effect of this is to decrease the potential fault current through different parts of the system.
- If a fault current protection device is located in the sub-array cable, the sub-array cable must have a rating equal to or greater than the current rating of the fault current protection device.
- If no fault current protection device has been included, the current carrying capacity of the PV sub-array cable will be rated according to:

$$CCC > 1.25 \times I_{SCARRAY}$$

Where:

$I_{SCARRAY}$  = sum of short circuit currents of all the strings in the array

### 17.6.2 PV Sub-Array Cables

- If a fault current protection device is located in the array cable, the sub-array cable must have a rating equal to or greater than the current rating of the fault current protection device.
- If no fault current protection device has been included, the current carrying capacity of the PV sub-array cable will be rated according to:

$$CCC > 1.25 \times I_{SCSUB-ARRAY} + I_n$$

Where:

$I_{SC\ SUB-ARRAY}$  = short circuit current of all other sub-arrays  
 $I_n$  = current rating of nearest downstream protection device

### 17.6.3 PV String Cables

- If sub-array fault current protection is used, the current carrying capacity of the string cable will be the rated trip current of the sub-array fault current device plus the fault current of the other strings in the sub-array:

$$CCC > I_{trip-subarray} + 1.25 \times I_{SC\ MOD} \times (\text{Number of Strings} - 1)$$

Where:

$I_{trip-subarray}$  = the rated trip current of the sub-array fault current protection device

- If no sub-array fault current protection device is used, the current carrying capacity of the string cable will be according to:

$$CCC \geq 1.25 \times (\text{sum of short circuit currents of all other strings in the array})$$

## 18. Voltage Drop

- The voltage drop between the PV array and the battery system should never exceed 5%
- The voltage drop between the PV array and PV inverter should never exceed 3% (ac coupled)
- The voltage drop between the PV array and MPPT should never exceed 3% (dc coupled)

### 18.1 Calculating Voltage Drop (Metric) for Systems That Include PWM Controllers

This section is for systems that are using PWM solar controllers. 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:

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

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

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.

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

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

$V_{dc}$  = dc system voltage in volts.

The resistivity of wires (conductors) varies with temperature. It is recommended that the maximum allowable temperature for the type of cable being used is applied for determining the resistivity of that cable.

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

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

Table 4 shows the respective resistivities for the different types of cables

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

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

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

### Worked Example 2

A solar array has been installed and the distance between the output of the array and the solar controller is 8 metres. The short circuit current of the array is 9.6A. The cable is copper and PVC

The cable has a cross sectional area of 10 mm<sup>2</sup>

The cable is copper with a resistivity of 0.0209 ohms/metres/mm<sup>2</sup>

The battery voltage of the system is 12V.

$$\begin{aligned}
 V_d &= \frac{2 \times L_{CABLE} \times I \times \rho}{A_{CABLE}} \\
 &= 2 \times 8 \times 9.6 \times 0.0209 / 10 \\
 &= 0.321
 \end{aligned}$$

$$\begin{aligned}
 \text{Voltage drop (in percentage)} &= \frac{V_d}{V_{dc}} \times 100 \\
 &= 0.4013 / 12 \times 100 \\
 &= 2.7\%
 \end{aligned}$$



## 18.2 Calculating Voltage Drop (Metric) 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).

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:

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

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

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.

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

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

$V_{MAX}$  = maximum line 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 3

A solar array has been installed and the distance between the output of the array and the solar controller is 8 metres. The short circuit current of the array is 9.6A. The cable is copper and PVC

The cable has a cross sectional area of 4  $mm^2$

The cable is copper with a resistivity of 0.0209 ohms/metres/ $mm^2$

The array has maximum power point voltage of 154.4V.

$$\begin{aligned} V_d &= \frac{2 \times L_{CABLE} \times I \times \rho}{A_{CABLE}} \\ &= 2 \times 8 \times 9.6 \times 0.0209 / 4 \\ &= 0.803V \end{aligned}$$

$$\begin{aligned} \text{Voltage drop (in percentage)} &= \frac{V_d}{V_{MAX}} \times 100 \\ &= 0.803 / 154.4 \times 100 \\ &= 0.52\% \end{aligned}$$

## 18.3 Calculating Voltage Drop (Imperial) for Systems That Include PWM Controllers

This section is for systems that are using standard pulse width modulated (PWM) solar controllers.

To determine the voltage drop, the following formula is used. The equation is derived from Ohm's Law i.e.  $V=IR$ :

$$V_d = \frac{I \times 2 \times d}{1000 \text{ ft/kft}} \times \left( \frac{\Omega}{\text{kft}} \right)$$

Where:

$V_d$  = voltage drop  
 $d$  = route length of dc cable in feet (2 x adjusts for total circuit wire length)  
 $I$  = dc current in amperes (commonly  $I_{mp}$ )  
 $\Omega/\text{kft}$  = ohms/thousand feet (resistance)

The resistance is dependent on the type of material. The resistance also depends on whether the cable is a single strand or multi-stranded.

Voltage drop (in percentage) =  $\times 100$

For PV arrays connected to a PWM controller the current is the short circuit current ( $I_{sc}$ ) of the string, sub-array or array. The  $V_{dc}$  is the nominal battery system voltage.

Table 5 is an extract from the National Electric Code.

**Table 5: Cable Resistance for uncoated copper cable at 75°C (167°F)**

Wire Size (AWG)	dc Resistance (Ohms per 1000 feet)	ac Resistance (Ohms to neutral per 1000 feet)
14	3.14	3.1
12	1.98	2.0
10	1.24	1.2
8	0.778	0.78
6	0.491	0.49
4	0.308	0.31
2	0.194	0.20
1	0.154	0.16
1/0	0.122	0.13
2/0	0.0967	0.10
4/0	0.0608	0.067

#### Worked Example 4

A solar array has been installed and the distance between the output of the array and the inverter is 33 feet.

- The short circuit current of the array is 9.6A.
- The cable is AWG 6
- The battery system voltage is 12V.

