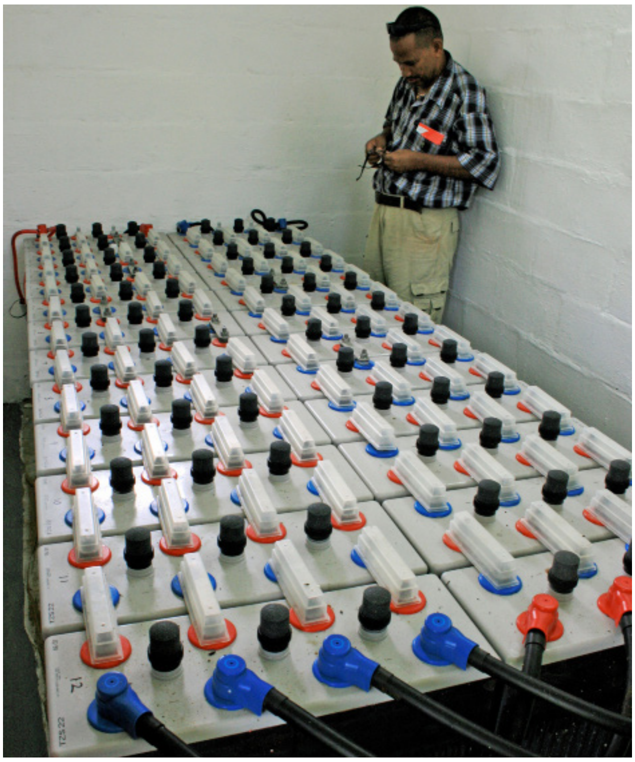
OFF GRID PV POWER SYSTEMS

SYSTEM INSTALLATION GUIDELINES



SEIAPI Sustainable Energy

SIDSDOCK SMALL ISLAND DEVELOPING STATES ISLAND ENERGY FOR ISLAND LIFE

WORLD BANK GROUP

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These guidelines have been developed for The Pacific Power Association(PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI).
They represent latest industry BEST PRACTICE for the Installation of Off-Grid PV Power Systems

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List of Abbreviations

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

AC	Alternating current
Ah	Amp hour
AS	Australian standards
CCC	Current carrying capacity
CSA	Cross section area
DC	Direct current
DVC	Decisive voltage classification
ELV	Extra low voltage
EN	European standards (European norms)
GFPD	Ground fault protective device
ICC	International code council
IEC	International electrotechnical commission
ISO	International organisation of standardisation
K	Kelvin
LV	Low Voltage
MPPT	Maximum power point tracker
NZS	New Zealand standards
NEC	National electricity code
NFPA	National fire protection association
PSH	Peak sun hour
PV	Photovoltaic
PVM	Pulse width modulation
STC	Standard test conditions
UL	Underwriters laboratories
VA	Voltage amperes
Wp	Watts peak (also known as peak-watt)
Wh	Watt-hour

1. Introduction

This document provides the minimum requirements when installing an Off Grid PV Power system.

The array requirements are generally 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.

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

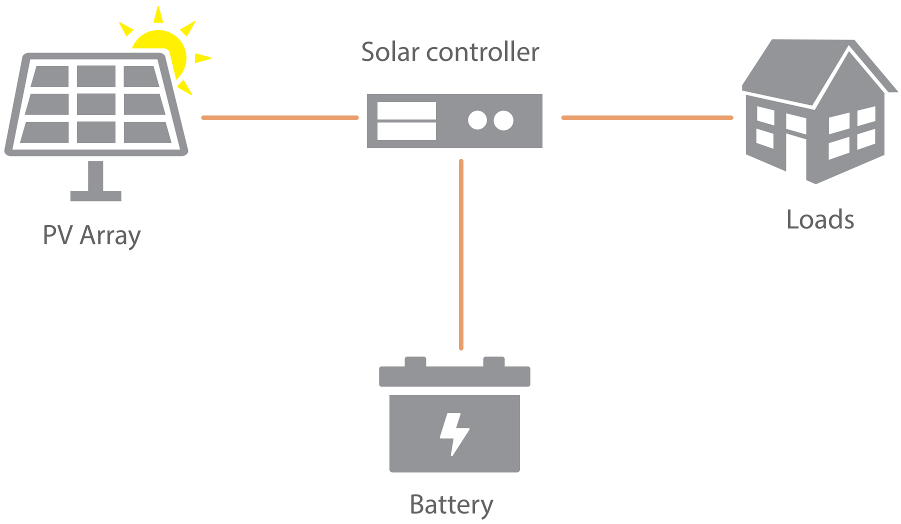

Figure 1: System Powering dc loads only (also known as a simple dc bus system)

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

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

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

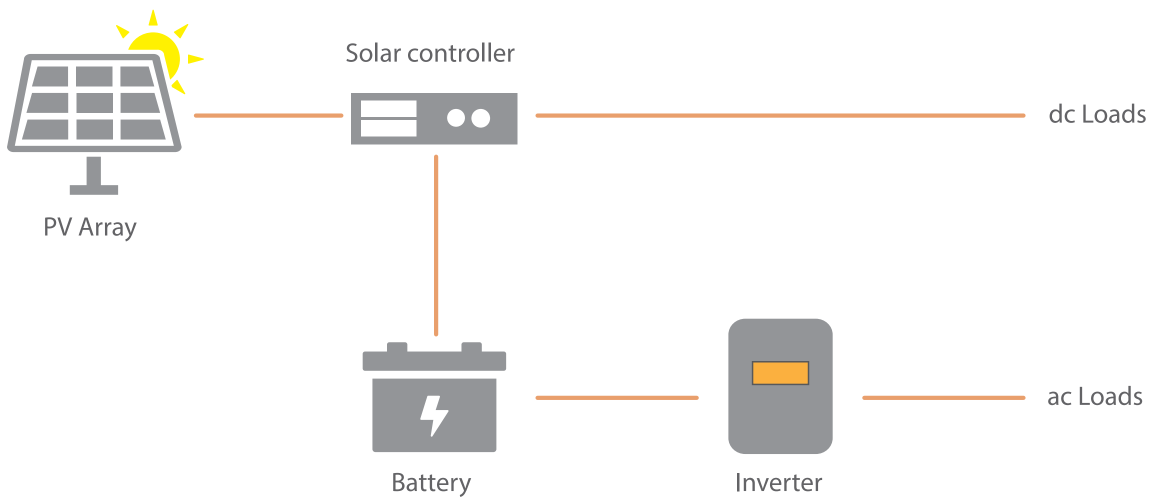

Figure 2: dc bus system

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

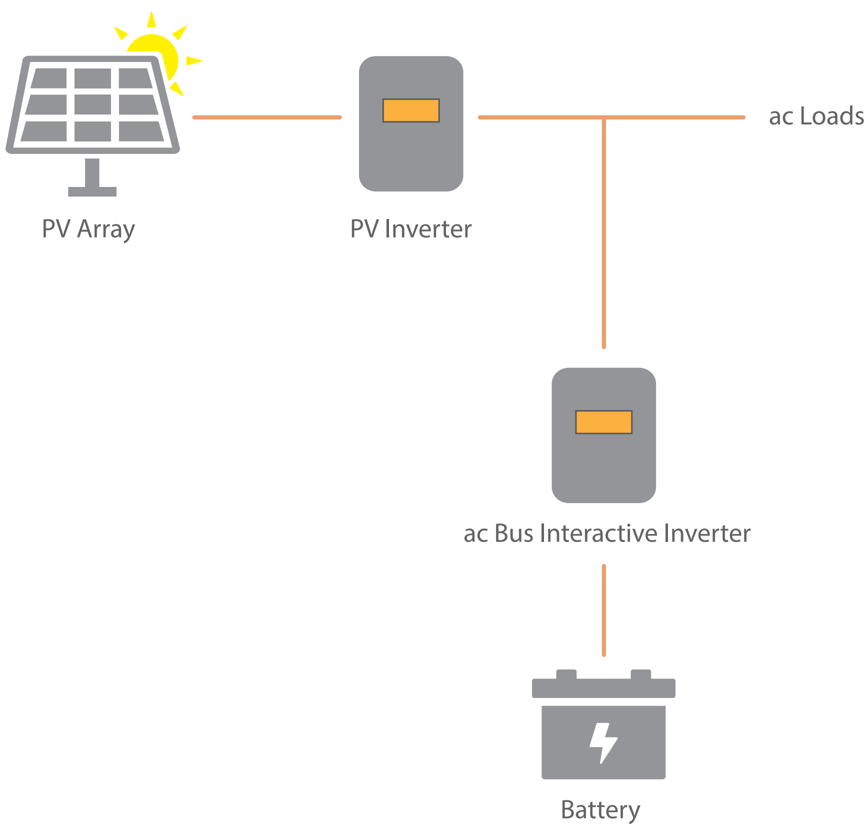

Figure 3: ac bus system

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

Note:
1. IEC standards use a.c. and d.c. for alternating and direct current respectively while the NEC uses ac and dc. This guideline uses ac and dc.

2. 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.

If your local temperatures are in Fahrenheit, then Appendix 1 has a table showing the conversion of °C to °F from 0°C to 50°C do the calculations.

2. Standards for Installation

System installations 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 the USA. Some Pacific island countries and territories follow those standards though with some modifications to better fit local conditions. 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 4086	Secondary Batteries for use with stand-alone power systems (Note this will soon be superseded by AS/NZS 5139 Electrical installations — Safety of battery systems for use with power conversion equipment).
- AS/NZS 4509	Stand-alone power ststems.
- AS/NZS 5033	Installation and safety requirements for PV Arrays.
- 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)$(S,Se)_2$ based photovoltaic (PV) modules.

- IEC 61215-2 — Part 2: Test Procedures.
- IEC 61730 — Photovoltaic (PV) module safety qualification.
  - IEC 61730-1 — Part 1: Requirements for construction.
  - IEC 61730-2 — Part 2: Requirements for testing.
- IEC 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.

3. Voltage Limits and Work Restrictions

System voltage classification in this guideline follows the Decisive Voltage Classification (DVC) as defined in IEC 62109 Safety of power converter for use in photovoltaic power systems and as shown in Table 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 ≤ 25	V ≤ 35.4	V ≤ 60
DVC-B	25 < V ≤ 50	35.4 < V ≤ 50	60 < V ≤ 120
DVC-C	V > 50	V > 71	V > 120

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

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

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

Extra Low Voltage Work:

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

Low Voltage Work:

- All low voltage work: >120V dc or >50V ac should be performed by a trained electrician or similar (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.

4. PV Modules

Solar modules shall comply with either:
The following IEC standards:

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

Or
The UL standard

- UL Standard 1703: Flat Plate Photovoltaic Modules and Panels

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

5. PV Array Installation

5.1 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 all be 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.

5.2 Maximum PV Array Voltage

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

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

The effective V_{oc} of the module due to the minimum temperature = V_{oc} plus the increase in V_{oc}.

Worked Example 1

(Refer to Design Guideline for Off Grid PV Power Systems)
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 = -0.32V/100 per degree C x 37.7V
= -0.121V/°C

Based on the minimum temperature of 15°C then the:
Increase in V_{oc} due to temperature = -10°C times the voltage temperature coefficient (V/°C).
= -10°C x -0.121V/°C
= 1.21V/°C

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 (Appendix 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 the example above, if there are 4 modules in a string, the maximum V_{oc} of the string will be 4 x 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 that contains the temperature ranges and multiplication factors to correct the voltage. (Note: this table does not apply if the modules are thin-film types, the voltage/temperature coefficient for the specific thin-film modules in use should be obtained from the module manufacturer).

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

Lowest expected operating temperature (degrees Celsius)	Correction factor	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 voltages/temperature coefficient for the specific thin-film modules in use should be obtained from the module manufacturer.

