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PV Mini-Grid Installation
Dos & Don'ts

PV MINI-GRID INSTALLATION

Dos & Don’ts

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PV MINI-GRID INSTALLATION
Dos & Don’ts

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ABOUT THE GUIDELINE

In recent years, off-grid solar power plants (PV mini-grid systems) have played an important role in increasing the electrification ratio in rural areas in Indonesia. Over a period of more than six years, several private and government institutions, especially the Directorate General of New and Renewable Energy (DG NREEC) have made efforts to improve the quality and reliability of the PV mini-grid system that have been built. This can be seen from the results of technical inspections carried out by EnDev during the period 2013 - 2015. Based on the results of inspections at more than 300 PV mini-grid locations, valuable information has been obtained in the form of a collection of photos related to installation quality and system performance that are worthy of sharing as material. evaluation in order to improve or improve the off-grid PV mini-grid installation in the future. With the existence of examples of good and bad installations, repetition of the same errors can be avoided, and examples of good installations can be used as a reference so that system and user security is guaranteed. With a good system installation, PV mini-grid will be more reliable, increase component life, operate efficiently with a lower risk of damage.

Purpose

This installation practice manual was written as a recommendation to improve and standardize the quality of existing and planned off-grid PV mini-grid installations. The book, which is dominated by good and bad installation photos, is expected to be a lesson learned and a source of reference for stakeholders, especially in the process of installation, design, inspection, and operation and maintenance of off grid PV mini-grids.

Good examples show recommendations on installation practices to avoid hazardous situations or reduce component life. Meanwhile, the bad examples indicate which installations should be repaired and avoided in future PV mini-grid systems.

Scope of Discussion

The PV Mini-Grids Installations: Dos and Don’ts book is divided into 14 chapters whose topics are discussed based on the core and supporting components in off-grid PV mini-grid. Because pictures are more efficient and effective in conveying information than words, this book is designed to present around 600 photos of good and bad practices of the off-grid PV mini-grid system. The example of the installation in the book is dominated by PV mini-grids which was built in the 2012-2014 period. Each chapter is preceded by an overview and function of the components and continues with the installation of each component. Each topic or component section is equipped with a pair of good and bad examples and is supported by a brief explanation behind the assessment. Each pair of good and bad photos is followed by a brief theoretical basis of the findings in the photo and recommendations for improving the quality of the installation. The assessment of good and bad practices is based on relevant international and Indonesia national standards, instructions from component manufacturers, and best practices in installing PV mini-grid. On certain topics there is a warning that the system performance will be reduced to a safety hazard if the recommendations are ignored.

Poor presentation of examples of installations does not represent the overall quality of the PV mini-grid that has been built. Poor photos are only a few examples found in a small number of locations that are used as examples to be avoided. In general, the off-grid PV mini-grid system is very well constructed and operates effectively in providing energy services to households.

Good design and quality workmanship are the firsts attempts to present a reliable system. However, the sustainability of the system cannot be ascertained if it is not properly operated and maintained. This book also provides several recommendations for operators in operating and maintaining the off-grid PV mini-grid. In general, this book presents:

1. The basic principles of off-grid PV mini-grid system and its components
2. Design concept and general installation tips
3. Tips for repairing the installation and avoiding safety hazards
4. Suggestions for the PV mini-grid performance verification process
5. Operational and maintenance recommendations for operators and technicians

Because this book is designed as a reference for general installation guidelines, this book cannot replace the function of the installation manuals of component manufacturers (especially power electronics components) as well as international and other national standards. Designers, installers, inspectors, and technicians must refer to specific and more detailed references in order to present a good off-grid PV mini-grid system. Along with the development of battery technology and power electronics, it is estimated that there will be specific differences in the PV mini-grid installation contained in the book and the newest off-grid PV mini-grid installation which is not the scope of this book.

Target Readers

In general, this book is aimed at anyone who wants to increase his/her technical knowledge in the off-grid PV mini-grid. However, the target is prioritized on stakeholders who are directly involved in the planning, construction, and maintenance of PV mini-grids. The content in this book is intended to be a reference for different stakeholders according to their respective needs. Here is a matrix for the use of the book

Reader	Information
System Designer	• General design concept • selection of components according to ideal specifications • Calculation of component sizes to avoid capacity mismatches
Installer	• Recommendations for proper component installation • Ways to avoid bad installations • Points that must be considered when configuring power electronics parameters
Inspector	• Items to be tested during inspection or commissioning • Impacts that arise if the test does not meet the requirements
Technicians	• Ways to fix and upgrade poor installations
Operator	• Recommendations for routine operation and maintenance

There are some activities that are only intended to be carried out by competent people. At least installers, inspectors, technicians and operators are able to identify hazards and risks associated with the installation and use of electrical devices and batteries as well as the installation and testing of electrical devices.

Symbols

The symbols below are used widely in the book.

Example of a good installation. Installations can be maintained and upgraded for better performance.

Examples of installations that can be repaired and upgraded to avoid damage and harm the system or do harm to the systems.

Notification showing important information that needs attention.

Warnings that could result in damage to systems or components, or a decrease in performance if the recommendations are ignored.

A warning that can create a safety hazard if the recommendations are ignored.

General information regarding how the component works, ideal specifications, configuration, calculation method, or factors that must be considered during installation.

Recommendations that should be made when conducting system testing or commissioning.

Recommendations that should be made when performing component maintenance

LIST OF ABREVIATIONS

A	Ampere
AC	Alternating Current
ACPDB	Alternating Current Power Distribution Box
Ah	Ampere hour
AM	Air Mass
BCR	Battery Charge Regulator
BRC	British Reinforced Concrete
BTS	Battery Temperature Sensor
C	Celcius
CCV	Closed Circuit Voltage
cm	centimeter
CRT	Chatode-Ray Tube
CV	Constant Voltage
DC	Direct Current
DCPDB	Direct Current Power Distribution Box
DHI	Diffuse Horizontal Irradiance
DNI	Direct Normal Irradiance
DoD	Depth of Discharge
ELCB	Earth-Leakage Circuit Breaker
EVA	Ethylene-Vinyl Acetate
GB	Gigabyte
GHI	Global Horizontal Irradiance
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
ID	Identification
IEC	International Electrotechnical Commission
IP rating	Ingress Protection rating
ISC	Short Circuit Current
I-V	Current-Voltage curve
km	kilometer
kW	kilowatt
LED	Light Emitting Diode
LV	low voltage
LVD	Low Voltage Disconnection
m^2	Square Meter

MCB	Miniature Circuit Breaker
MCCB	Molded Case Circuit Breaker
mm	milimeter
MPPT	Maximum Power Point Tracking
MV	medium voltage
OPzV	Ortsfest (stationary) PanZerplatte (tubular plate) Verschlossen (closed)
P3K	Pertolongan Pertama Pada Kecelakaan
PLN	National Utility Indonesia
PUIL	General Requirement for Electrical Installation (Indonesian Utility Standard)
PV	Photovoltaic
PVC	Polyvinyl Chloride
PV-VP	Photo Voltaic Village Power
RCD	Residual Current Device
RMS	Remote Monitoring System
SCC	Solar Charge Controller
SD Card	Secure Digital Card
SoC	State of Charge
SoH	State of Health
SPD	Surge Protection Device
STC	Standard Temperature Condition
TM	Tegangan Menengah
TR	Tegangan Rendah
TV	television
UOC	Open Circuit Voltage
UV	Ultra Violet
V	volt
VAC	volt Alternating Current
VDC	volt direct current
VRLA	Valve Regulated Lead Acid
W	watt
Wp	Watt Peak

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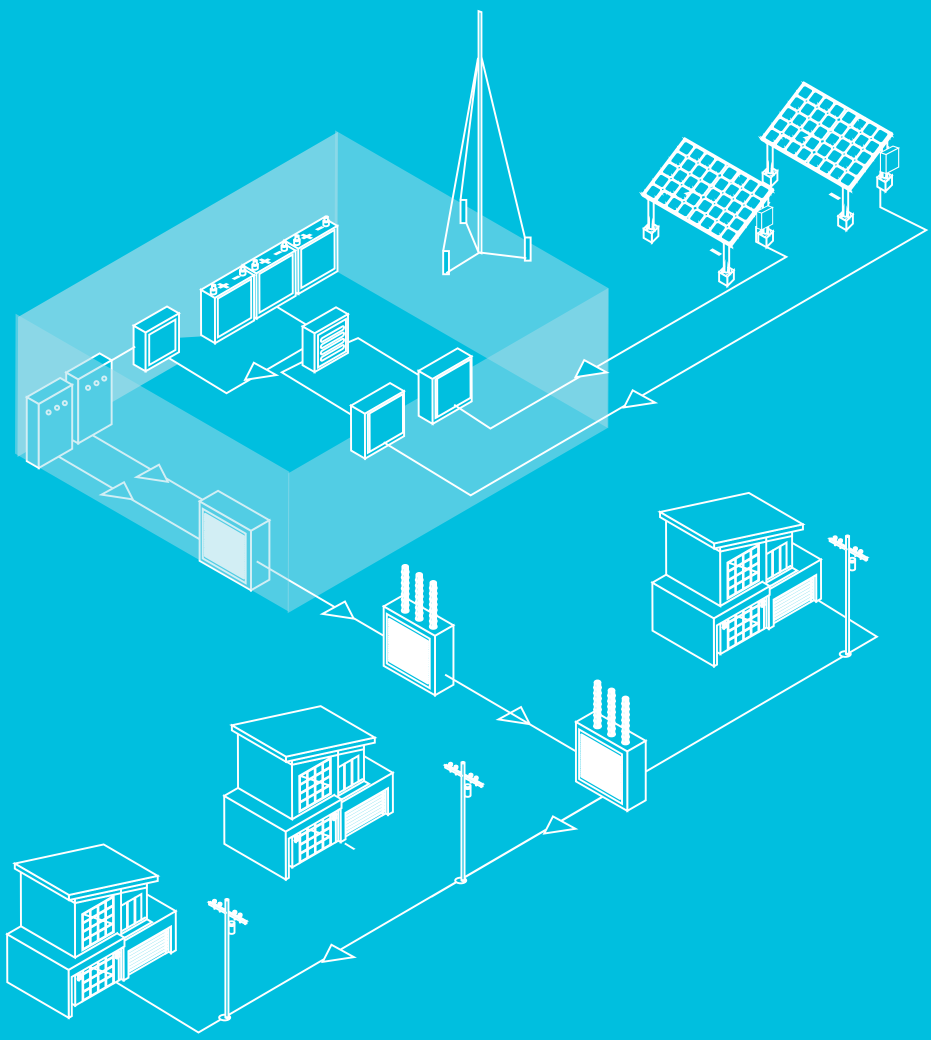
Photovoltaic Mini-Grid System

- EXPLANATION ON HOW A PV MINI-GRID SYSTEM WORKS
- DIFFERENCES BETWEEN AC-COUPLING SYSTEM AND DC-COUPLING SYSTEM
- COMPONENTS IN PV MINI-GRID SYSTEMS



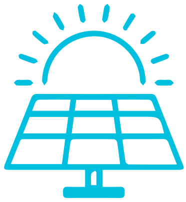
A photovoltaic (PV) system converts electromagnetic energy from the sun into electrical energy. It is one of the recommended solutions for the rural electrification where the sun is abundant, fuel is scarce and expensive. The main reasons of using PV technology can be summarised as follow:

Abundant energy resource at no cost

Energy resource is locally available and does not need to be transported

Minimum cost on operation and maintenance of a PV system

Less frequent regular maintenance which can be performed by a trained local operator



No emission of harmful gases, liquid or solid waste.

PV system is considered as an advanced system that consists of sensitive and expensive glass-covered thin photovoltaic cells, solar charge controller, battery, battery inverter, and several additional components. Indonesian manufacturers have been able to produce solar modules while most of the components of power electronics are still imported from other countries such as Germany, Thailand and China.

There are many types of PV systems both for grid-connected systems as well as stand-alone PV. Although solar home systems (SHS) are more common due to its low-cost and simple design, currently more mini-grids and PV hybrid systems are applied aiming for higher power and energy usage as well as achieving better system sustainability through collective ownership.

Compared to other renewable energy technologies, such as hydro power, PV systems are rather new in Indonesia. The Government was firstly implemented solar home system (SHS) for rural electrification in 1987. Overtime, PV system in Indonesia have been expanding from SHS to mini-grid systems. Despite the fact that Indonesia had been investigating in PV technology since 1970s, the expertise about it remains in infant stage. This is due to the inadequate availability of competent experts, skillful technicians, and engineering companies to design, construct, and maintain the systems. Meanwhile, better supply chains of spare components for PV system are urgently required to ensure the systems' sustainability in the country.

Establishing a service and spare parts provider in rural area usually requires a longer time. However, when proper maintenance of a system is regularly carried out, damages can be prevented and the lifetime can be prolonged. This book will explain how a good PV mini-grid should be designed and how bad practice can be avoided. It is intended to be a guide for stakeholders involved in PV mini-grid development, especially in the context of rural electrification.

1.1 PHOTOVOLTAIC MINI-GRID

A PV mini-grid, or as it is often called stand-alone PV system, operates independently from larger grids that are run by power companies or public utilities. The system requires batteries to store solar energy "harvested" during the day to provide electricity at dark. There are two common PV mini-grid configurations which will be described in this chapter, namely DC-coupling systems and AC-coupling systems.

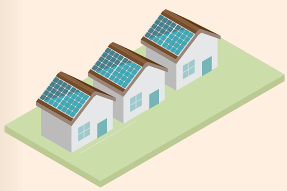
DC stands for direct current while AC for alternating current. Coupling refers to point to point connection. A DC-coupling system connects PV array to DC side of PV system, which is battery. Meanwhile, AC-coupling connects directly to the AC side of PV system with battery as a back-up. If there is any excess of power not used by the load,this is converted back to DC via an inverter and stored in the battery. The following figure illustrates an example of PV mini-grid system in DC-coupling configuration.

In general, both configurations use similar components except for the use of charge controller (the component installed after the combiner box). The use of charge controller in a DC-coupling system is substituted by a grid inverter in an AC-coupling system. The following graphic illustrates the function of each component.

Photovoltaic mini-grid system

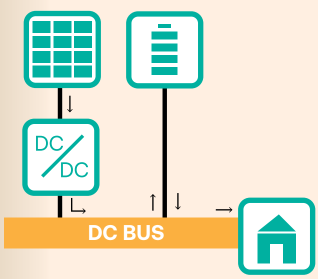
Differentiation of PV Systems

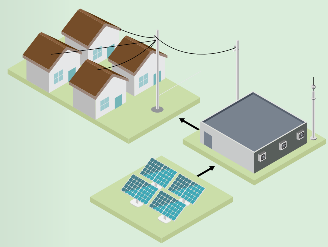
OFF-GRID PV



SOLAR HOME SYSTEM

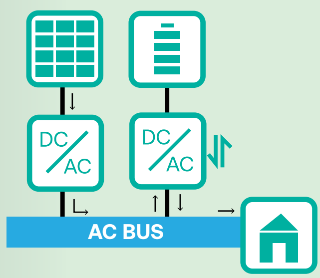
A solar PV plant is installed in every home for primary electricity needs such as DC lighting system with a capacity of 1 100 Wp. How it works is almost the same as PJU. Not connected to the national grid using batteries. When there is excess power from the PV-VP, it will be sent to the battery If the PV-VP power is less than the load, less power will be supplied from the battery

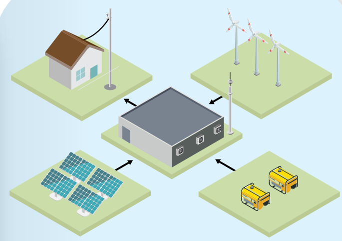




PV MINI-GRID

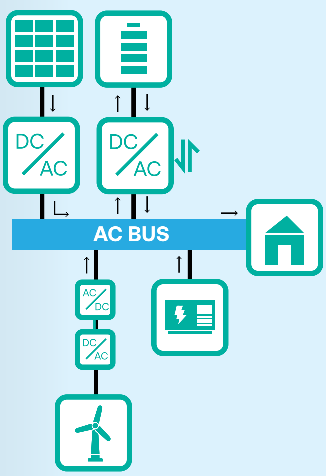
Off grid PV system for a group of people. A PV system is installed in a centralized place and electricity is distributed through an AC system with a capacity of more than 15 kWp that uses batteries for nighttime needs. When there is more power supply from the PV than demand, excess power will be stored in a battery.. If the PV power is less than the demand, the required power will be supplied by the battery



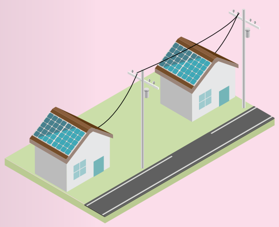


PV HYBRID

Optimizing and synergizing several plants to complement each other, for example: a PV system as the main source and a diesel generator as a backup. Generally, PV systems, diesel power plants, micro hydro and windmills are options for a hybrid. It can save at saving fuel and reduce the need for more battery capacity

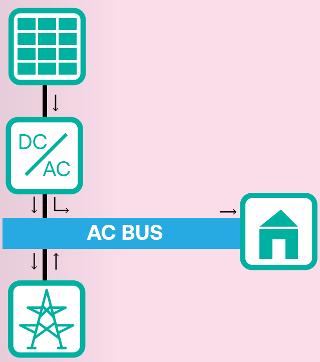


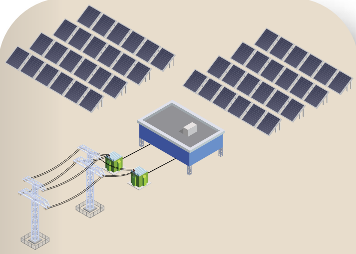
GRID-CONNECTED PV



PV ROOFTOP

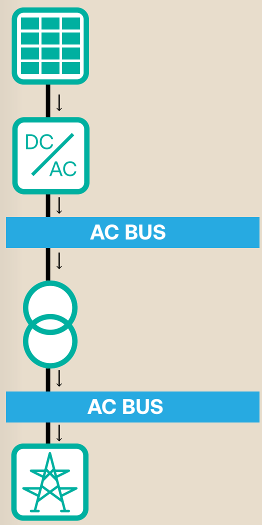
A PV rooftop system is installed on the roof of a house, an office or a factory. It connects directly to the main utility network via a solar inverter. When there is excess power from the PV rooftop that is not needed in the house, it will be supplied to the grid. If there is not enough PV power available, the required electricity will be supplied by the grid. Electricity can be sold to the grid using a Net Metering device that measures how much PV power has been supplied.