From Table 5, the dc Resistance in Ohms per 1000 feet =0.491

Therefore:

$$\begin{aligned}V_d &= \frac{I \times 2 \times d}{1000 \text{ ft/kft}} \times \left( \frac{\Omega}{\text{kft}} \right) \\ &= 9.6 \times 2 \times 33 \times 0.491/1000\text{V} \\ &= 0.311\text{V}\end{aligned}$$

$$\begin{aligned}\text{Voltage drop (in percentage)} &= \frac{V_d}{V_{MAX}} \times 100 \\ &= 0.311/12 \times 100 \\ &= 2.6\%\end{aligned}$$

## 18.4 Calculating Voltage Drop (Imperial) for Systems That Include a MPPT

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

To determine the voltage drop the following formula is used. The equation is derived from Ohm's Law i.e.  $V=IR$ :

$$V_d = \frac{I \times 2 \times d}{1000 \text{ ft/kft}} \times \left( \frac{\Omega}{\text{kft}} \right)$$

Where:

- $V_d$  = voltage drop  
 $d$  = route length of dc cable in feet (2 x adjusts for total circuit wire length)  
 $I$  = dc current in amperes (commonly  $I_{mp}$ )  
 $\Omega//\text{kft}$  = ohms/thousand feet (resistance)

The resistance is dependent on the type of material. The resistance also depends on whether the cable is a single strand or multi-stranded.

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

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 5

A solar array has been installed and the distance between the output of the array and the inverter is 33 feet.

- The short circuit current of the array is 9.6A.
- The cable is AWG 10
- The array has maximum power point voltage of 154.4V.

From Table 4, the dc Resistance in Ohms per 1000 feet = 1.24

Therefore:

$$\begin{aligned}V_d &= \frac{I \times 2 \times d}{1000 \text{ ft/kft}} \times \left( \frac{\Omega}{\text{kft}} \right) \\ &= 9.6 \times 2 \times 33 \times 1.24/1000\text{V} \\ &= 0.786\text{V}\end{aligned}$$

$$\begin{aligned}\text{Voltage drop (in percentage)} &= \frac{V_d}{V_{MAX}} \times 100 \\ &= 0.786/154.4 \times 100 \\ &= 0.51\%\end{aligned}$$

## 19. Installation of PV Array Cable Between Array and PV Inverter

- If the PV array has a rated output voltage greater than 120V dc the PV array cables within buildings installed in ceiling spaces, wall cavities or under floors, 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.
- PV array cables shall be installed in UV-resistant conduits if exposed to the outdoor environment.
- Conduits shall be installed so that they are adequately supported.
- Double insulation of each conductor shall be maintained within wiring enclosures (e.g. conduit).
- The wiring enclosure shall be labelled 'SOLAR' on the exterior surface of the enclosure at an interval not exceeding 2 metres.
- Where the PV array cable and conduit passes through a tile or steel roof, an appropriate collar flashing (e.g. dektite) shall be installed.
- Installing a conduit just through a hole in a metal roof and silicon sealing it is prohibited.



Figure 16: A Dektite® with a metal roof flashing

## 20. Installation of Cable Between PWM Controller and Battery System

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- The cables between the PWM and the battery system shall have a voltage rating equal to or greater than the maximum voltage of the battery system.
- The current carrying capacity of the cable between the controller and battery systems shall be capable of carrying the maximum charge current from the array.
- The current-carrying capacity of the cable between the battery system and PWM controller shall be based on the dc current rating of the associated over-current protection.
- Any battery system cable forming the connection between a battery system terminal and the respective battery system over-current protection device for the PWM controller 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 dc cables between the PWM controller and the battery system can be single insulated if the battery system is ELV.
- Cables and conduits shall be installed so that they are adequately supported.
- When using PWM controllers, it is recommended that under maximum solar current, the voltage drop from the most remote module in the array to the battery system should not exceed 5% of the battery system voltage.

## 21. Installation of Cable Between MPPT Controller and Battery System

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- If the PV array has a rated output voltage greater than 120V (DVC-C) and the MPPT is not electrically separated between the input and output, the dc cables between the MPPT and the battery system shall be double insulated and should be in medium duty conduit.
- The cables between a non-separated MPPT and the battery system shall have a voltage rating equal to or greater than the PV array maximum voltage determined in section 4.
- The cables between a separated MPPT and the battery system shall have a voltage rating equal to or greater than the maximum voltage of the battery system.
- The current carrying capacity of the cable between the controller and battery system shall be capable of carrying the maximum charge current from the MPPT.
- The current-carrying capacity of the cable between the battery and MPPT shall be based on the dc current rating of the associated over-current protection.
- Any battery system cable forming the connection between a battery system terminal and the respective battery system over-current protection device for the MPPT 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.

## 22. Installation of Cable Between Battery Inverter and Battery System

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- For systems with PWM controllers, the cable shall have a voltage rating equal to or greater than the maximum battery system voltage.
- For systems using a separated MPPT controller, the cable shall have a voltage rating equal to or greater than the battery system voltage.
- For systems using non-separated MPPT the cable shall have a voltage rating equal to or greater than the PV array maximum voltage determined in section 4.
- If the PV array has a rated output voltage is greater than 120V (DVC-C) and the solar controller is a non-separated MPPT unit, the dc cables between the battery system and the battery inverters shall be double insulated.
- For systems using PWM controllers or separated MPPT controllers and the battery system voltage is ELV, the dc cables between the battery system and the battery inverter can be single insulated.
- 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.
- Cables and conduits shall be installed so that they are adequately supported.

## 23. Installation of ac Cable between the PV Inverter and the Grid

- The installation of the ac cabling shall comply with any local wiring requirements.
- The PV inverter shall be connected by fixed wiring to a dedicated circuit on a switchboard or distribution board.
- All ac cables between the PV inverter and any switchboard and all the cables between any distribution boards and a main switchboard which carry current from the PV inverter shall be rated for at least the full output current of the PV inverter energy system.
- It is recommended that the voltage drop (based on the maximum ac current from the PV inverter(s) between the PV inverter ac terminals and the point of connection to the grid (supply) should be kept as small as possible (recommended <1%) to minimise voltage rise within the installation. This will limit inverter disconnections in areas where the grid voltage may be high to decrease incidents of overvoltage trips for PV inverters. This is also an issue for micro PV inverter installations where the ac cable run may be long.

### 23.1 Voltage Drop in ac Cables

For ac cables, the formulas in section 22 are applied with addition of power factor ( $\cos \Phi$ ). The resultant formula for determining the voltage drop on single phase ac cables is as follows:

The metric formula is:

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

Where:

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

$I$  = current in amperes.

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

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

$V_{MAX}$  = maximum line voltage in volts.