5.3 Orientation and Tilt

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

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

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

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

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

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

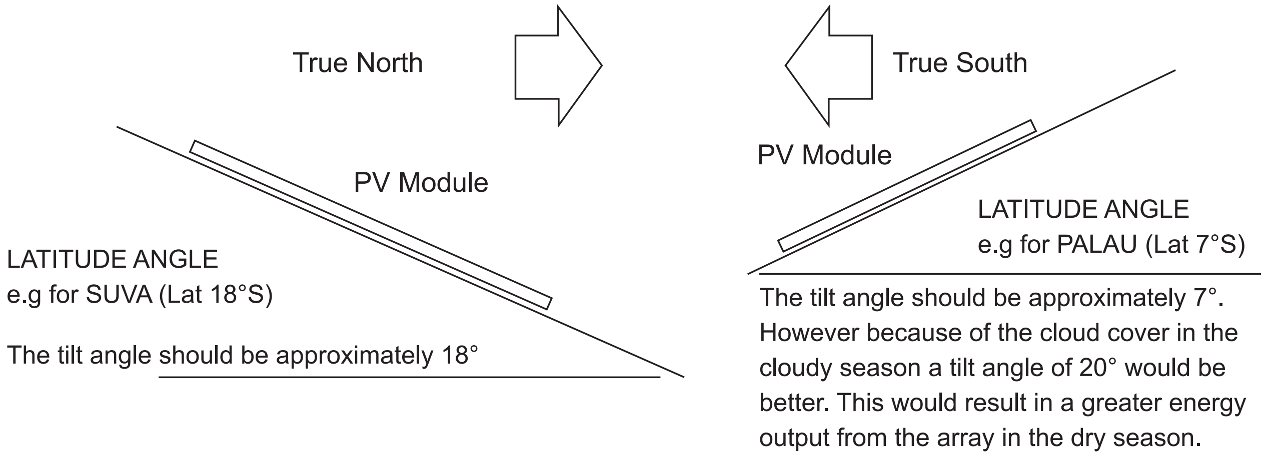

Figure 4: Examples of Tilt Angles

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

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

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

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

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

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

N°	Site	Latitude	Longitude
1	Nauru	0°32' South	166°56' East
2	Vaiaku, Tuvalu	8°31' South	179°13' East
3	Apia, Samoa	13°50' South	171°46' West
4	Suva, Fiji	18°08' South	178°25' East
5	Tongatapu, Tonga	21°08' South	175°12' West
6	Palikir, Pohnpei FSM	6°54' North	158°13' East
7	Hagåtña, Guam	13°28' North	144°45' East

The tables in Appendix 3 provide values for an array mounted in 36 orientations (azimuths) and 10 inclination (tilt) angles in increments of 10°.

Using these tables will provide the system installer with information on the expected output of a system (with respect to the maximum possible output) when it is located on a surface that is not facing true north (or south) or at an inclination not equal to the latitude angle. The designer can then use the peak sun hour data for the site to determine the expected peak sun hours of sun falling on the array at the actual orientation and tilt angle for the system to be installed. Note that in the case of arrays that are mounted on several roofs at different orientations and tilts, each roof must have the solar input calculated separately as the kWh per individual roof then all the kWh that result can be added together to get the total from all the modules in the installation.

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

5.4 Roof Mounting PV on an Existing Building

- If the modules use crystalline cells, then it is preferable to allow sufficient space below the array (> 50mm or 2 inches) for cooling by natural ventilation. Insufficient cooling will result in high module operating temperatures and lower outputs from the modules.
- It is important to allow sufficient clearance to facilitate self-cleaning of the roof to prevent the build-up of leaves and other debris.
- If fauna (e.g. rats) are a problem in the vicinity of the installation, then consideration should be given as to how to prevent them gaining access to the cables (see cable protection).
- The array structures shall be designed to withstand the aggressively salty atmosphere.
- All array supports, brackets, screws and other metal parts shall be of low-corrosion materials suitable for the lifetime and duty of the system and use materials that do not increase their rates of corrosion when mounted together in an array or 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: inserting non-reactive separators between metal surfaces and under screw and bolt heads and selection of materials with an appropriate type and thickness of anti-corrosive coating.
- Where timber is used it must be suitable for long-term external use and fixed so that trapped moisture cannot cause corrosion of the roof and/or rotting of the timber. The expected replacement time should be stated in the system documentation.
- Any roof penetrations must be suitably sealed and remain waterproof for the expected life of the system. If this is not possible then this must be detailed in the Maintenance Timetable
- If the roof uses tiles, 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 roof into a purlin or rafter below.
- All fixings must ensure structural security when subject to the highest wind speeds likely in the region and nearby areas - This may require specific tests of the fixing/substrate combination on that roof. Those countries that have experienced Category 5 cyclones/typhoons in the past shall have the frames and module attachments designed to meet the wind speeds expected in a Category 5 cyclone/typhoon.
- The installer shall ensure that the array frame that they install has applicable engineering certificates verifying that the frame meets wind loadings appropriate for that particular location.
- 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 the 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 attachment.
    - Size of batten/purlin required per attachment.
- 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.

5.5 Free Standing PV Arrays

- The array mounting frames must be wind rated in accordance with relevant wind loading standards. For those countries which have experienced Category 3 to Category 5 cyclones typhoons, the frames shall be designed to remain intact in 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.

5.6 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 that are suitable for the maximum wind at the site.
- The mounting of the PV modules should allow for the expansion and contraction of the PV modules under expected operating conditions.
- Where modules are installed in such way that a junction box is to the side or at the bottom, care must be taken to ensure this is permitted by the manufacturer.
- When using clamps, the solar module 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

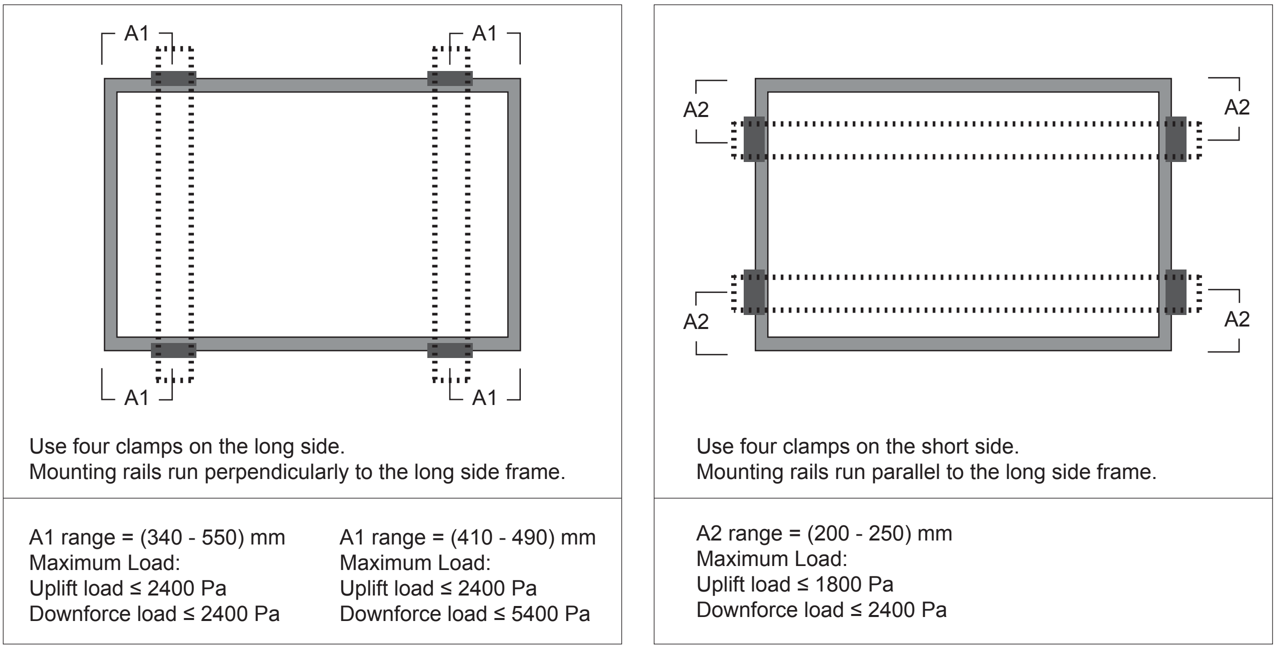

Figure 5: Example of Array Clamps (Source: Canadian Solar)

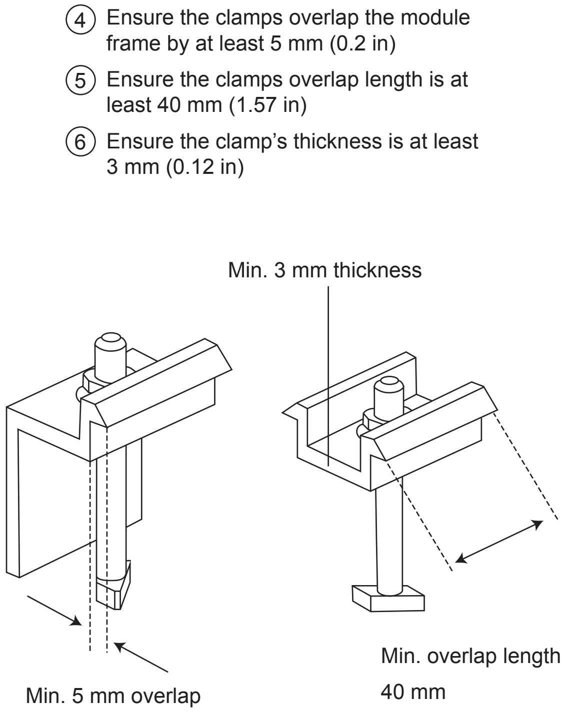

Figure 6: Module Clamps (Source: Canadian Solar)

Note: Attaching a solar module in such a manner that creates a hole in the anodised aluminium frame of the solar module (e.g. drilling, pop riveting) typically voids the manufacturer's product warranty with respect to defects in material and workmanship. 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 cyclones which have resulted in a "zipper" effect where by 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 with stand Category 5 cyclones. Array frames that are designed for winds experienced in Category 5 cyclones typically have mid-clamps longer than 50 mm (2 inches) in length and there can be as many as 3 railings per module. In a large system, consideration shall be given to using an end clamp for every fourth module so if one does become loose then only a few other modules would be affected, not necessarily the whole array.

6. Battery Installation

- The battery/batteries must be installed in a dedicated battery room or an enclosure.
- The location and/or enclosure selected must ensure that mechanical protection is guaranteed and access to the batteries is restricted to those people who are authorised to be in proximity to the batteries.
- Sufficient space should be available within the enclosure to allow for ease of battery installation and maintenance, and no metal objects should be in the vicinity such that one could fall across battery terminals and cause a short circuit.
- For large battery banks containing multiple batteries it is recommended that, if possible, the battery enclosure should not be located within an occupied building and the ideal location is within a building (e.g. shed) that is separated from the residence or other occupied building.
- If the battery enclosure is mounted outside, then those batteries that emit explosive fumes should be vented only to the outside.
- If the battery enclosure is a dedicated room and part of an occupied building, then the access should be from the outside and for batteries that emit explosive fumes (e.g. open-cell lead-acid type batteries) the internal walls should not have any vents/penetrations to the inside of the house and there must be venting to the outside.
- Explosive and/or corrosive gas-emitting battery systems should not be located within 500 mm (20 inches) horizontally of any other equipment from 100 mm (4 inches) below the battery terminals (Figure 7), except where there is a solid separation barrier (Figure 8).
- No electrical equipment shall be mounted above explosive and/or corrosive gas emitting batteries.
- No metal devices shall be installed above a battery that could fall onto the batteries.
- The location where the batteries are installed should be dry.
- Batteries must be raised off the ground or concrete floor. If left on the ground, the lower sections of the batteries 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 (8 inches) of any battery.
- The enclosure should not be located in direct sunlight and should be in a location that keeps the batteries 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.
- Batteries are typically heavy and the area under the batteries shall be capable of bearing the weight of the batteries without distortion.
- Guard against electrolyte spillage for those battery system types containing liquid chemicals. The material used for the construction of the enclosure should resist the electrolyte specific corrosive effects or be painted with a corrosion resistant paint.
- Ideally any electrolyte spillage should be contained within the enclosure or room.