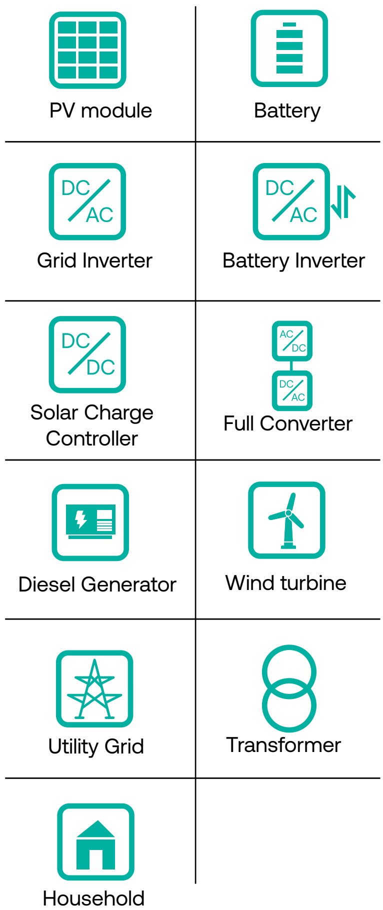




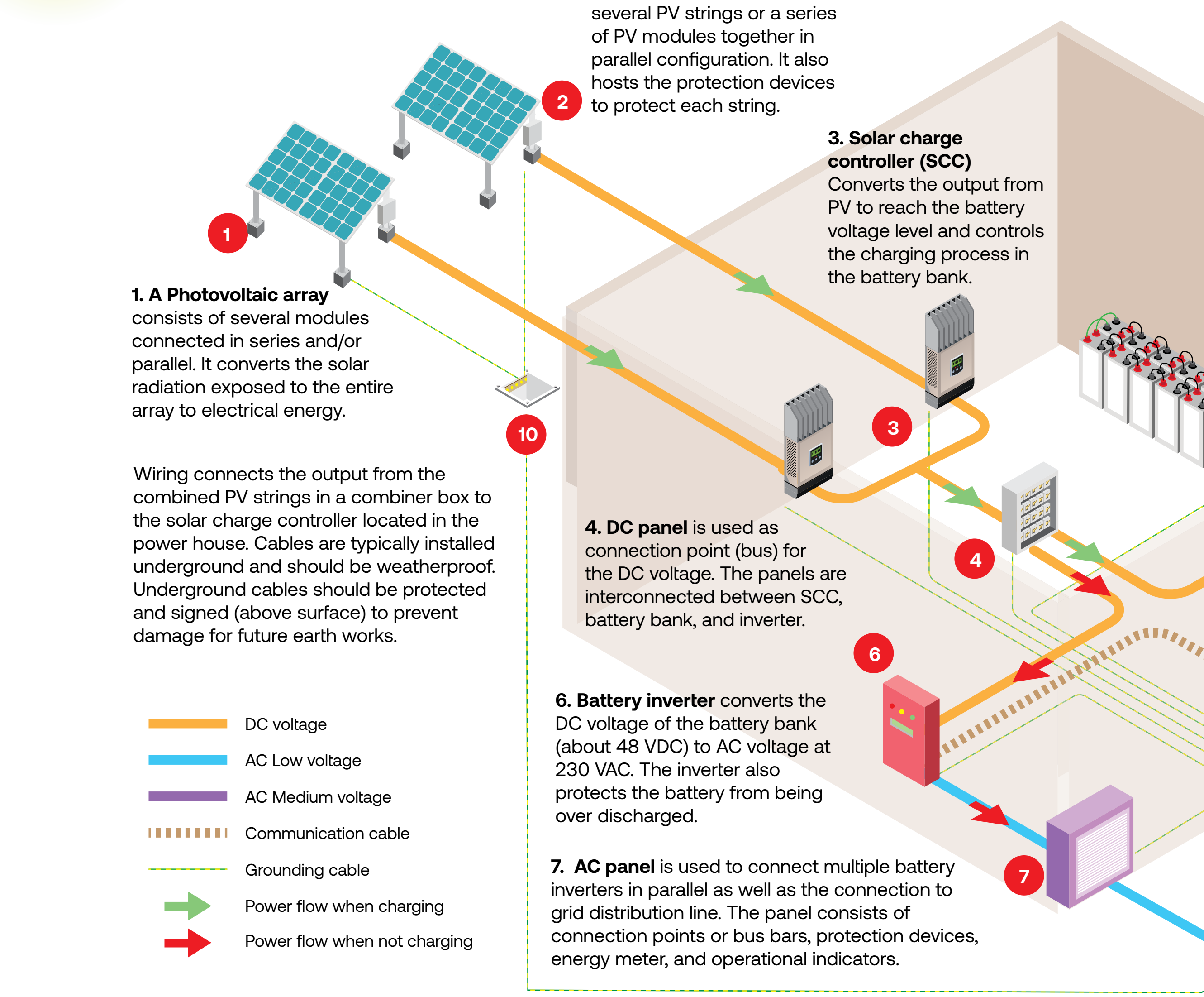
LARGE SCALE PV SYSTEMS

A Large-scale PV system (more than 100 kWp) utilizing Individual Power Producer (IPP) scheme, based on a Feed in tariff (FIT) system or other contractual systems. It connects directly to the main utility network through large scale solar inverter. Power from system will always supply to the grid if the grid is available





DC-Coupling PV mini-grid



1.2 DC-COUPLING SYSTEM

The system is considered as a DC-coupling configuration when all of the components are connected together in a DC bus. The power is first generated by the PV modules and is used to charge the battery through solar charge controller (SCC). The SCC is typically a DC-DC converter with a maximum power point tracker (MPPT). The MPPT optimises the captured energy and reduces the voltage into battery voltage level.

During the day, with sufficient solar irradiance, the battery is being charged to reach a maximum state of charge (SoC). As the electricity demand increases until it exceeds the PV power input, the battery inverter will deliver the energy from battery to the loads and will stop operating when the SoC of the battery reaches the minimum limit.

9. The power house is a building where most electrical components (AC distribution panel and battery bank) are installed. It protects the components from bad weather or other environmental condition.

13. Low voltage distribution consists of grid poles that are combined with streetlights to support the overhead cables. The distribution lines might be configured as single phase (230 VAC) or three-phase (400 VAC) depending on the total system capacity.

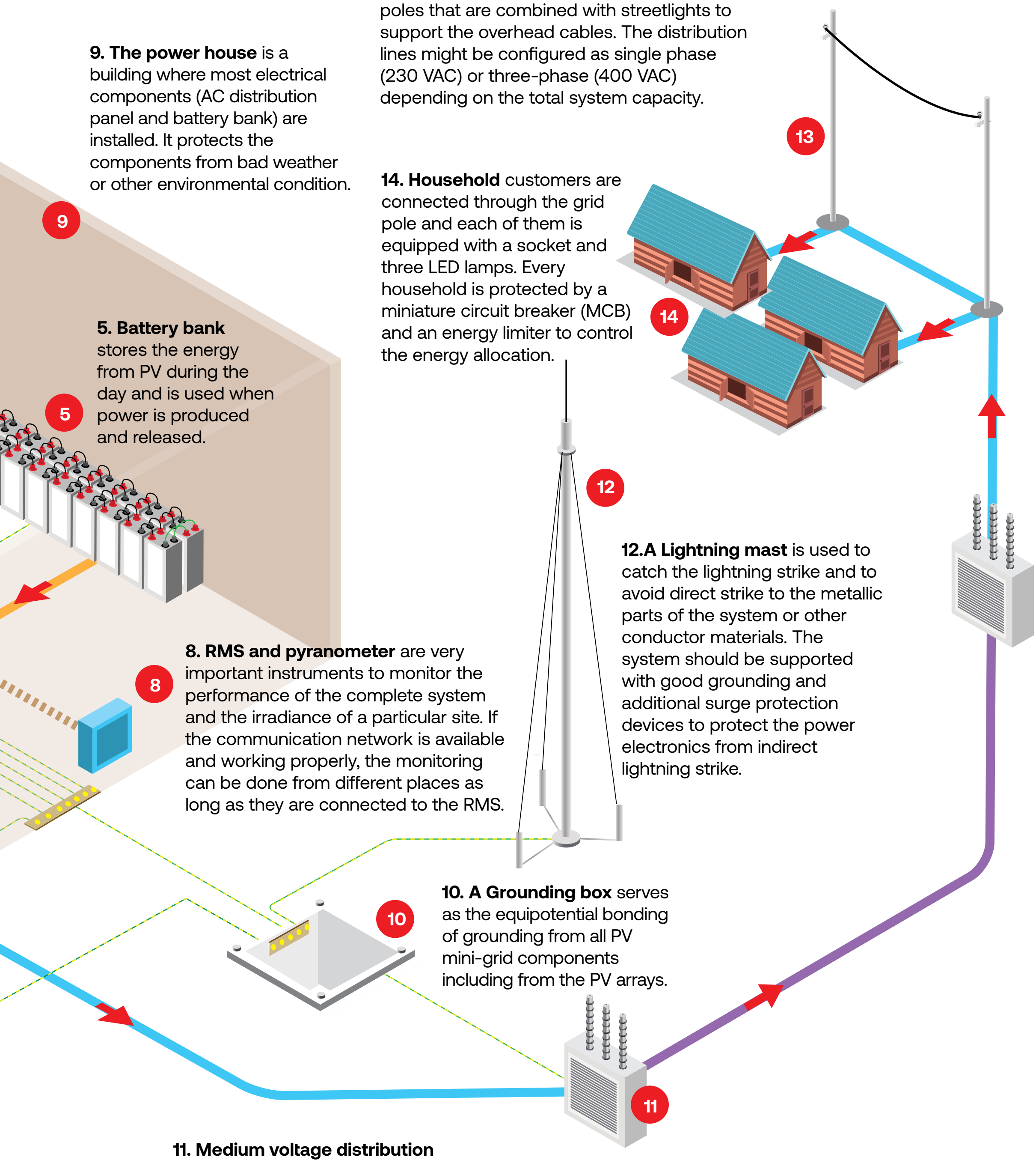
14. Household customers are connected through the grid pole and each of them is equipped with a socket and three LED lamps. Every household is protected by a miniature circuit breaker (MCB) and an energy limiter to control the energy allocation.

5. Battery bank stores the energy from PV during the day and is used when power is produced and released.

12.A Lightning mast is used to catch the lightning strike and to avoid direct strike to the metallic parts of the system or other conductor materials. The system should be supported with good grounding and additional surge protection devices to protect the power electronics from indirect lightning strike.

8. RMS and pyranometer are very important instruments to monitor the performance of the complete system and the irradiance of a particular site. If the communication network is available and working properly, the monitoring can be done from different places as long as they are connected to the RMS.

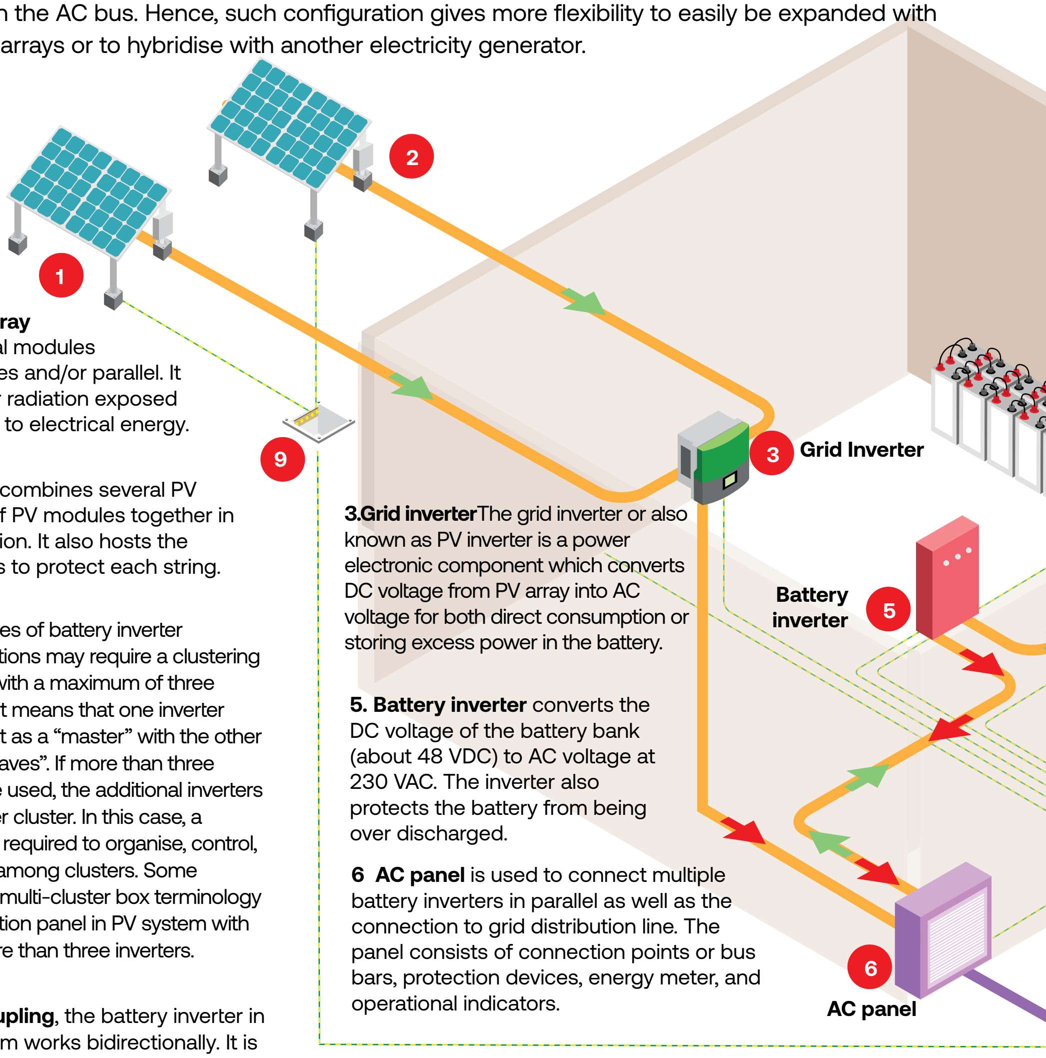
10. A Grounding box serves as the equipotential bonding of grounding from all PV mini-grid components including from the PV arrays.



11. Medium voltage distribution
is an alternative solution to reduce distribution losses including voltage drop. It consists of step-up and step-down power transformers to convert the voltage from low to medium and vice versa. MV distribution is necessary when the distance from PV system to the load or customers' connection is more than 1 to 3 km, depending on the size of the cable and the demand. Low voltage distribution consists of grid poles that are combined with streetlights to support the overhead cables. The distribution lines might be configured as single phase (230 VAC) or three-phase (400 VAC) depending on the total system capacity.

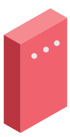
1.3 AC-COUPLING SYSTEM

The conversion in AC-coupling works in two ways; therefore, it causes more conversion losses compared to DC-coupling. However, the AC-coupling is more favourable when the higher load is more likely to occur during daytime as conversion losses will only occur in the grid inverter. It is less problematic to couple a new system in the AC bus. Hence, such configuration gives more flexibility to easily be expanded with additional PV arrays or to hybridise with another electricity generator.



1. Photovoltaic array consists of several modules connected in series and/or parallel. It converts the solar radiation exposed to the entire array to electrical energy.

2. Combiner box combines several PV strings or series of PV modules together in parallel configuration. It also hosts the protection devices to protect each string.



Some types of battery inverter configurations may require a clustering network with a maximum of three inverters. It means that one inverter should act as a "master" with the other two as "slaves". If more than three battery inverters are used, the additional inverters should form another cluster. In this case, a distribution panel is required to organise, control, and communicate among clusters. Some manufacturers use multi-cluster box terminology to describe distribution panel in PV system with combination of more than three inverters.

Unlike the DC-coupling, the battery inverter in AC-coupling system works bidirectionally. It is functioning as a charger (converting AC to DC) when there is sufficient irradiance and less energy is stored in battery (low SoC). As soon as the load surpasses the amount of PV power input, typically during the night or cloudy day, then the inverter will switch to DC-AC converter thus the energy from battery will be used to meet the load demand.

3.Grid inverter The grid inverter or also known as PV inverter is a power electronic component which converts DC voltage from PV array into AC voltage for both direct consumption or storing excess power in the battery.

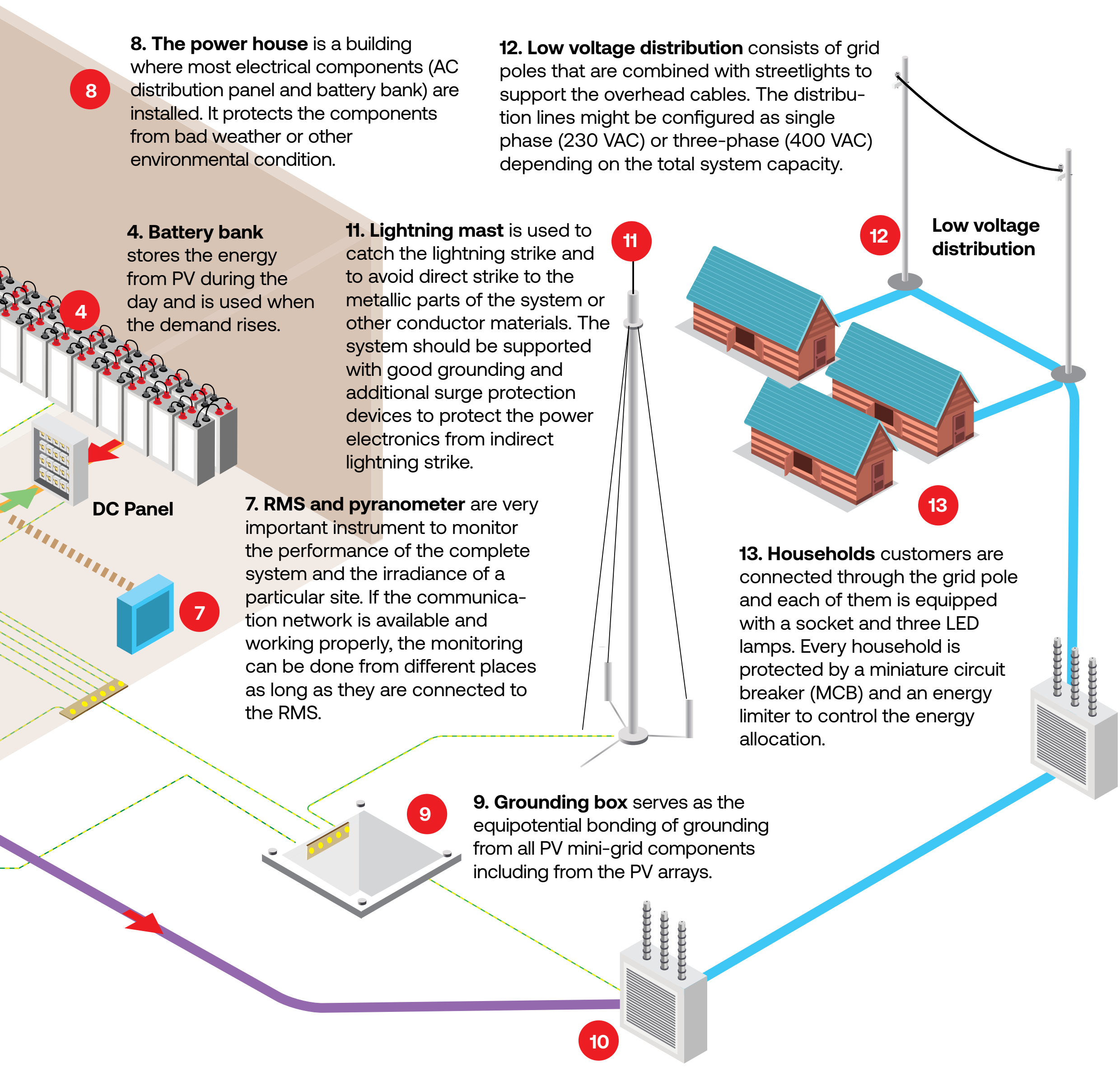
5. Battery inverter converts the DC voltage of the battery bank (about 48 VDC) to AC voltage at 230 VAC. The inverter also protects the battery from being over discharged.