$\cos \Phi$  = power factor

The Imperial Formula is:

$$V_d = \frac{I \times \cos \Phi \times 2 \times d}{1000 \text{ ft/kft}} \times \left( \frac{\Omega}{\text{kft}} \right)$$

Where:

$V_d$  = voltage drop

$d$  = route length of dc cable in feet (2 x adjusts for total circuit wire length)

$I$  = dc current in amperes (commonly  $I_{mp}$ )

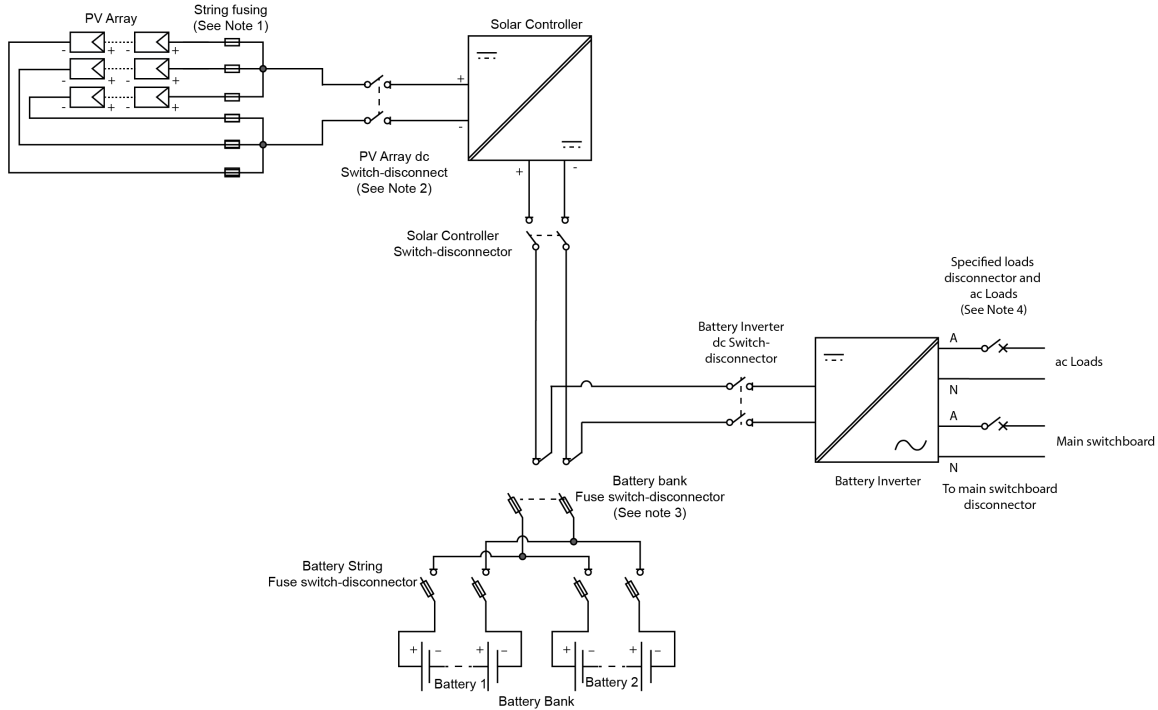
$\Omega/kft$  = ohms/thousand feet (resistance)

$\cos \Phi$  = power factor

## 24. Protection and Isolation Overview

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

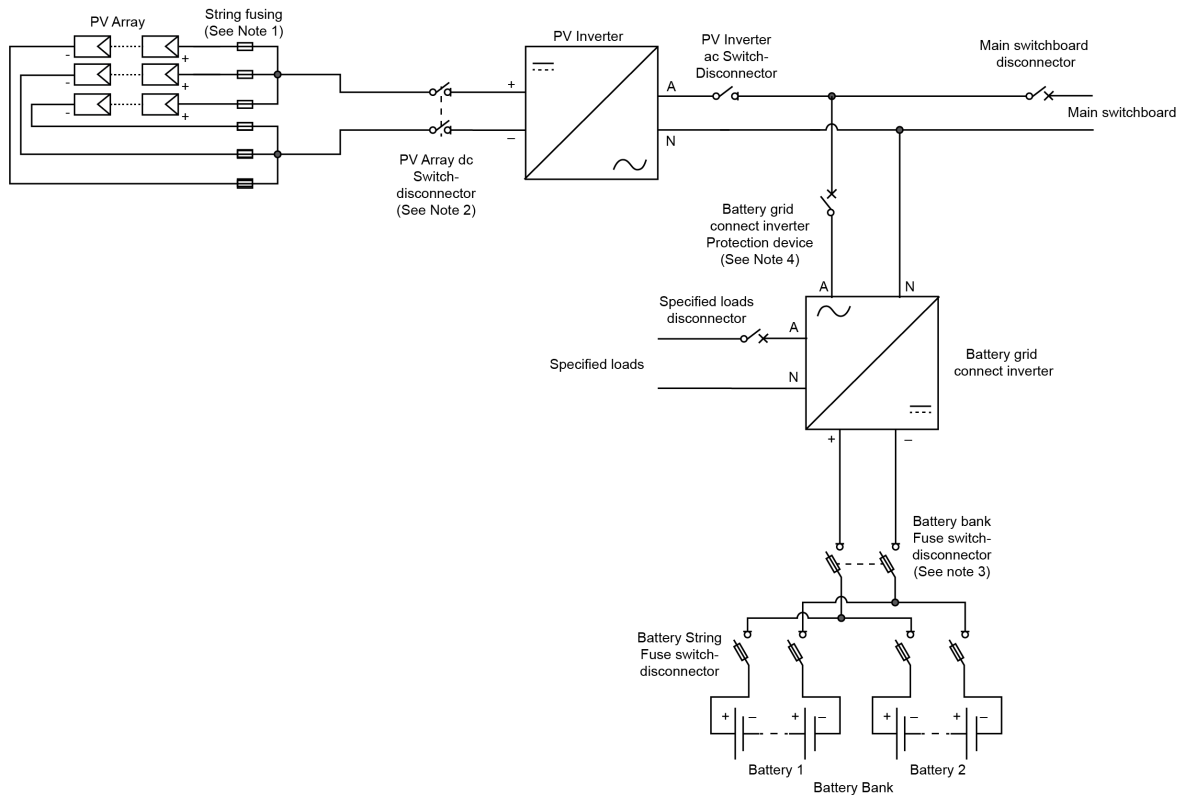
Figures 17, 18 and 19 show the typical protection and isolation (switch-disconnection) requirements in the three types of PC PV systems connected to BESS.