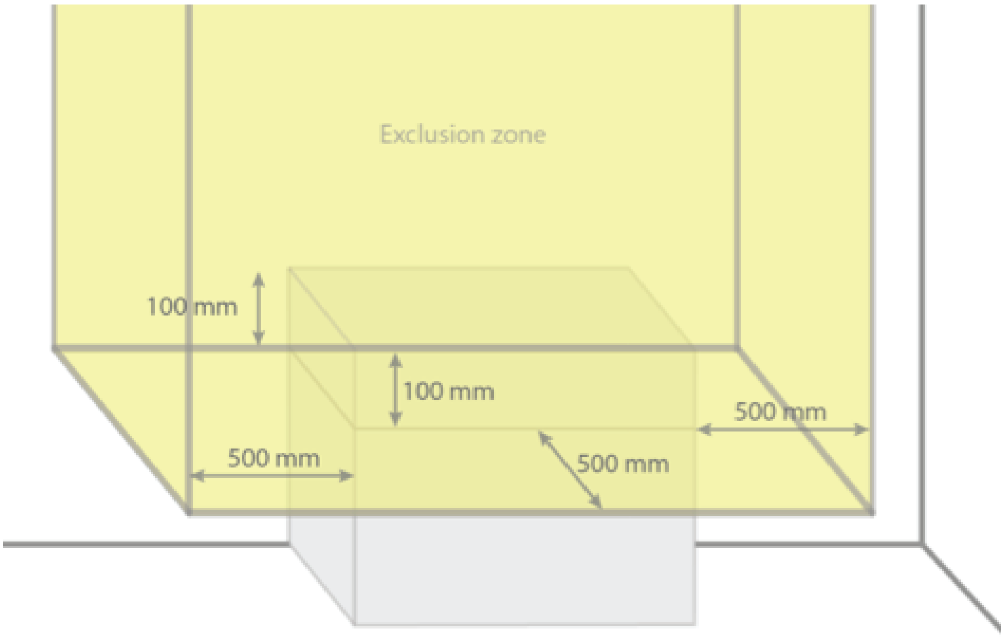

Figure 7: Exclusion zone for equipment located near a battery system (assuming battery terminals are on top surface)

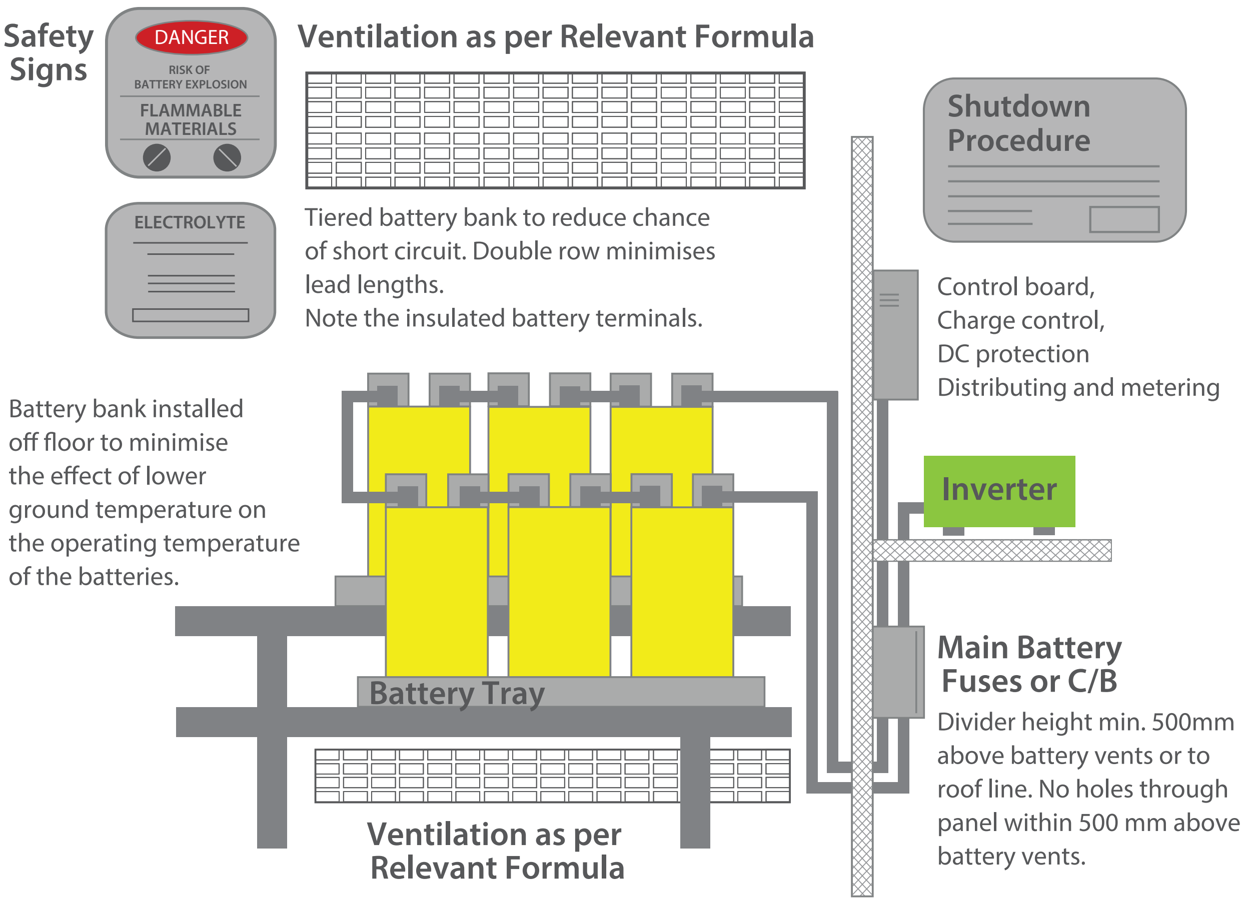

Figure 8: Example of Battery Room Layout with divided Wall

7. Ventilation Requirements

- Battery types that can emit explosive gases shall be installed in enclosures (rooms) with sufficient ventilation to prevent the build-up of explosive gases generated when the battery is being charged.
- Best practice is to provide the input ventilation vents on an outside wall below the level of battery and the output vents on an outside wall on the opposite side of the batteries as high as possible in the enclosure to prevent hydrogen build up (as shown in Figure 9).

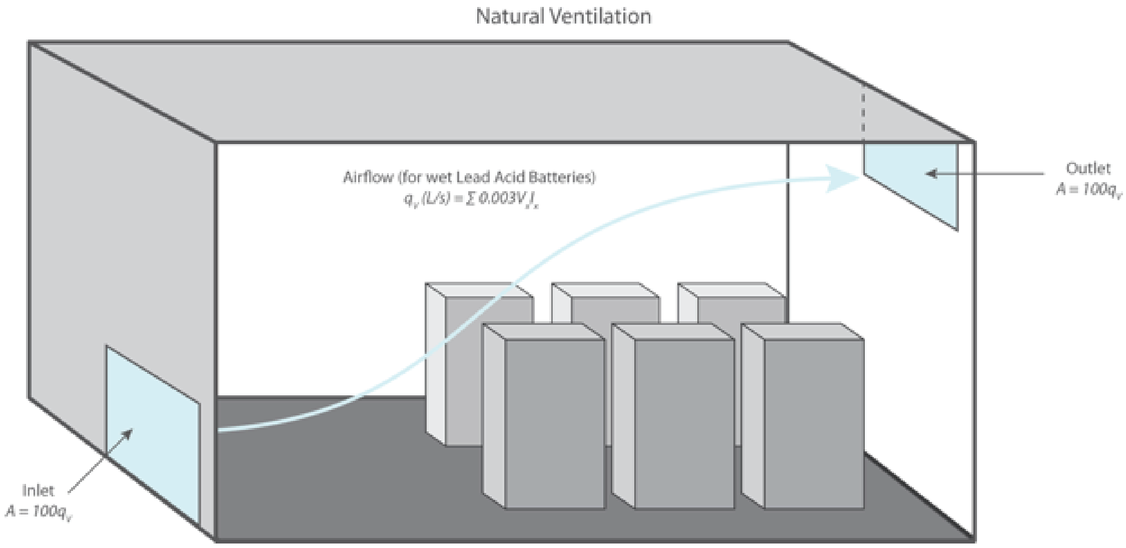

Figure 9: Natural ventilation arrangement for battery systems

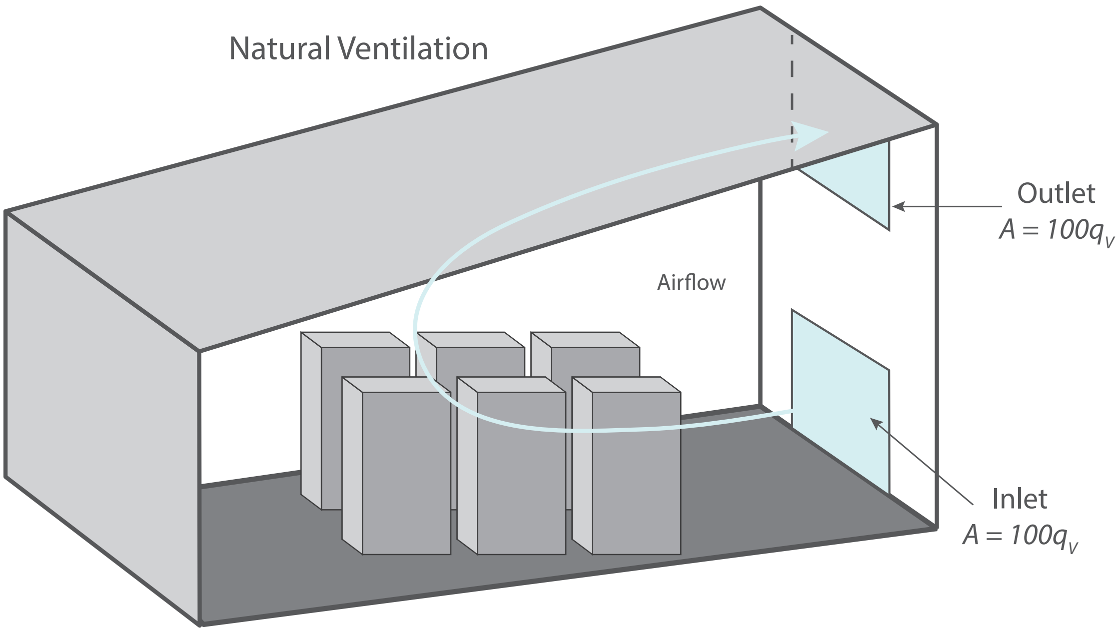

Figure 10: Natural ventilation arrangement for battery systems with vents on one side

7.1 Determining Size of Vents (Metric)

The minimum area required for natural ventilation for both inlet and outlet apertures (for lead acid batteries) are given by:

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

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

and n = the number of battery cells

I = the charging rate in amperes

Note: 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. Where two parallel battery banks are used, the charging rate is halved.

7.2 Determining Size of Vents (Imperial)

The minimum area required for natural ventilation for both inlet and outlet apertures (for lead-acid batteries) are given by:

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

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

and n = the number of battery cells

I = the charging rate in amperes

Note: 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. Where two parallel battery banks are used, the charging rate is halved.

7.3 Ventilation for Valve Regulated (Sealed) Batteries

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

e.g. battery has C_3 rating of 500Ah therefore the charge current used in ventilation formula is
I = (500Ah/100Ah) x 0.5A = 2.5A

Note: This is based on the charger (either a solar controller in dc bus systems or a battery inverter for ac bus systems) having an automatic overvoltage cut-off. If not, the maximum charge current must be used in the formula.

8. Solar Controller Installation

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

8.1 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 initiate an action to correct an earth fault.

