VeraSol

COMPONENT-BASED OFF-GRID SOLAR ENERGY SYSTEMS

June 2022

System Installation Guidelines

Includes Solar-only PV Systems and Hybrid Systems Comprising PV and Fuel Generators

LIGHTING GLOBAL — Catalyzing markets for modern off-grid energy | AN INNOVATION OF WORLD BANK GROUP — THE WORLD BANK, IFC | ESMAP Energy Sector Management Assistance Program

Acknowledgement

This Quality Assurance Framework for Component-Based Solar Home Systems was adapted from guidance documents initially developed by Global Sustainable Energy Solutions Pty Ltd (GSES) for the Government of Uganda. These documents were edited by staff at the Schatz Energy Research Center and Kevin Gauna of Sunbrothers to produce a more widely applicable framework across multiple countries and programs with funds gratefully acknowledged from the Energy Sector Management Assistance Program (ESMAP). The development of the original document was funded through the Energy for Rural Transformation Phase III (ERT III) Project, a World Bank project implemented by the Rural Electrification Agency of Uganda.

About Lighting Global

Lighting Global is the World Bank Group's initiative to rapidly increase access to off-grid solar energy for the 789 million people living without electricity worldwide. Managed by the Energy Sector Management Assistance Program (ESMAP), we work with governments, the private sector, development partners, and end-users, continually innovating to unlock key market barriers and enable access and affordability to those that would otherwise be left behind. Our support has expanded to technologies that go far beyond lighting, including systems to power the needs of households, businesses, schools, and health centres. We operate with funding gratefully acknowledged from ESMAP and their donors.

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While all care has been taken to ensure this guideline is free from omission and error, no responsibility can be taken for the use of this information in the design and installation of any off-grid solar energy system.

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List of Abbreviations

a.c.	Alternating Current
Ah	Amp hour
C	Celsius
CCC	Current Carrying capacity
CSA	Cross Sectional Area
d.c.	Direct Current
DVC	Decisive Voltage Classification
ELV	Extra-low voltage
EN	European Standards (European Norms
GFPD	Ground fault protective device
IEC	International Electrotechnical Commission
IP	Ingress Protection
ISO	International Organization for Standardization
LV	Low voltage

MPPT	Maximum Power Point Tracker
NEC	National Electricity Code
NFPA	National Fire Protection Association
PSH	Peak Sun Hours
PV	Photovoltaic
PVC	Polyvinyl Chloride
PWM	Pulse width Modulation
QAF	Quality Assurance Framework
SES	Solar Energy System
STC	Standard Test Conditions
UL	Underwriters Laboratories
UV	Ultraviolet
V	Volt
VA	Voltage Amperes
W_p	Watts Peak (also known as Peak-Watt)
Wh	Watt-hour
XLPE	Cross-Linked Polyethylene

Introduction

This document provides minimum requirements when installing an off-grid solar energy system and includes a section dedicated to fuelled generators. Part 1 covers solar only PV systems, while Part 2 is for hybrid power systems comprising PV and fuelled generators. Part 1 contains information common to all off-grid systems (both Solar Only and Hybrid with fuelled generators). These systems could also be applied as the power source for mini-grid systems.

In addition to the requirements listed in this document, systems and components shall also comply with the requirements found in *Component-based Off-Grid Solar Energy Systems* – ***Quality Assurance Framework Overview*** and ***Component-based Off-Grid Solar Energy Systems – Quality Assurance Framework System Design Guidelines***.

An off-grid solar energy system includes the following system configurations:

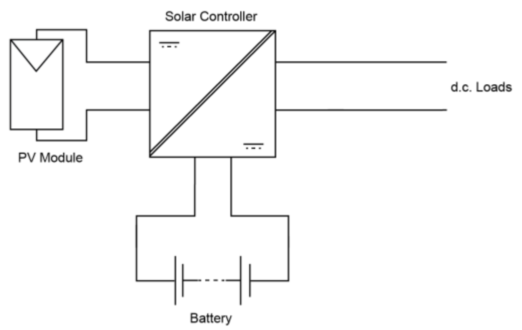
- d.c.-coupled systems that consist of a solar array(s) connected to the batteries by a solar controller(s) and loads are d.c. only
- d.c.-coupled systems that consist of solar array(s) connected to the batteries by a solar controller(s) and battery inverter(s)
- a.c.-coupled systems comprising solar array(s) connected to the a.c. side of grid forming battery inverter(s) (a.c.-coupled inverter) by PV inverter(s) (grid interactive inverter)
- PV systems comprising both a.c.-coupled and d.c.-coupled configurations and
- PV systems with a fuel generator (hybrid system).

These systems can be connected to single or multiple structures via a mini grid. This guideline does not include the design of the poles, wires and protection requirements of a mini-grid distribution network.

The array requirements are generally based on IEC 62548: Photovoltaic (PV) Arrays-Design Requirements.

Figure 1 shows the configuration of a system that provides d.c. Power only. These systems typically have an array range of less than one kW_p. Most solar installations installed on rural residences use this fundamental design.

FIGURE 1: SYSTEM PROVIDING D.C. LOADS ONLY (ALSO KNOWN AS A SIMPLE D.C.-COUPLED SYSTEM)

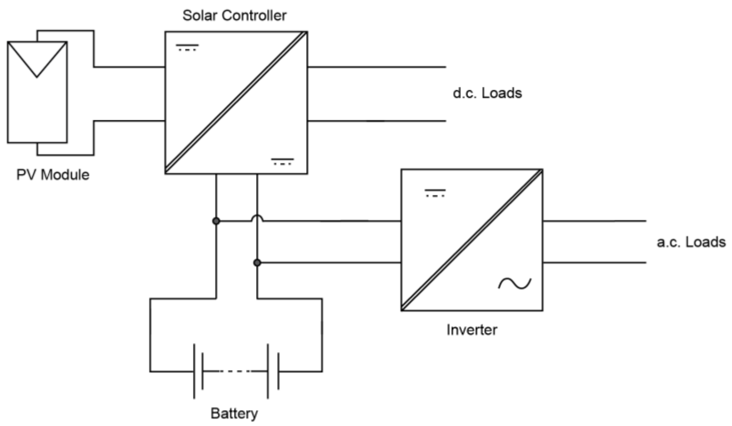


Note: Solar controller could be a Pulse Width Modulated (PWM) controller or a Maximum Power Point Tracking (MPPT) controller.

Systems that include an inverter providing a.c. power to end-user can be configured as either:

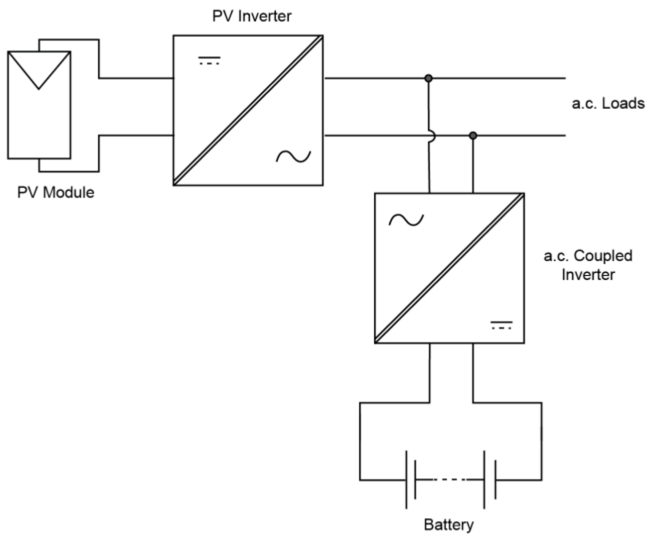
- d.c.-coupled systems (refer to Figure 2); or
- a.c.-coupled systems (refer to Figure 3).

FIGURE 2: D.C.-COUPLED SYSTEM POWERING D.C. AND A.C. LOADS



Note: Solar controller could be a PWM controller or an MPPT Controller.

FIGURE 3: A.C.-COUPLED SYSTEM



Some systems can combine a.c.-coupled and d.c.-coupled systems where d.c connects part of the array. Through a solar controller to the battery and part of the array is connected directly to the a.c. load side via a PV inverter. Configurations of Hybrid Systems are shown in Part 2.

This guideline shall be read in conjunction with existing host country laws and regulations concerning the design and installation of solar energy systems. Where this guideline has a requirement that contradicts a similar host country requirement, the requirement of this guideline should be followed when possible because this guideline is based on current best practices.

PART 1–PV ONLY SYSTEMS

1. 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.

TABLE 1: DECISIVE VOLTAGE CLASSIFICATION (D.C.V)

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

System voltage classification in this guideline follows IEC definitions including:

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

Subject to regulatory authority (RA) requirements, this guideline recommends the following:

Extra Low Voltage Work:

All ELV 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 perform the task required correctly."

Low Voltage Work:

All LV work: >120V d.c. or >50V a.c. should be performed by a trained electrician or similar (e.g., licensed or registered).

2. PV Array Installation

2.1. General

Correct installation of PV arrays is essential to the ongoing performance and safety of the system. Existing host country regulations may have additional guidance on support structures and cable routing.

- Modules electrically in the exact 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.
- None of the modules connected in a series string should come under shadow during sunny hours that is from 90 minutes after sunrise and 90 minutes before sunset.

2.2. Maximum PV Array Voltage

It is necessary to calculate the maximum PV array voltage to ensure that the array output matches (and does not exceed) the parameters of the solar charge controller or the PV inverter (a.c.-coupled systems) or the rest of the system and to know when to follow the requirements specified for different open-circuit voltages.

The maximum PV array voltage can be calculated using the minimum expected temperature at a site and the voltage/temperature coefficient of the modules installed.

The maximum open circuit voltage (Voc) of a module is determined by calculating the increase in Voc due to the effective cell temperature being less than 25°C.

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

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

The effective V_{oc} of the module at the minimum module temperature = V_{oc} plus any change in V_{oc} due to the temperature of the module being less than 25°C.

Note: While calculating maximum PV array voltage at minimum temperature, effective cell temperature is considered equal to minimum ambient temperature of the site of installation.

Worked Example 1

(Refer to Design Guideline for Off Grid Solar Energy Systems)

Assume the minimum effective cell temperature is 15°C,

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

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

The maximum V_{oc} of the string is then calculated by multiplying the maximum V_{oc} of one module by the number of the modules in the string. Thus, in the example above, if there are 4 modules in a string, the maximum V_{oc} of the string will be 4 x 38.91V = 155.64 V d.c.

If the temperature coefficients are not available and the array uses monocrystalline or polycrystalline modules, the maximum PV array 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
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.10
-1 to -5	1.12
-6 to -10	1.14
-11 to -15	1.16
-16 to -20	1.18
-21 to -25	1.20
-26 to -30	1.21
-31 to -35	1.23
-36 to -40	1.25

Note: This table does not apply if the modules are thin-film types, the voltage/temperature coefficient for the specific thin-film modules in use should be obtained from the module manufacturer.

2.3. Orientation and Tilt

In off-grid solar energy 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 and for ground mounting) or
- "flat" on the roof so it is parallel to the slope of the roof but raised off the roof, or
- on a pole mounted system separate from the building, or
- ground mounted if it is a large system.

Though the maximum output would be obtained using an array frame that is tilted to fix the array at the optimum angle, for practical reasons solar arrays are often mounted parallel to the roof.

For best year-round performance, a fixed PV array typically should be mounted facing true south in the Northern Hemisphere and true north for areas in the Southern Hemisphere.

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) 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 near the Equator if the tilt angle is not greater than 20 degrees. The 10-degree minimum tilt angle recommendation at the Equator allows water to drain from the solar modules which helps in self-cleaning.

2.4. Roof Mounting PV on an Existing Building

- If the modules use crystalline cells, then it is preferable to allow sufficient space below the array (>150mm) 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).
- 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 minimize 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.

- 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 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 fasteners to be used
    - Number of fasteners 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.

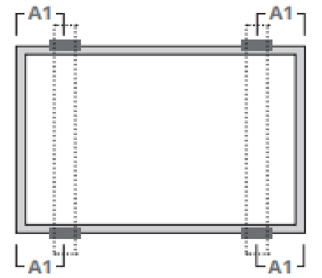
2.5. Free Standing PV Arrays

- The array mounting frames must be wind rated in accordance with relevant wind loading standards.
- Installation of footings, posts, fasteners and/or in-ground fasteners shall follow manufacturer's instructions and installation manuals.

2.6. 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. Examples of clamps are shown in Figures 4 and 5.
- 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 a 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 the module
    - size of clamp required

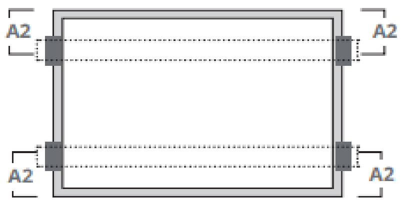
FIGURE 4: EXAMPLE OF ARRAY CLAMPS (SOURCE: CANADIAN SOLAR)



Use four clamps on the long side. Mounting rails run perpendicularly to the long side frame.

A1 range = (340 – 550) mm
Maximum Load:
Uplift load ≤ 2400 Pa
Downforce load ≤ 2400 Pa

A1 range = (410 – 490) mm
Maximum Load:
Uplift load ≤ 2400 Pa
Downforce load ≤ 5400 Pa

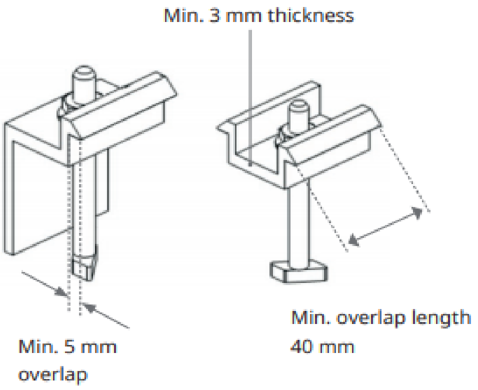


Use four clamps on the short side. Mounting rails run parallel to the long side frame.

A2 range = (200 – 250) mm
Maximum Load:
Uplift load ≤ 1800 Pa
Downforce load ≤ 2400 Pa

FIGURE 5: MODULE CLAMPS (SOURCE: CANADIAN SOLAR)

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



Note: Attaching a solar module in such a manner that creates a hole in the anodised aluminum 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.

2.7. Module Handling, Packaging, Transportation and Storage

It is very important to understand the installer about handling, packaging and storage of PV modules so that modules do not get damaged in transit and during installation.

If mishandled while loading, transporting and unloading, modules may be damaged. External damage or breakage is usually visible, but internal damage to cells is often not visible to the naked eye. Therefore, use extreme caution during loading, transportation and unloading of modules. Figures 6, 7, and 8 demonstrate correct and incorrect ways of storing and transporting modules.

Follow the instruction below carefully while handling, storing and installing the modules.

- Solar modules should be stacked, packed and transported vertically and separators should be placed between each module. Horizontal stacking should be avoided.
- If due to unavoidable reasons, stacked horizontally, good buffer materials between each module and around the modules are necessary to reduce potential damages and additional protection is to be added to the four corners of each module and NOT more than six modules should be packed in one box.
- Understand and follow the manufacturer's manual and recommendations.
- Do not step on the PV module as this might cause damage to the solar cells inside the module.
- Ensure electrical connectors are well protected from the ingression of water and dust.
- Do not handle PV modules under gusty winds or if there is rain.
- To avoid breakage and micro-cracks during loading, transportation and unloading, modules must be packaged properly (even if the distance of travel is short).
- Avoid rough handling during loading and unloading.
- Never walk on the module containers.
- When transporting modules on a rough road, vehicles should travel slowly enough to avoid unnecessary vibration and shifting.