**Figure 17: dc coupled 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 25.1)
2. The PV array dc switch disconnecter is recommended because it helps with maintenance and troubleshooting although many standards allow the battery system switch fuse to meet the isolation requirement. The switch disconnecter will be required as a protection device (e.g. a non-polarised dc circuit breaker) if the battery system fuse 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 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 system 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 disconnecter. Sometimes this might be a four (4) pole device to allow different size fuses to protect the battery inverter cable and the solar controller cable which will be generally be different cross-sectional areas (or gauges).
4. A separate ac load disconnecter is required if the battery inverter does not have a switch disconnecter on the ac output. This will be required as a protection device (e.g. an ac circuit breaker) for protecting the ac load cable.

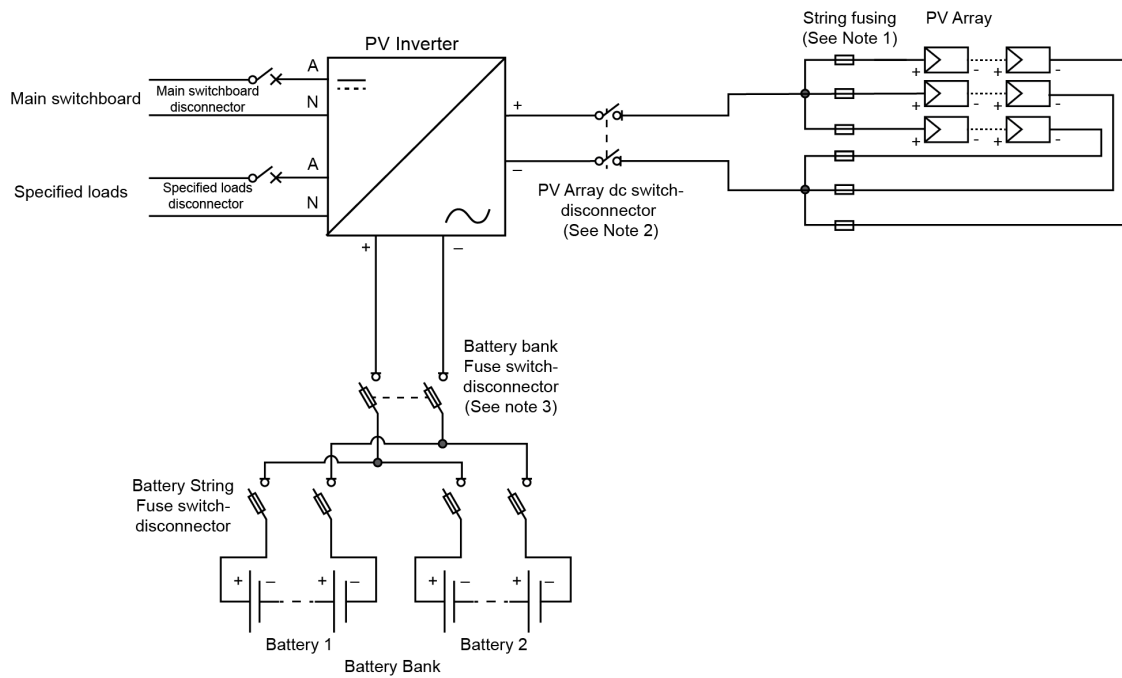


**Figure 18: ac coupled system**

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 25.1)
2. A PV array dc switch disconnector is required but it can be part of the PV inverter. (Refer to section 25.1)
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 using only one switch disconnector.
4. A separate ac battery grid connect inverter disconnecter device is required if the battery grid connect 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.
5. A separate specified load disconnecter device is required if the battery grid connect inverter does not have a switch disconnector on the specified load ac output. This will be required to be a protection device (e.g. ac circuit breaker) for protecting the ac load cable.





**Figure 19: Hybrid 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 25.1)
2. A PV array dc switch disconnector is required but it can be part of the PV inverter. (refer to section 25.1)
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 using only one switch disconnector.
4. A separate ac PV battery grid connect inverter disconnector device is required if the PV battery grid connect 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.
5. A separate specified load disconnector device is required if the battery grid connect inverter does not have a switch disconnector on the specified load ac output. This will be required to be a protection device (e.g. ac circuit breaker) for protecting the ac load cable.

## 25. Protection Requirements in a System

### 25.1 Solar Array dc Cable Protection

Each solar module has a maximum reverse current rating provided by the manufacturer. If the array consists of parallel strings such that the reverse current flow into a string with a fault can be greater than the maximum reverse current for the modules in that string, then protection shall be provided in each string. The protection to be used shall be dc rated fuses that meet the specification shown in 25.2

#### Worked Example 6

The reverse current rating for a module is 15A while the short circuit current is 8.9A. If the array consists of two (2) parallel strings and a fault occurs in one (1) string then the potential fault current will come from the other one (1) string which is only 8.9A and is less than the reverse current rating so no protection is required. However, if the array consists of three (3) parallel strings and a fault occurs in one (1) string then the fault current could come from the other two (2) strings. This current is 17.8A (2 x 8.9A) and is now greater than the reverse current rating of the module. Protection is now required.

A formula for determining the maximum number of strings allowed before fuses are required is:  
Maximum Number of Strings without string protection = reverse current rating of a module/Isc of the module

So in the above example; Max Number of strings = 15/8.9 = 1.69 rounded up to 2.

### 25.2 PV Fuses

Fuses used in PV arrays shall:

- be rated for dc use;
- have a voltage rating equal to or greater than the PV array maximum voltage determined via table 2;
- be rated to interrupt fault currents from the PV array; and
- be of an overcurrent and short circuit current protective type suitable for PV complying with IEC 60269-6 (i.e. Type gPV) or the equivalent through the NEC.

### 25.3 String Protection

The fuses shall have the following current rating:

$$1.5 \times I_{SC\ MOD} < I_{TRIP} < 2.4 \times I_{SC\ MOD}$$

and

$$Fuse\ Rating < I_{RC\ MOD}$$

Where:

$I_{SC\ MOD}$  = module short circuit current in amps.

$I_{TRIP}$  = rated trip current of the fault current protection device.

$I_{RC\ MOD}$  = module reverse current rating

Note: For countries following NEC the requirements are:

- Minimum fuse rating  $1.56 \times I_{sc}$  of module(string)
- Maximum fuse rating less than reverse current rating of the module(string)

## 25.4 Sub-Array Protection

An array may be broken up into sub-arrays for different reasons; for example, if two sections of the array are installed in separate areas. The need for sub-array overcurrent protection is similar in logic to that for string overcurrent protection – one sub-array could be operating differently from the other sub-arrays owing to shading or earth faults. The use of sub-array protection is to stop excessive currents from flowing into a sub-array.