9. PV Inverter Installation

- The PV inverter shall be installed as to the manufacturer`s instructions.
- The PV inverters shall be installed in a location that is appropriate for the IP rating of the PV inverter. Where this is not possible then the PV inverter/s should be in an appropriate weatherproof enclosure that has adequate ventilation.
- 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 inverter should have this IP rating or higher.
- 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 inverter shall be mechanically secured in such a manner that they cannot be inadvertently unplugged from the inverter. This can be achieved by:

- Having the inverter housed in an enclosure (with cables suitably supported).
- The use of an inverter which has the cable connection area of inverter covered by a removable enclosure/cover which protects the supported cables so that there are no exposed, unsupported cable loops.
- The use of conduit and secure wall fixings:
  Where the inverter requires dc connectors to be used, a maximum allowable distance of no more than 200mm (8 inches) of unprotected dc cable shall be permitted between connectors and conduit provided the location is not subject to mechanical damage.

- Where the inverter is exposed to the weather there shall be no open ends of conduit. If a cable is required to exit from a conduit, an appropriate cable gland shall be installed on the end of the conduit to ensure the IP rating is maintained.

9.1 Inverter 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 initiate an action to correct an earth fault.

9.2 Ground Fault Protection (countries following NEC requirements)

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

- 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 stops providing any output power.

Exception: PV arrays with not 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.

10. Battery Inverter Installation

- Non-separated (i.e. transformerless) battery inverters should not be used if the output of the inverter is going to be hard wired to a switchboard.
- Non-separated inverters should have loads directly connected via a plug to the ac output via the power outlet located on the inverter.
- 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 at least 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 inverter should have this IP rating or higher.
- 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 that hamper cooling of the battery inverter.

11. Safe Installation Practice

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

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

For ac bus systems or dc bus systems using MPPTs, a dangerous situation is only likely to occur at:

- the PV Array switch-disconnector (isolator) before the PV inverter or MPPT;
  AND
- the sub-array and array combiner boxes (if used).

To prevent the possibility of an installer coming in contact with live wires it is recommended practice that one of the interconnect cables of each string (as shown in Figure 11) is left disconnected until all the wiring is complete between the array and the inverter. Only after all switch-disconnectors and other hard wired connections are completed should the interconnect cable of the array be connected.

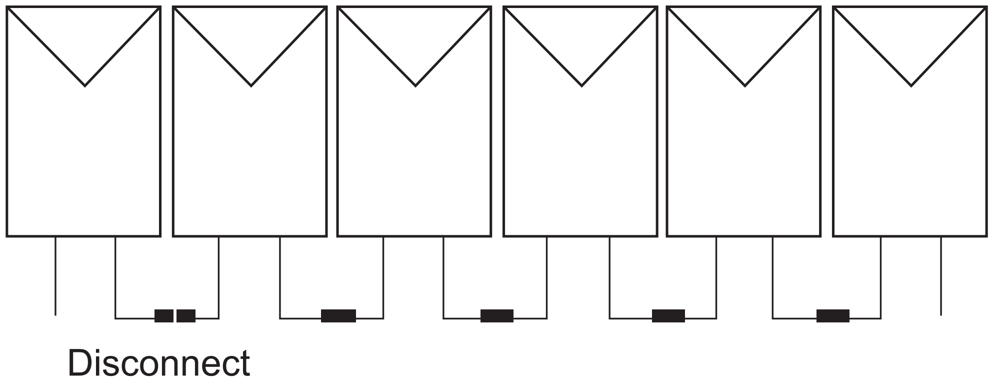

Figure 11: Disconnected interconnect cable

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

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

12. PV Array Wiring

12.1 Selection of dc Cable for PV Array

Figure 12: Double insulated solar DC cable

Cables used within the PV array wiring shall:

- Be suitable for dc applications.
- Have a voltage rating equal to or greater than the PV array maximum voltage determined in Section 5.2.
- Have a temperature rating appropriate to the application.
- If exposed to salt environments, used tinned copper, multi-stranded conductors to reduce degradation of the cable over time due to corrosion.
- 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 a metallic tray or metal conduit.
- It is recommended that string cables be sufficiently flexible to allow for thermal/wind movement of arrays/modules.
- For PV arrays that operate 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:

- No excessive voltage drops (which equates to an equivalent power loss) in the cables.
- The current in the cables will not exceed the safe current handling capability of the selected cables [known as current carrying capacity (CCC)]

12.2 Installation of the 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 (e.g. rats) 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 in 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 that are the same type/model and from the same manufacturer are allowed to be mated 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 solar controller or PV inverter should not exceed 3% of the V_{mp} voltage (at STC) for LV PV arrays.

12.3 Wiring Loops

- Cables need to be laid in parallel close together to avoid wiring loops which could cause damaging high voltage surges to the controller or inverter if there are nearby lightning strikes. Figures 13, 14 and 15 give examples on how a conductive wiring loop can be avoided while Figure 16 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.

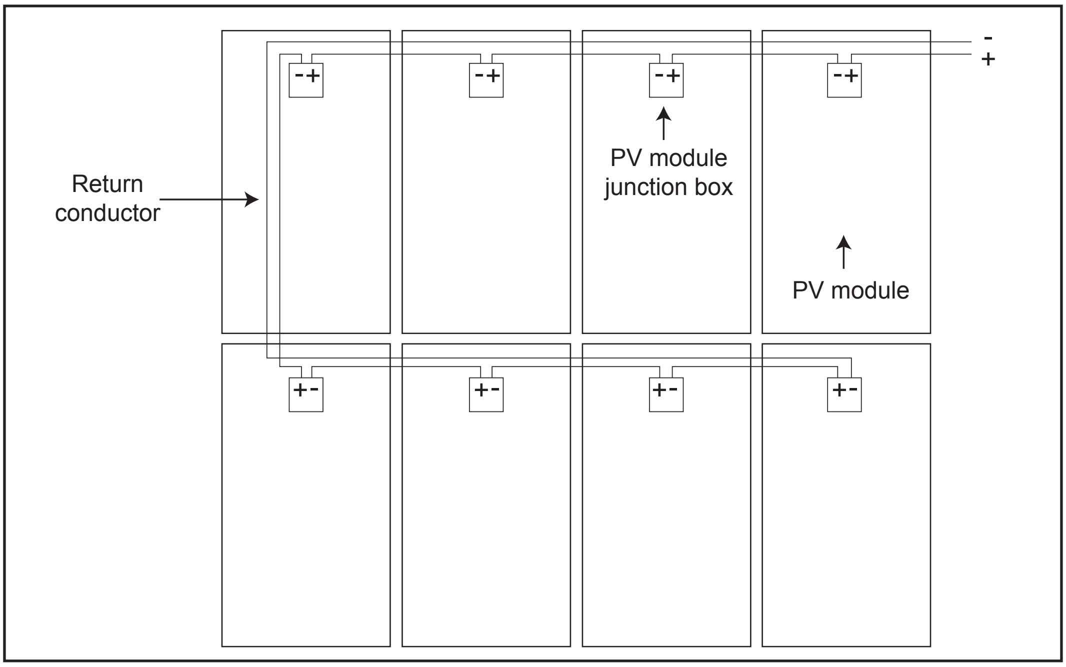

Figure 13: Example of Wiring to avoid Conductive Loops

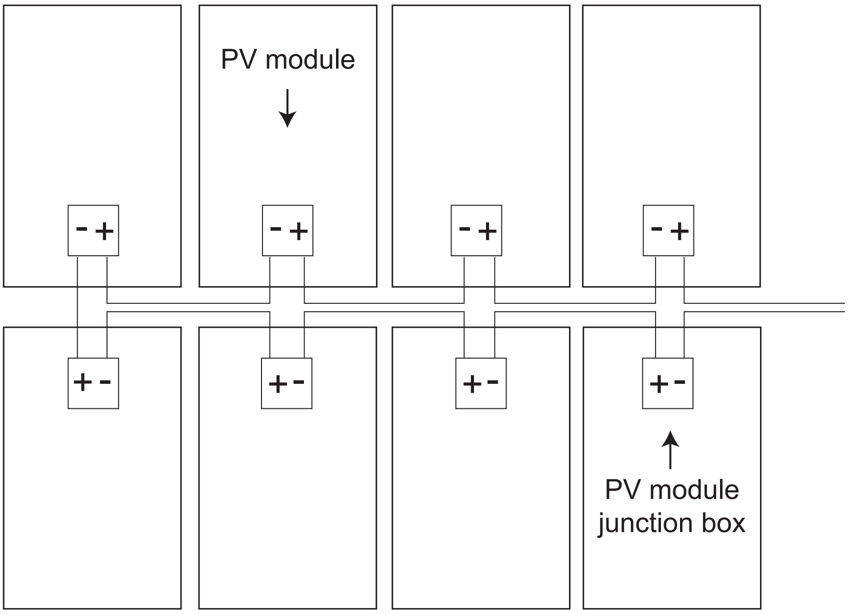

Figure 14: Example of Wiring to avoid Conductive Loops

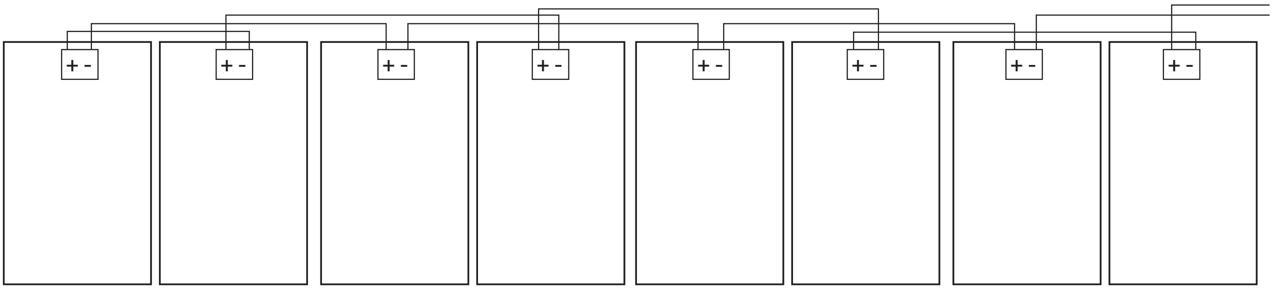

Figure 15: Example of Wiring to avoid Conductive Loops

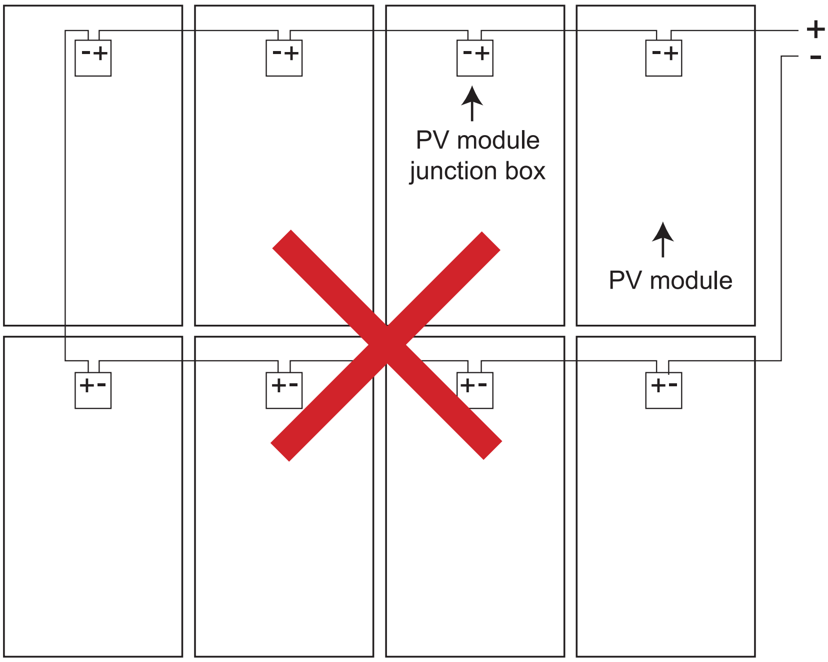

Figure 16: Example of Wiring to be avoided because it includes Conductive Loops

12.4 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:

$$CCC \geq 1.25 \times I_{SC\ MOD} \times (\text{Number of parallel connected Strings} - 1) + I_n$$

Where:

$I_{SC\ MOD}$ = short circuit current of PV module

I_n = is the current rating of the nearest downstream overcurrent protection device.