Important to note:

Horizontally stacked modules cause stress on the modules on the bottom and lead to micro-cracks that will not be detected by naked eyes. Even if separators are used, these are not strong and wide enough to sufficiently separate the modules from each other, thus the upper layers of the stack cause weight stress towards the lower layers that lead to micro-cracks in the cells.

FIGURE 6: CORRECT WAY OF PACKING MODULES

	
Solar modules should be stacked, packed and transported vertically	If stacked horizontally, NOT more than six modules should be packed in one box

Loading, transport and unloading:

- Modules may be damaged externally or internally causing micro-cracks while loading, transport and unloading. Any external damage or breakage is visible but internal damage to cells is not visible by the naked eye and therefore precaution during loading, transportation and unloading should not be underestimated even if there is no visible damage to the modules.
- To avoid breakage and micro-cracks during loading, transportation, and unloading, modules must be packaged properly even if the distance of travel is short. Rough handling during loading and unloading and walking on the package must be avoided. While carrying the modules in a truck on a bumpy road, the speed of the truck must be controlled at a minimum to avoid vibration and jerking.

FIGURE 7: CORRECT WAY OF UNPACKING OF MODULES (SOURCE: VIKRAM SOLAR)

- PV modules should be unpacked by two people from a vertical storage position as shown in Figure 7. Care should be taken so that modules do not fall inside the packaging box.

Correct storage of PV modules

Incorrect storage of PV modules

FIGURE 8: INCORRECT STORAGE OF MODULES - THIS MAY CAUSE IRREPARABLE DAMAGE TO THE MODULES

3. Battery Installation

3.1. Battery installation requirements

Batteries are a dangerous component in a solar energy system due to weight, explosive gases with some technologies and potentially high fault currents. Their performance, life and reliability are affected by their location and climatic conditions. Correct placement and protection are paramount to minimising risk and maximising performance. The following requirements and recommendations shall be observed when installing the battery system. Bullet points listed with the word “shall” are requirements. Bullet points listed with the word “should” are recommendations. Recommendations are optional but strongly encouraged:

- The battery/ batteries shall be installed in a dedicated enclosure. These enclosures can be boxes as shown in Figures 11 and 12 or a *no wall* enclosure as shown in Figure 13.
- The enclosure selected shall ensure that mechanical protection is guaranteed and limits unauthorised access to the batteries.
- The enclosure shall shelter the battery terminals to limit access and prevent accident short circuits. Appropriate covers on battery terminals are recommended, particularly for open enclosures (such as shown in Figure 13).
- Sufficient space should be available within the enclosure to allow for ease of battery installation and maintenance.
- No uninsulated metal objects --- that could fall across battery terminals and cause a short circuit --- shall be kept nearby.
- Explosive and/or corrosive gas-emitting battery systems: should not be located within 500 mm horizontally of any other equipment from 100 mm below the battery terminals (Figure 9), except where there is a solid separation barrier or in the following exception:
    - For battery types that are known as valve-regulated or sealed and where there are no more than four (4) monobloc batteries, these should not be located within 200 mm (8 inches) horizontally of any other equipment from 100 mm (4 inches) below the battery terminals (Figure 10), except where there is a solid separation barrier.
- No electrical equipment shall be mounted above explosive and/or corrosive gas-emitting batteries.
- No metal devices shall be installed above the batteries or the battery enclosures. These could fall onto the batteries when the enclosure is open.
- The location where the batteries are installed shall be dry.
- Batteries shall 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 shall not be installed directly above or within 200 mm of any battery that emits explosive gases unless the fitting is an explosive-rated fitting.

- The enclosure should not be in direct sunlight and should be in a location that keeps the batteries as cool as possible.
- Batteries are typically heavy, and the area under the batteries shall be capable of bearing the weight of the batteries without distortion.
- Electrolyte spillage should be guarded against for those battery system types containing liquid electrolytes. The material used to construct the enclosure should resist the electrolyte-specific corrosive effects or be painted with corrosion-resistant paint.
- Any electrolyte spillage (from flooded batteries) should be contained within the enclosure.

FIGURE 9: EXCLUSION ZONE FOR EQUIPMENT LOCATED NEAR A WET (FLOODED) BATTERY BANK THAT EMITS EXPLOSIVE GASES

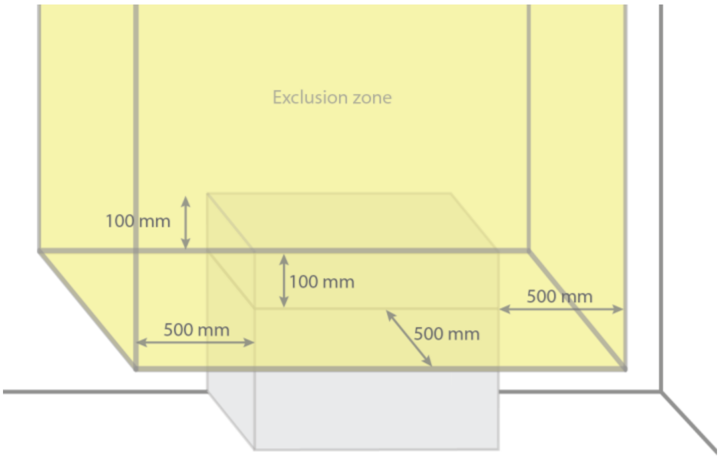
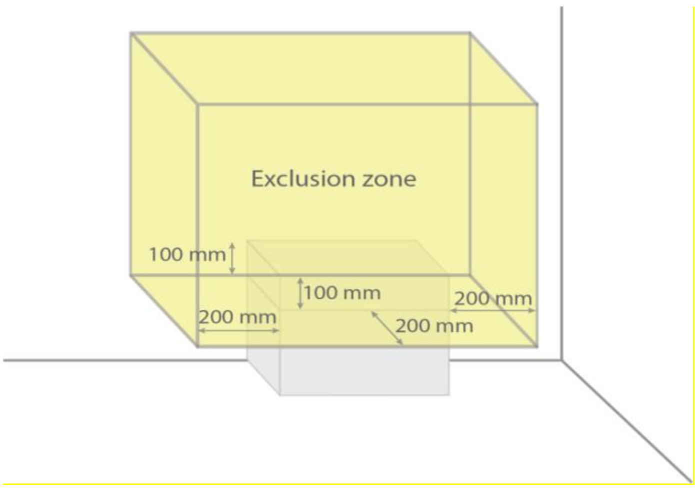


FIGURE 10: EXCLUSION ZONE FOR EQUIPMENT LOCATED NEAR A VALVE-REGULATED (SEALED) BATTERY BANK THAT EMITS EXPLOSIVE GASES (note a maximum of 4 monobloc batteries)



3.2. Battery ventilation requirements

- Battery types that emit explosive gases shall be installed in enclosures with sufficient ventilation to prevent the build-up of explosive gases generated when the battery is being charged. These enclosures can be boxes, as shown in Figures 11 and 12 or a *no-wall* enclosure as shown in Figure 13.

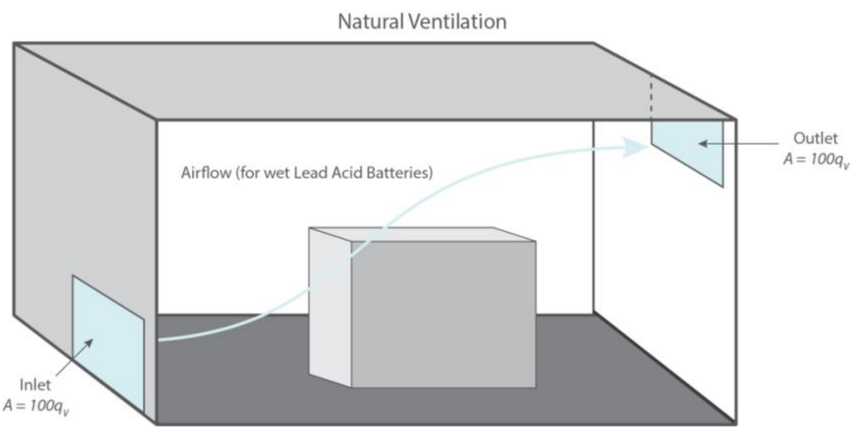
- Adequate ventilation should be available to assist in temperature control and, if necessary, to avoid the build-up of hydrogen or other gases associated with charging.

- For wet lead-acid batteries, the outlet ventilation should be to the outside of the building in which the battery system is located.

- For valve-regulated lead-acid batteries, if possible, the outlet ventilation should be to the outside of the building in which the battery system is located. However, if this is not possible, the room in which the battery enclosure is installed should be large enough to allow any emitted gases to disperse easily.

- Best practice is to provide the input ventilation vents on the enclosure wall below the battery level 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 11).

FIGURE 11: NATURAL VENTILATION ARRANGEMENT FOR BATTERIES.



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

FIGURE 12: NATURAL VENTILATION ARRANGEMENT FOR BATTERIES WITH VENTS ON ONE SIDE

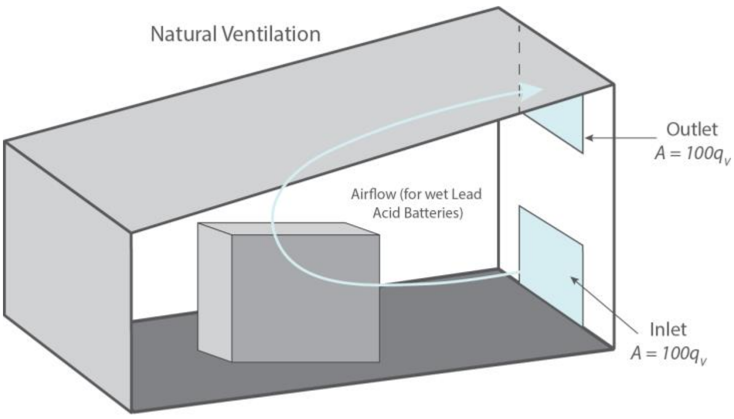
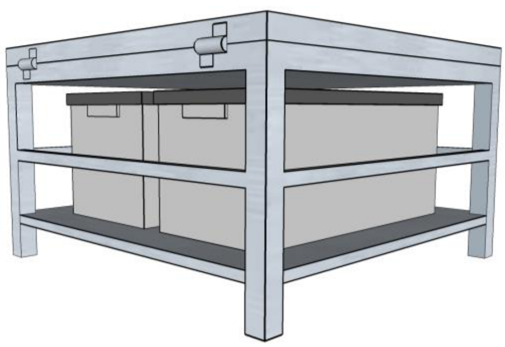


FIGURE 13: BATTERY ENCLOSURE WITH NO WALLS



3.3. Determining Size of Vents – Flooded Lead Acid Batteries

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

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

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

and n = the number of battery cells[1]

I = the charging rate in amperes[2]

Notes:

1. Lead-acid batteries comprise 2V cells. A 12V Monobloc battery consists of quantity 6 x 2V cells, while a 6V battery consists of quantity 3 x 2V cells. Hence, the number of cells in one battery bank string is the string's voltage divided by 2.

2. 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.

Table 3 provides examples of required ventilation areas for various nominal System Battery Voltage and total charge currents.

TABLE 3: VENTILATION AREA CM2 – NOMINAL SYSTEM BATTERY VOLTAGE VS TOTAL CHARGING CURRENT

Amps	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85
12V	18	36	54	72	90	108	126	144	162	180	198	216	234	252	270	288	306
24V	36	72	108	144	180	216	252	288	324	360							
48V	72	144	216	288	360	532											

3.4. 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. For example, a battery has a C_3 rating of 500Ah. Therefore, the charge current (I) used in the ventilation formula is:

I = (500Ah/100Ah) x 0.5A

= 2.5A

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

Table 4 provides examples of required ventilation areas for various nominal System Battery Voltage and Total C3 Battery Capacity.

TABLE 4: VENTILATION AREA CM2 – NOMINAL SYSTEM VOLTAGE VS TOTAL C3 BATTERY CAPACITY

C_3 capacity (Ah)	60	80	100	120	140	160	180	200	250	300	350	400	450	500	600	700	800
Amps	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.25	1.5	1.75	2	2.25	2.5	3	3.5	4
12V	1.08	1.44	1.8	2.16	2.52	2.88	3.24	3.6	4.5	5.4	6.3	7.2	8.1	9	10.8	12.6	14.4
24V	2.16	2.88	3.6	4.32	5.04	5.76	6.48	7.2	9	10.8	12.6	14.4	16.2				
48V	4.32	5.76	7.2	8.64	10.08	11.52	12.96	14.4	18								

4. Solar Controller Installation

The following requirements and recommendations shall be observed when installing solar controllers. Bullet points listed with the word "shall" are requirements. Bullet points listed with the word "should" are recommendations. Recommendations are optional but strongly encouraged:

- The solar controller shall be installed as per the manufacturer`s instructions.
- Installation of solar controllers (either PWM 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 shall 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.
- Solar controllers shall not be installed 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.
- Solar controllers should be installed in dust-free locations; however if a solar controller is installed outside, the controller should have an Ingress Protection (IP) rating of at least IP54.
- If the site experiences tropical rainstorms, then consideration should be given to using controllers with an IP rating of IP55 or IP56. (Note Annex 1 provides a table explaining what the various IP numbers refer to)
- Solar controllers are not to be installed in direct sunlight.

4.1. MPPT Earth Fault Indication

- Where the PV array maximum open-circuit voltage is greater than 100 V d.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.

5. PV Inverter Installation

The following requirements and recommendations shall be observed when installing PV inverters. Bullet points listed with the word “shall” are requirements. Bullet points listed with the word “should” are recommendations. Recommendations are optional but strongly encouraged:

- The PV inverter shall be installed as per the manufacturer`s instructions.
- The PV inverter shall be installed in a location appropriate for the IP rating of the PV inverter. Where this is not possible, the PV inverter/s should be in an appropriate weatherproof enclosure with adequate ventilation.
- PV inverters should be installed in dust-free locations; however if a PV inverter is installed outside, the PV inverter should have an IP rating of at least IP54 or be installed in a suitable enclosure. If the site experiences tropical rainstorms, then consideration should be given to using inverters with an IP rating of IP55 or IP56.
- PV inverters shall not 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 can be heavy; the surface on which the PV inverters will be mounted must be appropriately weight-bearing.
- The PV inverter heat sink shall be clear of any obstacles that may interfere with the cooling of the PV inverter.
- Cables connected to the inverter shall be mechanically secured so 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 that has the cable connection area of the 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 d.c. connectors to be used, a maximum allowable distance of no more than 200mm of unprotected d.c. cable shall be permitted between connectors and conduit, provided the location is not susceptible to mechanical damage.
- Where the inverter is exposed to the weather, there shall be no open ends of the 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.

5.1. Inverter Earth Fault Indication

- Where the PV array maximum open-circuit voltage is greater than 100 V d.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., email, or 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.