## 25.5 Requirements for Sub-Array Overcurrent Protection

Sub-array overcurrent protection protects a sub-array made up of a group of strings. It is required if one of the following conditions is met:

- $1.25 \times I_{SC\_ARRAY} >$  Current carrying capacity (CCC) of any sub-array cable, switching and connection device.
- More than two sub-arrays are present within the array.

Note: For countries following NEC the requirements are:

- Minimum fuse rating  $1.56 \times I_{sc}$  of sub array

## 25.6 Sizing for Sub-Array Overcurrent Protection

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

$$1.25 \times I_{SC\_SUB - ARRAY} \leq I_{TRIP} \leq 2.4 \times I_{SC\_SUB - ARRAY}$$

Where:

$I_{SC\_SUB-ARRAY}$  = short-circuit current of the sub-array.  
 $I_{TRIP}$  = rated trip current of the fault current protection device.

Note: For countries following NEC the requirements are:

- Minimum fuse rating  $1.56 \times I_{sc}$  of sub array

## 25.7 Array Cable Protection

Array overcurrent protection is designed to protect the entire PV array from external fault currents. For a grid connected PV system with BESS, it is required to prevent potential fault currents from the battery system to back-feed through the controller or battery inverter.

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

$$1.25 \times I_{SC\_ARRAY} \leq I_{TRIP} \leq 2.4 \times I_{SC\_ARRAY}$$

Where:

$I_{SC\_ARRAY}$  = short-circuit current of the array.  
 $I_{TRIP}$  = rated trip current of the fault current protection device.

Note: For countries following NEC the requirements are:

- Minimum fuse rating  $1.56 \times I_{sc}$  of array

## 25.8 Arc fault Protection

For countries following NEC, NEC Article 690.11 requires PV systems operating at 80 V dc or greater to be protected by a listed PV arc-fault circuit interrupter. The purpose is to detect and interrupt arcing faults.

There are exemptions including:

- PV systems not installed on buildings or in buildings where the building is a detached structure solely for housing PV system equipment.
- PV circuits and dc-to-dc converter output circuits that are direct buried, installed in metallic raceways, or installed in enclosed metallic cable trays.

Refer to the NEC for further information.

## 25.9 Rapid Shutdown of PV Systems on Buildings (Countries following NEC Requirements)

NEC Article 690.12 requires PV systems dc wiring installed on or in buildings to include a rapid shutdown device. (This would only be required for systems operating greater than 80V dc)

There is an exemption for ground mounted arrays frames where:

- the dc array cable never enters a building, or
- when the dc array cable does enter a building, the building is designed specifically to house only PV system equipment.

Refer to the NEC for further information.

### 25.10 Battery System Cable Protection- dc coupled

dc coupled systems as shown in Figure 17 can potentially have two different sized battery system cables:

- The battery system cable between the battery system and the solar controller.
- The battery system 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.

The protection device for the battery inverter will be determined via the process defined in section 25.12

### 25.11 Battery System Cable Protection- ac Coupled and Hybrid

ac coupled systems as shown in Figure 18 and hybrid inverter systems as shown in Figure 19 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 25.12.

## 25.12 Battery System Cable Protection- Battery Inverter

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

### Step 1

Obtain the battery inverter manufacturer's data of:

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

### Step 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]

### Step 3

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

$$I = \frac{\text{Inverter power rating (W)}}{\text{Inverter efficiency} \times \text{nominal battery system voltage (V)}}$$

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

For both ac and dc coupled systems, the battery inverter can also act as a battery charger if charging from the grid. In that case, the battery inverter fuse is being used as a main battery system 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.

## 26. Disconnection (Isolation) Requirements

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

- Battery system switch disconnector between battery system and the solar controller (dc coupled).
- Battery system switch disconnector between battery system and the battery inverter.
- PV array dc switch disconnector located near MPPT when array maximum voltage is LV,
- PV array dc switch disconnector located near PV inverter (ac coupled and hybrid).
- ac switch disconnector located near battery inverter. (if applicable, see section 26.7)
- ac main switch located within the switchboard or distribution board that is interconnected to the PV inverter.

It is recommended to have a PV array dc switch disconnector located near PWM controller however the battery system isolator is accepted in meeting this function.

Battery inverters generally have an inbuilt 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.

### 26.1 Disconnection Requirements Within an Array

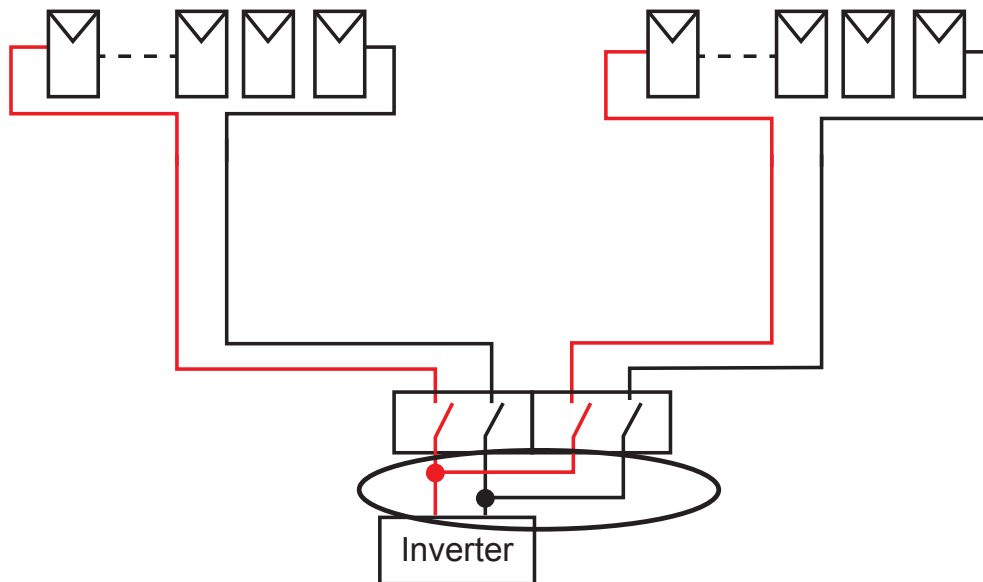
Every string shall be capable of being individually disconnected (isolated) from the rest of the system. This disconnection does not have to be load breaking. The module connectors can perform this function.