6 AC panel is used to connect multiple battery inverters in parallel as well as the connection to grid distribution line. The panel consists of connection points or bus bars, protection devices, energy meter, and operational indicators.

Similar to the DC-coupling system, the battery inverter should work in parallel to achieve high-power output. Since battery inverter is the brain of the grid distribution in mini-grid, there should be at least one inverter acting as a "master" providing reference voltage and frequency while the remaining inverters are acting as "slaves" that join the grid.

DC voltage
AC Low voltage
AC Medium voltage
Communication cable
Grounding cable
Power flow when charging
Power flow when not charging

Key components that different AC from DC-coupling system are the grid inverter. In AC-coupling configuration, PV modules and batteries are coupled on the AC bus through its dedicated inverters. The PV modules are connected to a grid inverter where the power is converted from DC to AC. Similar to charge controller, grid inverter is also equipped with MPPT to optimize the captured energy. The power from PV array can directly be used by the load during the day and to charge battery via battery inverter simultaneously.



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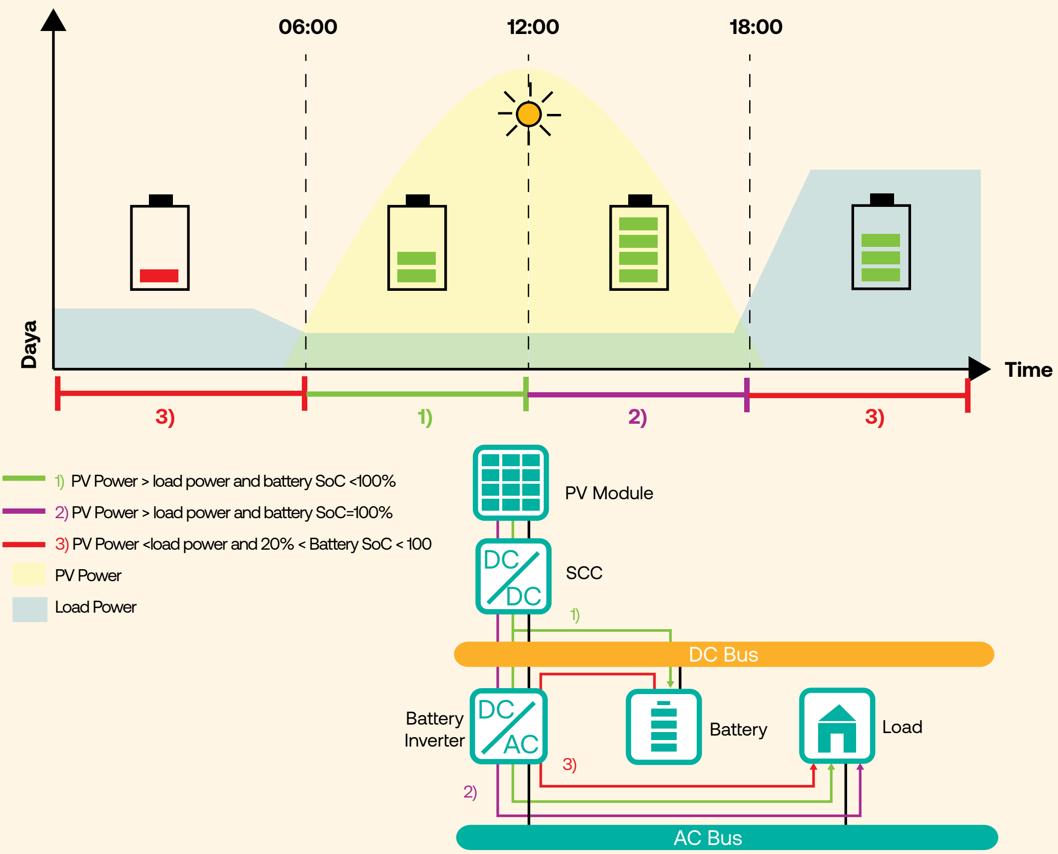
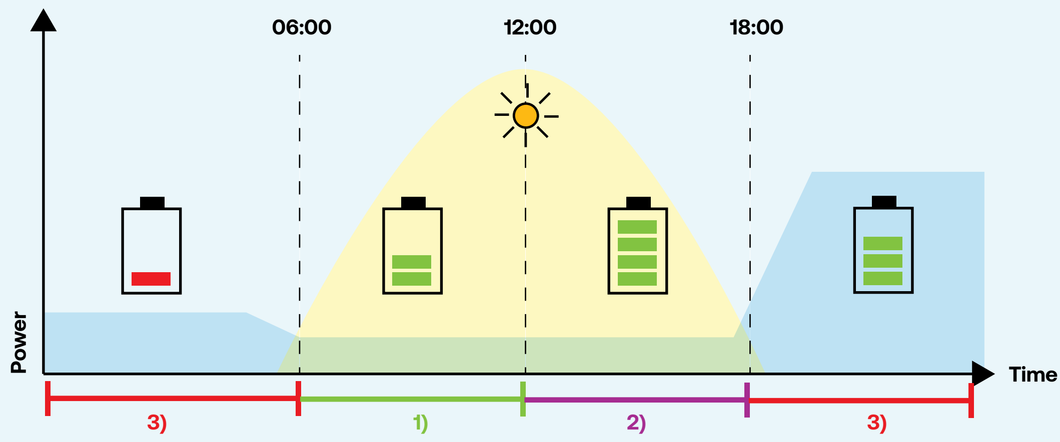
DC COUPLING SYSTEM

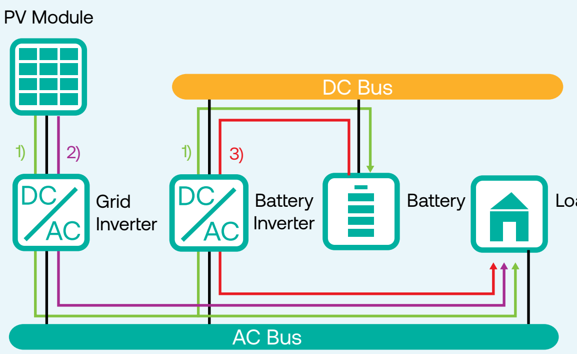
Plus	Minus
More efficiency for night use	Small efficiency for use afternoon twice a conversion
If the inverter dies because the battery runs out “, the solar module can still charge the battery.	
More suitable for small capacities	



AC COUPLING SYSTEM

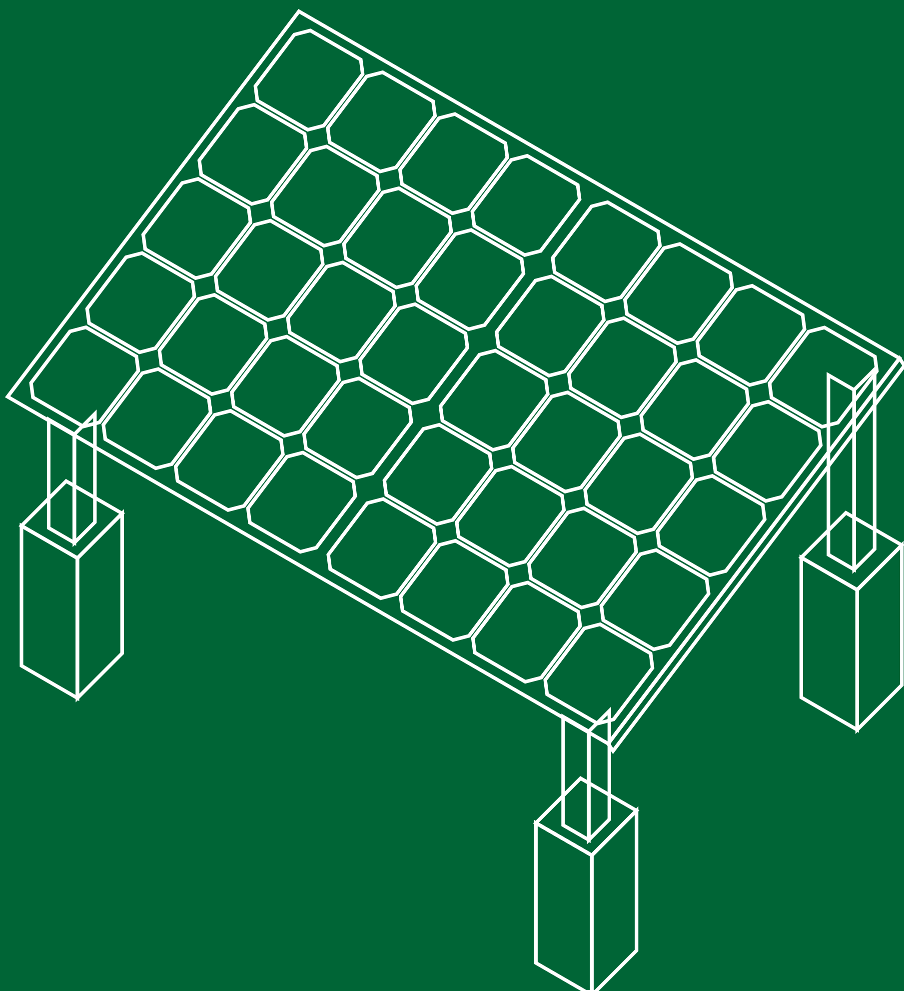
Plus	Minus
Easy to develop because AC standards and on grid ready	The network will turns off when the battery runs out
Cheaper for big capacity	
More efficiency for day use	Lower efficiency for night use





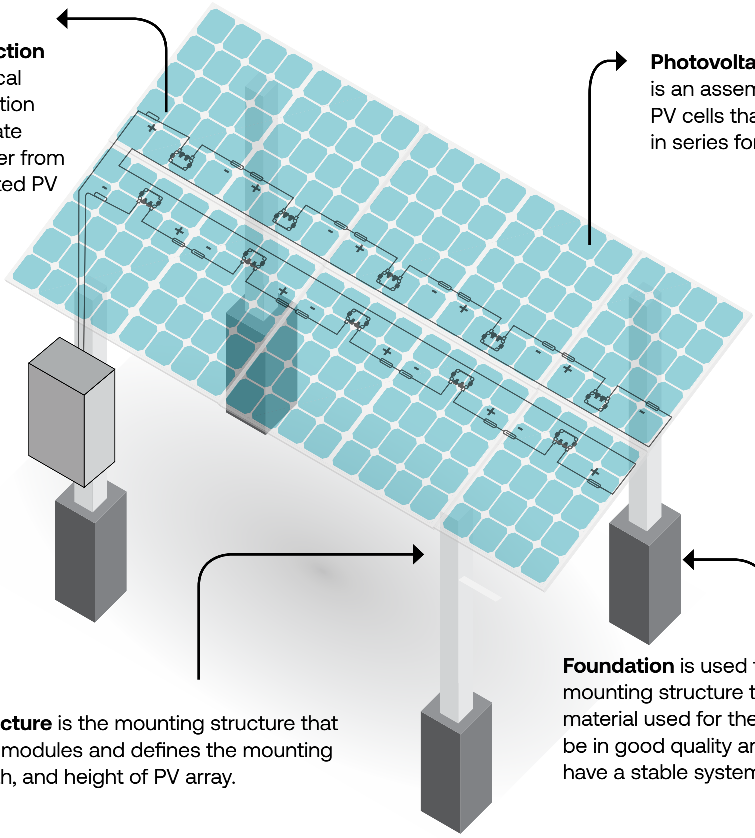
CHAPTER 2
Photovoltaic Array

- Identifying good and bad quality of photovoltaic modules
- Tips to avoid failures on photovoltaic modules
- Things to consider when combining photovoltaic modules in an array
- Guideline to improve the installation of photovoltaic array



2.1 BASICS OF PHOTOVOLTAIC

Photovoltaic generator is one of the most important components in PV mini-grid system. It converts solar radiation into electrical energy. PV generator installation comprises of the following components:



PV module interconnection is an electrical interconnection to accumulate output power from the connected PV modules.

Photovoltaic module is an assembly of several PV cells that are connected in series form.

Support structure is the mounting structure that holds the PV modules and defines the mounting angle, azimuth, and height of PV array.

Foundation is used to anchor the mounting structure to the ground. The material used for the foundation should be in good quality and deeply buried to have a stable system.

What are the factors affecting energy yield of PV generator?

Solar irradiance is the intensity of solar electromagnetic radiation incident on a surface. It is measured in kW/m^2 and the value varies in different places. Therefore a spot measurement is important before designing a PV system.

The output power of a PV module is linearly proportional to its solar irradiance.

Orientation and inclination of PV arrays. Sunlight obstructions and soiling that may cause shading.

PV modules technical performance and quality which include temperature coefficient.

PV ARRAY SHADING

Shading is a crucial problem in PV power plant as it may significantly reduce the system performance. Not only decreasing the energy production, both partial and full shading risk the affected PV module condition. When partially shaded, the heat dissipation in shady cell tends to get higher (known as hot spot) and may reduce the lifetime of the PV module.

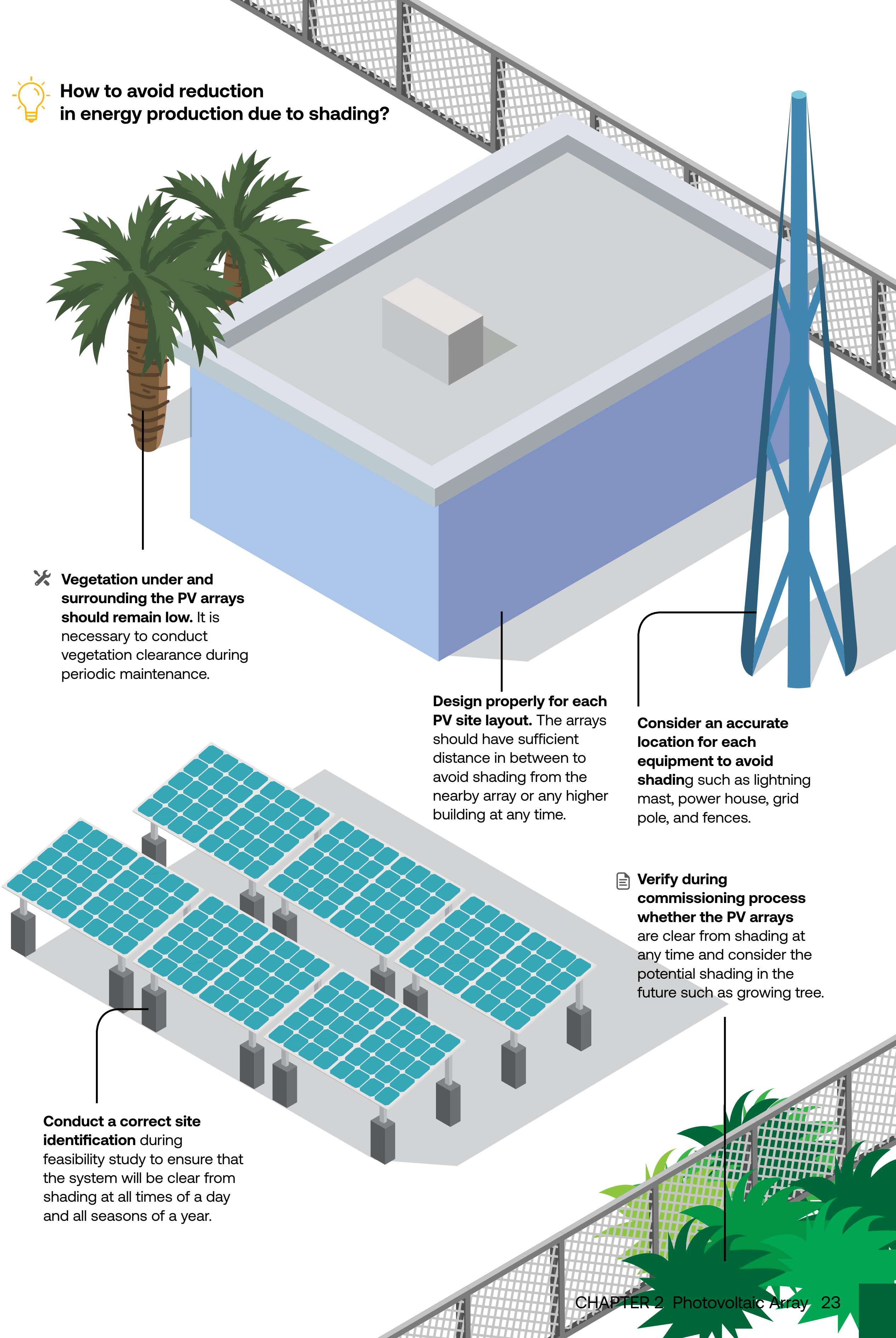
The PV arrays are located at higher terrain and in perfect distance between arrays.

PV arrays are free of shades, although there are massive numbers of lightning rods installed.

Partial shading by the power house built nearby the array.

Shading from big trees around could significantly reduce the power production up to 40%.

How to avoid reduction in energy production due to shading?



Vegetation under and surrounding the PV arrays should remain low. It is necessary to conduct vegetation clearance during periodic maintenance.

Design properly for each PV site layout. The arrays should have sufficient distance in between to avoid shading from the nearby array or any higher building at any time.

Consider an accurate location for each equipment to avoid shading such as lightning mast, power house, grid pole, and fences.

Verify during commissioning process whether the PV arrays are clear from shading at any time and consider the potential shading in the future such as growing tree.

Conduct a correct site identification during feasibility study to ensure that the system will be clear from shading at all times of a day and all seasons of a year.

Insufficient distance between arrays leads to partial shading on the lower array.

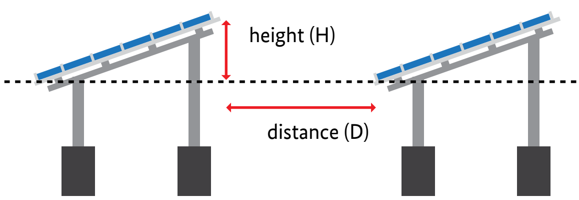
PV array is too low. Vegetations may shade the PV modules and reduce the airflow below the module.

What is the ideal distance between PV arrays?

It is important to calculate accurately the distance between PV arrays, especially when the arrays are not installed at the same height. An adjacent distance may lead to shading, while very distant arrangement between arrays results in excessive land use for the PV field.