6. Battery Inverter Installation

The following requirements and recommendations shall be observed when installing battery inverters. Bullet points listed with the word “shall” are requirements. Bullet points listed with the word “should” are recommendations. Recommendations are optional but strongly encouraged:

- Non-separated battery inverters should not be used if the output of the inverter is hard-wired to a switchboard.
- Non-separated inverters should have loads directly connected via a plug to the a.c. output via the power outlet located on the inverter.
- The battery inverter should be installed as close to the battery system to minimise voltage drop.
- Battery inverters should be installed in dust-free locations; however if the battery inverter is installed outside, the battery inverter should have at least an IP rating of at least IP54. If the site experiences tropical rainstorms, then consideration should be given to using battery inverters with an IP rating of IP55 or IP56.
- 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 can be heavy, the surface on which the battery inverters will be mounted must be appropriately weight-bearing.
- The battery inverter heat sink shall be clear of any obstacles that hamper the cooling of the battery inverter.

Note: If the battery inverter also includes an inbuilt solar charge controller, then the installation requirements shall meet the requirements specified in this section and any additional requirements for the solar controller specified in Section 4.

7. Safe Installation Practice

A dangerous situation occurs when the person installing the system comes 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 120 V d.c.). This could occur with d.c.-coupled systems using MPPTs as the controller or with a.c.-coupled systems using PV inverters.

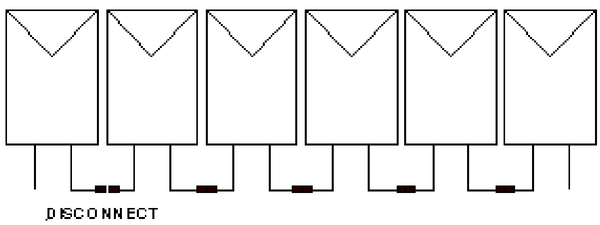
Most systems use approved solar modules, which are connected using double insulated leads with polarised shrouded plug and socket connections.

For a.c.-coupled systems or d.c.-coupled systems using MPPTs, a dangerous situation is only likely to occur when connecting wires/cables in:

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

To prevent the possibility of an installer meeting live wires, it is recommended practice that one of the interconnect cables of each string (as shown in Figure 14) is left disconnected until all the wiring is complete between the array and the inverter. Only after all switch-disconnectors and other hard-wired connections are completed should the interconnecting cable of the array be connected.

FIGURE 14: DISCONNECTED INTERCONNECT CABLE



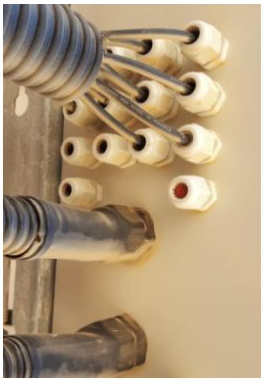
The installer shall ensure that all connectors used are waterproof and connected securely to avoid the possibility of a loose connection. Only connectors of the same type from the same manufacturer are allowed to be mated at a connection point.

When connecting a cable connector to the solar cable, the installer shall use the specific tool specified by the connector manufacturer (supplier). Care must be taken to ensure that the connection between the solar cable and the connector is physically secure.

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

Tighten cable connectors using appropriate tools (Figure 15a). Tightening by hand will leave the connector enclosure loose, causing ingression of water and damage to the contacts. Similarly, tighten the cable glands using appropriate tools (Figure 15c) and use an EDPM rubber stopper (Figure 15b) to block unused holes in the combiner box.

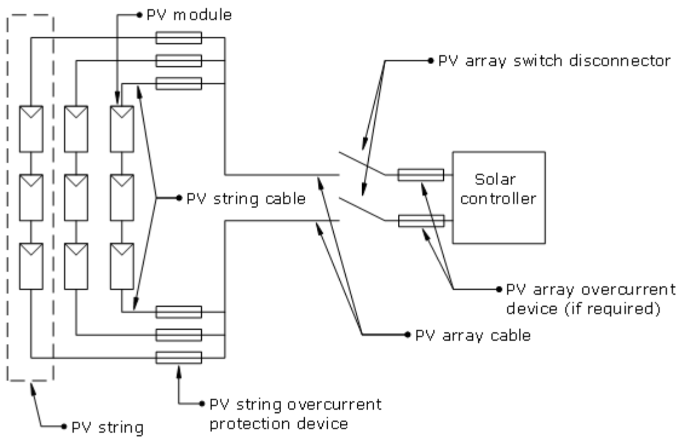
FIGURE 15: TOOLS FOR CABLE CONNECTOR AND CABLE GLANDS

		
(a) Tools for cable connector	(b) Rubber stopper to block unused holes in a CB	(c) Tool to tighten cable glands

8. PV Array Wiring

The formulas in this section are from IEC62548: Photovoltaic (PV) Arrays-Design Requirements. Figure 16 helps explain the various cables and components within a PV array. PV string cables are those that interconnect modules in a string. The PV array cable is the cable between the array and the solar controller.

FIGURE 16: PV ARRAY DIAGRAM SHOWING MULTIPLE STRINGS



8.1. Selection of d.c. Cable for PV Array

FIGURE 17: DOUBLE INSULATED SOLAR D.C. CABLE

Cables used within the PV array wiring shall:

- Be suitable for d.c. applications.
- Have a voltage rating equal to or greater than the maximum PV array voltage determined using Table 2.
- Have a temperature rating appropriate to the application.
- If exposed to salt environments, use tinned copper, and 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 (>60 V d.c.), cables shall be selected to minimise the risk of earth faults and short-circuits. This is commonly achieved using reinforced or double-insulated cables, mainly for cables that are exposed or laid in a metallic tray or metal conduit (refer to Figure 17).
- It is recommended that string cables be sufficiently flexible to allow for the thermal/wind movement of arrays/modules.

- For PV arrays that operate at voltages above DVC-A, cables should comply with IEC 62930: Electric Cables for Photovoltaic Systems with a voltage rating of 1.5 kV d.c.

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)].

8.2. Installation of the PV Array Wiring

- The cable should be supported and not allowed to move in the wind.
- Plastic cable ties should not be used as the primary means of support.
- In all systems operating at voltages above 35 V d.c. 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, the wiring system shall be selected accordingly, or special protective measures shall be adopted.
- All external wiring must be protected from UV by using UV-rated cables or installing the cables in enclosures/conduits.
- 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 from the same type/model and from the same manufacturer are allowed to be mated at a connection point.
- Use connector assembly tools as recommended connector manufacturer. These tools include stripping pliers, crimping pliers, open-end spanner sets, adjustable torque screwdriver, socket wrench, socket wrench adapter and a test plug.
- It is recommended that under maximum solar current (Isc at STC), the voltage drop from the most remote module in the array to the input of the MPPT controller or PV inverter should not exceed 3% of the Vmp voltage (at STC) for PV arrays.
- It is recommended that under maximum solar current (Isc at STC), the voltage drop from the most remote module in the array to the battery terminal should not exceed 5% of the battery's nominal voltage.
- Keep bending radius of cables more than 40mm or as recommended by the module manufacturer. Maintain correct cable routing as shown in Figure 18 below.

FIGURE 18: MAINTAIN MODULE BENDING RADIUS

Bending radius of cables >40mm	Incorrect routing of cable	Correct routing of cable

- Exterior cables should be installed using drip loops where the cables enter junction boxes, a building, or other enclosed space. A drip loop is an extra length of cable that hangs below an electrical connection or cable entrance.

8.3. 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 19, 20 and 21 give examples on how a conductive wiring loop can be avoided while Figure 22 shows a wiring arrangement that will cause a conductive loop and should not be used. To minimize lightning generated voltage surges, the positive and the negative wires should always be run together.

FIGURE 19: EXAMPLE OF WIRING TO AVOID CONDUCTIVE LOOPS

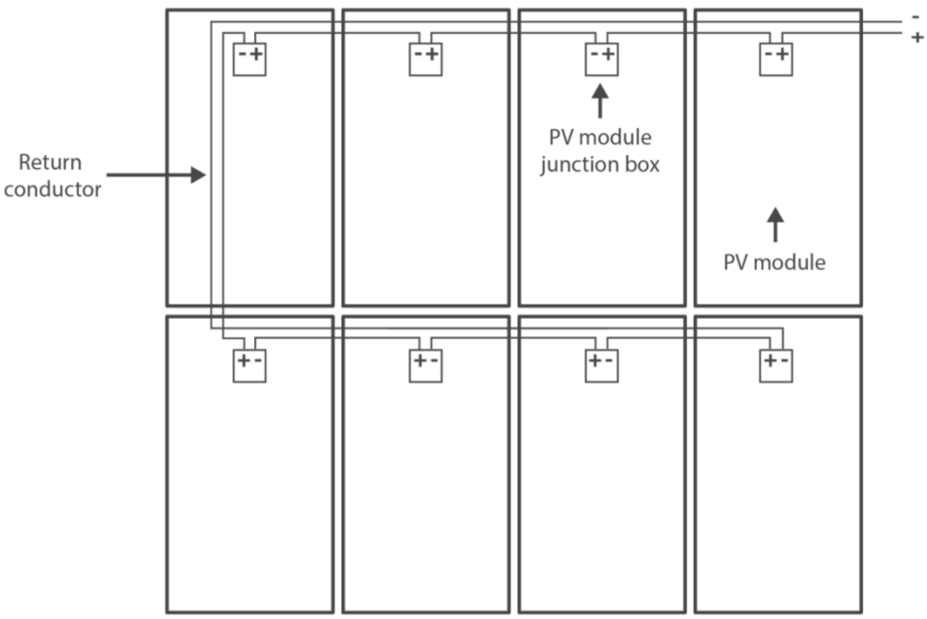


FIGURE 20: EXAMPLE OF WIRING TO AVOID CONDUCTIVE LOOPS

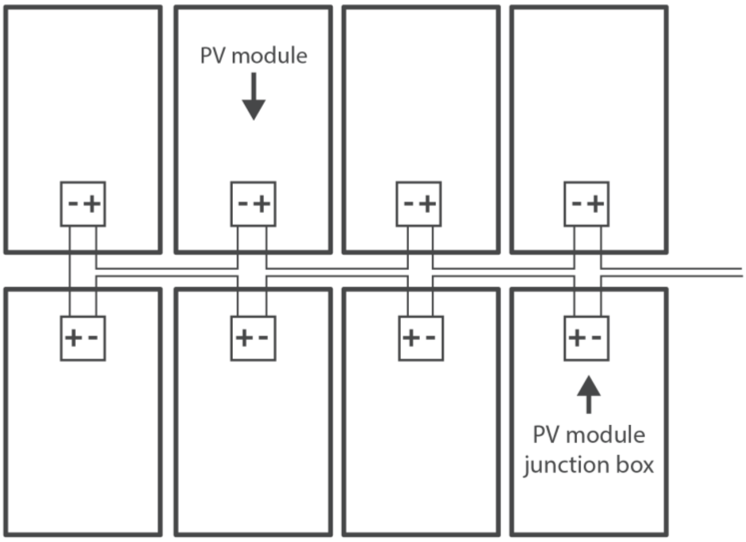


FIGURE 21: EXAMPLE OF WIRING TO AVOID CONDUCTIVE LOOPS

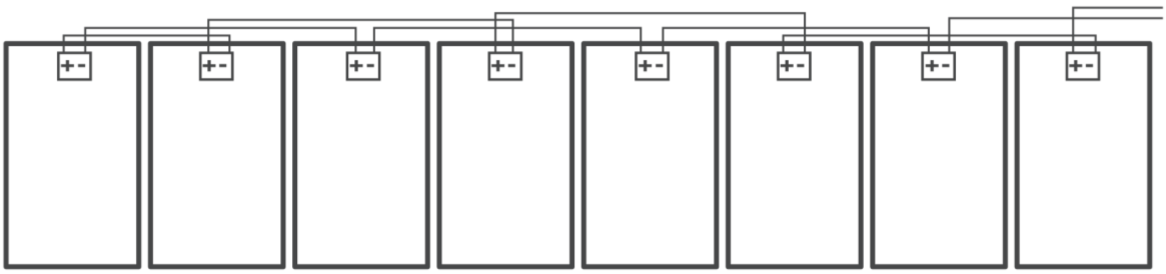
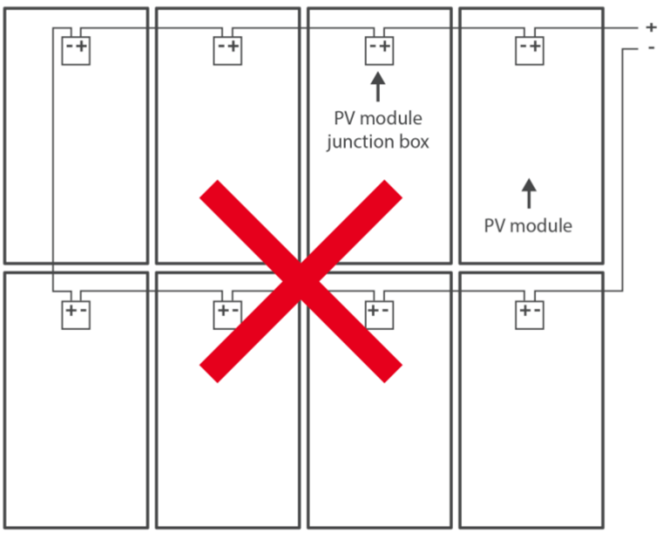


FIGURE 22: EXAMPLE OF WIRING TO BE AVOIDED BECAUSE IT INCLUDES CONDUCTIVE LOOPS



8.4. 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 8 A, the string must be rated with a current-carrying capacity (CCC) of a minimum of 8 A.

- 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_n is the current rating of the nearest downstream overcurrent protection device.

8.5. Selection of Current Carrying Capacity of PV Array Cables

- If a fault current protection device is located in the array cable, the array cable shall have a rating equal to or greater than the current rating of the fault current protection device. Note for d.c.-coupled off-grid PV systems, array protection shall be required.

- If no fault current protection device has been included (mainly in a.c.-coupled PV system configurations), the current carrying capacity of the PV array cable shall be rated according to:

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

Where:

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

8.6. Selection of Cables when Array Comprises Sub-Array PV Systems

8.6.1. PV Array Cables

- In a large PV system, the array could consist of several 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 d.c.-coupled off-grid PV systems, array protection will be required.

- If no fault current protection device has been included (mainly in a.c.-coupled PV 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

8.6.2. PV Sub-Array Cables

- Suppose a fault current protection device is located in the sub-array cable. In that case, 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:

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

Where:

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

I_n = current rating of the PV array protection device.

8.6.3. 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:

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

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:

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

8.7. Installation of PV Array Cable between Array and Solar Controller (d.c.-Coupled System) or PV Inverter (a.c.-Coupled System)

- Suppose the PV array has a rated output voltage greater than 100 V d.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-circuiting is reduced. In all other locations, it shall be installed in a 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 such 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, appropriate mechanical protection should be installed.
- Installing a conduit just through a hole in a metal roof and sealing it with silicone is prohibited.

Note: If the battery inverter is of a type that includes an inbuilt solar controller, then the interconnection between the array and the inverter shall follow the requirements of this clause.

9. Installation of Combiner Boxes

- Combiner boxes (PV string or PV array) installed outside shall be at least IP54 and UV resistant. If the site experiences tropical rainstorms, then consideration should be given to using combiner boxes with an IP rating of IP55 or IP56.
- PV array and PV string combiner boxes that 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.
- It is recommended that there are no top cable entries into combiner boxes, and cable drip loops are utilised at the bottom of the combiner box to minimise the risk of water ingress.

10. Segregation of d.c. and a.c. Circuits

- Within enclosures, segregation shall be provided between d.c. and a.c. circuits by insulation barriers.
- Where switches for d.c. and a.c. circuits are mounted on a common mounting rail the mounting rail shall not be conductive (e.g., a non-metallic material).
- d.c. and a.c. circuits should be clearly marked.