Sub-arrays shall be capable of being individually disconnected (isolated) from the rest of the system. It is recommended that this is a load-break switch disconnector.

### 26.2 PV Array dc Switch Disconnector Near PV Inverter or MPPT Controller (if Array is LV)

Every string shall be capable of being individually disconnected (isolated) from the rest of the:

- A PV array switch-disconnector/s shall be installed adjacent to the PV inverter and/or MPPT.
- 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.
- For PV inverters with an integrated switch-disconnector: a separate switch-disconnector is not required at the PV inverter if the switch-disconnector is mechanically interlocked with a replaceable module of the PV inverter and allows the module to be removed from the section containing the switch-disconnector without risk of electrical hazards.
- 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 multiple supplies to isolate the equipment.
  - Where there is more than one isolator, they shall be individually labelled e.g. "PV Array DC isolator inverter 1 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/MMPT itself.



**Figure 20: Paralleling strings on PV inverter/MPPT side of PV array disconnecter devices**

- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP 56NW, however it is recommended that they are rated to IP 66.
- It is recommended that there are no top entries into the switch-disconnector and drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 26.6.

### 26.3 PV Array dc Switch Disconnecter Near PWM Controller

For ELV systems this is optional since the battery system switch disconnector meets the requirements however if one is installed it should meet the following:

- 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 multiple supplies to isolate the equipment.
  - Where there is 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 56NW, however it is recommended that they are rated to IP 66.
- It is recommended that there are no top entries into the switch-disconnector and drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 26.6

### 26.4 Battery System Switch Disconnection Devices

- All equipment connected to the battery system shall be capable of being individually isolated from the battery system.
- For a dc coupled system, two isolating devices are required for:
  - The solar controller
  - The battery inverter.
- For an ac coupled system, two isolating devices are required for:
  - The PV inverter (which in some cases may be a component in the PV inverter)
  - The battery inverter
- All battery system isolating devices shall be dc switch disconnectors capable of breaking the maximum current for the particular equipment the battery system is connected to.

- All battery system 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 the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP 56NW, however it is recommended that they are rated to IP 66.
- Battery system switch-disconnectors shall meet the requirements of section 26.6.

## 26.5 Load Disconnection Requirements

- All dc and ac load circuits shall be capable of being isolated.
- For dc coupled systems, ac switch disconnectors should be located in the output cables from battery inverter unless there is an ac switch disconnector included on the battery 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 section 26.6.
- ac load switch disconnectors shall meet the standard requirements for ac switch disconnectors as required in the country of installation and have minimum current ratings equivalent to the rated output current of the battery inverter and/or PV inverter.

## 26.6 dc Switch Disconnector Requirements

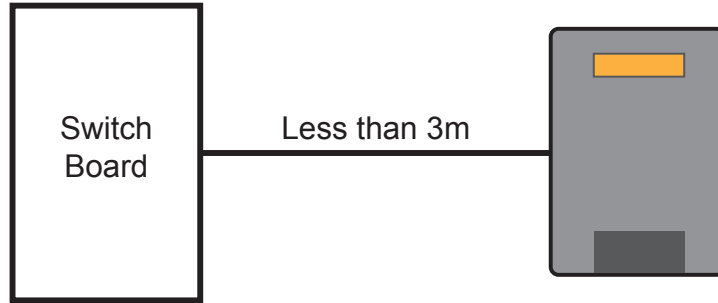
Switch-disconnectors shall:

- be rated for dc use.
- be rated to interrupt full load and prospective fault currents.
- not be polarity sensitive.
- interrupt all live conductors simultaneously.
- shall not have exposed live parts in connected or disconnected state.
- shall comply with the requirements of IEC 60947-3 and shall have a utilization category of at least DC-21B (as per IEC 60947-3)
- For PV array switch connectors, the switch disconnectors shall have voltage ratings as follows:
  - For non-functionally earthed systems with separated PV inverter (transformer based) or separated MPPT: the sum of the voltage rating of both poles together of the switch disconnector shall be at least the PV array maximum voltage ( $V_{oc}$  of the array adjusted for the lowest ambient temperature at site)
  - For non-separated PV inverter (transformerless based) or non-separated MPPT: the voltage rating of each pole of the disconnector shall be at least the PV array maximum voltage ( $V_{oc}$  of the array adjusted for the lowest ambient temperature at site)
- For battery system switch disconnectors, the switch disconnectors shall have voltage ratings as follows:
  - For non-separated MPPT: the voltage rating of each pole of the disconnector shall be at least the PV array maximum voltage ( $V_{oc}$  of the array adjusted for the lowest ambient temperature at site)
  - For all switch type controllers and battery inverters connected to battery system that are not earthed/grounded the voltage rating of the sum of the two poles (positive and negative) of the switch-disconnector shall be at least the maximum battery system voltage expected when under charge
  - For all switching type controllers and battery inverters connected to battery systems that are earthed/grounded the voltage rating of each pole of the switch disconnector shall be at least the maximum battery system voltage expected under charge.
- Battery system switch disconnectors 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.