The minimum required separation distance (D) between PV arrays is highly dependent on latitude point of the site, height of the PV array (H), and time, especially in the place where the sun path changing significantly during the year. In the case of site near to equatorial area, the rule of thumb is that the distance should be at least twice the height from the PV surface.

$$\frac{\textbf{Distance (m)}}{\textbf{Height from the PV surface (m)}} \geq 2$$

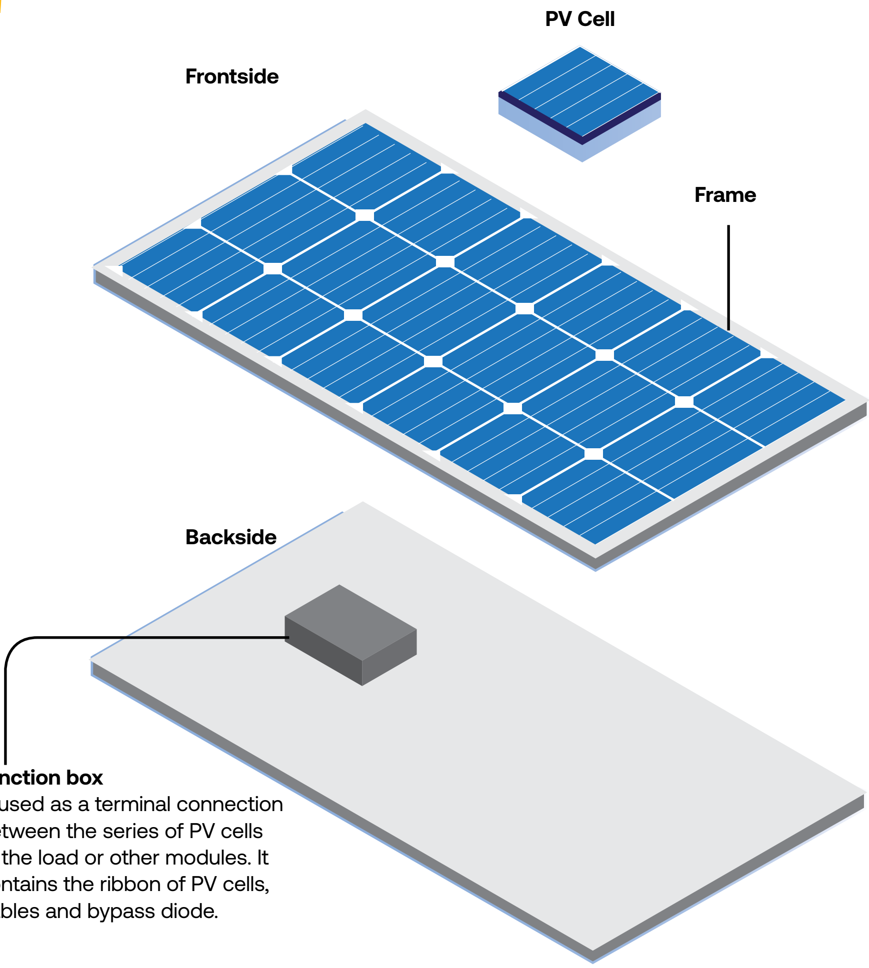


There are several software tools to simplify the shading analysis (i.e. PV SOL). The software allows the engineers or designers to create layout of their system, complete with the sun-path chart at the appointed location and results in the amount of energy yield which also includes the losses when PV array is shaded.

2.2. PHOTOVOLTAIC MODULE

A PV module consists of a number of photovoltaic cells that are interconnected in series form and manufactured into a single robust unit. The cells and interconnecting busbar are protected by encapsulating materials that will protect them from harsh environment and mechanical force which may damage the thin cells. Electrical performance of a PV module is characterised by its current-voltage (I-V) curve. The curve represents the current and voltage operating points for a PV module at a certain solar irradiance and module temperature. Since PV module is an essential component in PV mini-grid, good quality PV module is vital to sustain the operation of the system.

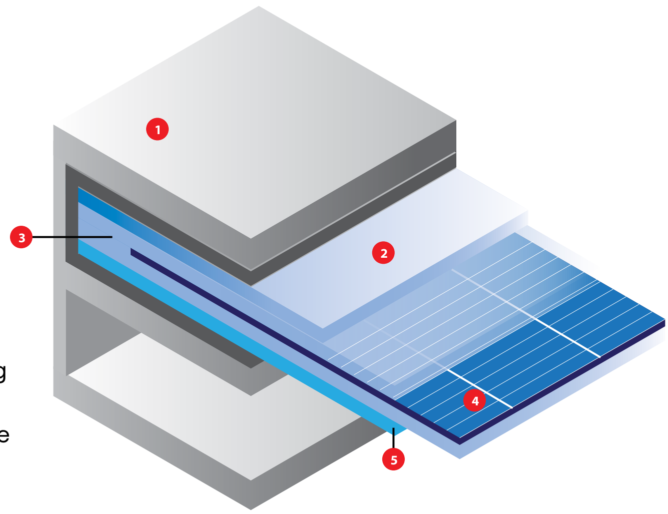
Typical silicon-based PV module



Junction box
is used as a terminal connection between the series of PV cells to the load or other modules. It contains the ribbon of PV cells, cables and bypass diode.

PV module should be tested and comply with its quality standard according to IEC 61215 for mono and polycrystalline module while thin film type adheres to IEC 61646. The modules should also have warranty period that exceeds 20 years operation with maximum performance degradation of 10 % per 10 years.

Typical silicon-based PV module



1. **Frame** is typically made of anodized aluminium to avoid corrosion. As framing is done at the end of manufacturing process, it has the function to ensure the robustness of the module.

2. **Glass cover** protects the PV cell from harsh environment condition and ensuring the robustness of the module. In consequence of its function, glass cover takes the highest proportion of total PV module weight.

3. **Encapsulant material** or lamination is a layer between PV cells and glass cover. The lamination is used to prevent mechanical damage to the solar cells and electrically insulating the cells from the rest of the panel. Typically, ethylene-vinyl acetate (EVA) is used for the lamination sheet.

4. **Photovoltaic cell** is the main component of PV module. It is made of semiconductor material that captures the sunlight and convert it to electricity. The cells are interconnected in series to increase the total voltage by a thin busbar ribbon. Silicon material is commonly used for photovoltaic cells, such as polycrystalline and monocrystalline.

5. **Insulating back-sheet** is made of plastic material to protect and electrically insulate the cells from moisture and weather.

What should be considered when choosing the PV module?

- Use PV module with efficiency greater than 15%. Using high efficient PV modules will minimise the land use.

- PV module frame should be resistant against corrosion, i.e. anodized aluminium.

- Power tolerance of the PV module should be less than 2.5% under standard test conditions (STC). This information can be found at PV module performance label on the back of each PV module, for example: "Peak power 100 W ± 2%" or "Output tolerance ± 2%".

- Maximum system voltage must be below 1,000 VDC. Setting limit to maximum system voltage adheres to the voltage of other equipment that connect to PV module in which most of them are rated less than 1,000 VDC. Thereby, interconnecting cable of PV module should be pre-assembled with plug-in socket that is rated at 1,000 VDC.

PERFORMANCE LABEL

Label is attached on the back-sheet showing the electrical characteristics of PV module.

Label may soon be detached from the module over period of time.

The PV module should be labelled with its performance characteristics on the back side of the panel.

Why is it important to have label?

- It serves as a reference for PV module performance during commissioning and inspection.
- Providing information about the required electrical characteristics in case of PV module replacement is needed.
- It provides a basis in designing array configuration as well as sizing and selecting the proper cables, connectors and protection devices.

Brand and type of solar module	Manufacturer and specific type of the module.Contact of manufacturer for warranty claim.
Type	Type of cell (e.g. monocrystalline, polycrystalline, etc.)
Module nominal power, P_{MAX} [Wp]	Nominal power of the module under standard test condition (STC). STC encompasses conditions with solar irradiance of 1,000 W/m^2, 25°C module temperature, and air mass[1] (AM) of 1.5.
Open circuit voltage, U_{OC} [V]	Voltage at the output of the module when there is no load.
Short circuit current, I_{SC} [A]	Current through PV module when the circuit is shorted. A short circuit occurs when the current finds a way to bypass the appliance on a path that has little or no resistance, which causes an excessive current flow.
Voltage at maximum power point [U_{mp}]	Operating voltage at maximum power.
Current at maximum power point [I_{mp}]	Operating current at maximum power.
Maximum permissible system voltage [U_{max}]	Maximum voltage that the module can operate safely

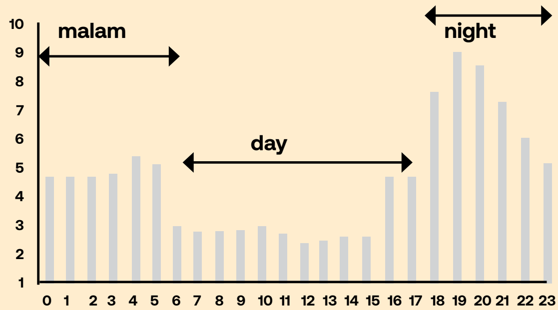
1 Air mass (AM) represents the thickness of atmosphere. AM in Europe: 1.5, while in equator : 1.

How do I calculate the capacity of a photovoltaic module needed?

1. Calculate energy needs at night (17.00-07.00) and during the day (07.00-17.00) by using the electricity consumption pattern of the village community and the estimated load increase of 30%

Night energy: 71.5 KwH x 130% = 92.95 KwH
Day energy : 18 kW x 130% = 24.05 kWh

2. Check daily solar irradiation available at the site. data can be obtained through direct measurement or statistical data (NASA, Renewable Ninja, or Global Solar Atlas). Find the lowest average daily irradiation in the year



Jan	Feb	Mar	Apr	Mei	Jun
5.75	5.59	6.17	6.12	5.85	5.54

Jul	Aug	Sep	Oct	Nov	Dec
5.76	6.45	7.09	7.34	6.96	5.99

Average	6.22	kWh/m²/ day
Minimum	5.59	kWh/m²/ day

Lowest irradiant on Feb 5.59 kWh/m²/ day

3. Calculate the total system efficiency for night and day use taking into account the losses in the photovoltaic module (temperature rise, dust accumulation, module mismatch), losses in power electronics and cables, and losses in the battery (nighttime).

☀☽ **Losses in the photovoltaic module**	**= 11.5%**
☀☽ **Losses in the grid inverter/ chrarge controller**	**= 3%**
☀☽ **Losses in battery inverter**	**= 6%**
☀☽ **Losses in cable**	**= 2%**
☽ **Losses in battery**	**= 15% (lead-acid)**
☽ **Total Losses at night**	**= 37%**
☀ **Total losses at day**	**= 22.5%**

4. Calculate the total system efficiency for night and day use taking into account the losses in the photovoltaic module (temperature rise, dust accumulation, module mismatch), losses in power electronics and cables, and losses in the battery (nighttime).

$$\text{Total Modules}^{\wedge}\text{' Energy} = \frac{\text{Night Time Energy}}{\text{100\%-losses at night}} + \frac{\text{Day time energy}}{\text{100\%-Daytime losses}}$$

$$\text{Total Modules}^{\wedge}\text{' Energy} = \frac{92.95\text{ kWh}}{62.5\%} + \frac{24.05\text{ kWh}}{77.5\%} = 179.75\text{ kwH}$$

5. Calculate the capacity of photo voltaic module and required number of modules if the nominal power of module is 200 Wp

$$\textbf{Module capacity} = \frac{\textbf{total modules' energy}}{\textbf{minimum average irradiation}} \times G_{STC}$$

$$\frac{\textbf{179.75 kWh}}{\textbf{5.59 kWh/m}^2\textbf{/hari}} \times \textbf{1,000 W/m}^2$$

32.15 kWp

min. 162 x 200 Wp → 32.4 kWp

PV CELL

PV cell is very sensitive and susceptible to breakage due to mechanical load. The thin ribbon busbar, which holds the interconnection between PV cells, is also inclined to crack due to improper PV module manufacturing process. These defects will surely reduce the performance and output of the PV module or the worst case might be no output.

How to mitigate any damage on PV cells?

- Establish a comprehensive quality assurance process at the factory such as:
  - o sorting out bad cells;
  - o conducting an electroluminescence[2] inspection to identify poor soldering, micro cracks, and bad lamination;
  - o running a mechanical load test to determine possible damages caused by such vibration or load.

Regular inspections must be conducted to check the condition of PV modules as part of preventive maintenance. A PV module that consists of bad cells has to be replaced by the manufacturer during the warranty period.

Perfect condition of PV cell which is free from crack, snail track[3], and has good soldering.

Snail track defect on modules, might be caused by material defect. In long term, such defect may cause hotspot.

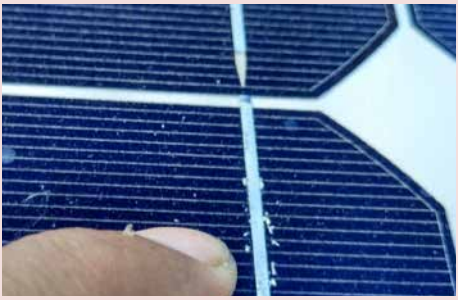
2. Electroluminescence is an optical and electrical phenomenon in which a material emits light in response to an electric current applied to the material.
3. The snail track is a mark that resembles a snail's path across the surface of a photovoltaic cell in a photovoltaic module.

What is hot spot?

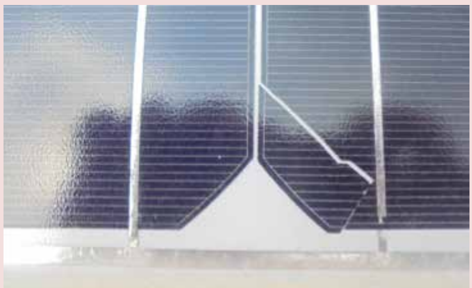
An expanding areas of localized heat on PV cell happens when there are differences in illumination among the PV cells. As the output of a cell is proportional to irradiance, the cells may behave differently and may create problems when connected in series. The substandard cells current will reduce and limit the operating current of the entire string. During this time, the substandard cells will generate reverse power or dissipate power. It becomes more severe when the substandard cells are completely covered and dissipating the total power produced by the good cells in the string. Hence, this course creates hot spot.

Since there is a limitation in a cell to handle power dissipation, the substandard cells may be overheated thus results in hot spot. Not limited to partial shading, temperature inclination might also emanates from resistive heating due to poor quality of cells, lousy solder joints between the cells and the presence of low-shunt cells. Low-shunt resistance provides route diversion for the light-generated current thus causes power losses in solar cells. An ideal cell should have high-shunt resistance, low-shunt resistance is typically caused by manufacturing defect.

Hot spot may degrade or damage the cell, melt the interconnection, and initiate arc due to the deterioration of back sheet and lamination.



Poor soldering may increase series of resistance and thus deteriorating the PV module characteristics.



A cracked PV cell in a string of cells. Such crack will reduce performance and possibly leads to hot spot.

Hot spot and low-quality modules that could reduce the power production.

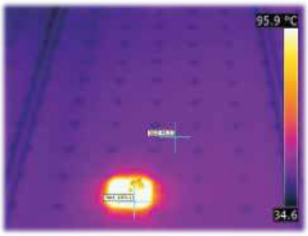
Burnt PV cell due to significant increase of heat.

How to avoid hot spot?

- Early detection of hot spot by regular check on temperature of PV module surface using thermal imaging camera.
- Connect a bypass diode in reverse parallel with a cell or a group of cells. During normal operation, when all cells are irradiated, the cells produce electricity and bypass diode is blocked. The bypass diode starts conducting when one or several cells are shaded.

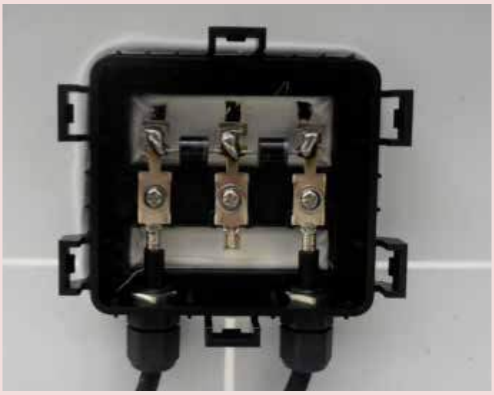
How to identify the hot spot using thermal imaging camera?

Example of thermal imaging camera[4]. The spot is identified by pointing out the camera to the PV module.



Detection of hot spot on a PV module. There is a block of cell that has significantly higher temperature compared to the neighbouring cells.

PV module is equipped with six bypass diodes located inside junction box to protect a string of 72 cells.



Absence of bypass diode may risk the PV module during shading.

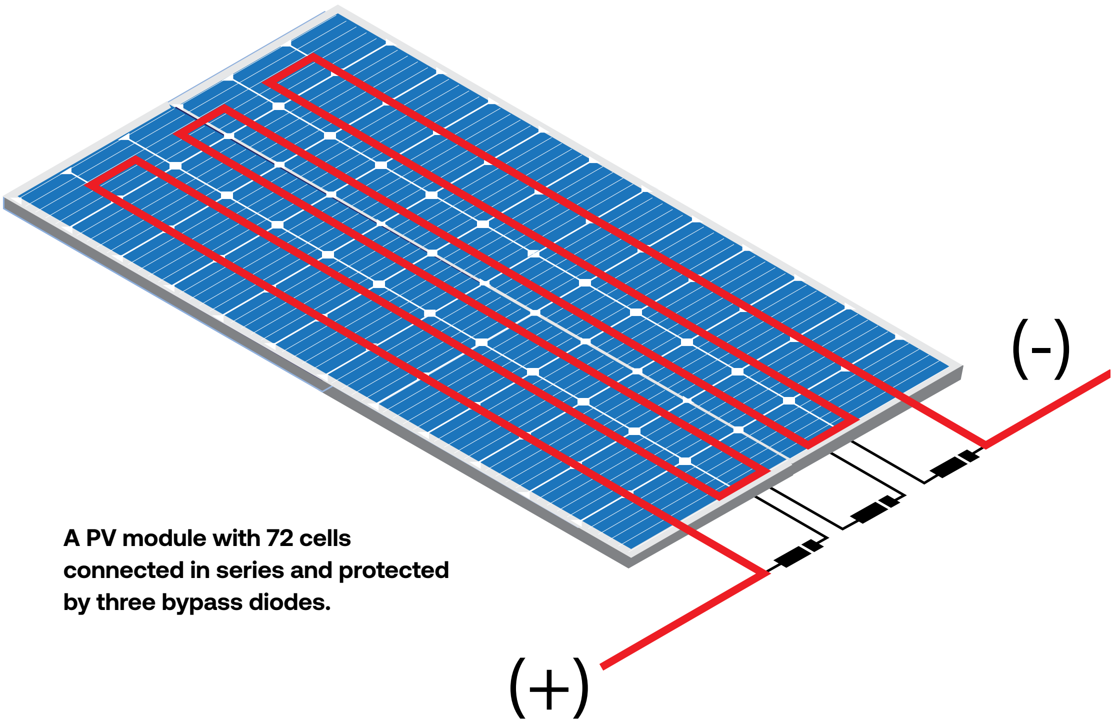
4 FLIR. Available: http://www.flir.fr/cs/display/?id=60636 (Accessed: 27 February 2017).

How to choose a bypass diode

The figure illustrates a PV module with 72 cells connected in series and protected by three bypass diodes during normal operation. Maximum number of cells to be protected by one diode is mainly calculated based on breakdown voltage of the cells and forward voltage (VF) of the diode. Typically, the breakdown voltage of the cell is 30 V for monocrystalline and 12 to 24 V for polycrystalline.

The Schottky diode is often used for this purpose as it has low VF in the range of 0.15 to 0.5 V. A Schottky diode may protect up to 24 cells by assuming that the open circuit voltage of a silicon-based cell is 0.5 V[5]. Therefore, three diodes are used to protect 72 cells module.

Besides, the diode should have sufficient maximum repetitive reverse voltage (VRRM). It is required because at lowest temperature the voltage might be equal to the value of maximum open circuit voltage of the module divided by the number of diodes. Considering module with open circuit voltage of 40 V and maximum of 48 V due to decreasing module temperature, the VRRM of each diode should be higher than 16 V.



A PV module with 72 cells connected in series and protected by three bypass diodes.