12.5 Selection of Current Carrying Capacity of PV Array Cables

- If a fault current protection device is located in the array cable, the array cable must have a current 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 array cable will be rated according to:

$$CCC \geq 1.25 \times I_{SC\ ARRAY}$$

Where:

$I_{SC\ ARRAY}$ = sum of short circuit currents of all the strings in the array

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

12.6.1 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 array cable, the array cable must have a rating equal to or greater than the current rating of the fault current protection device. Note for dc bus off-grid systems array protection will be required.
- If no fault current protection device has been included (mainly in ac bus system configurations), the current carrying capacity of the PV array cable will be rated according to:

$$CCC \geq 1.25 \times I_{SC\ ARRAY}$$

Where:

$I_{SC\ ARRAY}$ = sum of short circuit currents of all the sub-arrays in the array

12.6.2 PV Sub-Array Cables

- If a fault current protection device is located in the array cable, the sub-array cable must have a current 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:

$$CCC \geq 1.25 \times I_{SC\ SUB\text{-}ARRAY} + I_n$$

Where:

$I_{SC\ SUB\text{-}ARRAY}$ = sum of short circuit currents of all the other sub-arrays

I_n = current rating of the nearest downstream overcurrent protection device.

12.6.3 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:

$$CCC \geq I_{TRIP\_SUBARRAY} + 1.25 \times I_{SC\ MOD} \times (\text{Number of parallel connected Strings} - 1)$$

Where:

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

$I_{SC\ MOD}$ = the short circuit current rating of the PV module.

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

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

Note: Refer to Grid Installation Guidelines for some worked examples in determining the current carrying capacity in arrays.

13. Installation of PV Array Cable Between Array and Solar Controller (dc Bus System) or PV Inverter (ac Bus System)

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

Figure 17: A Dektite* with a metal roof flashing

14. Installation of Cable Between Standard Solar Controller and Battery

- The cables between the standard solar controller and the battery shall have a voltage rating greater than the maximum voltage rating of the battery when being charged.
- The current carrying capacity of the cable between the controller and battery shall be capable of carrying the maximum charge current from the array.
- The current-carrying capacity of the cable between the battery and solar controller shall be based on the dc current rating of the associated over-current protection.
- Any battery cable forming the connection between a battery system terminal and the solar controller, shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the associated over-current protective device
- The dc cables between the solar controller and the battery bank can be single insulated if the battery bank is ELV.
- Cables and conduits shall be installed so that they are adequately supported.
- When using switching controllers, it is recommended that under maximum solar current, the voltage drop from the most remote module in the array to the battery should not exceed 5% of the battery voltage.

15. Installation of Cable Between MPPT Controller and Battery

- 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 bank shall be double insulated and should be in medium duty conduit.
- The cables between a non-separated MPPT and the battery shall have a voltage rating greater than the maximum voltage of the array.
- The cables between a separated MPPT and the battery shall have a voltage rating greater than the maximum voltage of the battery.
- The current carrying capacity of the cable between the controller and battery 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 cable forming the connection between a battery system terminal and the MPPT, shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the associated over-current protective device.

16. Installation of Cable Between Battery and Battery Inverter (if applicable)

- For systems using switching type solar controllers, the cable shall have a voltage rating greater than the battery voltage when being charged.
- For systems using a separated MPPT controller, the cable shall have a voltage rating greater than the battery voltage when being charged
- For systems using non-separated MPPT the cable shall have a voltage rating greater than the maximum voltage of the array.
- If the PV array has a rated output voltage greater than 120V (DVC-C) and the solar controller is a non-separated MPPT unit, the dc cables between the battery and the battery inverters shall be double insulated.
- For systems using switching type solar controllers or separated MPPT controllers and the battery bank voltage is ELV, the dc cables between the battery and the battery inverter can be single insulated.
- Any battery system cable forming the connection between a battery system terminal and the inverter, 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 bank and the battery inverter shall be capable of carrying the maximum current based on either the 30 minute power rating of the inverter (if provided) or the continuous power rating of the inverter.
- The current-carrying capacity of the cable between the battery and 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.

17. Voltage Drop

- The voltage drop between the PV array and the battery bank should never exceed 5%
- The voltage drop between the battery bank and any DC load should never exceed 5%
- The voltage drop between the PV array and Solar Controller should never exceed 3% (dc bus)
- The voltage drop between the PV array and PV inverter should never exceed 3% (ac bus)

17.1 Calculating Voltage Drop (Metric) for Systems That Include Switching Type Solar Controllers

This section is for systems that are using standard pulse width modulated (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:

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

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

Where:

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

I = current in amperes.

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

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

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

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

Worked Example 2

A solar array has been installed and the distance between the output of the array and the solar controller is 10 metres. The short circuit current of the array is 9.6A.
The cable has a cross sectional area of 10 mm^2
The cable is copper with a resistivity of 0.0183 ohms/metres/mm^2
The battery voltage of the system is 12V.

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

= 2 x 10 x 9.6 x 0.0183/10 V
= 0.35V

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

= 0.351/12 × 100
= 2.9%

17.2 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 bus) or a PV inverter that includes an MPPT controller (ac bus).
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:

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

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

Where:

- L_{CABLE} = route length of cable in metres (multiplying it by two adjusts for total circuit wire length since a complete circuit requires a wire out and another wire back along the route).
- I = current in amperes.
- ρ = resistivity of the wire in $\Omega/m/mm^2$
- A_{CABLE} = cross sectional 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 bus) or PV inverter (ac bus) 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 10 metres. The short circuit current of the array is 9.6A.
The cable has a cross sectional area of 4 mm^2
The cable is copper with a resistivity of 0.0183 ohms/metres/mm^2
The array has maximum power point voltage of 154.4V.

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

= 2 x 10 x 9.6 x 0.0183/4 V
= 0.35

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

= 0.88/154.4 x 100
= 0.57%

17.3 Tables Providing Route Lengths for Twin Cable for Various Specified Voltage Drop (Metric)

Table 4: Maximum distance in metres to produce 5% voltage drop (12V system)

Current (A)	$1mm^2$	$1.5mm^2$	$2.5mm^2$	$4mm^2$	$6mm^2$	$10mm^2$	$16mm^2$
1	16.4	24.6	41	65.6	98.4	163.9	262.3
2	8.2	12.3	20.5	32.8	49.2	82	131.1
3	5.5	8.2	13.7	21.9	32.8	54.6	87.4
4	4.1	6.1	10.2	16.4	24.6	41.0	65.6
5	3.3	4.9	8.2	13.1	19.7	32.8	52.5
6	2.7	4.1	6.8	10.9	16.4	27.3	43.7
7	2.3	3.5	5.9	9.4	14.1	23.4	37.5
8	2.0	3.1	5.1	8.2	12.3	20.5	32.8
9	1.8	2.7	4.6	7.3	10.9	18.2	29.1
10	1.6	2.5	4.1	6.6	9.8	16.4	26.2
11	1.5	2.2	3.7	6.0	8.9	14.9	23.8
12	1.4	2.0	3.4	5.5	8.2	13.7	21.9
13		1.9	3.2	5.0	7.6	12.6	20.2
14		1.8	2.9	4.7	7.0	11.7	18.7
15		1.6	2.7	4.4	6.6	10.9	17.5
16		1.5	2.6	4.1	6.1	10.2	16.4
17			2.4	3.9	5.8	9.6	15.4
18			2.3	3.6	5.5	9.1	14.6
19			2.2	3.5	5.2	8.6	13.8
20			2.0	3.3	4.9	8.2	13.1

Table 5: Maximum distance in metres to produce 3% voltage drop (12V system)

Current (A)	$1mm^2$	$1.5mm^2$	$2.5mm^2$	$4mm^2$	$6mm^2$	$10mm^2$	$16mm^2$
1	9.8	14.8	24.6	39.3	59.0	98.4	157.4
2	4.9	7.4	12.3	19.7	29.5	49.2	78.7
3	3.3	4.9	8.2	13.1	19.7	32.8	52.5
4	2.5	3.7	6.1	9.8	14.8	24.6	39.3
5	2.0	3.0	4.9	7.9	11.8	19.7	31.5
6	1.6	2.5	4.1	6.6	9.8	16.4	26.2
7	1.4	2.1	3.5	5.6	8.4	14.1	22.5
8	1.2	1.8	3.1	4.9	7.4	12.3	19.7
9	1.1	1.6	2.7	4.4	6.6	10.9	17.5
10	1.0	1.5	2.5	3.9	5.9	9.8	15.7
11	0.9	1.3	2.2	3.6	5.4	8.9	14.3
12	0.8	1.2	2.0	3.3	4.9	8.2	13.1
13		1.1	1.9	3.0	4.5	7.6	12.1
14		1.1	1.8	2.8	4.2	7.0	11.2
15		1.0	1.6	2.6	3.9	6.6	10.5
16		0.9	1.5	2.5	3.7	6.1	9.8
17			1.4	2.3	3.5	5.8	9.3
18			1.4	2.2	3.3	5.5	8.7
19			1.3	2.1	3.1	5.2	8.3
20			1.2	2.0	3.0	4.9	7.9

17.4 Calculating Voltage Drop (Imperial) for Systems that Include a Switching Type Solar Controller

This section is for systems that are using switching type (e.g. 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:

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

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})
Ω/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) = $\frac{V_d}{V_{batt}} \times 100$

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 battery voltage is the nominal battery voltage of the battery bank.

Table 6 is an extract from the National Electric Code.

Table 6: 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 voltage of the system is 12V.

From Table 6, the dc Resistance in Ohms per 1000 feet = 0.491

Therefore:

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

= 9.6 x 2 x 33 x 0.491/1000 V
= 0.311V

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

= 0.311/12 × 100
= 2.6%

17.5 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 bus) or a PV inverter that includes an MPPT controller (ac bus).

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

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

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})
Ω/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) = $\frac{V_d}{V_{batt}} \times 100$

For PV arrays connected to a MPPT type solar controller (dc bus) or PV inverter (ac bus) 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 6, the dc Resistance in Ohms per 1000 feet = 1.24

Therefore

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

= 9.6 x 2 x 33 x 1.24/1000 V
= 0.786V

Voltage Drop (in percentage) = $\dfrac{V_d}{V_{batt}} \times 100$

= 0.786/154.4 x 100
= 0.51%

17.6 Tables Providing Route Lengths for Twin Cable for Various Specified Voltage Drops (Imperial)

Table 7: Maximum distance in feet to produce 5% voltage drop (12V system)

Wire Size-AWG (mm²)	14 (2.08)	12 (3.31)	10 (5.26)	8 (8.36)	6 (13.29)	4 (21.14)	2 (33.61)	1 (42.39)
Current (A)								
1	34.10	54.26	86.23	137.05	217.87	346.56	550.98	694.92
2	17.05	27.13	43.11	68.52	108.93	173.28	275.49	347.46
3	11.37	18.09	28.74	45.68	72.62	115.52	183.66	231.64
4	8.52	13.57	21.56	34.26	54.47	86.64	137.75	173.73
5	6.82	10.85	17.25	27.41	43.57	69.31	110.20	138.98
6	5.68	9.04	14.37	22.84	36.31	57.76	91.83	115.82
7	4.87	7.75	12.32	19.58	31.12	49.51	78.71	99.27
8	4.26	6.78	10.78	17.13	27.23	43.32	68.87	86.86
9	3.79	6.03	9.58	15.23	24.21	38.51	61.22	77.21
10	3.41	5.43	8.62	13.70	21.79	34.66	55.10	69.49
11	3.10	4.93	7.84	12.46	19.81	31.51	50.09	63.17
12	2.84	4.52	7.19	11.42	18.16	28.88	45.92	57.91
13	2.62	4.17	6.63	10.54	16.76	26.66	42.38	53.46
14	2.44	3.88	6.16	9.79	15.56	24.75	39.36	49.64
15	2.27	3.62	5.75	9.14	14.52	23.10	36.73	46.33
16	2.13	3.39	5.39	8.57	13.62	21.66	34.44	43.43
17	2.01	3.19	5.07	8.06	12.82	20.39	32.41	40.88
18	1.89	3.01	4.79	7.61	12.10	19.25	30.61	38.61
19	1.79	2.86	4.54	7.21	11.47	18.24	29.00	36.57
20	1.70	2.71	4.31	6.85	10.89	17.33	27.55	34.75