11. Installation of Cable Between PWM Solar Controller and Battery Bank

- The cables between the PWM solar controller and the battery bank 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 bank shall be capable of carrying the maximum charge current from the array.
- The current-carrying capacity of the cable between the solar controller and the battery bank shall have a minimum rating based on the d.c. current rating of the associated over-current protection.
- Any battery cable forming the connection between a battery bank and the associated over-current protective device shall be rated to withstand the prospective fault current for at least equal the operating time of the associated over-current protective device.
- The d.c. cables between the solar controller and the battery bank can be single insulated if the nominal battery bank voltage is 100 V d.c. or less.
- Cables and conduits shall be installed so that they are adequately supported.
- When using PWM controllers, it is recommended that the voltage drop from the most remote module in the array to the battery bank under maximum solar current should not exceed 5% of the battery voltage.

12. Installation of Cable Between MPPT Controller and Battery Bank

- If the PV array has a rated output voltage greater than 100 V and the MPPT is not electrically separated between the input and output, the d.c. 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 bank shall have a voltage rating greater than the maximum voltage of the array.
- The cables between a separated MPPT and the battery bank shall have a voltage rating greater than the battery's maximum voltage.
- The current carrying capacity of the cable between the MPPT and the battery bank shall be capable of carrying the maximum charge current from the MPPT.
- The current-carrying capacity of the cable between the MPPT and the battery bank shall have a minimum rating based on the d.c. current rating of the associated over-current protection device.

- Any battery cable forming the connection between a battery bank and the associated over-current protective device 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.
- It is recommended that under maximum MPPT charger current, the voltage drop from the MPPT module to the battery bank should not exceed 2% of the battery voltage.

13. Installation of Cable Between Battery Bank and Battery Inverter

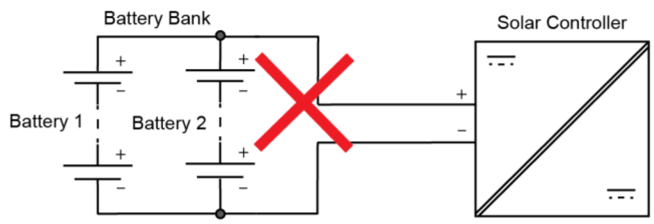
- For PWM solar controllers systems, the cable shall have a voltage rating greater than the battery bank voltage when being charged.
- For systems using a separated MPPT controller, the cable shall have a voltage rating greater than the battery bank voltage when being charged.
- For systems using non-separated 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 100 V d.c. and the solar controller is a non-separated MPPT unit, the d.c. cables between the battery bank and the battery inverters shall be double insulated.
- For systems using switching type solar controllers or separated MPPT controllers and the nominal battery bank voltage is less than 100 V d.c., the d.c. cables between the battery and the battery inverter can be single insulated.
- Any battery system cable forming the connection between a battery bank and the associated over-current protective device 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 the continuous power rating of the inverter.
- The current-carrying capacity of the cable between the battery bank and inverter shall have a minimum rating based on the d.c. current rating of the associated over-current protection.
- Cables and conduits shall be installed so that they are adequately supported.

Note: If the battery inverter is of a type that includes an inbuilt solar controller, then the interconnection between the battery and the inverter shall follow the requirements of this clause plus any additional requirements specified in either Section 11 (PWM controller) or 12 (MPPT controller).

14. Installation of Cables to Parallel Batteries

- Battery banks that comprise batteries connected in parallel shall not have the wiring of the batteries in a daisy chain, as shown in Figure 23, that is, from one battery to another such that only one battery is connected to the equipment, e.g., solar controller or inverter.

FIGURE 23: DAISY CHAINED BATTERIES



- Within a battery bank comprising batteries in parallel, the cables from each battery to a charging source (solar controller) and load source (inverter and solar controller) shall be of the same resistance. This is achieved by having the same cable lengths between the battery terminals of each battery and the charging and load sources. Examples of how to achieve this are shown in Figures 24, 25 and 26. The cross-sectional area of the cables must also be the same, and though only the solar controller is shown in the drawings, this shall be repeated for the inverter.

FIGURE 24: EXAMPLE OF CORRECT CABLING OF PARALLEL BATTERIES

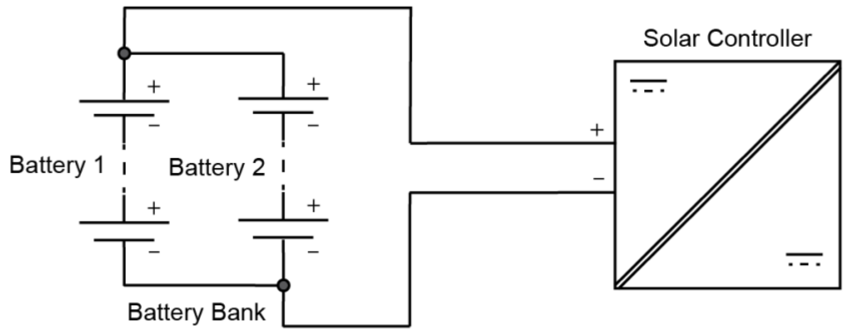


FIGURE 25: EXAMPLE OF CORRECT CABLING OF PARALLEL BATTERIES

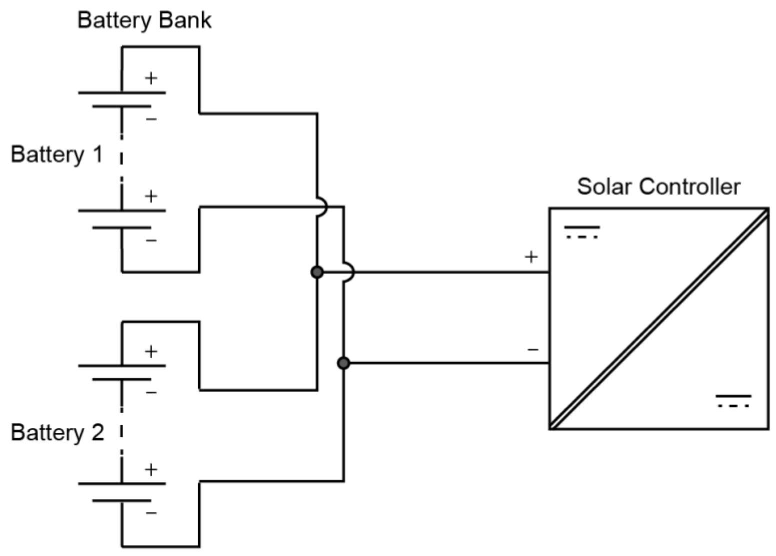
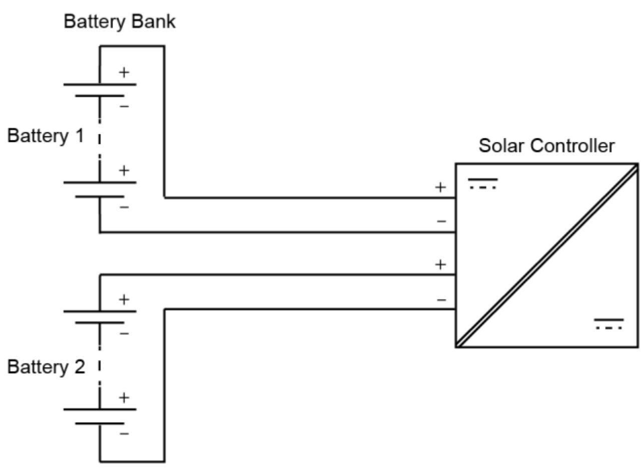


FIGURE 26: EXAMPLE OF CORRECT CABLING OF PARALLEL BATTERIES



15. Cable Joints and Termination

- A faulty cable joint and termination cause a loose connection or short circuit.
- Unnecessary cable joints can be avoided by carrying out a pre-installation site survey and measuring the cable route.

- All wire connections, switches, receptacles and breakers should be mounted in electrical boxes. If the box is mounted, outdoor, the minimum ingress protection rating should be IP54. If the site experiences tropical rainstorms, then consideration should be given to using boxes with an IP rating of IP55 or IP56.
- When connectors are used to join wires, the minimum ingress protection rating of connectors should be IP65.
- The male and female parts of the connectors must be of the same type/ model and from the same manufacturer.
- Use appropriate size and type of cable lugs in all cable terminals.
- Do not terminate cable without a cable lug.
- Use a heavy-duty industrial type crimping tool or as recommended by the connector manufacturer.

16. 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 d.c. load should never exceed 5%
- The voltage drop between the PV array and MPPT controller should never exceed 3% (d.c.-coupled system)
- The voltage drop between the PV array and PV inverter should never exceed 3% (a.c.-coupled system)

16.1. Calculating Voltage Drop for Systems that Include PWM Controllers

This section is for systems using 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:

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

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

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 Ω/m/mm2

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

$\mathbf{V_{batt}}$ = the nominal voltage of the battery, which is the d.c. system voltage.

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

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

Polyvinyl Chloride (PVC)- maximum temperature 75°C

Cross-Linked Polyethylene (XLPE)- maximum temperature 90°C

Cross-Linked Polyethylene (XLPE)- maximum temperature 110°C

Table 5 shows the respective resistivities for the different types of cables.

TABLE 5: RESISTIVITY FOR DIFFERENT CABLES (W/M/MM²)

Cable Type	Copper	Aluminum
PVC-75oC	0.0209	0.0328
XLPE 90oC	0.0219	0.0345
XLPE 110oC	0.0233	0.0367

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

Worked Example 3

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

The cable has a cross sectional area of 10 mm²

The cable is copper with a resistivity of 0.0209 ohms/meters/mm²

The battery voltage of the system is 12 V.

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

= 2 x 8 x 9.6 x 0.0209/10 V

=0.321 V

Voltage Drop in percentage = $\frac{V_d}{V_{Batt}}$ × 100 %

= 0.4013/12 × 100 %

= 2.7%

16.2. Calculating Voltage Drop for Systems that Include a MPPT

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

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) = $\frac{V_d}{V_{MAX}} \frac{V_{DROP}}{V_{MAX}}$ × 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 W/m/mm²

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 (d.c.-coupled) or PV inverter (a.c.-coupled) the current is the short circuit current (I_{sc}) of the string, sub-array or array. The maximum line voltage in volts is the maximum power point voltage of the string, sub-array or array (V_{mp}).

Worked Example 4

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

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

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

The array has maximum power point voltage of 154.4 V.

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

= 2 x 8 x 9.6 x 0.0209/4 V

=0.803 V

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

= 0.803/154.4 x 100 %

= 0.52%

17. Protection and Isolation Requirements in a Solar Energy System with Maximum Four (4) Batteries in a Series String and Four (4) Battery Strings in Parallel

This section provides the minimum requirements allowed for solar energy systems with battery banks comprising monobloc batteries (maximum 4 in series and 4 in parallel). A system designer/installer could follow the requirements as specified in Sections 18 and 19 for these types of systems but it is accepted the protection and isolation requirements specified in those sections would add to the cost of these smaller systems.

All electrical standards state that all cables shall be electrically protected from fault currents that could occur. However, because of the difficulty in some situations of installing protection equipment at the start of a cable some electrical wiring standards allow 2 to 3 metres of cable to be unprotected. This guideline adopts that philosophy.

When fuses are installed, spares should be left with the system owner.

If circuit breakers are used, then they should be suitably rated d.c. circuit breakers. Some a.c. circuit breakers do have a small d.c. voltage rating however many do not and should not be used unless they have the appropriate d.c. voltage rating.

This guideline does not specify that separate isolation devices are required to be installed in a solar energy system comprising monobloc batteries (maximum 4 in series and 4 in parallel) however this section does show where they could be installed. When an installer (designer) decides to install these devices, then they should meet the requirements of Section 23.

No separate disconnection devices are required within an array because the solar module connectors will meet the isolation of the array requirement. However, they should never be disconnected under load. Refer to Section 25 Shutdown procedure.

17.1. Solar Energy System with d.c. Loads Only

The cables in a d.c. only solar energy system are as follows:

- Cable between the battery bank and the solar controller
- Cable between the controller and the PV array
- Cable between the controller and the loads such as d.c. lights and d.c. appliances

Any fault current in this system would come from the battery, and even with a small 100 Ah battery, the fault current can be as high as 2000 A. If this fault current flows in any of the cables, the cables will catch on fire.

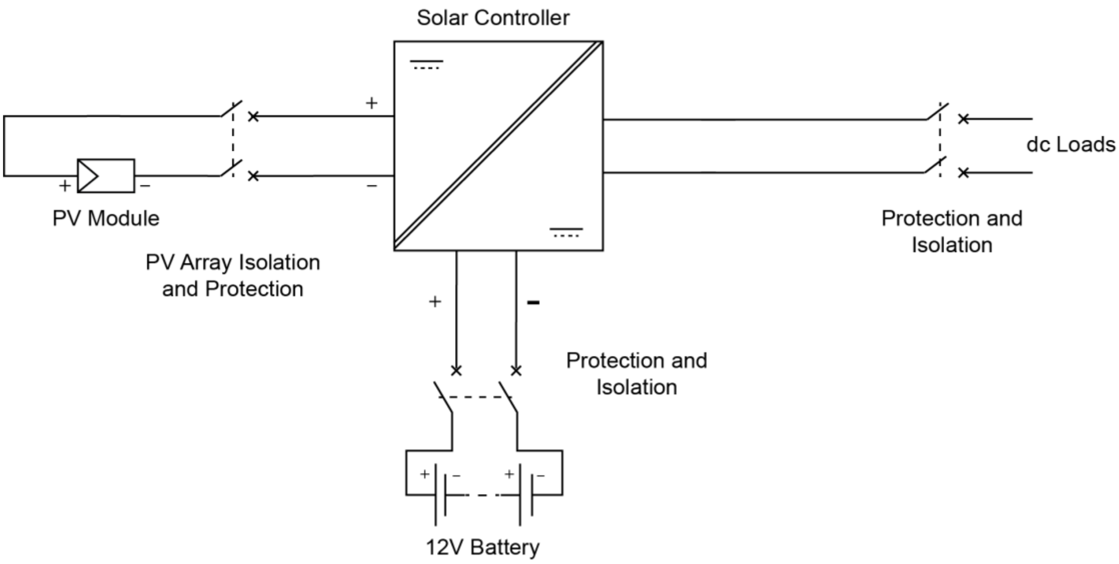
Figure 27 shows the possible options for protection and isolation (switch-disconnection) requirements in the solar energy system with d.c. only loads. It shows isolation and protection in positive and negative cables for each of the three cables using circuit breakers performing both isolation and protection. This is the ideal (safest), but it is also the most expensive.

The minimum requirement for the electrical protection of the cables is summarised as follows:

- Suppose the cable between the battery and the controller is less than 2 metres in length, and there is a single monobloc battery (that is: no parallel batteries or battery strings). In that case, protection is not required to be installed in that cable. (Note: If no protection is installed, the cable shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the nearest located associated over-current protective device.)
- The cables to the PV array and the loads shall be protected.
- If the solar controller includes fusing that protects both the PV array and load cables, no further protection is required.
- If the solar controller only protects one of the cables, either the load cable or the PV array cable, then the other cable shall be protected.

- Suppose protection is installed between the battery bank and controller and it is suitably rated to protect the smallest of all the cables installed. In that case, that protection will meet the protection required for the system.