5 STMicroelectronics. How to choose a bypass diode for a silicon panel junction box. Application Note AN3432, 2011.

PV MODULE GLASS COVER

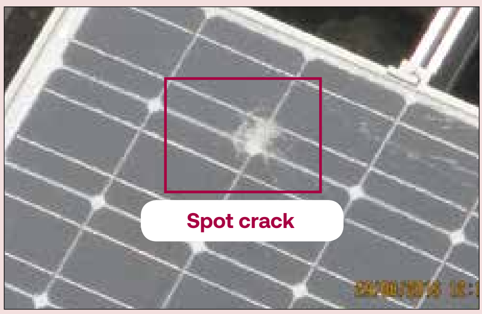
One of the glass cover functions is protecting the entire photovoltaic module. The glass cover should be free from crack to ensure the optimum module performance as well as protecting the module. However, several damages may be unavoidable, for example a stone landing during landslide, falling trees, and human errors such as bad material handling and packaging during shipment and inventory. A significant rising temperature due to hot spot, misuse of support structure, and tension applied by the module frame may also cause the glass to crack.

PV modules should be free from cracks and avoid connecting a cracked PV module in an array.

Why a broken glass should never be connected?

- Moisture, oxygen and water could enter the broken part and corrode the wiring, and possibly cause short circuit.
- A severe glass damage may harm the PV cells and interrupt wiring connection between the cells thus it may disconnect the entire string.
- The cracks may reduce the transmission of light to PV cell; therefore, lessen the output power of module. Damages due to escalation of heat dissipation or hot spot heating in the cell with least sun exposure may happen if bypass diodes are not installed in the module.
- Declining amount of power generation.

Shattered module in the middle of good modules.



Spot crack on the glass possibly due to stone throwing.

How to avoid power cutback due to glass crack?

- Ensure that the modules are well-attached to the support structure.
- Improve material handling and packaging methods during transportation.
- Always store PV modules that are covered inside its packaging.
- Check condition of all PV modules regularly to identify possible cause of crack such as landslide hazard or loose PV modules. A module with cracks should be immediately replaced with similar module type.

Why the glass cover should always be cleaned?

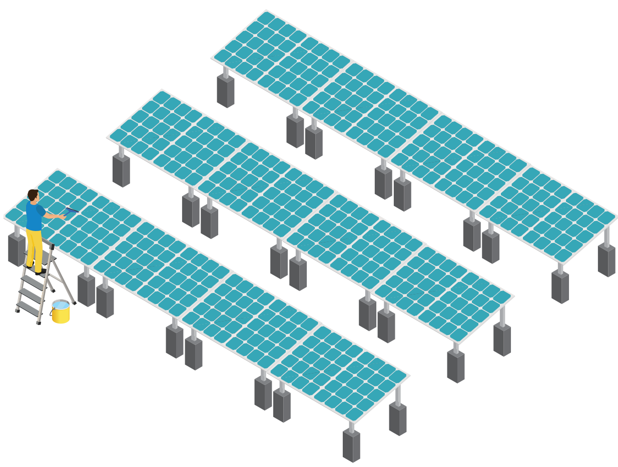
PV modules should be cleaned regularly to optimize the transmission of light to the cells. Soiled PV modules significantly reduce its performance.

How to maintain the cleanliness of the module?

Mounting the PV array with at least 10° tilt angle to enable self-cleaning mechanism through rainwater. The modules should be installed with sufficient distance among them.

Schedule a regular cleaning of PV arrays according to characteristics of the site location. Weekly cleaning is recommended when the site is located in dry and dusty area such as nearby the beach, close to a volcanic caldera, desert or sand dunes. The sand or dust on the glass cover has to be flushed with water and swept to avoid accumulation of dirt on it.

Ensure the modules are free of residues on the glass cover during installation.



How to clean PV modules?

- It is best to clean the modules early in the morning as the dew that emerges during the night has moisten the dirt.
- Brush the dust and dirt before applying water. Never use any metal tool to clean the glass cover as it may scratch the glass thus creates shadow.
- Only use clean water as the cleaning agent. Avoid using chemical cleaning agents such as detergent to avoid unexpected scratches.

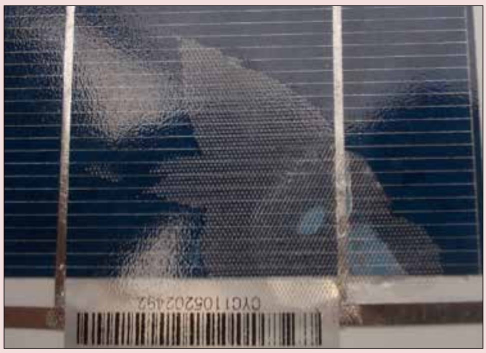
Clean PV modules to maintain optimum light transmission to the PV cells.

Dusty PV modules located in sandy area.

PV LAMINATION

Delamination can occur between the glass cover and encapsulant material as well as between the encapsulant and PV cells. A defect mainly occurs due to inadequate quality of adhesive bond that is sensitive to ultraviolet (UV) radiation, humidity, or contamination from the material. Delamination results in reduction of light transmission thus lessen the output power.

Bad lamination around the busbar creating a gap between the glass and cell.



Big bubble under the glass cover indicating a bad manufacturing quality of PV module.

How to avoid delamination?

- Select an adhesive that is adequately stable to moisture and is resistant to UV radiation.
- Conduct module testing to eliminate alteration in material and process.
- All encapsulants, back-sheets and labels have to be periodically tested under UV exposure and high temperature.

BACK-SHEET OF THE PV

The back sheet is made of a thin foil polymer that should be mechanically strong, UV resistant, and functioning as a good barrier against direct exposure to the environment such as protecting from weather, dirt, and moisture. The sheet also provides safe operation of PV module as it is used to isolate the possible high DC voltage on the string of cells. Back-sheet of the PV module should be free from cracks, bubbles, and delamination. This is to avoid water leakage that may reduce the performance of the module due to corrosion of the internal metal parts, degradation of the encapsulant, and internal short circuit.

Good condition of back-sheet.

Delamination and broken back-sheet may risk the internal connection.

Delamination leads to higher possibility of exposure to live (or electrified) components. The situation might be worsened when the delamination forces the internal connection to break. The broken busbar may create spark gap and thus generate arc[6] especially at high voltage.

How to reduce the risk of having delaminated back-sheet?

- More selective in choosing material and adhesive that is durable to humidity and UV radiation.
- Testing the module in a long-term period with outdoor exposures. The module should pass the test adhered to IEC 61730 – Photovoltaic (PV) module safety qualification.
- Conduct visual screening of the modules before shipment to the site.

6 Electric arc is a high-density electric current between two separated conductors in gas or vapor with a relatively low potential difference, or voltage, across the conductors.

JUNCTION BOX

What is a good junction box?

- Junction box is attached using a good quality adhesive system to maintain a long-term adhesion.
- The junction box should be covered and rubbery sealed to avoid water ingress, short circuit, and electrical hazard because of the existence of live voltage. A good junction box should have at least IP 65 rating which provides protection against dust and low pressure water jets.
- Equipped with appropriate cable glands suit to the conductor size. The cable glands should be tightened to avoid water entering the box.
- Secure connection by having conductors that had been crimped and soldered.
- Installed with bypass diodes to protect the module from inflicting hot spot.

A good junction box is well attached and closed tightly.

Junction box is not closed properly thus it may lose ingress protection (IP) rating. Moisture and water may enter the box and cause corrosion.

Vibration or physical movement during high wind speed may shift the wood block and leave the box open.

Exposed junction box with unsecured cable glands lead to corrosion of internal connection and short circuit.

PV MODULE FRAME

A PV module should be designed to withstand against heavy mechanical stress. The frame should keep its form to ensure the robustness of the module and maintain the bonding to the support structure. Moreover, having a non-uniform frame may increase the stress on the glass, thus may risk the glass cover and the PV cell of being cracked over period of time.

The PV module frame should be in a good condition and securely fasten.

Twisted PV module frame causing glass cracking. PV module with broken glass should be replaced.

Bent PV module frame due to missing screw.

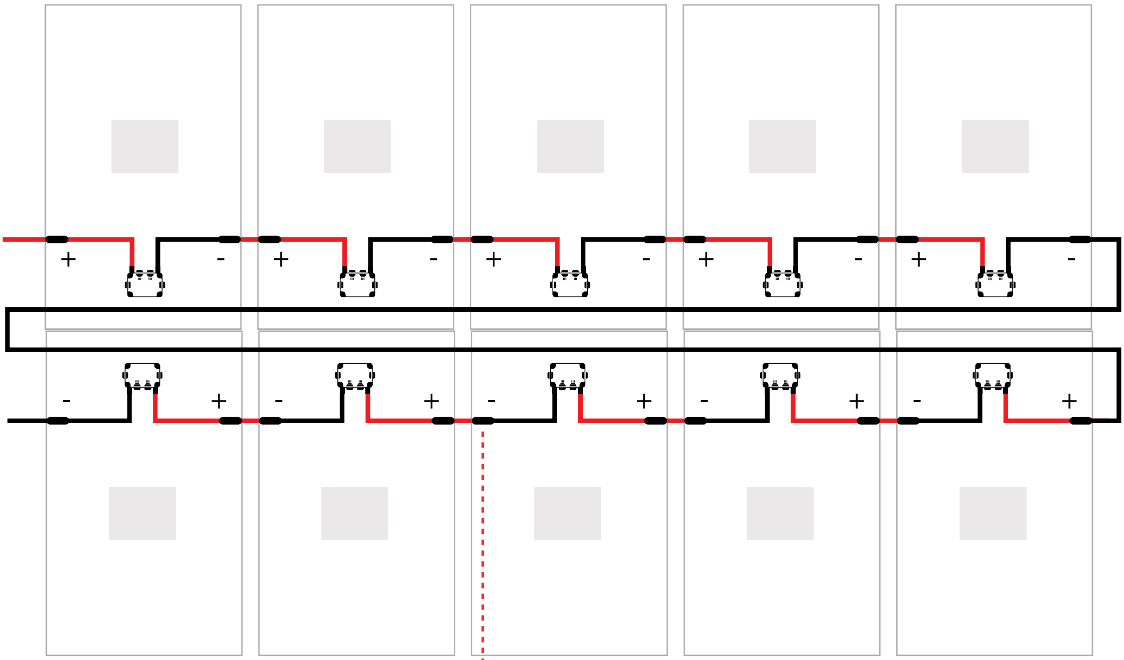
What can be done to avoid deformity on frame?

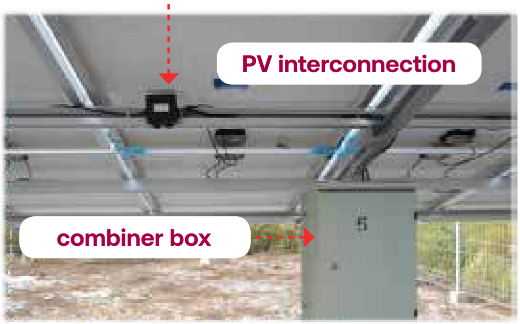
- The PV module must be securely fastened and prevented from failing due to high wind or other mechanical loads.
- A proper handling during transportation of PV modules. The packaging should shun vibration and bump to a minimum level.

2.3 PV MODULES INTERCONNECTION

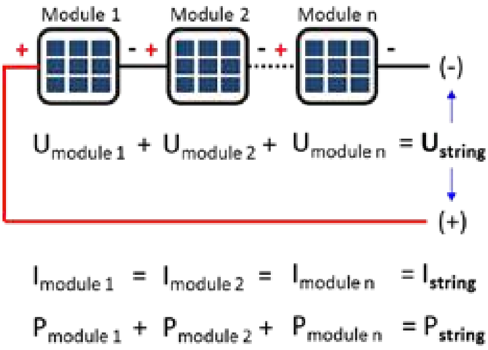
Photovoltaic generator is built from the series and parallel connections of individual PV modules to achieve an intended voltage and current. It consists of individual PV modules connected in series to increase the voltage. Once the intended output voltage is achieved, the individual series connection of PV modules is connected in parallel in the combiner box to increase the current. The desired output power is linear with the number of modules. As the PV module has voltage limitation, the number of modules and the total open circuit voltage should not exceed to voltage rating of the individual module.

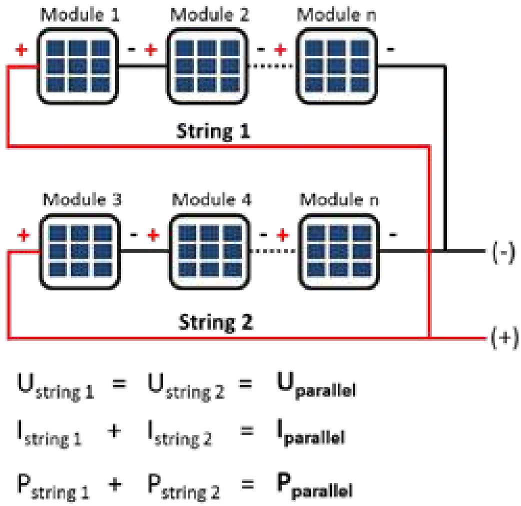
Example configuration of several PV modules forming a PV string





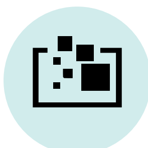
How to electrically connect the PV modules?



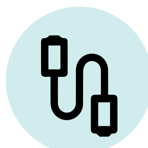


What to consider when interconnecting PV modules?

The number of modules formed in series should consider the maximum and minimum input voltage of solar charge controller and grid inverter.



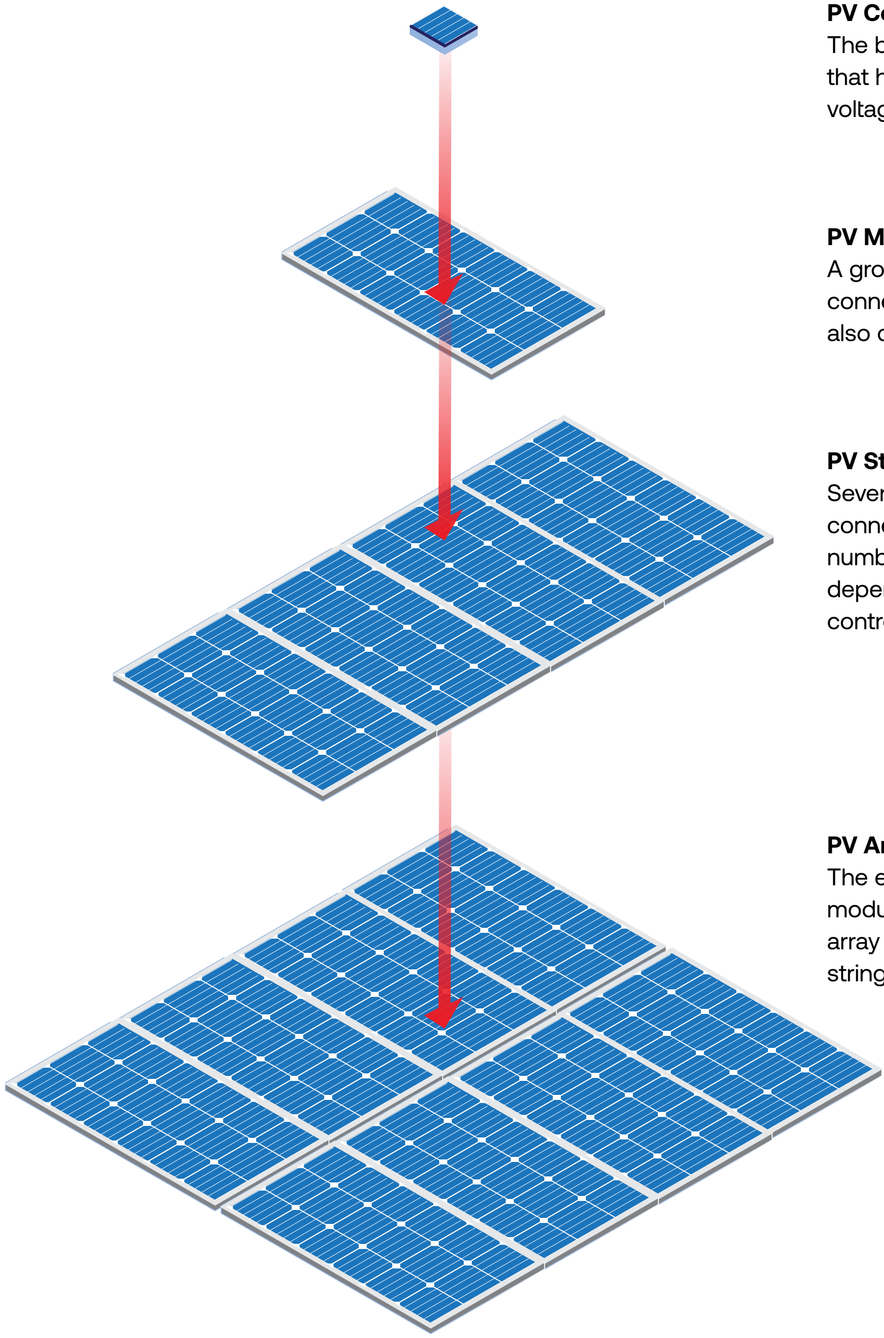
All components should have insulation rating of 1000 VDC or at least the maximum open circuit voltage of the entire PV string at any condition. The PV string voltage should not exceed the rated voltage (1000 VDC) or the maximum voltage that all the equipment could withstand.



PV string must consists of similar type of PV modules to avoid reduction of power.

The drawing of the complete array configuration should be available on site. Each combiner box or even string should be labelled with number for tracking purposes.

What is PV cell, PV module, PV string, and PV array?



PV Cell
The basic building block that has typically an output voltage of 0.5 VDC.

PV Module
A group of PV cells connected in series. It is also called a solar panel.

PV String
Several PV modules connected in series. The number of PV modules depends on the charge controller or grid inverter.

PV Array
The entire group of modules in a system. An array can be multiple PV string connected in parallel.

Module composition in an array

PV arrays with identical modules to ensure equal performance of each PV module.

Mix of various modules in an array indicating differences in performance.

The complete PV array should contain identical PV modules with similar brand, type, and characteristics. During commissioning, it is required to verify performance verification of each PV string for the expected output and similarity between each PV string. The measurement could be conducted in the combiner box.

Combining PV modules with different characteristics in an array is not strictly prohibited, but not recommended as the module mismatch will reduce the performance of the total array. Notice that an array should consists of modules with similar specifications as follow: type of cell (monocrystalline, polycrystalline or thin film), nominal power, operating voltage and current at maximum power, open circuit voltage, and short circuit current.

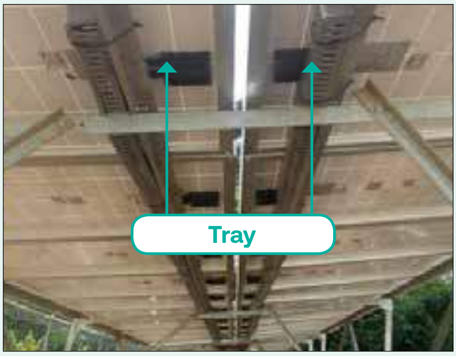
Why should an array consist of similar type of modules?

- The total current and voltage in an array is limited to the weakest PV module. If in a PV string there is a module with rated current lower than the others, the total current will be reduced to the current value produced by the weakest module. For modules connected in parallel, the voltage will be equal to the voltage of the lowest rated module.
- Maximum power point tracker (MPPT) in the solar charge controller and grid inverter will not be able to find the most optimum operating voltage and current as the electrical characteristics are different.
- Degradation rate of power is different among PV modules.