Table 8: Maximum distance in feet to produce 3% voltage drop (12V system)

Wire Size-AWG (mm²)	14 (2.08)	12 (3.31)	10 (5.26)	8 (8.36)	6 (13.29)	4 (21.14)	2 (33.61)	1 (42.39)
Current (A)								
1	20.46	32.56	51.74	82.23	130.72	207.93	330.59	416.95
2	10.23	16.28	25.87	41.11	65.36	103.97	165.30	208.48
3	6.82	10.85	17.25	27.41	43.57	69.31	110.20	138.98
4	5.11	8.14	12.93	20.56	32.68	51.98	82.65	104.24
5	4.09	6.51	10.35	16.45	26.14	41.59	66.12	83.39
6	3.41	5.43	8.62	13.70	21.79	34.66	55.10	69.49
7	2.92	4.65	7.39	11.75	18.67	29.70	47.23	59.56
8	2.56	4.07	6.47	10.28	16.34	25.99	41.32	52.12
9	2.27	3.62	5.75	9.14	14.52	23.10	36.73	46.33
10	2.05	3.26	5.17	8.22	13.07	20.79	33.06	41.70
11	1.86	2.96	4.70	7.48	11.88	18.90	30.05	37.90
12	1.70	2.71	4.31	6.85	10.89	17.33	27.55	34.75
13	1.57	2.50	3.98	6.33	10.06	15.99	25.43	32.07
14	1.46	2.33	3.70	5.87	9.34	14.85	23.61	29.78
15	1.36	2.17	3.45	5.48	8.71	13.86	22.04	27.80
16	1.28	2.03	3.23	5.14	8.17	13.00	20.66	26.06
17	1.20	1.92	3.04	4.84	7.69	12.23	19.45	24.53
18	1.14	1.81	2.87	4.57	7.26	11.55	18.37	23.16
19	1.08	1.71	2.72	4.33	6.88	10.94	17.40	21.94
20	1.02	1.63	2.59	4.11	6.54	10.40	16.53	20.85

18. Protection Requirements In System

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

Figures 18, 19, 20 and 21 show the typical protection and isolation (switch-disconnection) requirements in dc and ac bus systems.

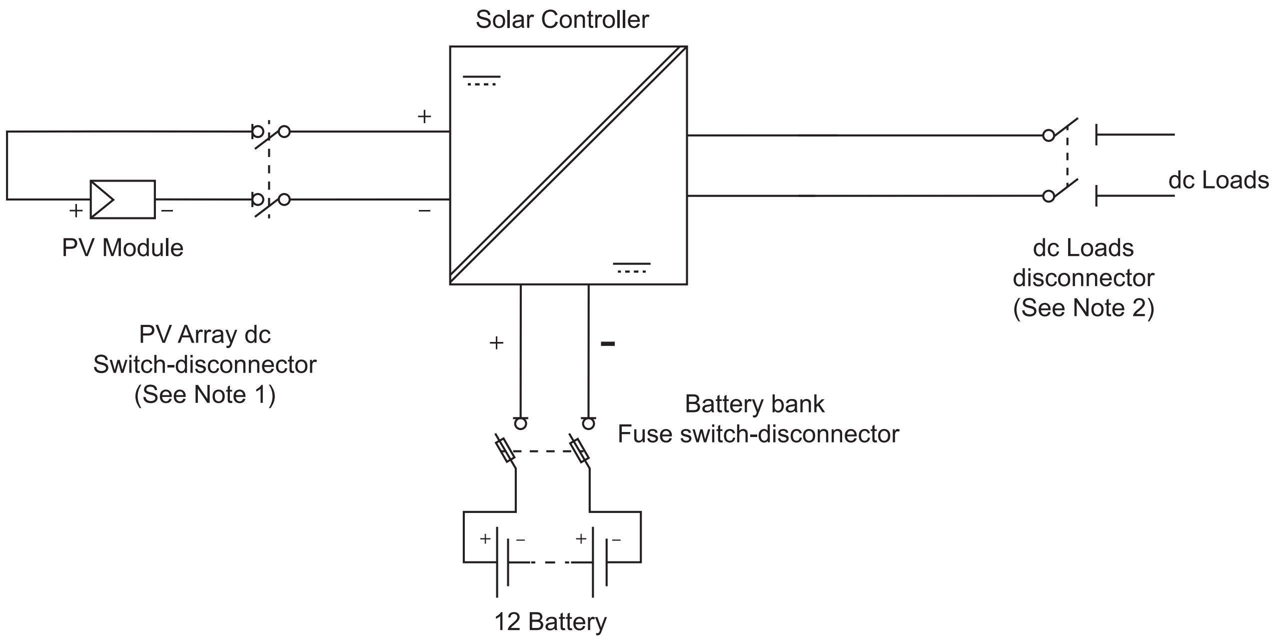

Figure 18: dc bus - simple dc only system (typical for rural residences)

Notes:

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

2. A loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting. However the battery bank switch-fuse can meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables

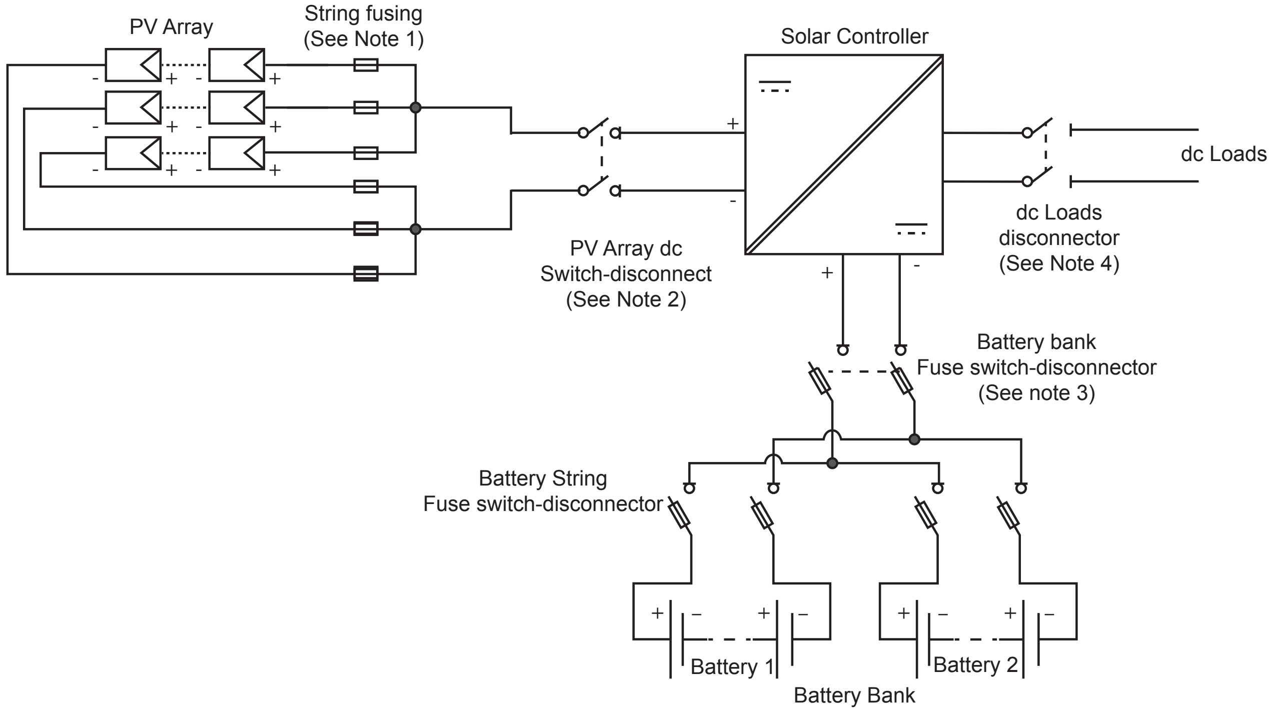

Figure 19: dc bus - larger dc only system

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 18.1).

2. The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows back feed from the battery bank.

3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank via the one switch disconnector.

4. The loads dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch-fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables.

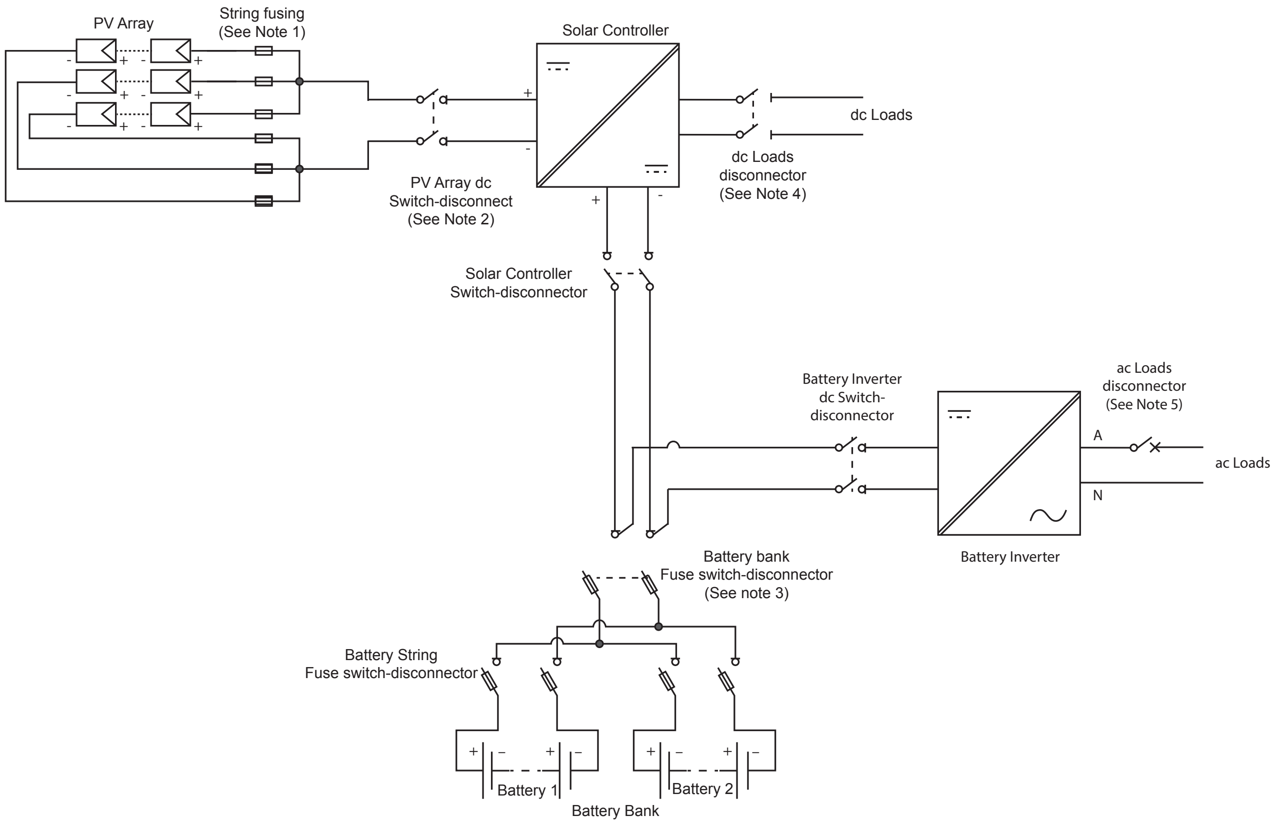

Figure 20: dc bus with dc and ac Loads

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 18.1).

2. The PV array dc switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required as a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the PV array cables and the solar controller allows backfeed from the battery bank.

3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank via the one switch disconnector. Sometimes this might be a four (4) pole device to allow different size fuses to protect the inverter cable and the solar controller cable which will be generally be different cross sectional areas (or gauges)

4. The loads dc switch disconnector is recommended because it helps with maintenance and trouble shooting although many standards allow the battery bank switch-fuse to meet the isolation requirement. The switch disconnector will be required to be a protection device (e.g. a non polarised dc circuit breaker) if the battery bank fuse ratings are greater than the current carrying capability of the load cables.