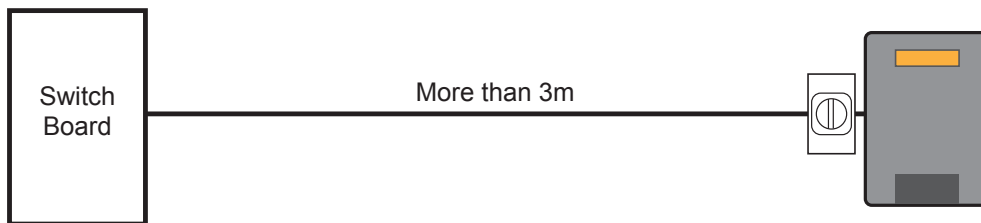


## 26.7 ac Switch Load Disconnecter Near PV Inverter

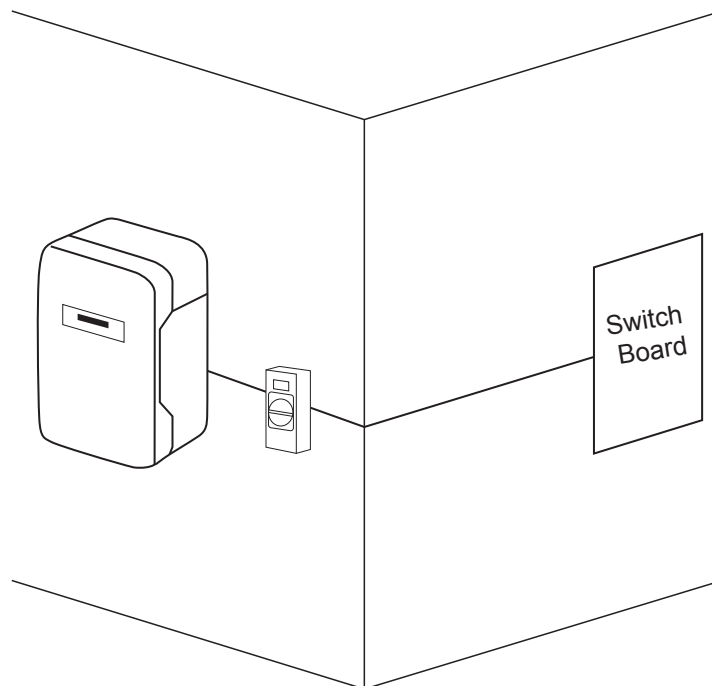
Where the PV inverter is not within 3 metres (10 feet) and in the line of sight of the switchboard to which it is connected, an isolator shall be provided at the PV inverter so that a person operating the switch has a clear view of any person working on the PV inverter. (refer to Figure 21, Figure 22 and Figure 23).



**Figure 21: An ac switch-disconnector is not required - the distance between the switchboard and PV inverter is less than 3m (10 feet) and the PV inverter is visible from the switchboard**



**Figure 22: An ac switch-disconnector is required- the distance is greater than 3m or the switchboard is not visible from the PV inverter**



**Figure 23: An ac switch-disconnector required - the switchboard is away from the line of sight**

- Where the disconnection device is exposed to the weather, it shall have an IP rating of at least IP56NW, however it is recommended that they are rated to IP66.
- It is recommended that there are no top entries into the switch-disconnector and drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- The switch shall have a minimum current rating equal to the maximum ac rating of the PV inverter

## 26.8 Solar Supply Main Switch in Switchboard

- The PV inverter should be connected directly to the main switchboard via a main switch.
- Where this is not possible or not desirable, the PV inverter energy system should be connected to the distribution board located physically nearest to the PV inverter, and the main switchboard.
- The main switch for the switchboard or the distribution board, to which the PV inverter is connected, shall be a lockable circuit breaker to provide protection for the cable to the PV inverter.

## 26.9 ac Isolator for Micro PV Inverter Installation

- A labelled, lockable, switch-disconnector (PV inverter ac isolator) shall be installed at the point of transition from the micro PV inverter interconnect cable to fixed wiring. The purpose of the ac isolator is to de-energise the ac from the micro PV inverter(s) for maintenance or fault rectification.
- The isolator shall be installed adjacent to the PV inverter or PV inverter group. This switch-disconnector may be a single switch-disconnector and can be used to isolate multiple adjacent PV inverters.
- Where micro PV inverters are not installed adjacent to each other, additional switch-disconnectors shall be installed.
- Switch-disconnector enclosures shall be IP56 rated, however it is recommended that it is rated to IP66.
- All entry points (conduit and cable glands) to the switch-disconnector enclosure should be on the lower end of the enclosure either underneath or facing down the roof.
- If exposed to the weather a secondary shield is recommended to shelter the PV inverter ac switch-disconnector from direct exposure to rain and sun.

## 26.10 ac Isolator for Specified Loads

- The specified loads terminal of the battery inverter should be connected directly to the main switchboard or a dedicated distribution board via a main switch.
- This specified load main switch should connect to the circuits will be supplied by the BESS when the grid is unavailable.

## 27. Earthing (Grounding) of Array Frames for a PV Array with Maximum Voltage Greater Than ELV

- All exposed metal module frames and array mounting frames shall be earthed (grounded) where the PV array has a PV array maximum voltage greater than ELV (DVC-C) or when ac modules or micro PV inverters with LV outputs are installed.
- Minimum cable size of 6 mm<sup>2</sup> (NEC states it shall be no smaller than 14 AWG) shall be used but if the array structure is to be earthed (grounded) for lightning protection then it should be minimum 16 mm<sup>2</sup> (6 AWG).
- Earth/ground connection shall be:
  - by a purpose-made fitting providing earthing/grounding 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
  - arranged so that the removal of a single module earth connection will not affect the continuity of the earthing/grounding or bonding connections to any other module.
- Self-tapping screws shall not be used.

- Ensure that rail joiners (splice) provide earth (ground) continuity. Some rail manufacturers state that the use of 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 earth/grounding 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 earth/grounding cable should be installed in parallel and in close proximity to the PV array cable (both positive and negative), the PV inverter and then PV inverter ac cables going to the switchboard or distribution board.
- The earthing/grounding conductor from the PV array can connect to PV inverter's main earth conductor in the ac output cable provided the following conditions are met:
  - Installation is not subject to lightning
  - PV 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 grounding cables will be connected to the same earth grounding point. If multiple grounding points are used, all ground points will be connected together with a grounding cable.

## 28. Installation of Combiner Boxes

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- 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.

## 29. Segregation of ac and dc Circuits

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- Segregation shall be provided between ac and dc 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).
- ac and dc circuits should be clearly marked.

## 30. Plugs and Sockets

---

Plugs, sockets and connectors for the PV array shall:

- comply with EN 50521;
- be protected from contact with live parts in connected and disconnected states (e.g. shrouded);
- have a current rating equal to or greater than the current carrying capacity for the circuit to which they are fitted;
- require a deliberate force to separate;
- have a temperature rating suitable for their installation location;
- if multi-polar, be polarized;
- comply with Class II;
- if exposed to the environment, be rated for outdoor use, be of a UV-resistant type and be of an IP rating suitable for the location;

## 31. Shutdown Procedures

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- 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:
  - Turn off the main switch solar supply at the ac switchboard and then the ac isolator at the PV inverter (when installed)
  - Isolation of PV input. (locations should be specified)
  - Isolation of the ac loads connected to the battery inverter
  - Isolation of the battery system by disconnecting battery system fuses or opening battery system circuit breakers.

## 32. Metering

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The installer shall notify the customer of the metering process. If the metering arrangement with the local electrical utility does not allow metering of the ac output energy of the grid connected PV systems, it is recommended that if the PV inverter does not have that capability then a separate meter is installed. This will help to verify that the system is performing as expected.