▶ **What can be done when a module need to be replaced?**

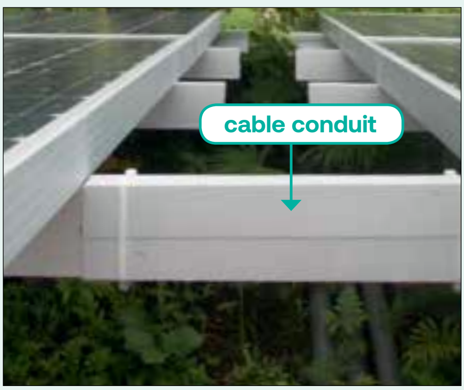
- Replace the broken module in a PV string only with module of the same brand, type, and rate of current at maximum power and short circuit.
- Replace the broken module in a PV block only with module of the same brand, type, and rate of voltage at maximum power and open circuit.

CABLE INSTALLATION AND SUPPORT

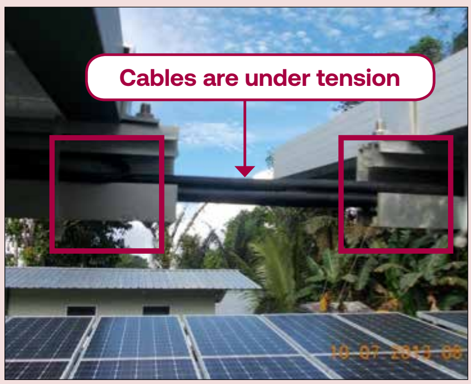


Cables are securely installed inside cable conduits.

Cables are hanging loosely below the modules and are not supported with cable tray.



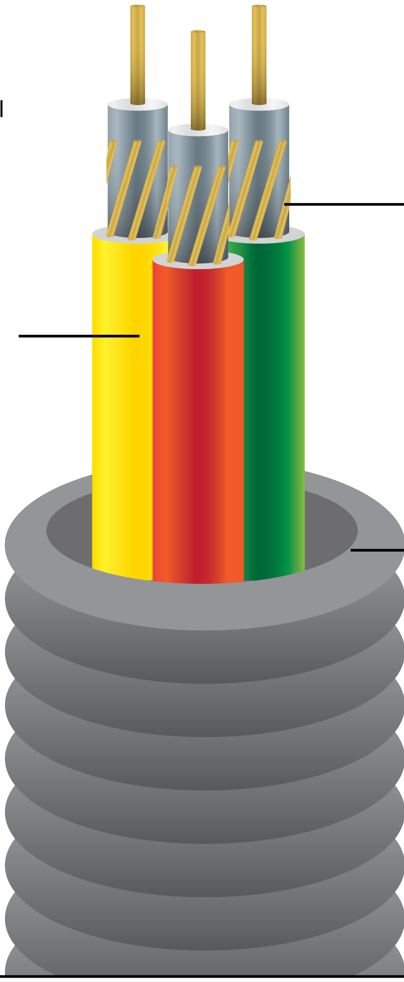
Cables are protected inside the cable conduit. Providing cable support may increase the lifetime of the cable.



Cables are unprotected, directly exposed to the sun, and under tension.

How to improve the installation?

- Loosen cable tension to avoid frequent disconnection that can be triggered only by small mechanical move.
- Despite UV and water-resistant cables are used, it is preferable to install the cables inside a cable tray or trunking to also help against mechanical movement during high wind.
- Regular inspections must be performed to check the condition of cables and its connection. Cables which exhibit signs of bad connection, such as melted or burnt and broken insulation, have to be repaired or replaced.



- Re-route the cable and, if necessary, reduce the cable length to cut down losses.
- Avoid cable loop between the positive and negative phase. The positive and negative phase of PV string cable should be as close as possible to avoid induced voltage caused by lightning strike.
- Always support the cables with cable conduit to prevent direct contact between cables and nearby sharp edges that may lead to damage of external sheath or insulation. Cable conduit should be suitable for outdoor application such as fire and UV-resistant.

Broken insulation may lead to electric shock hazard and creating electric arc.

How to route the PV cables?

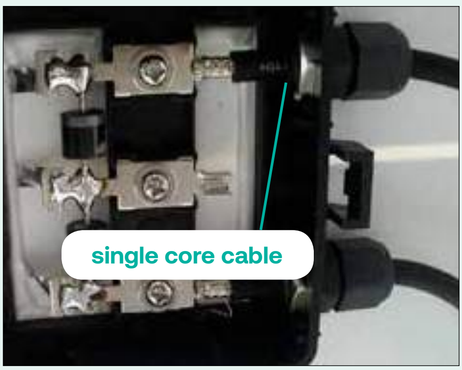
- Install PV modules in one string in top-to-top configuration where the top-side of the modules are placed in parallel with the top-side of other modules.
- Use a longer wire to connect between the top and bottom row. Long path will slightly increase the voltage drop but reduce the risk of having induced voltage.
- Route the wire along the junction boxes of the PV modules to reduce the distance between positive and negative wires (see diagram of Example configuration of several PV modules forming a PV string).

Cables are installed inside a conduit. Derating factor of the cable should be considered when calculating the conductor size.

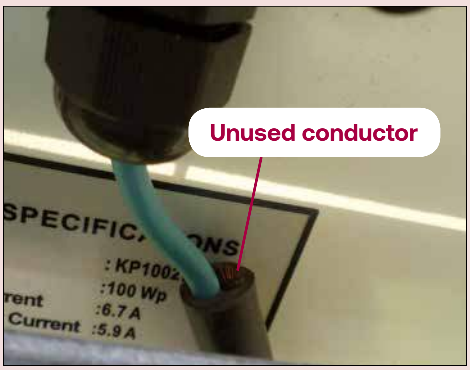
Cables are not protected in a conduit. There is a risk of insulation damage due to sharp edges.

Wires are installed along the junction box.

A short path connection may result in big cable loop, thus increase the risk of induced voltage.



Cable with proper type (single core cable) and size is used.



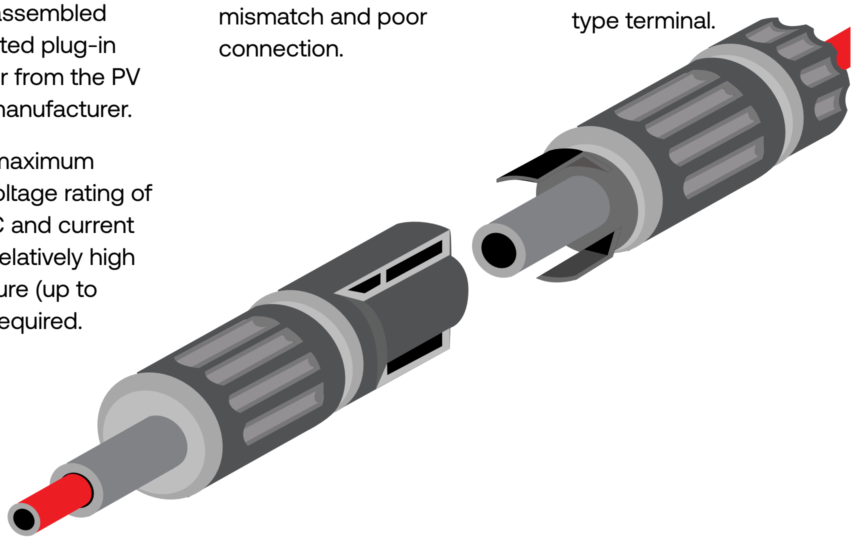
Make-shift solution of using only single wire from multi-core cable.

The cross-sectional area of the interconnecting cables between solar modules in one module string photovoltaic must not be less than 4 mm2. Avoid extreme bending of the cable. The minimum bending radius must not be less than four times the diameter cable (Radius ≥ 4D).

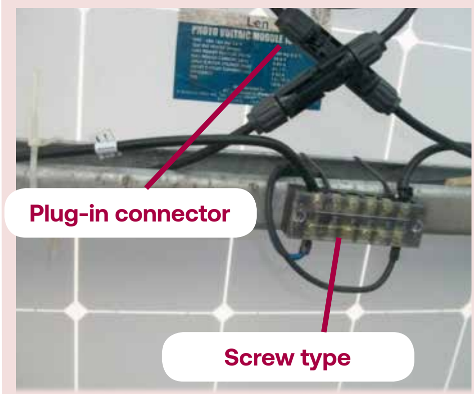
CABLE INTERCONNECTION BETWEEN PV MODULES

What to consider when selecting a PV cable connector?

- It is highly recommended to use pre-assembled or dedicated plug-in connector from the PV module manufacturer.
- Suitable maximum system voltage rating of 1000 VDC and current rating at relatively high temperature (up to 80°C) is required.
- Use plugs with similar model and type to avoid mismatch and poor connection.
- Avoid using strip connector or screw type terminal.

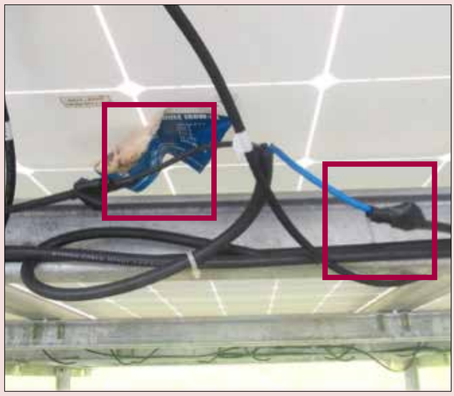


Proper plug-in connector with single core cable is used. Cables including the connectors are also located inside cable tray.



Screw terminal is installed without any protection. Exposed terminals lead to serious electric shock hazard as well as electric faults.

Neat wiring with fixed installation of connection box. Quality of the internal connection must be verified during inspection.



Poor cable connection and isolated by unsafe and lousy electrical tape. Using electrical tape may result in inadequate insulation.

Avoid using screw type terminals and unreliable electrical tape. Poor and unprotected connector as well as underrated equipment may cause internal arcs, overheating, electric shock hazard, and risk of fire.

How to fix the installation?

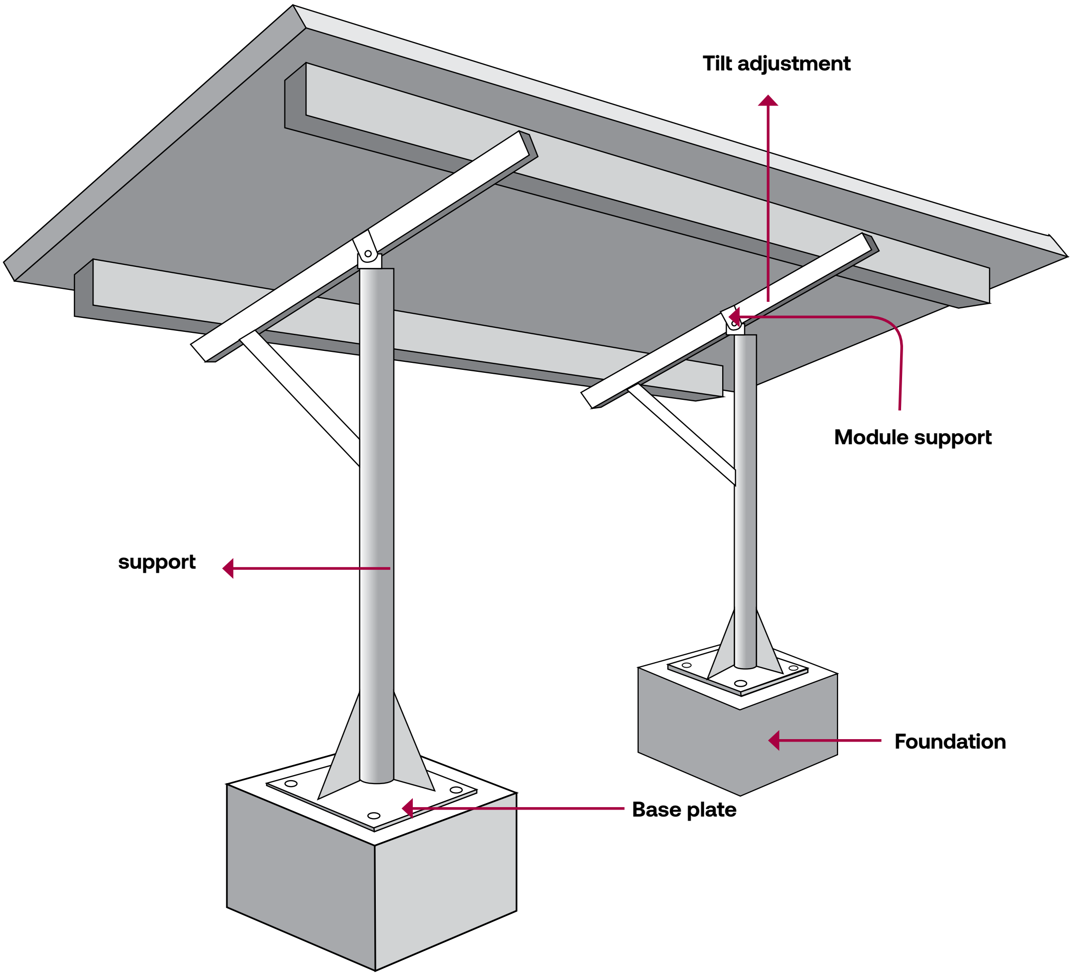
- Since the voltage at the output of PV module will always be present during the day, always use a pair of insulated gloves when working with the live conductor. Individual module may generate voltage greater than 30 VDC. Direct contact with that voltage level is potentially dangerous.
- Always disconnect the PV string from the load before interrupting the circuit or disconnecting PV modules.
- Install or replace the screw type terminal with a plug connector. Make sure that the conductors are crimped and connected properly to avoid poor contact. Bad contact will increase resistance and possibly create electric arc.
- Use the correct connector size for the cable used. Oversized cable insertion will result in water intrusion into the internal connection.
- If a plug connector is not available, screw type terminal rated at 1000 VDC and suitable current can be used. The terminal has to be installed inside an enclosure and proper cable shoes must be crimped correctly.

Never disconnect the PV module under load. Disconnecting a module under load leads to electrical arcing.

2.4 Support structure and foundation of PV array

Support structure and foundation selections are critical to determine reliability of a PV array. It is important to conduct a proper site identification during feasibility study to obtain detailed information concerning the soil type, land topography, possible obstacles for sunlight, land area, local climate condition, and required tilt angle.

A PV array structure that consists of concrete foundation, support pole, and module support

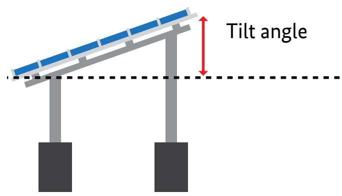


The result of the complete structure should be a sustainable permanent mounting of the PV modules array such as robust and free of corrosion. The array must be installed with correct tilt angle, azimuth[7] angle, sufficient distance between the array and nearby obstacles and with suitable foundation.

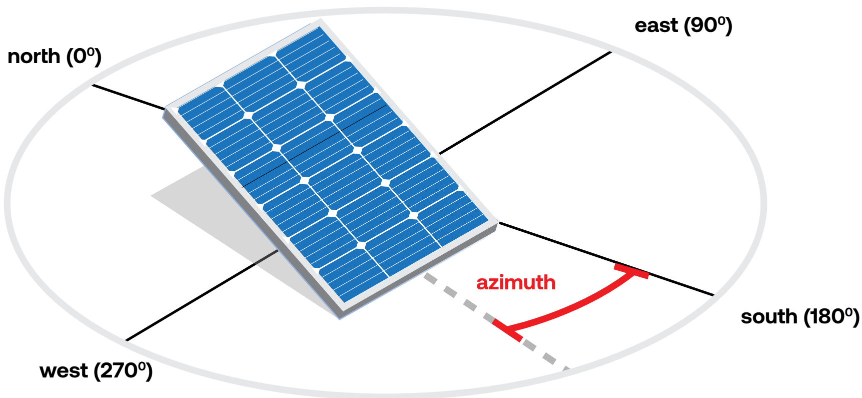
7. Azimuth angle is the compass direction from which the sunlight is coming.

PV ARRAY ORIENTATION

The tilt angle or inclination angle is defined by the latitude of the site. In a place located nearby the equator like Indonesia, the sunlight nearly hit straight on. Therefore, inclination angle of 0° is the most optimum angle to capture the direct irradiance[8]. However, 0° or relatively flat angle may cause water pooling or an accumulation of dust on the panel surface. Therefore, it is recommended to incline the module to a minimum of 10° to establish self-cleaning mechanism especially during rainy day. In the place where the solar altitude varies throughout the year, the optimum angle to maintain high performance is determined based on the average of solar altitude in different seasons.



The tilt angle can be measured using clinometer or protractor.



The azimuth angle is also known as the direction where the sun is coming. The PV module should be oriented to face the equator to obtain an optimized energy yield.

As the azimuth varies with the latitude and time, in the northern hemisphere where the latitude is above 0°, the optimum orientation of the module is 180° or facing to the south. And in the southern hemisphere or below the equator, the module should face to the true north or 0°. The direction is allowed to be deviated by up to 45° to the east or west without significantly reducing the energy yield.

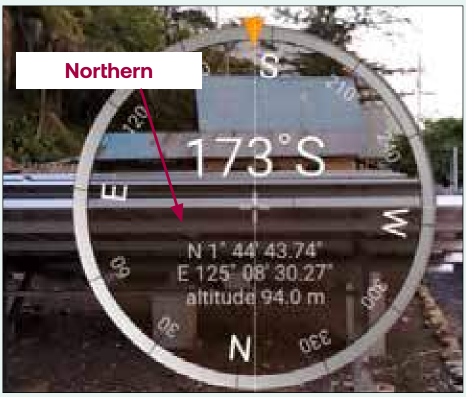
The coordinate of the sites can be found using handheld GPS (Global Positioning System). Once the latitude is known, the orientation can be defined.

8. The total amount of radiation from the sun reaching the ground surface is represented by Global Horizontal Irradiance (GHI). The amount includes Direct Normal Irradiance (DNI) which comes straight directly from the sun and Diffuse Horizontal Irradiance (DIF) which is the radiation that has been scattered by the particle in the atmosphere.

The orientation of PV modules highly determines the amount of power output from the power plant. Ideally, the orientation of PV modules should be arranged perpendicular to the sunlight to receive direct radiation. The orientation should be properly defined during the design and construction phases as it is directly affected by the orientation of foundation and structure.

PV modules are located in the equator and are tilted at the angle of 13° to establish self-cleaning mechanism.

Tilt angle of less than 10° might be insufficient for self-cleaning in the rain.



PV arrays are in a perfect orientation. It is located in the northern hemisphere and is facing south.

The site is located in the southern hemisphere but the PV is facing south (when it should be facing north). It increases the solar incident angle[9] (>0°), thus reducing the output power.