5. A separate ac load disconnector is required if the battery inverter does not have a switch disconnector on the ac output. This will be required as a protection device (e.g. an ac circuit breaker) for protecting the ac load cable.

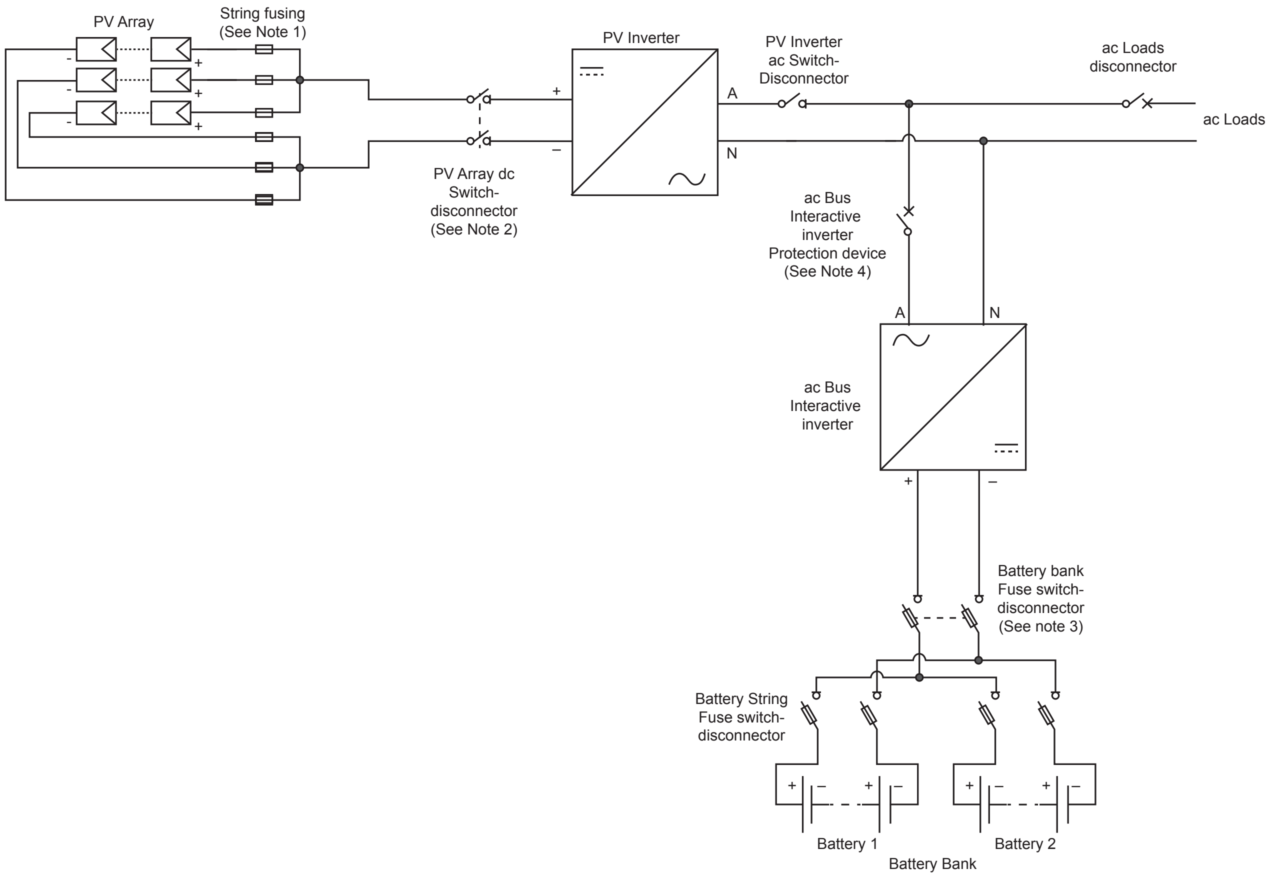

Figure 21: ac bus with ac loads

Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer section 18.1).

2. A PV array dc switch disconnector is required but it can be part of the inverter (refer to section 19.2).

3. Batteries in parallel each require their own isolation and protection devices. Over-current protection is required for the battery bank cable when the current-carrying capacity of the battery bank cable is less than the sum of all individual battery over-current protection devices. A battery bank switch disconnecting device is recommended because it allows the disconnection of the complete battery bank using only one switch disconnector.

4. A separate ac bus interactive inverter disconnector device is required if the battery inverter does not have a switch disconnector on the ac output. This will be required to be a protection device (e.g. ac circuit breaker) for protecting the ac load cable.

18.1 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 18.2.

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/I_{sc} of the module

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

18.2 PV Fuses

Fuses used in PV arrays shall —

(a) be rated for dc use;
(b) have a voltage rating equal to or greater than the PV array maximum voltage determined in section 5.2;
(c) be rated to interrupt fault currents from the PV array; and
(d) 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.

18.3 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

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

Where

$I_{SC\ MOD}$ = Module short circuit current
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 x I_{sc} of module(string)
- Maximum fuse rating less than reverse current rating of the module(string)

18.4 Sub-Array Protection

An array may be broken up into sub-arrays for several reasons; for example, if two sections of the array are installed in separate areas, have different orientations or the array consists of a number of identical sub-arrays. 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.

18.5 Requirements of 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 present:

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

Note: For countries following NEC the requirements are:

- Minimum fuse rating 1.56 x I_{sc} of sub-array

18.6 Sizing the 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:

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

Where:

$I_{SC\_SUB\text{-}ARRAY}$ = 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 x I_{sc} of sub-array

18.7 Array Cable Protection

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

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 x I_{sc} of array

18.8 Arc Fault Protection (countries following NEC requirements)

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.

18.9 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.

18.10 Battery Cable Protection- dc Bus – dc Loads Only

For dc bus systems with dc loads only, as shown in Figures 18 and 19, the only battery cables are those between the battery bank and the controller. The protection devices will be rated to allow the maximum charge current provided by the solar controller and the maximum dc load current that is to be provided by the solar controller.

18.11 Battery Cable Protection- dc Bus – ac and dc Loads

dc bus systems with ac and dc loads as shown in Figure 20 can potentially have two different sized battery cables:
1. The battery cable between the battery bank and the solar controller.
2. The battery cable between the battery bank and the battery inverter.

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

The protection device for the battery cable to an inverter will be determined via the process defined in section 18.13

18.12 Battery Cable Protection - ac Bus

Systems with an ac bus as shown in Figure 21 only have one set of cables from the battery bank and that is to the battery inverter.

The protection device for the battery inverter will be determined via the process defined in section 18.13

18.13 Battery Cable Protection- Battery Inverter

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

1. Obtain the battery inverter manufacturer's data of:
   - Continuous power rating (Watts)
   - 3 to 10 second surge rating (Watts)
   - Average inverter efficiency (%)

2. Obtain Time-Current characteristics for the overload protection to be used.
   [All manufacturers publish time-current information for their circuit breaker and HRC fuse ranges]

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

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

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

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

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

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

19. Disconnection (Isolation) Requirements

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

- A battery switch disconnector between the battery and the solar controller (if installed).
- A battery switch disconnector between the battery and the battery inverter (if installed).
- A PV array dc switch disconnector located near the MPPT controller when the array maximum voltage is LV,
- A PV array dc switch disconnector located near the PV inverter (ac bus).

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

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

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

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

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

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

19.2 PV Array dc Switch Disconnector Near PV Inverter and MPPT (if array is LV)

- A PV array switch-disconnector/s shall be installed adjacent to the PV inverter and/or MPPT (if Maximum PV voltage is LV (DCV-C)).
- All PV array switch-disconnectors shall be capable of being reached easily 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 inverter and allows the module to be removed from the section containing the switch-disconnector without risk of electrical hazard.

- Where multiple disconnection devices are required to isolate the array(s) from the PV inverter(s) or MPPT's they shall be grouped so that they all operate simultaneously, or they shall all be grouped in a common location and have warning signs indicating the need to isolate all the multiple supplies in order to isolate the equipment.
    - Where there are more than one isolator, they shall be individually labelled e.g. "PV Array DC isolator inverter 1 and MPPT A or MPPT 1"
- Where strings are paralleled at the PV inverter or MPPT, it is recommended that this occurs on the PV inverter or MPPT side of the disconnection device or in the PV inverter/MMPT itself as shown in Figure 22.

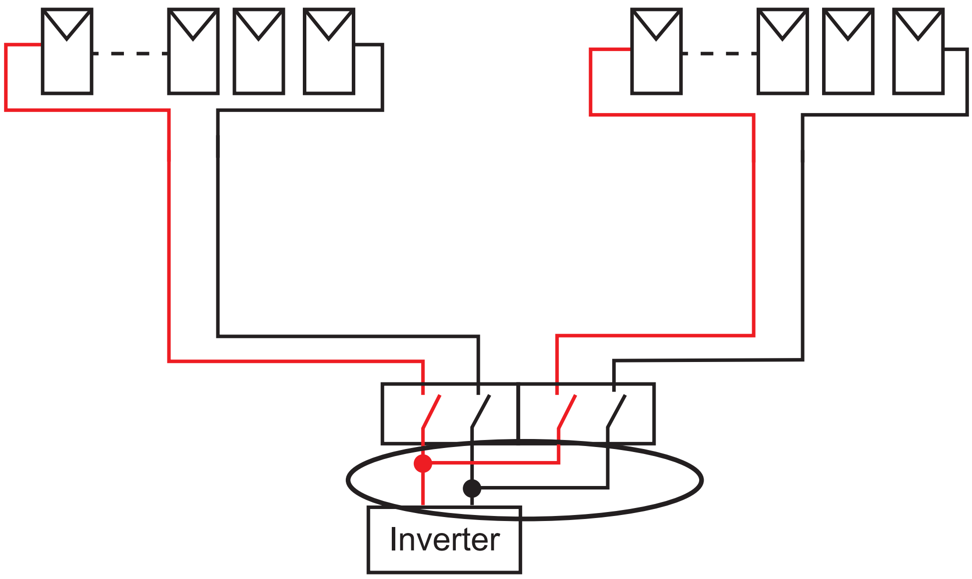

Figure 22: Paralleling strings on inverter/MPPT side of PV array disconnector devices

Note: In Figure 22 the Inverter could also be an MPPT.

- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP 56, however it is recommended that they are rated to IP 66.
- It is recommended that there are no top cable entries into the switch-disconnector and cable drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 19.6.

19.3 PV Array dc Switch Disconnector Near Standard Solar Controller

For ELV systems this is optional since the battery switch disconnector meets the requirements. However, if a switch disconnector is installed it should meet the following requirements:

- All PV array switch-disconnectors shall be capable of being reached for inspection, maintenance or repairs without necessitating the dismantling of structural parts, cupboards, benches or the like.
- Where multiple disconnection devices are required to isolate the array(s) from the solar controller(s) they shall be grouped so that they all operate simultaneously, or they shall all be grouped in a common location and have warning signs indicating the need to isolate all the multiple supplies to isolate the equipment.
    - Where there are more than one isolator, they shall be individually labelled e.g. "PV Array DC isolator Solar Controller 1".

- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP 56, however it is recommended that they are rated to IP 66.
- It is recommended that there are no top cable entries into the switch-disconnector and cable drip loops are utilised at the bottom of the switch-disconnector to minimise risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of section 19.6.

19.4 Battery Bank Disconnection Devices

- All equipment connected to the battery bank shall be capable of being individually isolated from the battery bank.
- For dc bus systems with dc loads only then the only isolation requirement is for the solar controller.
- For dc bus systems with ac loads then two isolating devices are required:
    - One for the solar controller
    - One for the battery inverter.
- For ac bus systems with ac loads then two isolating devices are required:
    - One for the PV inverter. (which in some cases may be a component in the inverter)
    - One for the battery inverter.
- All battery isolating devices shall be dc switch disconnectors capable of breaking the maximum current for the particular equipment the battery is connected to.
- All battery 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 56, however it is recommended that they are rated to IP 66.
- Battery switch-disconnectors shall meet the requirements of section 19.6.