As a minimum each system should have meters showing:

- Battery system voltage.
- Current from solar
- Load current from the battery system

## 33. Signage

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- A sign should be included in the switchboard stating: 'WARNING', 'MULTIPLE SUPPLIES' and 'ISOLATE ALL SUPPLIES BEFORE WORKING ON THIS SWITCHBOARD'.
- A sign with text 'MAIN SWITCH (SOLAR SUPPLY)' shall be permanently fixed adjacent to the main switch for the PV inverter.
- Where the PV inverter is connected to the main switchboard, a sign with text 'MAIN SWITCH GRID SUPPLY)' shall be permanently fixed adjacent to the main switch for the grid supply.
- Where the PV inverter is connected to the distribution switchboard, a sign with text 'MAIN ISOLATOR (NORMAL SUPPLY)' shall be permanently fixed adjacent to the isolator for the normal supply to the distribution switchboard.

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

- If the PV inverter is not mounted near the switchboard then there should be a sign in the switchboard stating where the PV inverter is located.
- All battery systems that can emit explosive gases shall have a "No Smoking, No Spark, No Flames Warning sign. (Example provided in Figure 20)
- All battery systems that contain chemicals which could burn the eyes or skin shall have a warning sign prominently displayed. (Example provided in Figure 21)
- All disconnectors shall be labelled and where there is more than one, numbered. For example:
  - Battery system dc disconnect 2
  - PV array dc disconnect
  - Solar controller dc disconnect
  - ac load disconnect 3
- A sign showing the proper Shutdown Procedure shall be located near the system.
- Solar cables shall be labelled every 2 metres where exposed.
- Battery system cables shall be labelled "BATTERY" at intervals less than 2 m.

- Any solar array combiner box should be labelled warning that it is dc supply and if LV (DCV-C) then a prominent sign should warn of hazardous voltages.



Figure 24: Example of risk and battery explosions warning sign

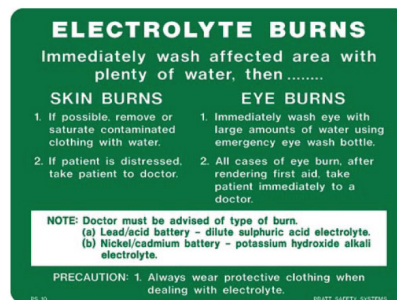


Figure 25: Electrolyte burns signs

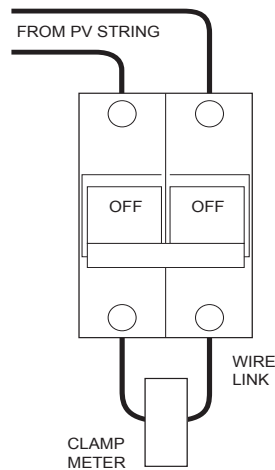
## 34. Commissioning

The commissioning sheets provided with these guidelines (Annex 2) should be completed by the installer. A completed copy shall be provided to the customer in 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.

### 34.1 Short Circuit Current Measurement for Arrays Greater than DVC-A

Where short circuit currents are required, undertake the following steps to measure the short circuit current safely as shown in Figure 22.

- Ensure each string fuse (where required) is not connected or that LV array is disconnected somewhere in each string as shown in Figure 10 of these guidelines.
- Leave solar array cable connected to the PV array switch disconnecter.
- Remove the cable from the PV array switch disconnecter to the PV inverter.
- With the PV array switch disconnecter off - put a link or small cable between the positive and negative outputs of the PV array switch disconnecter.
- Install the string fuse for string 1 or connect the string disconnect (Figure 10) to complete the wiring of the string. Turn on PV array switch disconnecter - using a dc. clamp meter measures the dc short circuit current for String 1. Turn off PV array switch disconnecter. Disconnect string fuse for string 1 or remove disconnecter to break string circuit.
- Repeat each string



**Figure 26: Measuring short circuit current**

### 34.2 Insulation Resistance Method

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

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

The insulation resistance test shall be carried out with an insulation test device connected between earth and the PV array positive connection, and then the test repeated with the test device connected between earth and PV array negative connection. Test leads should be made secure before carrying out the test. The values of insulation resistance shall be recorded. Table 6 shows the minimum values that should be achieved for different system voltages.

**Table 6: Minimum insulation resistance values.**

System Voltage (V × 1.25)	Test Voltage	Minimum Insulation Resistance, MΩ
< 120	250	0.5
120 – 500	500	1
> 500	1000	1

## 35. Documentation

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All complex systems require a user manual for the customer. Grid-connected PV systems with BESS are no different.

The documentation for system installation that shall be provided to the system owner includes:

- Battery system information including total storage capacity, commissioning date, system provided contact details
- List of equipment supplied with model, description and serial numbers
- List of action to be taken in the event of an earth fault alarm and how to identify when the system is not operating correctly
- Operating instructions and a description of the function and operation of all installed equipment
- Shutdown and isolation procedure for emergency and maintenance
- Start up procedure and verification checks
- Maintenance procedure and timetable
- Commissioning sheet and installation checklist
- Warranty information
- A basic connection diagram that includes electrical ratings of the PV array and the ratings of all overcurrent devices and switches as installed
- System performance and operation configuration
- Description and meaning of any state of health measurements
- Recommended maintenance procedure and timetable for the system
- Equipment manufacturer's documentation and handbooks for all equipment supplied
- Array frame engineering certificate for wind and mechanical loading
- Installer/designer's declaration of compliance
- Voltage rise calculations or measurements
- Details of central protection, phase balancing or export control installed

## Annex 1: Temperature Conversion Tables

°F	°C	°F	°C	°F	°C
32	0	64	18	96	36
33	1	65	18	97	36
34	1	66	19	98	37
35	2	67	19	99	37
36	2	68	20	100	38
37	3	69	21	101	38
38	3	70	21	102	39
39	4	71	22	103	39
40	4	72	22	104	40
41	5	73	23	105	41
42	5	74	23	106	41
43	6	75	24	107	42
44	6	76	24	108	42
45	7	77	25	109	43
46	8	78	26	110	43
47	8	79	26	111	44
48	9	80	27	112	44
49	9	81	27	113	45
50	10	82	28	114	46
51	11	83	28	115	46
52	11	84	29	116	47
53	12	85	29	117	47
54	12	86	30	118	48
55	13	87	31	119	48
56	13	88	31	120	49
57	14	89	32	121	49
58	14	90	32	122	50
59	15	91	33	123	51
60	16	92	33	124	51
61	16	93	34	125	52
62	17	94	34	126	52
63	17	95	35	127	53