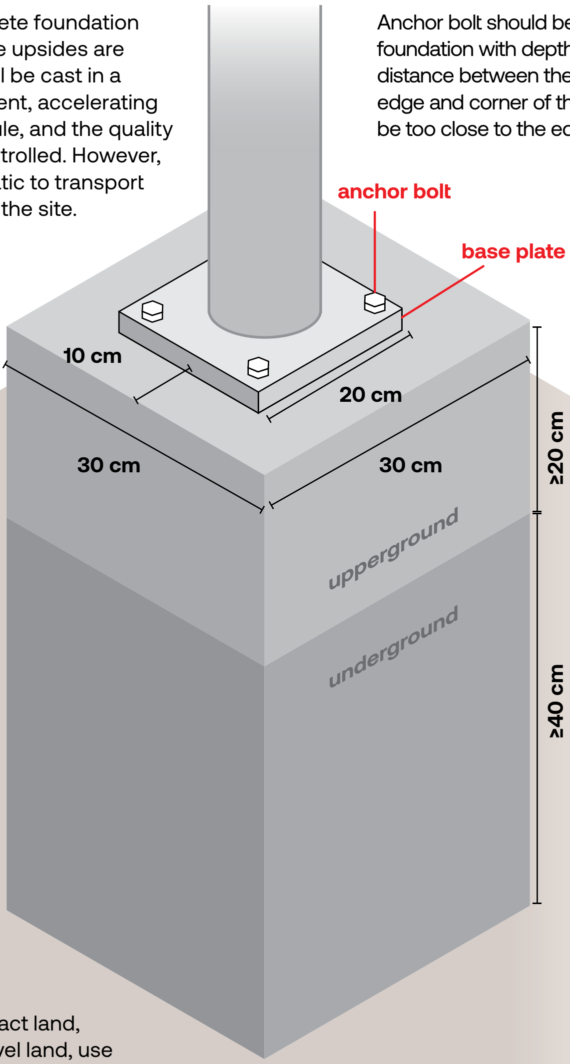
9. Angle of incident is the angle between the incident solar radiation and normal to PV array surface.

ARRAY FOUNDATION

How the foundation should look like?

Using precast concrete foundation as an alternative. The upsides are that the concrete will be cast in a controlled environment, accelerating construction schedule, and the quality could be closely controlled. However, it could be problematic to transport the precast block to the site.

Anchor bolt should be cast inside the foundation with depth of ≥ 30 cm. The distance between the anchor bolt to the edge and corner of the foundation should not be too close to the edge (≥ 10 cm).



The foundation should be reinforced with 10 cm steel framework.

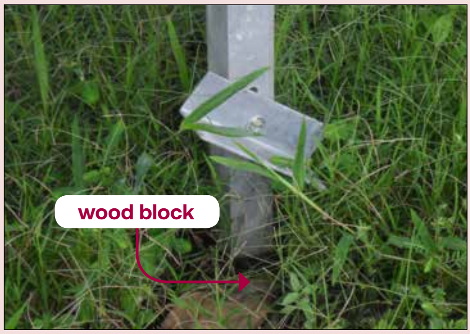
Never use wood as foundation as wooden material might be rotten and weaken the structure.

Construction of foundation should comply with a minimum dimension of 35 cm x 35 cm x 60 cm (length x width x height). If 60 cm of height is used, the installation depth of the foundation should be at least 40 cm or two third of total height (20 cm remains visible).

For stable and compact land, such as rocky or gravel land, use concrete foundation as an option. The concrete should be constructed with a good mixture of cement, sand, coarse gravel, and water. A good mixture has a ratio of 1 part of cement, 3 parts of coarse gravel, and 3 parts of sand.

In case of incompact soil of a land, such as boggy or farm land, drive-in piles may provide more stable foundation, although concrete that is buried deeper can still be used.

PV array is mounted on concrete foundation. A solid concrete foundation will ensure the stability of the structure.

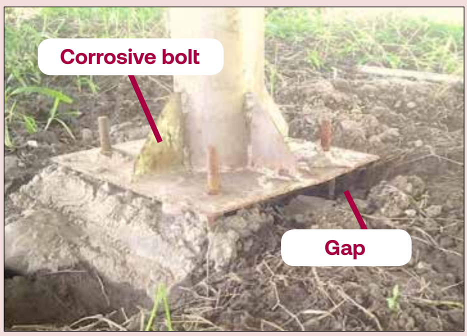


Unburried and exposed wood block is used as foundation. Small mechanical force leads to huge instability.

Very good quality foundation with plastered concrete, perfect dimension, and firmly fixed to the base plate by the anchor bolts.

Undersized foundation may not be able to withstand high mechanical load and possibly the reason of the cracks.

The concrete foundation is not burried but is placed on a flat surface of other solid concrete foundation. However, a ballast foundation is acceptable only and only if it fulfills some preconditions[10] .

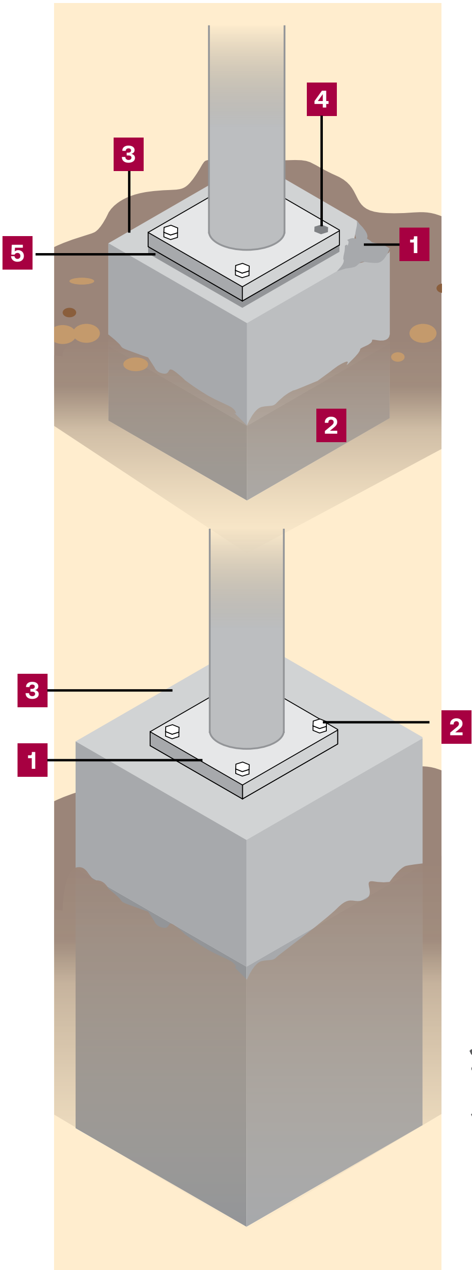


Cracking and crumbling array foundations due to bad mix of concrete. The base plate and anchor bolts are not firmly attached.

10. Preconditions for a ballast foundation are flat surface and no gap in between the surfaces, able to balance forces from the PV array structure, remain stable in case of strong wind and other mechanical forces.

How to fix the concrete foundation?

- Reconstruct the foundation by expanding the size of the concrete block and follow by increasing the distance between anchor bolts and the foundation edges.
- Clean and compact the soil around the foundation and patch with correct mix of concrete. The base plate should be properly mounted onto the foundation.



What could cause damages to foundation?

1. Poor mixture of concrete or porous structure due to excessive water use.
2. Insufficient depth of foundation.
3. Undersized foundation and insufficient distance between anchor bolts and foundation edges.
4. Missing anchor bolts that may cause vibration and increasing stress on the other bolts.
5. Gap between base plate and foundation causes unstable structures.

How to fix the foundations?

1. Fasten the nuts[11] until the base plate is firmly attached with the foundation.
2. Cut the bolts and screw new anchor bolts to securely attach the base plate.
3. Relocate the concrete foundation to align the base plate right in the middle of the block

How to maintain a good quality foundation?

1. Regularly check the condition of the anchor bolts. The bolts should be securely fastened and free from corrosion. Stainless steel or galvanized steel must be used.
2. Compact the soil prior to installation of foundation avoiding unstable structure.
3. Always check the quality of the concrete and conduct preventive action when necessary. Preventive actions comprise of grouting or patching any signs of cracks, enlarge dimension of the foundation.

11. Nut is a type of fasteners with a threaded hole

Perfect visible height of the foundation

Insufficient height of foundation. The base plate is not well-attached to the foundation results in unstable foundation.

Misaligned and unsecured array mounting plate. Better calculation and construction work are required.

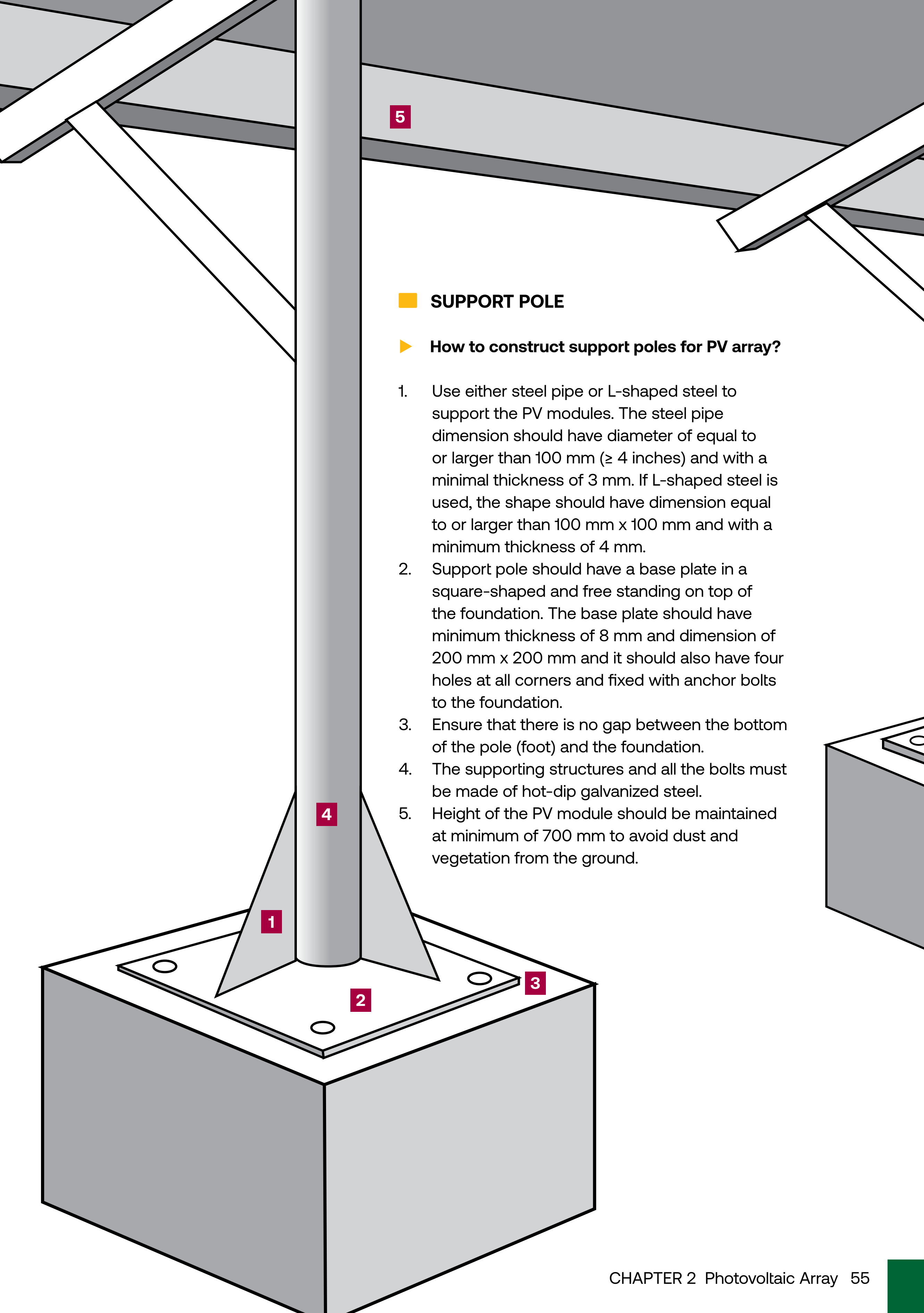
Base plate is too close to a particular side of foundation edge and is not properly screwed with anchor bo lts.

Drainage system is built to avoid erosion and flooding.

Eroded foundation may cause problem to the entire structure. Foundation should be repaired.

Although the quality has to be maintained from the early phase, grouting is one way to fill the gap.

Unfastened and corrosive anchor bolts. The bolts should be hot-dip galvanized and fastened.



SUPPORT POLE

How to construct support poles for PV array?

1. Use either steel pipe or L-shaped steel to support the PV modules. The steel pipe dimension should have diameter of equal to or larger than 100 mm (≥ 4 inches) and with a minimal thickness of 3 mm. If L-shaped steel is used, the shape should have dimension equal to or larger than 100 mm x 100 mm and with a minimum thickness of 4 mm.
2. Support pole should have a base plate in a square-shaped and free standing on top of the foundation. The base plate should have minimum thickness of 8 mm and dimension of 200 mm x 200 mm and it should also have four holes at all corners and fixed with anchor bolts to the foundation.
3. Ensure that there is no gap between the bottom of the pole (foot) and the foundation.
4. The supporting structures and all the bolts must be made of hot-dip galvanized steel.
5. Height of the PV module should be maintained at minimum of 700 mm to avoid dust and vegetation from the ground.

Strong PV modules supports and structures with neat wiring

Infirm PV array with nonuniform tilt angle.

High quality galvanized support pole.

Poor quality of galvanized support pole with missing bolts.

Make-shift solution of using wood block to fill the gap between the pole and module support. The gap should be closed by fastening the screws.

Undersized foundation may not be able to withstand high mechanical load and possibly the reason of the cracks.

Base plate is used at the bottom of the pole to anchor the pole to the foundation and increase stability.

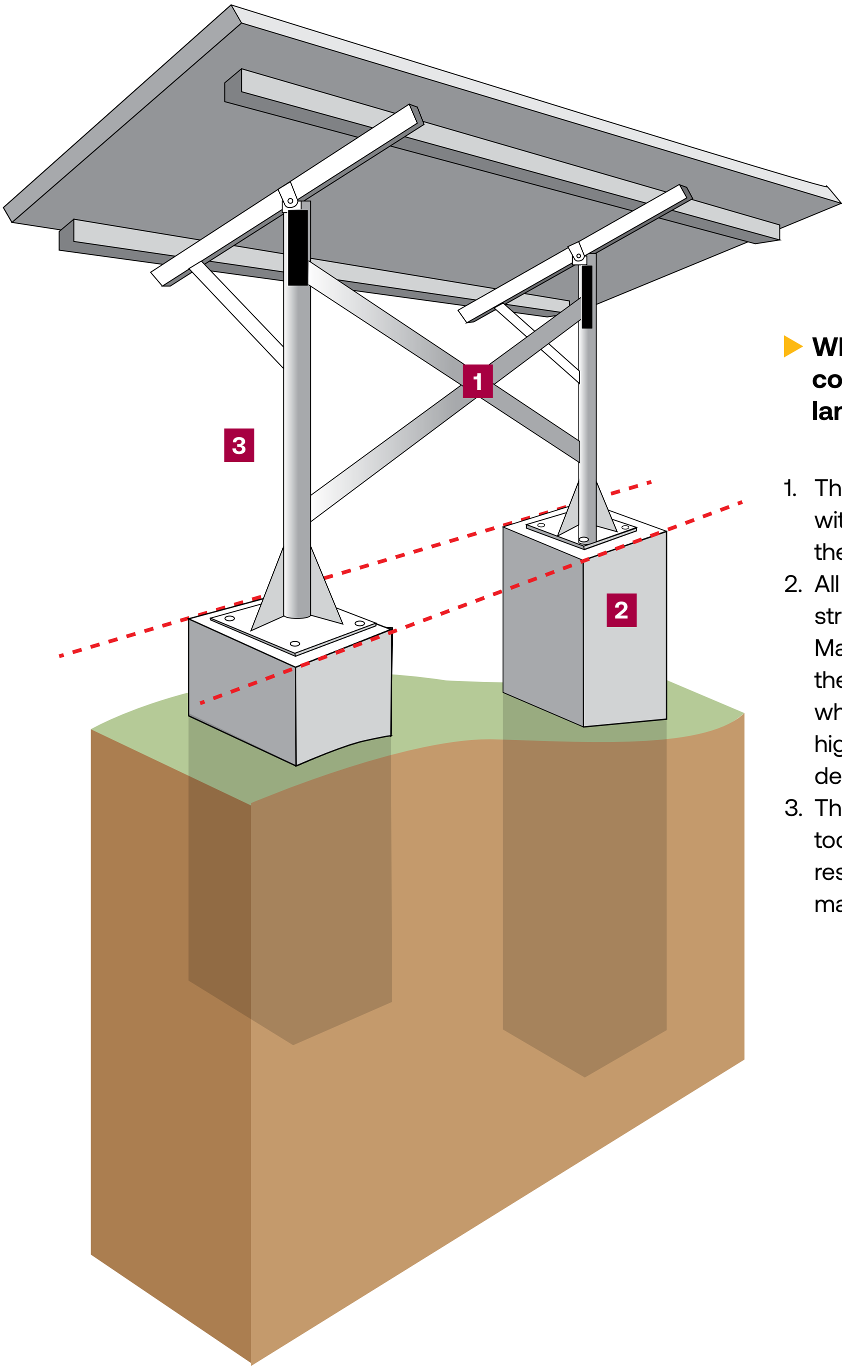
Cracked foundation possibly due to absence of a base plate. Brittle structure could not resist medium mechanical load thus the foundation is prone to damages.

Sufficient distance between the PV module and the ground.

PV near to the ground is prone to accumulation of dust and shading due to vegetations. The height is also insufficient for the wind to flow and blow off the dust.

Stable and rigid mounting structure with multiple struts.

Leaning foundaiton and insufficient steel support struts resulting an unrobust and unstable array.



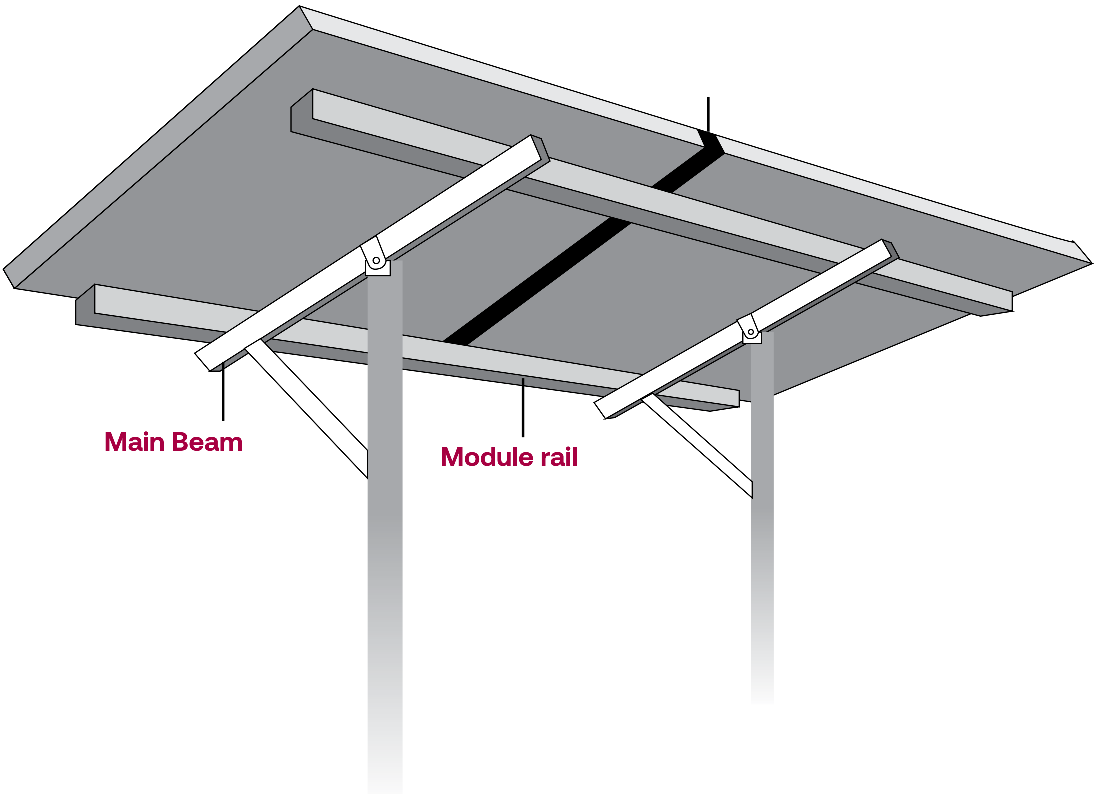
What to consider when constructing in a slope landscape?