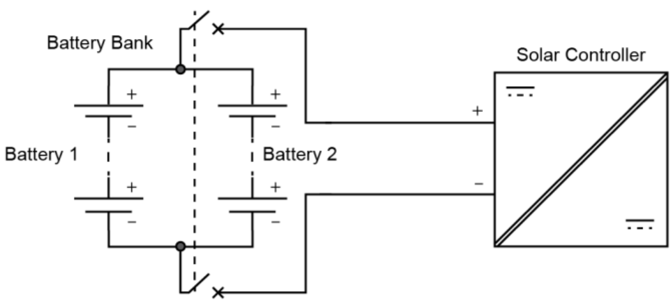
FIGURE 27: SOLAR ENERGY SYSTEM WITH D.C. LOADS ONLY



For maintenance and fault finding (troubleshooting) purposes, it is preferable that each cable: PV array, loads and battery to the controller, can be individually isolated, as shown in Figure 27. However, it is accepted that due to costs, the isolation can be achieved by removing the cable from the solar controller.

When there are parallel batteries (or battery strings), protection is required between the battery bank and the controller. The protection is located where the cables from the parallel strings of batteries join to have one cable going to the controller, as shown in Figure 28.

FIGURE 28: LOCATION OF FUSING FOR PARALLEL BATTERY BANKS IN SHS WITH D.C. LOAD ONLY



When protection devices (suitably rated d.c. circuit breakers or fuses) are installed, they should be installed in both the positive and negative cables.

17.2. Solar Energy System with d.c. and a.c Loads

The cables in a solar energy system with both d.c. and a.c loads are as follows:

- d.c. cable between the battery and the solar controller
- d.c. cable between the controller and the PV array
- d.c. cable between the controller and the loads such as d.c. lights and d.c. appliances
- d.c. cable between the battery and the inverter; and
- Possible a.c. cables from the inverter to a switchboard or distribution board.

Any fault current in this system would come from the battery, and even with a small 100 Ah battery, the fault current can be as high as 2000 A. If this fault current flows in any of the d.c. cables, the cables will catch on fire.

Figure 29 shows the possible options for protection and isolation (switch-disconnection) requirements in the solar energy system with d.c. and a.c loads. It shows isolation and protection in positive and negative cables using circuit breakers for each d.c. cable. This is the ideal (safest), but it is also the most expensive.

The minimum requirement for the electrical protection of the cables is summarised as follows:

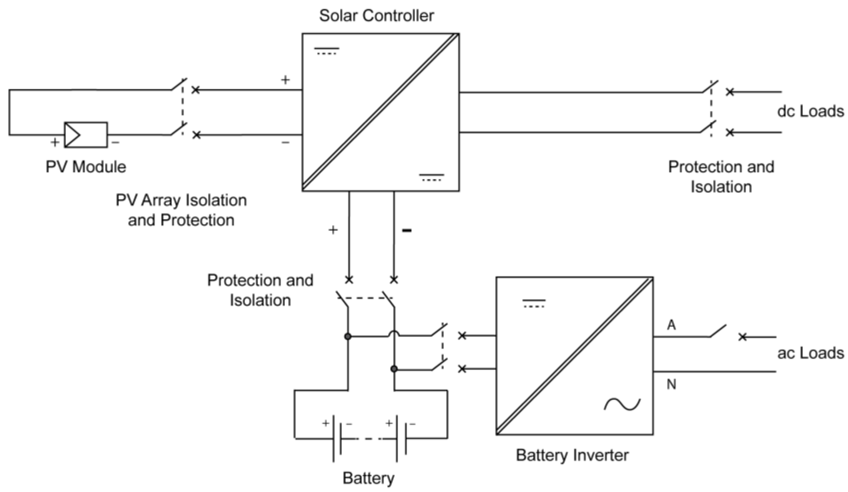
- Suppose the cable between the battery and the controller is less than 2 metres in length, and there is a single monobloc battery (that is: no parallel batteries or battery strings). In that case, no protection is required to be installed in that cable. (Note: If no protection is installed, then the cable shall be rated to withstand the prospective fault current for a time at least equal to the operating time of the nearest located associated over-current protective device)
- The cables to the solar array and the d.c. loads shall be protected.
- If the solar controller includes fusing that protects both the PV array and load cables, no further protection is required.
- If the solar controller only protects one of the cables, either the load cable or the PV array cable, then the other cable shall be protected.
- Suppose protection is installed between the battery bank and controller and it is suitably sized to protect the smallest of all the cables installed. In that case, that protection will meet the protection required for the controller, solar array and d.c. loads cables.
- Protection (either double pole suitable rated d.c. circuit breaker or fuses) shall be located in the cable between the battery and the inverter.
- If the inverter only provides loads directly connected to power points located on the inverter, no further protection is required.

- If the inverter a.c. output is being hardwired to a switchboard or distribution board, and the inverter does not have circuit protection on the output (a.c. side) of the inverter, then a double pole a.c. circuit breaker should be installed in the cable going to the switchboard (distribution board)

When protection devices (suitably rated d.c. circuit breakers or fuses) are installed, they should be installed in both the positive and negative cables.

For maintenance and fault finding (troubleshooting) purposes, it is preferable that each cable: PV array, loads and battery bank to the controller, and battery bank to the inverter can be individually isolated, as shown in Figure 29. However, it is accepted that due to costs, the isolation for the PV array, d.c. loads and battery bank to controller cable is achieved by removing the respective cable from the solar controller. The battery bank to inverter protection device should meet the isolation requirement for that cable. This is achieved using a battery switch fuse device or a suitably rated d.c. circuit breaker.

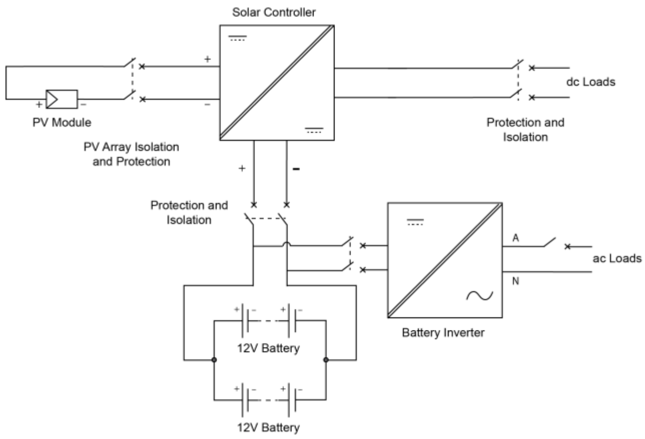
FIGURE 29: LOCATION OF FUSING FOR SHS WITH D.C AND A.C. LOADS



Note: Protection is for the cable between the battery and the controller or inverter, and it should be located as close as possible to the battery.

When there are parallel batteries (or battery strings), protection is required between the battery bank and the controller. The protection is located where the cables from the parallel strings of batteries join to have one cable going to the controller, as shown in Figure 30.

FIGURE 30: LOCATION OF FUSING FOR PARALLEL BATTERY BANKS IN SHS WITH D.C. AND A.C. LOAD

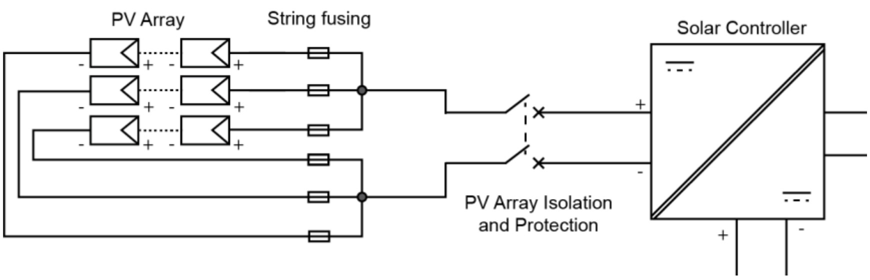


Note: Protection is for the cable between the battery and the controller or inverter, and it should be located as close as possible to the point where the batteries are connected in parallel.

17.3. Arrays with Parallel Strings

Figure 31 shows the location of string and array isolators when the array has parallel strings.

FIGURE 31: ARRAY WITH PARALLEL STRINGS IN SHS



The minimum requirement for the electrical protection of the cables in an array with parallel strings is summarised as follows:

- String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer to Section 22). Circuit breakers are not recommended.
- PV array cable protection is required if the cable is not protected by either the solar controller or protection device located between the battery and the controller.

For maintenance and fault finding (troubleshooting) purposes, it is preferable that the PV array cable can be individually isolated, as shown in Figure 31. However, it is accepted that due to costs, the isolation for the PV array and cable is achieved by removing the cable from the solar controller.

18. Protection Requirements in an Off-Grid Solar Energy System

18.1. Cable Protection within Arrays with Parallel Strings

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 d.c. rated fuses that meet the specification shown in Section 22. Circuit breakers are not recommended.

Worked Example 5

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

A formula for determining the maximum number of strings allowed before fuses are required is:

Maximum Number of Strings without string protection

= reverse current rating of a module/Isc of the module

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

18.2. String Protection

The fuses shall have the following current rating:

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

and

Fuse Rating < $I_{RC\ MOD}$

Where:

$I_{SC\ MOD}$ = Module short circuit current

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

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

18.3. 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 several 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 stops excessive currents from flowing into a sub-array.

18.4. 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 × ISC_ARRAY > Current carrying capacity (CCC) of any sub-array cable, switching and connection device.

More than two sub-arrays are present within an array.

18.5. 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:

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

Where:

$I_{SC\_SUB-ARRAY}$ = short-circuit current of the sub-array.

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

18.6. 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 d.c.-coupled 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.

18.7. Battery Cable Protection: d.c.-coupled – d.c. Loads Only

As stated in Section 17.1 for solar energy systems with no more than four monobloc batteries in series, if the cable between the battery and the controller is less than 2 metres in length, and there are no parallel batteries (or battery strings) then protection is not required to be installed in that cable.

For d.c.-coupled systems with d.c. loads only, (refer to Figures 33 and 34), 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 d.c. load current that is to be provided by the solar controller.

18.8. Battery Cable Protection: d.c.-coupled – a.c. and d.c. Loads

As stated in Section 17.2 for solar energy systems with no more than four monobloc batteries in series, if the cable between the battery and the controller is less than 2 metres in length, is a single monobloc battery (that is: no parallel batteries or battery strings) then protection is not required to be installed in that cable.

d.c.-coupled systems with a.c. and d.c. loads (refer to Figure 35) 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 bank will be rated to allow the maximum charge current provided by the solar controller to the battery bank and the maximum d.c. load current that is to be provided at the output of the solar controller, whichever is larger. This protection device will need to be suited for motors if there are any d.c. motors connected to the system. These fuses are a specific type to allow for motor surge capability.

d.c.-coupled systems with a.c. and d.c. loads (refer to Figure 36) where the battery inverter has an inbuilt controller then there will be only one set of cables between the battery inverter and bank.

The protection device for the battery cable to an inverter will be determined via the process defined in Section 18.10.

18.9. Battery Cable Protection: a.c.-coupled systems

Systems with an a.c.-coupled configuration (refer to Figure 37) 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 18.10.

18.10. 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:

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

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 d.c. 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 d.c.-coupled system). These smaller would be placed on the output side of the main battery disconnection device and in the circuit for d.c. cable to the solar controller.

For d.c.-coupled systems where the inverter protection is being used for the main battery protection and there are d.c. 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 d.c. loads being supplied by the solar controller.

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

18.11. Surge Protection Requirements

PV array cable, particularly if there is a risk of a surge, either direct or indirect, in any of the cables within the system then consideration should be given to the installation of appropriate Surge Protection Devices (SPD) to protect the associated equipment.

Cables where surge risk is possible:

- if the cable between the array and controller or PV inverter is buried undergrounds.
- a.c. load cable from battery inverter, particularly if this cable is buried underground.

Either type I SPD's or type II SPD's or a combination of both could be installed.

18.12. Residual Current Devices (RCD) for a.c loads.

Consideration should be given to installing Type B Residual Current Devices (RCDs) in an off-grid PV system that includes a battery inverter a.c. providing a.c. loads. These should be installed in an appropriate switchboard at the site however at times these might need to be installed in the a.c. load cable from the battery inverter.

19. Disconnection (Isolation) Requirements within an Off-Grid Solar Energy System

Switch disconnectors are load breaking devices and are 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 d.c. switch disconnector located near the MPPT controller when the array maximum voltage is LV; and
- A PV array d.c. switch disconnector located near the PV inverter (a.c.-coupled).

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

It is recommended that a PV array d.c. switch disconnector is 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 d.c. loads being supplied directly by the system.

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

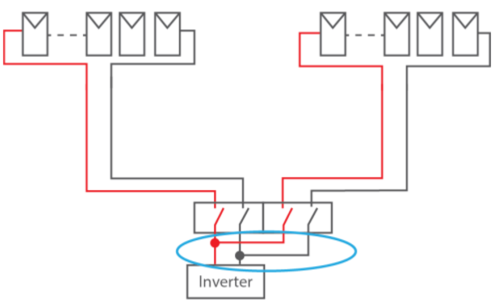
19.1. Disconnection Requirements Within an Array

- 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 they must 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 d.c. Switch Disconnector near PV Inverter and MPPT (if array maximum voltage is >100 V d.c.)

- A PV array switch-disconnector/s shall be installed adjacent to the PV inverter and/or MPPT (if Maximum PV voltage is >100 V d.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 MPPTs 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 is more than one isolator, they shall be individually labelled e.g. "PV Array D.C. isolator inverter 1" and "MPPT A" or "MPPT 1"
- Where strings are paralleled at the PV inverter or MPPT, this is recommended to occur on the PV inverter or MPPT side of the disconnection device or in the PV inverter/MPPT itself as shown in Figure 32.

FIGURE 32: PARALLELING STRINGS ON INVERTER/MPPT SIDE OF PV ARRAY DISCONNECTOR DEVICES



Note: In Figure 32 the inverter could also be a MPPT.

- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP56.
- 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 the risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of Section 23.

19.3. PV Array d.c. Switch Disconnector near PWM Solar Controller

For systems where battery voltage is less than 100 V d.c. 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 is more than one isolator, they shall be individually labelled e.g. "PV Array d.c. isolator Solar Controller 1."
- Where the switch-disconnector is exposed to the weather it shall have an IP rating of at least IP56.
- 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 the risk of water ingress.
- PV array switch-disconnectors shall meet the requirements of Section 23.

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 d.c.-coupled systems with d.c. loads only then the only isolation requirement is for the solar controller.
- For d.c.-coupled systems with a.c. loads then two isolating devices are required:
    - One for the solar controller
    - One for the battery inverter.
- For a.c.-coupled systems with a.c. 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 d.c. 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.
- Battery switch-disconnectors shall meet the requirements of Section 23.

19.5. Load Disconnection Requirements

- All d.c. and a.c. load circuits shall be capable of being isolated.
- For d.c. loads this could be performed by the controller and for d.c. only systems this could be the battery switch disconnector. However, it is recommended that a separate d.c. switch disconnector is located in the load output cables from the solar controller.
- For d.c.-coupled systems with a.c. loads, a.c. switch disconnectors should be located in the output cables from the battery inverter unless there is an a.c. switch disconnector included on the inverter.
- For a.c.-coupled systems, a.c. switch disconnectors should be located in the output cables from
    - a battery inverter,
    - a PV inverter.
- d.c. load switch disconnectors shall meet the requirements of Section 23.
- a.c. load switch disconnectors shall meet the standard requirements for a.c. 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.