19.5 Load Disconnection Requirements

- All dc and ac load circuits shall be capable of being isolated.
- For dc loads this could be performed by the controller and for dc only systems this could be the battery switch disconnector. However, it is recommended that a separate dc switch disconnector is located in the load output cables from the solar controller.
- For dc bus systems with ac loads, ac switch disconnectors should be located in the output cables from battery inverter unless there is an ac switch disconnector included on the inverter.
- For ac bus 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 19.6
- 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.

19.6 dc Switch-Disconnector Requirements

dc switch-disconnectors shall:

- be rated for dc use.
- be rated to interrupt the full load and prospective fault currents.
- not be polarity sensitive.
- interrupt all live conductors simultaneously.
- shall not have exposed live parts in the 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 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 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 banks 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 voltage expected when under charge
  - For all switching type controllers and battery inverters connected to battery banks that are earthed/grounded the voltage rating of each pole of the switch disconnector shall be at least the maximum battery voltage expected under charge.
- Battery 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.

20. Earthing (Grounding) of Array Frames for a PV Array With Maximum Voltage Greater Than ELV (including AC modules and micro-inverter systems)

- All exposed metal module frames and array mounting frames shall be earthed (grounded) if the PV array has a PV array maximum voltage greater than ELV (DVC-C) or when ac modules or micro inverters with LV outputs are installed.
- Minimum cable size of 4 mm^2 (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^2 (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 (splices) provide earth (ground) continuity. Some rail manufacturers state that the use of a rail joiner (splice) provides earth continuity between rails. If the manufacturer does not provide this information, a conductive earthing strap or 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 with and in close proximity to the PV array cable (both positive and negative), the inverter and then inverter ac cables going to the switchboard or distribution board.
- The earthing/grounding conductor from the PV array can connect to inverter's main earth conductor in the ac output cable provided the following conditions are met:
    - Installation is not subject to lightning
    - Inverter ac earth is of an appropriate size
- Earth cable cannot pass through a tile or steel roof without additional mechanical protection (conduit) and an appropriate collar flashing (e.g. Dektite). The same conduit used for PV array cable can also be used for the earth cable.
- All 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.

21. Installation of Combiner Boxes

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

22. Segregation of dc and ac Circuits

- Within enclosures, segregation shall be provided between dc and ac circuits 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. a non-metallic material).
- dc and ac circuits should be clearly marked.

23. Plugs and Sockets

Plugs, sockets and connectors for the PV array shall:

- comply with EN 50521 or UL equivalent;
- 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;

24. Shutdown Procedure

- A shutdown procedure is required to ensure safe de-energisation of the system.
- The shutdown procedure shall reflect the specific requirements of the individual system.
- All isolating switches (switch-disconnectors) referred to in the shutdown procedure shall correspond to individual switch-disconnector (isolator) labels. e.g “PV array dc isolator 2”, “Battery Isolator 3”.
- In general the shutdown procedure shall require the system to be shut down in the following order:
    - Isolation of PV input. (locations should be specified)
    - Isolation of the AC loads and also DC loads
    - Isolation of the battery bank by disconnecting battery fuses or opening battery circuit breakers.

25. Metering

As a minimum each system should have meters showing:

- battery voltage.
- charge current from solar.
- load current from the battery bank.

26. Signage

- All battery systems that can emit explosive gases shall have a “No Smoking, No Spark, No Flames" Warning sign. (Example provided in Figure 23)
- All battery systems that contain chemicals which could burn the eyes or skin shall have a warning sign prominently displayed. (Example provided in figure 24)
- All disconnectors shall be labelled and where there is more than one, numbered. For example:
  - Battery dc disconnector 2
  - PV array dc disconnector
  - Solar controller dc disconnector
  - dc load disconnector
  - ac load disconnector 3
- A sign showing the proper Shutdown Procedure shall be located near the system.
- Solar cables shall be labelled every 2 metres where exposed.
- Any solar array combiner box should be labelled warning that it is dc supply and if LV (DCV-C) than a prominent sign should warn of hazardous voltages.

Figure 23: Example of Risk of Battery Explosion Warning Sign

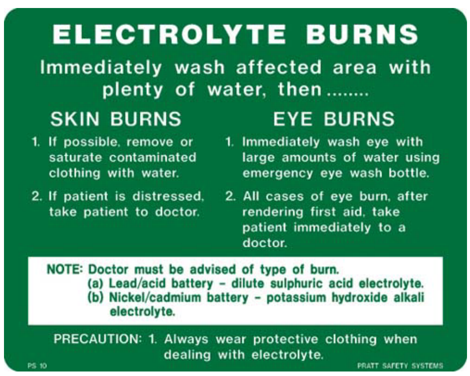

Figure 24: Electrolyte Burns Sign

27. Commissioning

The commissioning sheets provided with these guidelines (Appendix 2) should be completed by the installer. A completed copy shall be provided to the customer as part of the system documentation and a copy retained by the installer that has been initialled by the customer showing it to be a true copy of the commissioning sheets provided to the customer.

27.1 PV Array Short Circuit Current Measurement for arrays Greater than DVC-A

Where short circuit currents are required to be measured, undertake the following steps to measure the short circuit current safely as shown in Figure 25.

- Ensure each string fuse (where required) is not connected or that any LV array is disconnected somewhere in each string as shown in Figure 11 of these guidelines.
- Leave the solar array cable connected to the PV array switch disconnector.
- Remove the cable from the PV array switch disconnector to the inverter.
- With the PV array switch disconnector off - put a link or small cable between the positive and negative outputs of the PV array switch disconnector.
- Install the string fuse for string 1 or connect the string disconnect (figure 11) to complete the wiring of the string. Turn on PV array switch disconnector and using a dc. clamp meter, measure the dc short circuit current for String 1. Turn off the PV array switch disconnector. Disconnect the string fuse for string 1 or remove the disconnector to break the string circuit.
- Repeat for each string

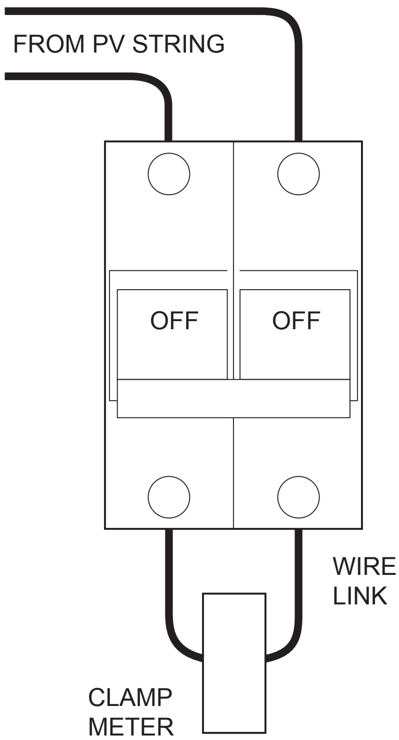

Figure 25: Measuring Short Circuit current

27.2 PV Array Insulation Resistance Measurement

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

This test is required for all arrays where the maximum array voltage is LV, that is, greater than DVC-C. The insulation resistance test should be undertaken when all the system wiring has been completed.

The insulation resistance test shall be carried out with an insulation test device connected between earth and the PV array positive connection, and then the test repeated with the test device connected between earth and PV array negative connection. Test leads should be made secure before carrying out the test. The values of insulation resistance shall be recorded. Table 9 shows the minimum values that should be achieved for different array voltages.

Table 9: Minimum Insulation Resistance

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

28. Documentation

All complex systems require a user manual for the customer. Off Grid PV power systems are no exception. The documentation for system installation that shall be provided includes:

- List of equipment supplied with each item's model, description and serial number
- List of action to be taken in the event of an earth fault alarm
- Shutdown and isolation procedures for emergencies and for maintenance
- Maintenance procedures and timetable
- Commissioning sheet and installation checklist
- Warranty information
- A basic connection diagram that includes electrical ratings of the PV array, the battery bank, the solar controllers, battery inverters, PV inverters and the ratings of all overcurrent devices and switches as installed
- System performance estimate including completed load assessment forms.
- Recommended maintenance procedures and timetable for the installed system
- Equipment manufacturer's documentation and handbooks for all equipment supplied
- Array frame engineering certificate for wind and mechanical loading
- Installer/designer's declaration of compliance

Appendix 1: Temperature Conversion Tables

°F	°C
32	0
33	1
34	1
35	2
36	2
37	3
38	3
39	4
40	4
41	5
42	5
43	6
44	6
45	7
46	8
47	8
48	9
49	9
50	10
51	11
52	11
53	12
54	12
55	13
56	13
57	14
58	14
59	15
60	16
61	16
62	17
63	17

°F	°C
64	18
65	18
66	19
67	19
68	20
69	21
70	21
71	22
72	22
73	23
74	23
75	24
76	24
77	25
78	26
79	26
80	27
81	27
82	28
83	28
84	29
85	29
86	30
87	31
88	31
89	32
90	32
91	33
92	33
93	34
94	34
95	35

°F	°C
96	36
97	36
98	37
99	37
100	38
101	38
102	39
103	39
104	40
105	41
106	41
107	42
108	42
109	43
110	43
111	44
112	44
113	45
114	46
115	46
116	47
117	47
118	48
119	48
120	49
121	49
122	50
123	51
124	51
125	52
126	52
127	53

Appendix 2: Installation and Commissioning Sample

This is just a sample for a small system.

Installer name:	
Installer signature:	
Testing and Commissioning date:	
System Location	
Equipment Data	
PV module manufacturer:	
PV module model number:	
PV module peak power rating:	W_p
PV Module rated short circuit current (I_{sc})	A
PV Module rated maximum power current (I_{mp})	A
PV Module rated open circuit voltage (V_{oc})	V
PV Module rated maximum power voltage (V_{mp})	V
Number of Modules:	
Battery manufacturer:	
Battery model:	
Battery Voltage	V
Battery Capacity	Ah
Solar controller manufacturer	
Solar controller model	
Solar controller input and output current rating.	A
Solar controller voltage ratings	V
Battery Inverter manufacturer	
Battery Inverter model	
Battery Inverter Input current ratings	A
Inverter Input dc voltage rating	V
Inverter Power Rating	W or VA

Switch disconnector manufacturer	
Switch disconnector model	
Switch disconnector current rating	A
Switch disconnector voltage rating	V
Solar battery fuse current rating	A
Solar battery fuse voltage rating	V
Inverter battery fuse current rating (if there are a separate fuses for inverter and	A
solar)	V
Inverter battery fuse voltage Rating (if there are a separate fuses for inverter and	
solar)	W/m²
Testing of System (System Not On Yet)	A
Solar Irradiance at same angle of solar module	V
Module No 1: I_{sc}	A
Module No 1: V_{oc}	V
Module No 2: I_{sc}	
Module No 2: V_{oc}	
Continuity between PV array, dc switch-disconnector and controller:	
Array Positive (Tick if correct)	
Array Negative (tick if correct)	
Correct polarity between PV array and solar controller	
Continuity between controller, fuse holders and battery	
Battery Positive (Tick if correct)	
Battery Negative (tick if correct)	
Correct polarity between controller and battery	
Continuity between battery, fuse holders and inverter	
Battery Positive (Tick if correct)	
Battery Negative (tick if correct)	
Correct polarity between inverter and battery	

Continuity between solar controller, light switch and lights	
Positive (Tick if correct)	
Negative (tick if correct)	
Correct polarity between controller and dc loads (This could be expanded if testing dc circuits if they have been installed as part of system installation)	V
Battery Voltage at Terminals	
If 2V cells than this would be expanded to record each cell voltage	
If batteries are wet lead acid than the specific gravities would be recorded	V
Turn System On - including dc loads	A
Array voltage at Controller input	V
Array current	V
Battery voltage at controller	
Voltage at furthest dc load (array turned off)	
Solar charging the batteries	
Controller operating correctly (tick if correct)	
Inverter operating correctly (tick if correct)	
dc loads operating correctly (tick if correct)	