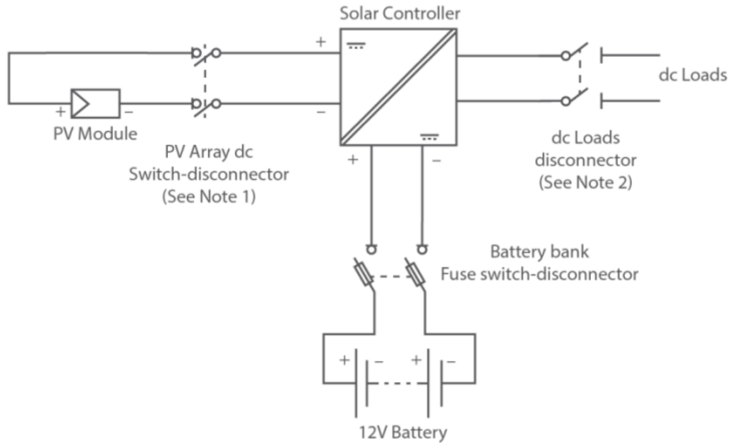
20. Location of Protection and Isolation (Disconnection) in an Off-Grid Solar Energy System

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

Figures 33, 34, 35, 36 and 37 show the typical protection and isolation (switch-disconnection) requirements in d.c.-coupled and a.c.-coupled systems.

The figures show switch-disconnectors, if circuit breakers are used, then they should be suitably rated non-polarised d.c. circuit breakers. Some a.c. circuit breakers do have a small d.c. voltage rating however many do not and should not be used unless they have the appropriate d.c. voltage rating.

FIGURE 33: D.C.-COUPLED: SIMPLE D.C. ONLY SYSTEM (TYPICAL FOR RURAL RESIDENCES)

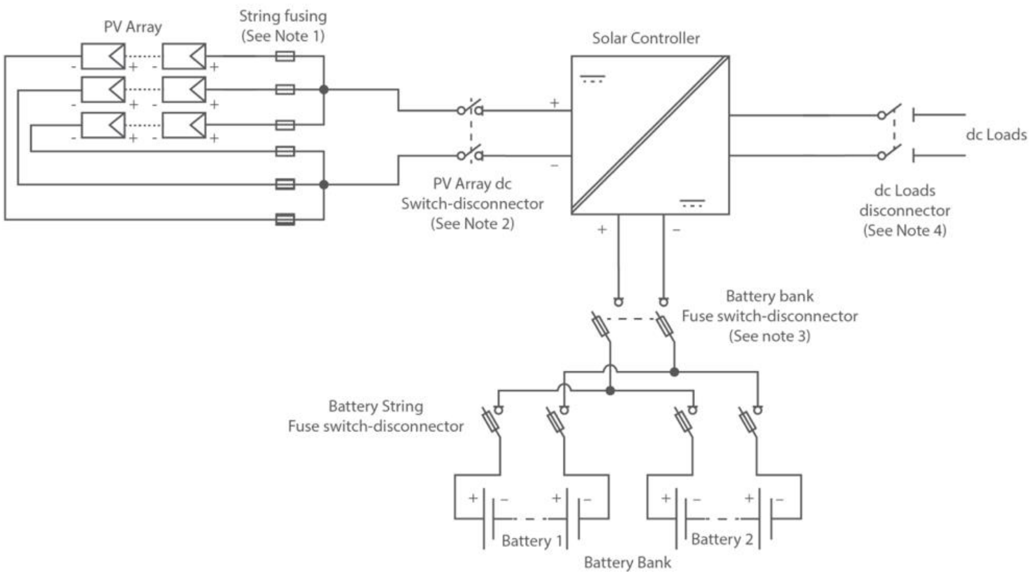


Notes:

1. A PV array d.c. 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 d.c. 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 d.c. 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 d.c. circuit breaker) if the battery bank fuse ratings are greater than the current-carrying capability of the load cables.

FIGURE 34: D.C.-COUPLED SYSTEM: LARGE D.C.-ONLY SYSTEM



Notes:

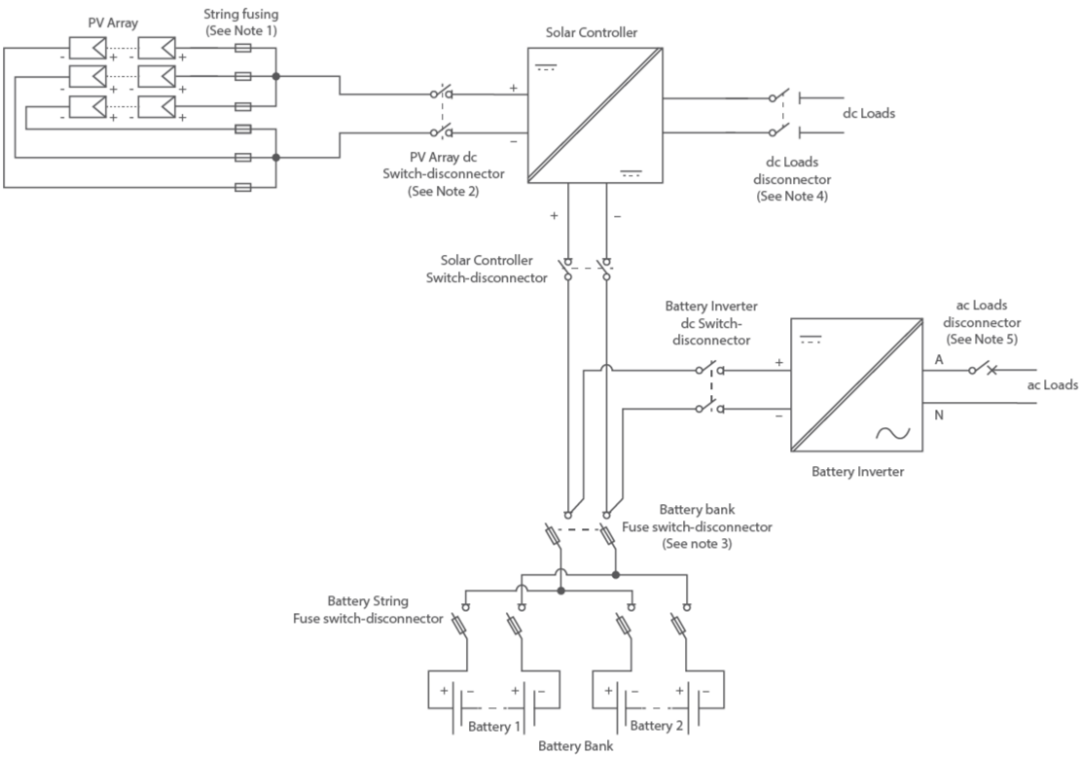
1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer to Section 18.1).

2. The PV array d.c. 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 d.c. 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 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 d.c. 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 d.c. circuit breaker) if the battery bank fuse ratings are greater than the current-carrying capability of the load cables.

FIGURE 35: D.C.-COUPLED SYSTEM WITH D.C. AND A.C. LOADS



Notes:

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

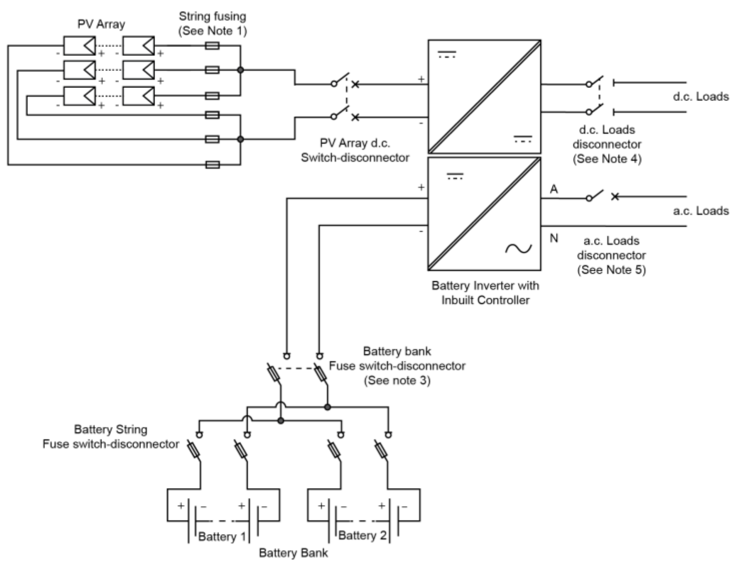
2. The PV array d.c. switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required as a protection device (e.g. a non-polarised d.c. circuit 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 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 generally be different cross-sectional areas (or gauges).

4. The loads d.c. 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 d.c. circuit breaker) if the battery bank fuse ratings are greater than the current-carrying capability of the load cables.

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

FIGURE 36: D.C.-COUPLED SYSTEM WITH D.C. AND A.C. LOADS (BATTERY INVERTER WITH INBUILT SOLAR CONTROLLER)



Notes:

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

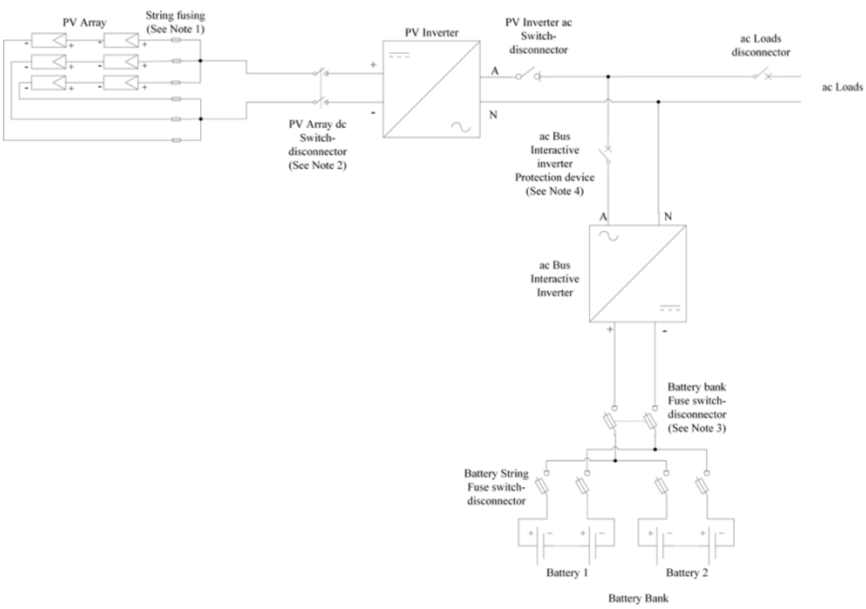
2. The PV array d.c. switch disconnector is recommended because it helps with maintenance and troubleshooting although many standards allow the battery bank switch fuse to meet the isolation requirement. The switch disconnector will be required as a protection device (e.g. a non-polarised d.c. circuit 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 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 generally be different cross-sectional areas (or gauges)

4. The loads d.c. 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 d.c. circuit breaker) if the battery bank fuse ratings are greater than the current-carrying capability of the load cables.

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

FIGURE 37: A.C.-COUPLED SYSTEM WITH A.C. LOADS



Notes:

1. String fusing is required if the potential fault current is greater than the reverse current rating of the PV module. (Refer to Section 18.1).
2. A PV array d.c. switch disconnector is required but it can be part of the inverter (refer to Section 19.2).
3. Batteries in parallel each require their 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 a.c.-coupled interactive inverter disconnector device is required if the battery inverter does not have a switch disconnector on the a.c. output. This will be required to be a protection device (e.g. a.c. circuit breaker) for protecting the a.c. load cable.

21. Earthing (Grounding) of Array Frames for a PV Array with Maximum Voltage Greater than 100 V d.c. (including a.c. 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 100V d.c. or when a.c. modules or microinverters with LV outputs are installed.
- Minimum cable size of 6 mm^2. If required for lightning protection, then it should be a minimum of 16 mm^2.
- 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 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 close proximity to the PV array cable (both positive and negative), the inverter and then inverter a.c. cables going to the switchboard or distribution board.
- The earthing/grounding conductor from the PV array can connect to the inverter's main earth conductor in the a.c. output cable provided the following conditions are met:
    - Installation is not subject to lightning
    - Inverter a.c. earth is of an appropriate size
- Earth cable cannot pass through a tile or steel roof without additional mechanical protection (conduit). The same conduit used for PV array cable can also be used for the earth cable.
- All earthing cables will be connected to the same earth earthing point. If multiple grounding points are used, all ground points will be connected with an earthing cable.

22. PV Fuse Requirements

Fuses used in PV arrays shall —

- be rated for d.c. use;
- have a voltage rating equal to or greater than the PV array maximum voltage determined in Section 2.2;
- be rated to interrupt fault currents from the PV array; and
- be of an overcurrent and short circuit current protective type suitable for PV
- complying with IEC 60269-6 (i.e. Type gPV) or the equivalent through the NEC.

23. d.c. Switch Disconnector Requirements

d.c. switch-disconnectors shall:

- be rated for d.c. 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-PV2 (as per IEC 60947-3)

- For PV array switch connectors (when installed), the switch disconnectors shall have voltage ratings as follows:
- For PWM controller and separated MPPT controllers: the sum of the voltage rating of both poles together of the switch-disconnector shall be at least the PV array maximum voltage (Voc of the array adjusted for the lowest ambient temperature at the site)
- 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 (Voc of the array adjusted for the lowest ambient temperature at the 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 (Voc of the array adjusted for the lowest ambient temperature at the 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 (Voc of the array adjusted for the lowest ambient temperature at the 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.

24. Plugs, Sockets and Connectors

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; and
- 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.

25. Shutdown Procedure

- A shutdown procedure is required to ensure the 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 d.c. 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 A.C. loads and also D.C. loads; and
- Isolation of the battery bank by disconnecting battery fuses or opening battery circuit breakers.

For SES where the battery comprises a maximum of four monobloc batteries in series string and a maximum of 4 parallel battery strings, the shutdown procedure shall require the system to be shut down in the following order:

1. Isolation of PV input either via separate isolator on array cable, switch at the controller or removing cables from the controller
2. Isolation of the d.c. loads either via separate isolator on array cable, switch at the controller or removing cables from the controller
3. Isolation of the a.c. loads by turning off separate isolator in a.c. load cables at a switchboard (distribution board) or inverter
4. If possible, isolation of the battery bank by disconnecting battery fuses or opening battery circuit breakers.

26. Metering

As a minimum each system should have meters showing:

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

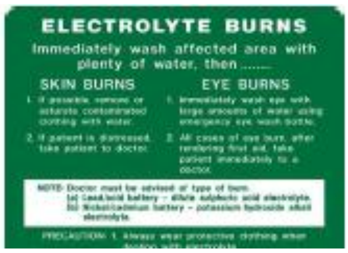
Note: This is not a requirement for SES where the battery comprises a maximum of four monobloc batteries in series string and a maximum of four parallel battery strings

27. Signage

- All battery systems that can emit explosive gases shall have a "No Smoking, No Spark, No Flames" Warning sign. (Example provided in Figure 38).
- All battery systems that contain chemicals that could burn the eyes or skin shall have a warning sign prominently displayed. (Example provided in Figure 39).
- All disconnectors shall be labelled and where there is more than one, numbered. For example:
    - Battery d.c. disconnector 1
    - Battery d.c. disconnector 2
    - PV array d.c. disconnector
    - Solar controller d.c. disconnector
    - d.c. load disconnector
    - a.c. load disconnector 1
    - a.c. load disconnector 2
    - a.c. 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 d.c. supply and if >100 V d.c. then a prominent sign should warn of hazardous voltages.

FIGURE 38: EXAMPLE OF RISK OF BATTERY EXPLOSION WARNING SIGN

FIGURE 39: ELECTROLYTE BURNS SIGN



28. Commissioning

The installer should complete the commissioning sheets provided with these guidelines (Annex 2 and Annex 3). 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.

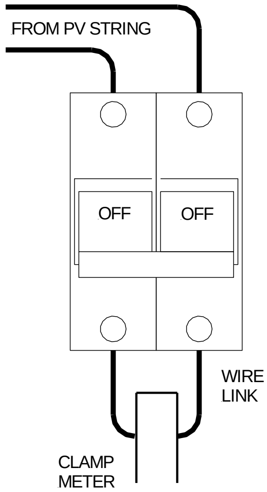
28.1. PV Array Short Circuit Current Measurement for arrays with maximum voltage greater than 100 V d.c.

Where short circuit currents are required to be measured, undertake the following steps to measure the short circuit current safely, as shown in Figure 40.

- Ensure each string fuse (where required) is not connected or that any array is disconnected somewhere in each string, as shown in Figure 14 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 14) to complete the string wiring. Turn on the PV array switch disconnector and use a d.c. clamp meter to measure the d.c. 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 40: MEASURING SHORT CIRCUIT CURRENT



28.2. PV Array Insulation Resistance Measurement

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

This test is required for all arrays where the maximum array voltage is greater than 100 V d.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 the earth and PV array negative connection. Test leads should be made secure before carrying out the test. The values of insulation resistance shall be recorded. Table 6 shows the minimum values that should be achieved for different array voltages.

TABLE 6: MINIMUM INSULATION RESISTANCE

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

29. 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 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

PART 2-HYBRID SYSTEMS

30. Installation of Hybrid Systems

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

How the fuelled generator interconnects within the hybrid system depends on the type of inverter, the load characteristics and the size of the system. Figure 41 to Figure 44 show typical configurations for PV/fuelled generator hybrid systems.

FIGURE 41: FUELLED GENERATOR CONNECTED TO BOTH THE BATTERY (VIA A BATTERY CHARGER) AND THE LOADS (VIA A CHANGEOVER SWITCH)

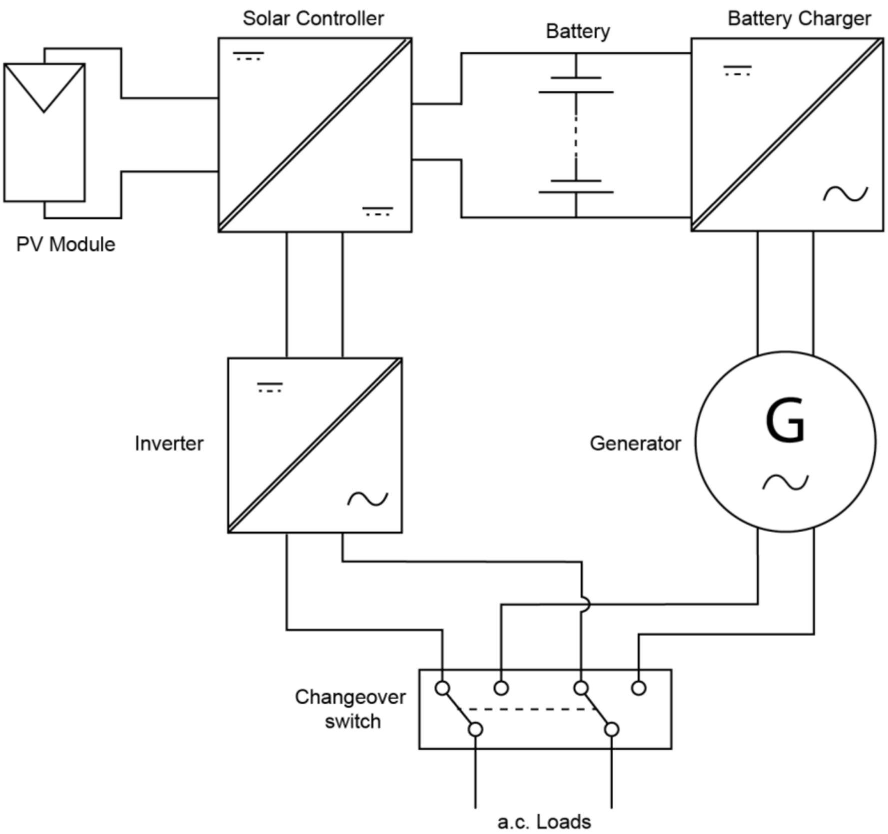


FIGURE 42: FUELLED GENERATOR CONNECTED TO AN INVERTER/CHARGER OR AN INTERACTIVE D.C.-COUPLED INVERTER CONNECTING AS A D.C.-COUPLED SYSTEM.

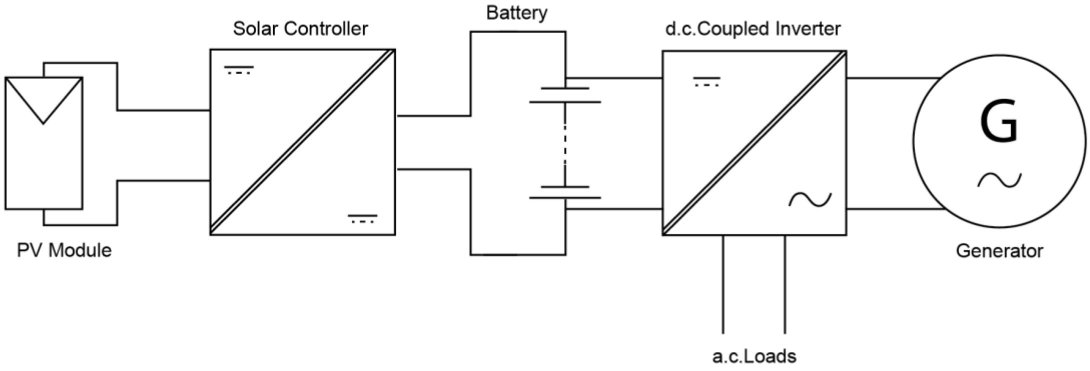


FIGURE 43: GENERATOR CONNECTED TO AN A.C.-COUPLED INVERTER CONNECTING AS AN A.C.-COUPLED SYSTEM

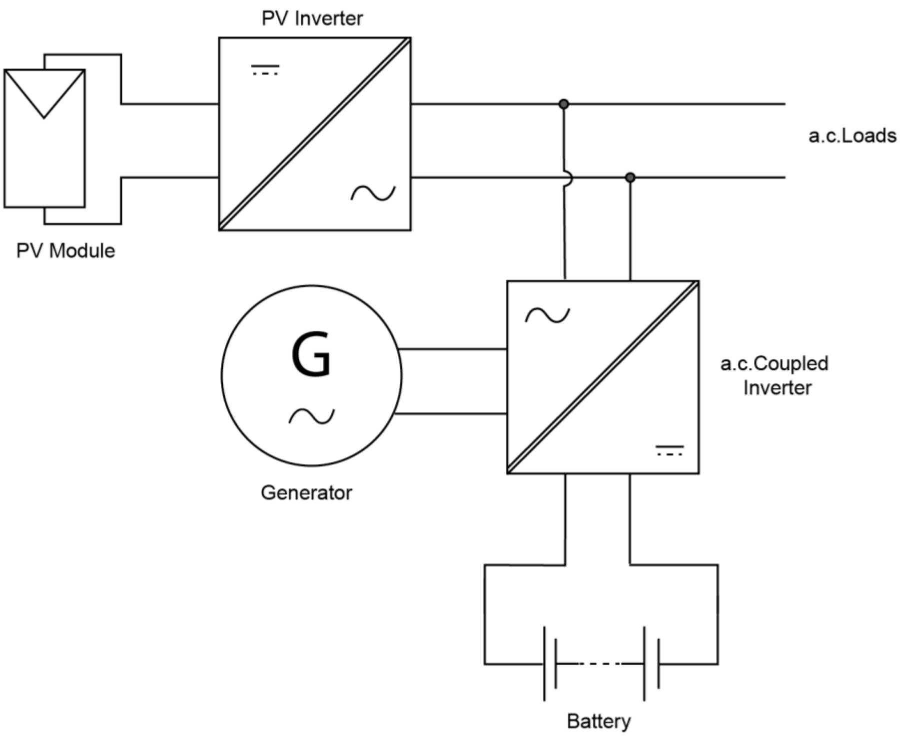
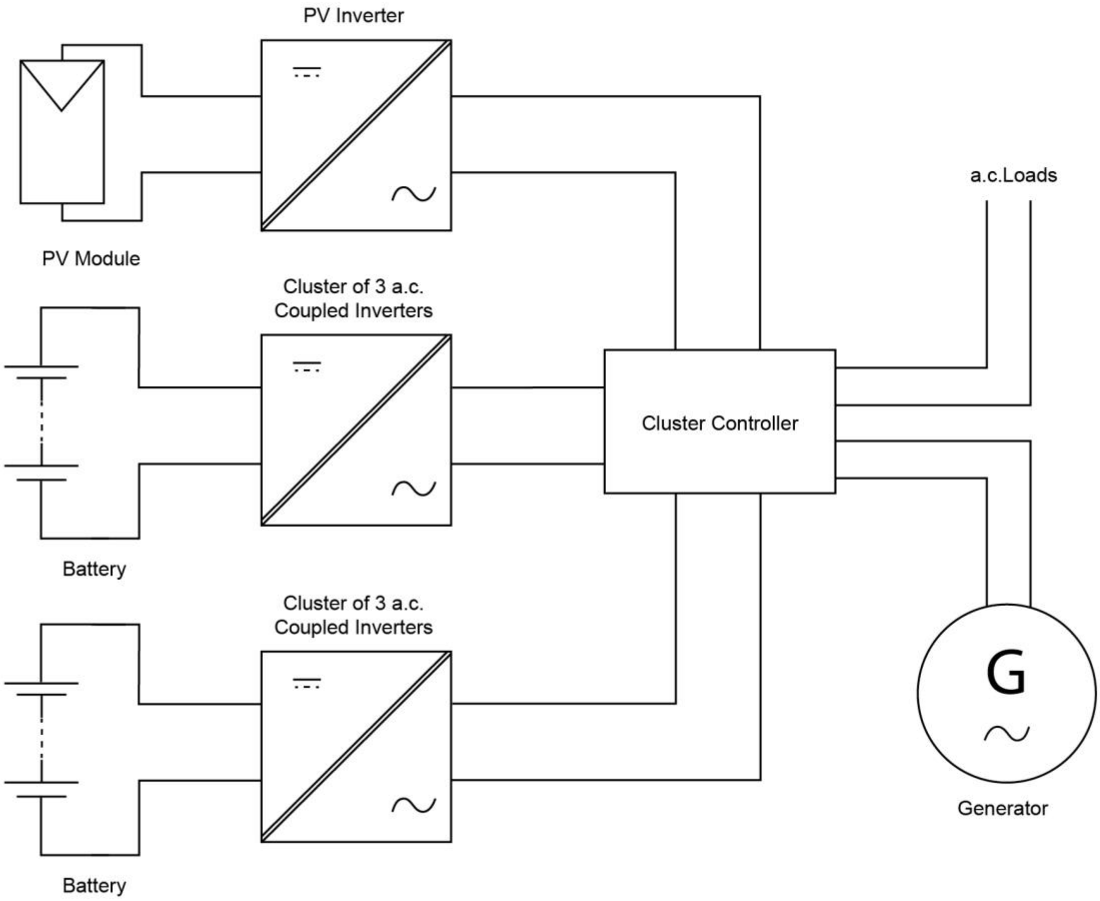


FIGURE 44: A.C.-COUPLED SYSTEM WITH MULTIPLE INVERTERS CONNECTED TO A CLUSTER CONTROLLER WITH THE GENERATOR CONNECTED TO IT.



Certain models of a.c.-coupled interactive inverters require a cluster controller or cluster box for interconnecting the multiple a.c. generating devices. These are generally required when numerous clusters of a.c-coupled inverters are parallel. Each cluster comprises three single-phase inverters providing 3-phase power.

The manufacturer of the a.c.-coupled inverter provides the cluster controller (or box), and the installer shall follow the manufacturer's installation requirements. Note that Figure 44 shows the PV inverter connected to the cluster controller. The PV inverter can also be connected directly to the a.c. load line and the PV systems do not need to be located in the same location as the rest of the system (battery, a.c.-coupled inverters, cluster control and generator)

30.1. Array Installation

Refer to Section 2 for the installation of PV arrays. Depending on the size of the PV array with the hybrid system, the PV array may be broken into many sections, each with its separate solar controller and/or PV inverter.

30.2. Solar Controller and/or PV Inverter Installation

Refer to Section 4 for installing solar controllers and Section 5 for installing PV inverters.

Suppose the PV array installation does include multiple solar controllers. In that case, the number of controllers in parallel shall not be greater than that recommended by the manufacturer. The relevant intercommunications wiring shall be installed so that the controllers operate together.

30.3. Battery Installation

Refer to Section 3 for installing battery banks and the ventilation requirements.

In larger hybrid systems comprising multi-cluster inverters, the system may consist of several individual battery banks, each connected to their cluster of battery inverters and PV arrays.

30.4. Battery Inverter Installation

Refer to Section 6 for the installation of the battery inverters.

In small hybrid systems made up of inverter/chargers and d.c.- or a.c.-coupled inverters, the fuelled generator will be electrically connected to the inverter along with communication/control cables to allow the inverter to stop/start the generator.

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

Some system configurations may require the inverters' electrical outputs to interconnect through a cluster control box (refer to Figure 44); this is where the generator will also be electrically connected.

30.5. Battery Charger Installation

If the hybrid system includes a separate battery charger:

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

- Battery chargers are not to be installed in direct sunlight.

30.6. Generator Installation

- The generator should be installed in a separate room or shed that only contains the generator and ancillary equipment such as its controller, fuel tank, etc.
- The generator enclosure should be lockable to protect against tampering, theft or accidental contact by unauthorised persons.
- The foundation supporting the generator is generally a concrete slab that is reinforced and capable of supporting 125% of the pressure exerted by the generator, including fuel, and typically between one and two times the mass of the overall Genset.
- The location must be easy to access, and cable distances to other components are minimised while still being far enough away from dwellings to avoid annoyance to residents due to noise and exhaust fumes.

Combustion and Cooling Air Supply: Air is essential both for the combustion of fuel in the engine and the cooling of the equipment. As a rule of thumb, cooling requires six to eight times as much air as combustion. Air intake and exhaust vents should be located to permit smooth airflow over the set. The air should be as cool as possible when it reaches the air cleaner. In excessively dusty conditions, additional intake filtration may be required. To minimise the ingress of dust and dirt, cooling fans/vents should not face the predominant wind directions.

Fuel Supply: Depending on the size of the generator, the fuel tank may be a small gravity feed unit, a base mounted unit, an external day tank or an underground tank. Fuel storage may be subject to local regulations or standards, so installers must check with the relevant government department. Generally, this will mean storage is kept away from potential sources of ignition (including the generator and its associated electrical equipment), and provision of bunding or other means of containing a spill from the primary storage vessel is usually required. Warning signs and access control provisions will almost certainly be required with their content depending on the quantity of fuel stored and the type of storage installed.

Exhaust: If the flow of exhaust gases is restricted, back pressure will reduce the engine's power output. The exhaust pipe should be of adequate diameter for its length, and if bends are to be included, they should be of a long radius. Suppose the exhaust pipe is mounted to a fixed structure. In that case, a flexible fitting must be included to isolate it from engine vibration and provide for dimensional changes due to temperature changes. Because heat reduces an engine’s efficiency, exhaust components adjacent to the generator should be lagged with heat-resistant insulating material to reduce heating engine components.

Mechanical and Exhaust Noise: Noise from the generator includes general mechanical noise and noise from the exhaust. To attenuate mechanical noise, it will be necessary to insulate the interior of the generator room with a sound retardant material. It is common to fit noise attenuating louvres to the air intakes and outlets. Exhaust noise can be lessened by fitting a silencer or muffler. The attenuation degree depends on the silencer's quality (and cost). The direction in which exhaust is discharged will also affect noise levels.

Generator Starting Battery System: The starting battery must have sufficient capacity to crank the engine under cold start conditions and to attempt multiple starts if required. An auxiliary battery charger must be installed if the generator is not guaranteed to run for 4 to 6 hours at least once weekly.

Ancillary Electrical Equipment: A licensed electrician must carry out Electrical installation work. A circuit breaker will be required for the a.c. outputs and appropriate instruments should be fitted.

Cabling: Cabling should be supported, protected from the damage of all types (including vermin, temperature, fuel and lubricants, external influences etc.) and installed per relevant local rules or international standards from the IEC. Particular attention should be paid to including an anti-vibration loop between where the cable is secured to the generator and where it is secured to the remainder of the installation.

30.7. PV Array Wiring

Refer to Sections 7, 8 and 9 for the safe wiring installation practices (Section 7), the wiring of the PV array (Section 8) and the installation of combiner boxes (Section 9).

30.8. Battery Cabling

Refer to Sections 11, 12 and 13 for installing cables between the battery and solar controllers (Sections 11 and 12) and battery inverters (Section 13). Refer to Section 14 for the installation of wiring in parallel bank strings.

30.9. Voltage Drop

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

Refer to Section 16 for the formulas for determining voltage drop and the recommended voltage drops for the rest of the hybrid system.

30.10. Protection Requirements

A suitably rated circuit breaker shall protect the cable between the generator and the hybrid system.

Refer to Section 18 for the protection requirements for the rest of the hybrid system.

30.11. Disconnection (isolation) Requirements

The generator shall be capable of being isolated from the rest of the hybrid system by a load-breaking disconnection device. The circuit breaker mentioned in Section 30.10 can meet this requirement.

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

Refer to Section 19 for the disconnection (isolation) requirements for the rest of the hybrid system.

30.12. Earthing (Grounding)

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

Refer to Section 21 for the earthing (grounding) requirements for the rest of the hybrid system.

30.13. Shutdown Procedure

The system shutdown procedure should include the process for shutting down the generator.

Refer to Section 25 for the shutdown procedure for the rest of the hybrid system.

30.14. Signage

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

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

30.15. Commissioning

Commissioning of the system shall include:

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

Refer to Section 28 for the commissioning requirements for the rest of the hybrid system.

30.16. Documentation

All manuals related to the generator and a service book for maintenance should be included with the system documentation provided to the client. Refer to Section 29 for the documentation requirements for the rest of the hybrid system.

Annexe 1: Ingress Protection

Ingress Protection (IP) is defined in IEC 60529 Ingress Protection Code classifies and rates the degree of protection provided by enclosures against the ingress of solid particles and water. It is a two-digit code.

The first number (digit) indicates the level of protection that the enclosure provides against access to hazardous parts (e.g., electrical conductors, moving parts) and the ingress of solid foreign objects. The second number (digit) indicates the level of protection that the enclosure provides against harmful water ingress. Details are presented in Tables 7 and 8. A summary of IP requirements is shown in Table 9.

TABLE 7: FIRST NUMBER IN IP CODE

Level sized	Effective against	Description
X		Means there is no data available to specify a protection rating with regard to this criterion.
0	—	No protection against contact and ingress of objects
1	>50 mm 2.0 in	Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part
2	>12.5 mm 0.49 in	Fingers or similar objects
3	>2.5 mm 0.098 in	Tools, thick wires, etc.
4	>1 mm 0.039 in	Most wires, slender screws, large ants etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment.
6	Dust-tight	No ingress of dust; complete protection against contact (dust-tight). A vacuum must be applied. Test duration of up to 8 hours based on airflow.

TABLE 8: SECOND NUMBER IN IP CODE

Level	Protection against	Effective against	Details
X	—	—	X means there is no data available to specify a protection rating with regard to these criteria.
0	None	—	No protection against ingress of water
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect on the specimen when mounted in an upright position onto a turntable and rotated at 1 RPM.	Test duration: 10 minutes Water equivalent to 1 mm (0.039 in) rainfall per minute
2	Dripping water when tilted at 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle of 15° from its normal position. A total of four positions are tested within two axes.	Test duration: 2.5 minutes for every direction of tilt (10 minutes total) Water equivalent to 3 mm (0.12 in) rainfall per minute
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with a counterbalanced shield. Test a) is conducted for 5 minutes, then repeated with the specimen rotated horizontally by 90° for the second 5-minute test. Test b) is conducted (with shield in place) for 5 minutes minimum.	For a spray nozzle: Test duration: 1 minute per square meter for at least 5 minutes[6] Water volume: 10 liters per minute (0.037 impgal/s) Pressure: 50–150 kPa (7.3–21.8 psi) For an oscillating tube: Test duration: 10 minutes Water volume: 0.07 liters per minute (0.00026 impgal/s) per hole
4	Splashing of water	Water splashing against the enclosure from any direction	Oscillating tube: Test duration: 10 minutes, or spray nozzle (same

		shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with no shield. Test a) is conducted for 10 minutes. b) is conducted (without shield) for 5 minutes minimum.	as IPX3 spray nozzle with the shield removed)
5	Water jets	Water projected by a nozzle (6.3 mm (0.25 in)) against enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes Water volume: 12.5 litres per minute Pressure: 30 kPa (4.4 psi) at distance of 3 meters (9.8 ft)
6	Powerful water jets	Water projected in powerful jets (12.5 mm (0.49 in)) against the enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes Water volume: 100 liters per minute (0.37 impgal/s) Pressure: 100 kPa (15 psi) at distance of 3 meters (9.8 ft)
6K	Powerful water jets with increased pressure	Water projected in powerful jets (6.3 mm (0.25 in) nozzle) against the enclosure from any direction, under elevated pressure, shall have no harmful effects. Found in DIN 40050, and not IEC 60529.	Test duration: at least 3 minutes [citation needed] Water volume: 75 liters per minute (0.27 impgal/s) Pressure: 1,000 kPa (150 psi) at distance of 3 meters (9.8 ft)
7	Immersion, up to 1 meter (3 ft 3 in) depth	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 meter (3 ft 3 in) of submersion).	Test duration: 30 minutes.[4] Tested with the lowest point of the enclosure 1,000 mm (39 in) below the surface of the water, or the highest point 150 mm (5.9 in) below the surface, whichever is deeper.

8	Immersion, 1 meter (3 ft 3 in) or more depth	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects. The test depth and duration are expected to be greater than the requirements for IPx7, and other environmental effects may be added, such as temperature cycling before immersion.	Test duration: agreement with manufacturer Depth specified by the manufacturer, generally up to 3 meters (9.8 ft)
9K	Powerful high-temperature water jets	Protected against close-range high pressure, high-temperature spray downs. Smaller specimens rotate slowly on a turntable, from 4 specific angles. Larger specimens are mounted in the intended position when being used, no turntable required, and are tested freehand for at least 3 minutes at a distance of 0.15–0.2 meters (5.9 in–7.9 in). The specific requirements for the test nozzle are shown in figures 7, 8, & 9 of IEC (or EN) 60529. This test is identified as IPx9 in IEC 60529.	Test duration: Fixture: 30 sec. in each of 4 angles (2 min. total), Freehand: 1 min/m², 3 min. minimum Water volume: 14–16 liters per minute (0.051–0.059 impgal/s) Pressure: 8–10 MPa (80–100 bar) at distance of 0.10–0.15 meters (3.9 in–5.9 in) Water temperature: 80 °C (176 °F)

Source for the tables: https://en.wikipedia.org/wiki/IP_Code

TABLE 9: SUMMARY OF IP REQUIREMENTS FOR COMPONENTS IN OFF-GRID POWER SYSTEM

Component	IP Requirement	Comment
Solar Controller	IP54	If mounted outside
PV Inverter	IP54	If mounted outside
Battery Inverter	IP54	If mounted outside
Battery Charger	IP54	If mounted outside
Combiner Boxes	IP54	If mounted outside
PV Array Switch disconnector	IP56	If exposed to the weather
Battery Bank disconenction device	IP56	If exposed to the weather
Cable connector	IP65	Minimum rating

If the site experiences tropical rainstorms, it should be considered to use an IP rating of IP55 or IP56 for those items listed as IP54 if they are located outside.

Annexe 2: Installation and Commissioning Sample: Solar Energy System with Maximum Four(4) Batteries in a Series String and Four (4) Battery Strings in Parallel

This is a sample for a small system.

Installers name:	
Installers signature:	
Testing and Commissioning date:	
System Location	
Equipment Data	
PV module manufacturer:	
PV module model number:	
PV module peak power rating:	W_p
PV Module rated short circuit current (I_{sc})	A
PV Module rated maximum power current (I_{mp})	A
PV Module rated open circuit voltage (V_{oc})	V
PV Module rated maximum power voltage (V_{mp})	V
Total Number of Modules	
Number of modules in a series string	
Number of module strings in parallel	
Battery manufacturer:	
Battery model:	
Individual Battery Voltage	V
Individual Battery Capacity	Ah
Total Number of batteries	
Total Capacity of Battery bank	Ah

System d.c. voltage	V
Number of batteries in a string	
Number of parallel strings of batteries	
Solar controller manufacturer	
Solar controller model	
Type of controller-PWM or MPPT?	
Solar controller input and output current rating.	A
Solar controller input voltage setting or range	V
Solar controller output voltage setting	V
Inverter manufacturer	
Inverter model	
Inverter Input current ratings	A
Inverter Input d.c. voltage rating	V
Inverter Power Rating	W or VA
Complete this section on switch disconnection and protection devices if applicable	
PV array Switch disconnector manufacturer	
PV array Switch disconnector model	
PV array Switch disconnector current rating	A
PV array Switch disconnector voltage rating	V
Solar battery fuse or circuit breaker current rating	A
Solar battery fuse or circuit breaker voltage rating	V
Inverter battery fuse or circuit breaker current rating (if there are a separate fuse for inverter and solar)	A
Inverter battery fuse voltage Rating (if there are a separate fuse for inverter and solar)	V

Testing of System (the following is to be undertaken before turning the system on)		
Solar Irradiance at same angle of solar module (if possible)	W/m²	
Module No 1: I_{sc}	A	
Module No 1: V_{oc}	V	
Module No 2: I_{sc}	A	
Module No 2: V_{oc}	V	
Continuity between PV array, d.c. switch-disconnector (if applicable) and controller:		
Array Positive (Tick if correct)		
Array Negative (Tick if correct)		
Correct polarity between PV array and solar controller		
Continuity between controller, protection device (if applicable) and battery		
Battery Positive (Tick if correct)		
Battery Negative (Tick if correct)		
Correct polarity between controller and battery		
Continuity between battery, protection device 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 d.c. loads (This could be expanded if testing d.c. circuits if they have been installed as part of system installation)		
Solar Array Strings Cables		
Cross Sectional Area of string cables		mm²

Current Carry Capacity of string cables	A
Maximum current from string	A
Maximum length of string cables	m
Maximum voltage drop in string cables	V
String V_{mp} (MPPT or PV Inverter) or battery voltage (PWM)	V
Maximum voltage drop (string cables) as %	%
Array String Cables	
Cross Sectional Area of array cable	mm^2
Current Carry Capacity of array cable	A
Maximum current on from array	A
Maximum length of array cable	m
Maximum voltage Drop in Array able	V
Array V_{mp} (MPPT or PV Inverter) or Battery Voltage (PWM)	V
Maximum voltage drop (array cables) as %	%
Total maximum voltage drop- array to MPPT or PV Inverter as % array Note: not relevant for PWM controller-required % is from array to battery	%
Controller to Battery Cable	
Cross Sectional Area of controller to battery cable	mm^2
Current Carry Capacity of controller to battery cable	A
Maximum current from the controller to/from battery	A
Maximum length of controller to battery cable	m
Maximum voltage drop in controller to battery Cable	V
Battery Voltage	V
Maximum voltage drop (controller to battery cable) as %	%
Total maximum voltage drop -array to battery (array cables) as % battery voltage (PWM controller)	%
Battery to Inverter Cable	

Cross Section Area of battery to inverter cable	mm^2
Current Carry Capacity of battery to inverter cable	A
Maximum Current on from/to battery to inverter	A
Maximum Length of battery to inverter cable	m
Battery Voltage	V
Maximum voltage drop (battery to inverter cable) as %	%
Note the above is just an example of voltage drop for the d.c. side of the system. Voltage drop on a.c. side might also need to be determined if required also voltage drop on d.c. cable from controller to loads might also need to determined.	
Battery Voltage at Terminals	V
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	
Turn System On - including d.c. loads	
Array voltage at Controller input	V
Array current	A
Battery voltage at controller	V
Voltage at furthest d.c. load (array turned off)	V
Solar charging the batteries	
Controller operating correctly (Tick if correct)	
Inverter operating correctly (Tick if correct)	
d.c. loads operating correctly (Tick if correct)	

Annexe 3: Installation and Commissioning Sample: Hybrid System

Installers name:	
Installers signature:	
Testing and Commissioning date:	
System Location	
Equipment Data	
PV module manufacturer:	
PV module model number:	
PV module peak power rating:	W_p
PV Module rated short circuit current (I_{sc})	A
PV Module rated maximum power current (I_{mp})	A
PV Module rated open circuit voltage (V_{oc})	V
PV Module rated maximum power voltage (V_{mp})	V
Number of Modules:	
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
a.c. systems 3 phase or 1 phase	
Battery Inverter manufacturer	

Battery Inverter model	
Battery Inverter Input current ratings	A
Inverter Input d.c. voltage rating	V
Inverter Power Rating	W or VA
Generator Manufacturer	
Generator Model	
Generator Power Rating	W or VA
PV array Switch disconnector manufacturer	
PV Array Switch disconnector model	
PV Array Switch disconnector current rating	A
PV Array 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 separate fuses for inverter and solar)	A
Inverter battery fuse voltage Rating (if there are separate fuses for inverter and solar)	V
Generator a.c. Circuit Breaker Rating	
Testing of System (System Not on Yet)	
Solar Irradiance at same angle of solar module	W/m^2
Module No 1: Isc	A
Module No 1: V_{oc}	V
Module No 2: Isc	A
Module No 2: V_{oc}	V
Continuity between PV array, d.c. 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 d.c. loads (This could be expanded if testing d.c. circuits if they have been installed as part of system installation)	
Solar Array String Cables	
Cross Sectional Area of string cables	mm^2
Current Carry Capacity of string cables	A
Maximum current from string	A
Maximum length of string cables	m
Maximum voltage drop in string cables	V
String V_{mp} (MPPT or PV Inverter) or battery voltage (PWM)	V
Maximum voltage drop (string cables) as %	%
Array String Cables	
Cross Sectional Area of array cable	mm^2
Current Carry Capacity of array cable	A
Maximum current on from array	A

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