1. The poles should be supported with additional struts[9] to ensure the steadiness of the structure.
2. All concrete foundations of a PV string should be at the same level. Maintain the proportion between the visible and buried part that when the visible foundation is higher, it should be followed by deeper foundation.
3. The structure should not be too high. A very high structure results in difficulty to conduct maintenance on the PV module.

9. Strut is a long, thin piece of wood or metal used for support in a building, vehicle, etc

MODULE SUPPORT

The module support is used to fix the module to the support structure. The module support should be robust while the PV modules should be properly mounted to prevent damages due to forces by strong wind.



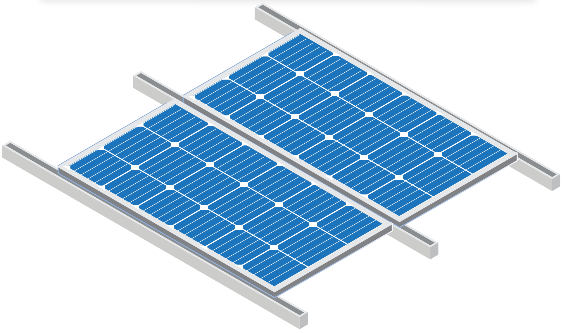
How is a good installation of a PV module support?

1. To prevent galvanic corrosion between aluminium frame and the mounting structure, separation is required such as PVC or stainless steel washer. All materials should be non-corrosive materials such as aluminium or stainless steel.
2. Use stainless steel in the place with high humidity and high salt content.
3. It is recommended to have minimum distance of 20 mm between the PV module frames to improve air circulation and anticipate the thermal expansion. The combiner box should not be installed under the gap to avoid direct sun exposure.

How to mount the PV module?

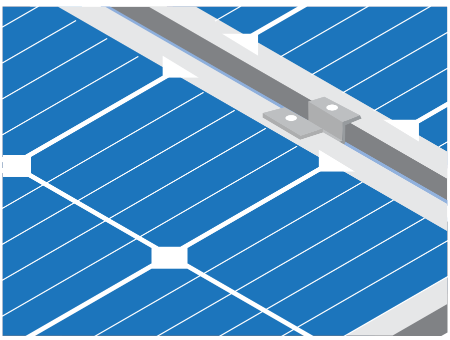
Good PV arrays construction and robust installation of the main beam and module rails.

Insufficient height of foundation. The base plate is not well-attached to the foundation results in unstable foundation.



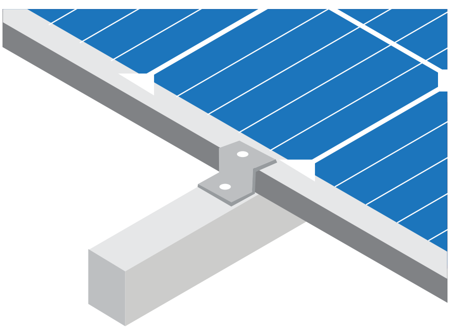
Insertion system

- PV module is installed sliding into the inner side of the mounting rail.
- To protect the frame surface from damage, PVC frame protection can be used inside the rail.



Mid-clamp

- PV module is pressed by the clamp on both sides.
- Clamps are mounted on the support structure along the PV module frame and must be in symmetrical position.
- Excessive pressure should not be applied to avoid deformation of the frame that will soon harm the glass cover.

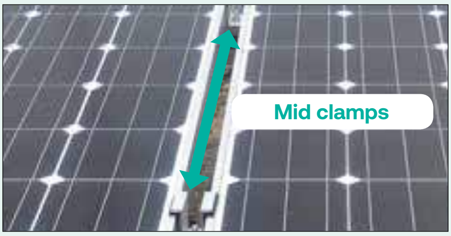


Frame mounting holes

- PV modules are directly mounted to the mounting structure.
- PV modules should have four pre-drilled mounting holes along the longer sides of the frame with two mounting holes on each side.

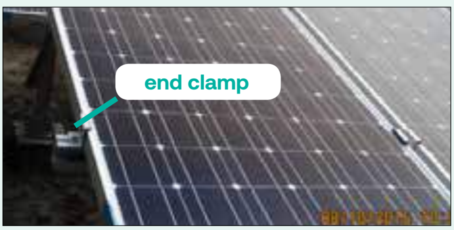
A loose PV module due to missing bolts. High wind force may lift the module and twist the frame.

Cable ties is used to mount the frame. The holes on the PV module frame should be alligned with the rail and secured with mounting bolts.



Clamps are well mounted and press the frame. The clamps should not shade the cell.a

Mid-clamp does not firmly hold the PV modules. Need to readjust the PV module by closing the gap in between.

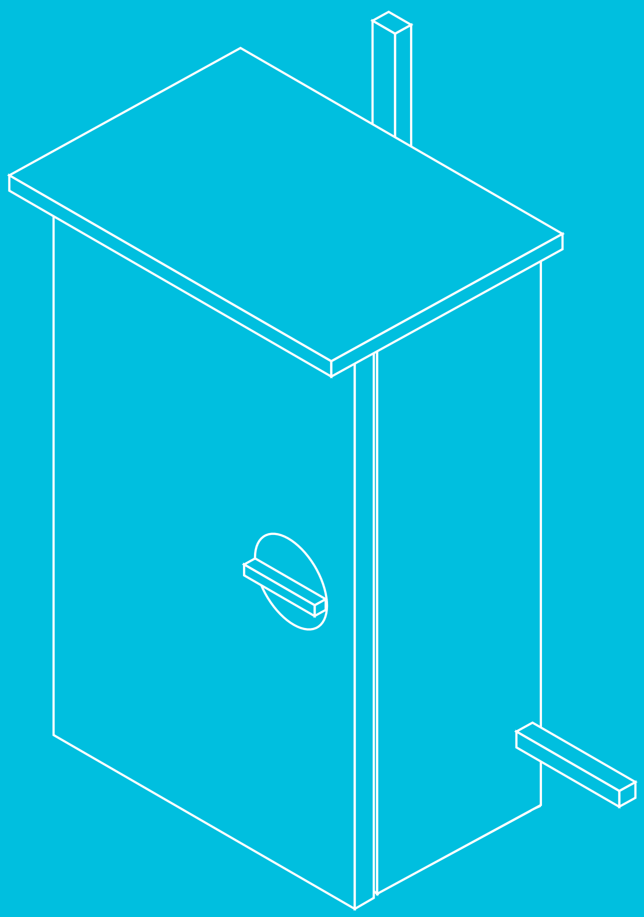


The PV module is perfectly mounted to the module rail.

Insufficient length of module rail. Extending or replacing the rail and end-clamps mounting are required.

CHAPTER 3
PV Combiner Box

- Main functions of a combiner box
- Components inside a combiner box
- Best practices to design and install a combiner box

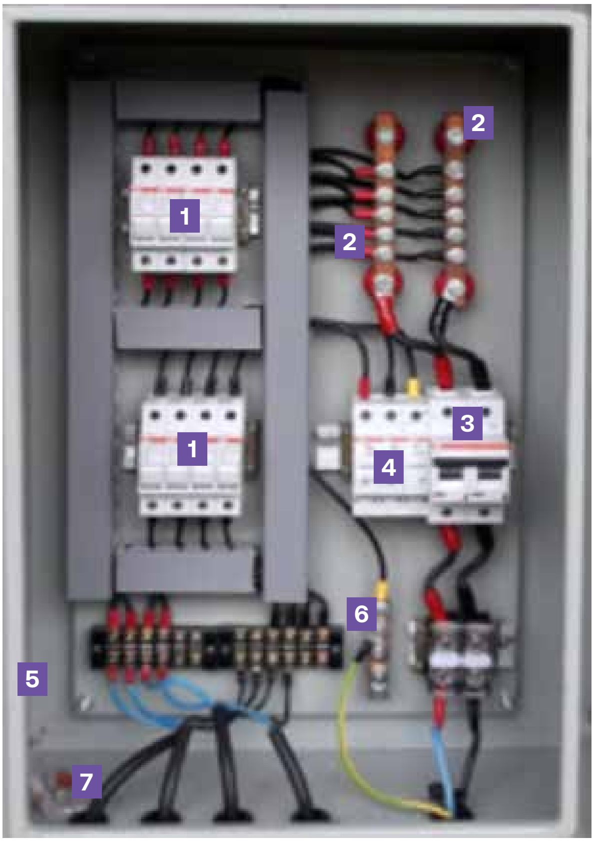


3.1. PV COMBINER BOX

The primary function of combiner box is to bring the individual PV strings into one output to obtain a higher PV output current. Individual PV strings are connected together on the busbars and both electrically and mechanically protected inside an enclosure. A typical combiner box contains string protection devices, surge protection devices, busbars or additional terminals, a disconnector switch and a grounding bar. The combined output from the combiner box is then connected directly to either solar charge controller in DC-coupling system or grid inverter in AC-coupling system.

Combiner box with four PV strings connected in parallel

1. **PV string protection** device is used to protect individual PV string against overcurrent. A fuse is typically used for this purpose.
2. **DC busbar** is the connection point for several PV strings. It brings multiple strings into a common conductor. It is made of solid copper conductor and tin-plated for corrosion protection.
3. **Disconnector switch** allows the combiner box to be safely disconnected from solar charge controller or grid inverter before maintenance work is carried out.
4. **Surge protection device** is used to limit voltage in the event of overvoltage, lightning strikes. The device is wired to positive DC bus, negative DC bus and ground.
5. **Enclosure houses** the internal components and protects them from harsh environmental condition.
6. **Grounding bar** provides grounding connection of the box (if metal box is used) and to divert voltage from surge protection device when overvoltage occurs.
7. **Cable insertion from PV string**



All components in the combiner box is operating in DC voltage that may reach up to 1,000 VDC, depending on the grid configuration. An AC-coupling system with grid inverter typically has higher input voltage of up to 1,000 VDC, while a DC-coupling system with solar charge controller is in the range of maximum 150 VDC. It is preferable and safer to have a lower voltage in PV mini-grid, although higher voltage system will reduce the losses in the circuit.

What to consider when designing a combiner box?

- The enclosure is located outdoor thus it should endure a wide range of environment condition, resisted against UV, and has a high IP[1] rating to avoid water and small object intrusion.
- Designed in accordance to IEC 60364-7-712 “Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems”.
- Ambient condition and power losses of the components affect the heat in combiner box. Managing the heat in combiner box can prevent overheating and derating of the internal components.
- Maintaining definite separation of the positive and negative sides to prevent accidental short circuit.
- All cable connections should be securely tightened to prevent fire hazards.

Combiner box made of Poly-carbonate

Combiner box made of metal sheets

1. IP Rating stands for ingress protection rating that is used to define levels of sealing effectiveness of electrical enclosures against intrusion from foreign bodies (tools, dirt, etc.) and moisture. http://www.enclosurecompany.com/ip-ratings-explained.php

3.2. ENCLOSURE

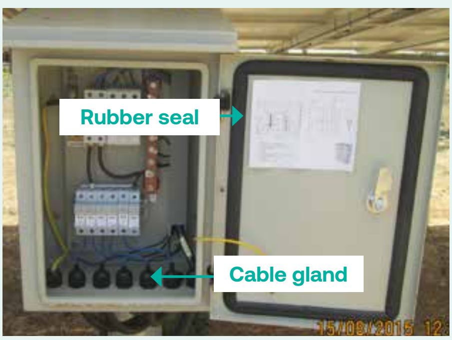
PV combiner boxes are installed outdoor and might be exposed to various environmental condition such as humidity, temperature variation, and rain. Therefore, it requires appropriate outdoor rating and should have high IP rating and UV-proof. Special consideration should also be given to the heat management inside the enclosure to increase the lifetime of the internal components.

How to improve the installation?

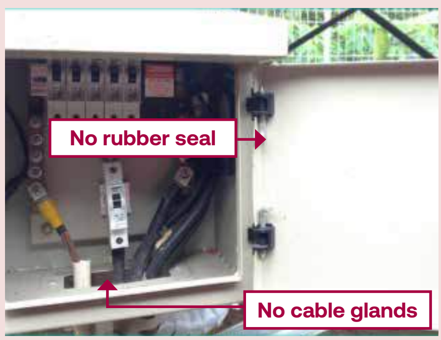
- Double insulation or protection class II. This type of enclosure does not require additional connection to the ground because of the multiple layers of insulating material between the internal components and the box surface.
- Polycarbonate, polyester, or painted steel material can be used for the enclosure. However, it is recommended to use polycarbonate material due to its durability in a wide range of environments, resisted against UV, and is an insulating material.
- As an additional safety precaution, the combiner box should be labelled and protected from unauthorised personnel.
- Combiner box should be properly sized in accordance to required PV strings to be connected.

QUALITY OF THE ENCLOSURE

The enclosure should have protection class of IP 66 or is protected against dust and powerful water jets. In order to achieve this, the door should have rubber seal and cable glands at the cable insertions to avoid water entering the box.



The rubber seal around the door and cable glands improve the IP rating of the box.



Absence of rubber seal around the door and cable glands will allow water and animal to enter the box.

How to improve the installation?

- Install rubber seal around the door and close the big hole at the bottom of the box.

- Reorganise the cable installation. If possible, recalculate the required cable size because overrated cable will reduce its flexibility.

- Drill holes for the cable glands and use glands according to the cross section of the cable.

How to ensure the ingress protection (IP) rating of an enclosure?

Bad IP rating is indicated by water intrusion, sign of corrosion, and animal inside the box. Regular check and cleaning should be done as preventive maintenance.

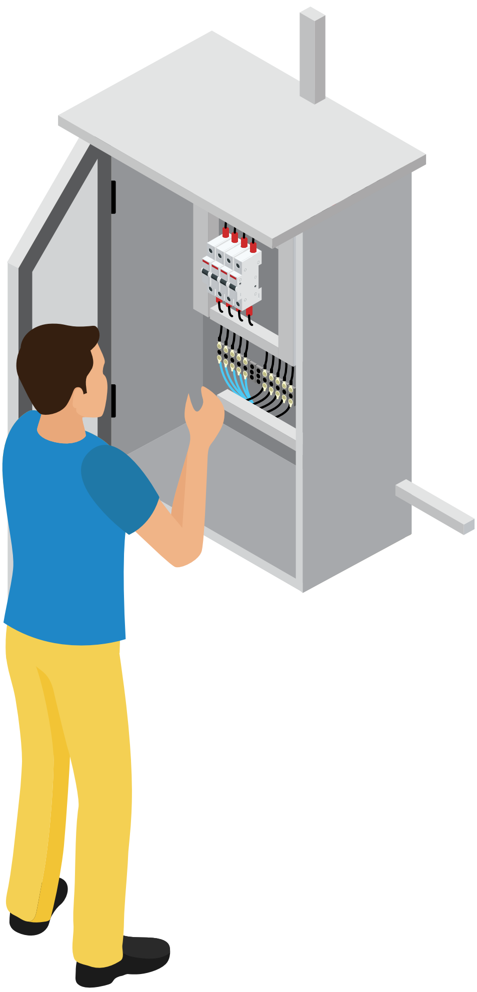
Close the door of the combiner box properly.

- All cable insertion should pass through a cable gland. The gland should be correctly sized and tightened according to the outer diameter of the cable. Do not put several cables through a single gland.

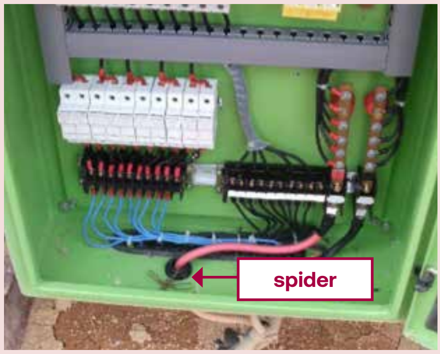
- Seal the air vent on the enclosure to increase the IP rating. However, drain valve or breather should be provided to minimize condensation.

- It is recommended to have a preassembled combiner box that is factory tested according to IEC 61439.

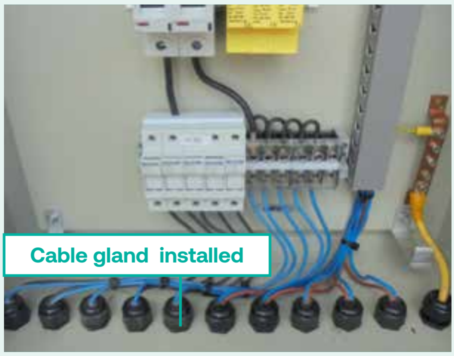
Check during commissioning that the combiner box is rated at IP 66. If written information is not provided, ensure that there is no open hole bigger than 1 mm.



Insect nests inside the combiner box due to poor ingress protection (IP).



Spider inside combiner box.



Cable glands are sized and installed perfectly.

Cable glands are not used. The sharp edge may damage the cable insulation.

Combiner box is well painted or coated to cover the material from corrosion

Corroded combiner box. the box may not be well coated or painted

How to prevent corrosion on the combiner box?

- Provide barrier between corrosive material and metal housing by painting with anti-corrosive paint.
- Consider using stainless steel material if metal box is required.
- Hot-dip galvanize the metal box or provide additional zinc or aluminium coating.
- Use anti-corrosive material such as polycarbonate or polyester.

What are the safety consideration if the box is made from metal?

- The box may not have protection class II. However, make sure the box is grounded to ensure safety for the operator.
- Additional wire should be connected between the box and door to obtain safe grounding.

Combiner box should be safe to touch in case of fault or live conductor makes contact with the box. This could be achieved by having double insulation or grounded box if conductive material is used.

Polycarbonate box provides a good insulation in case of electrical fault. Additional grounding is not needed.

Ungrounded metal enclosure endanger the operator or technician in case of fault.

INSTALLATION OF COMBINER BOX

Environmental condition will significantly influence ambient temperature in combiner box thus devalue the internal electrical components. The combiner box should be installed in a safe location and below the PV modules to maintain the desired internal temperature of the box.

Direct sunlight must be avoided as it may heat up the box and affects the housing condition during long-term use.

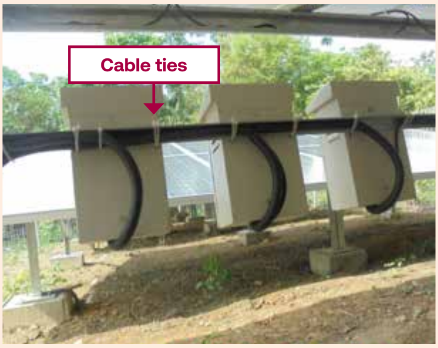
Combiner box is located under the PV module to avoid direct exposure from sun and rain.

The sun radiation will heat up the box and increase the temperature inside the box.

Ideal position of the box. Cable glands should be located at the bottom or side of the box.

Make-shift solution to cover the box from sun exposure using cardboard. Improper installation may also reduce the specified IP rating.

Combiner box is fixed and mounted firmly using suitable fasteners.

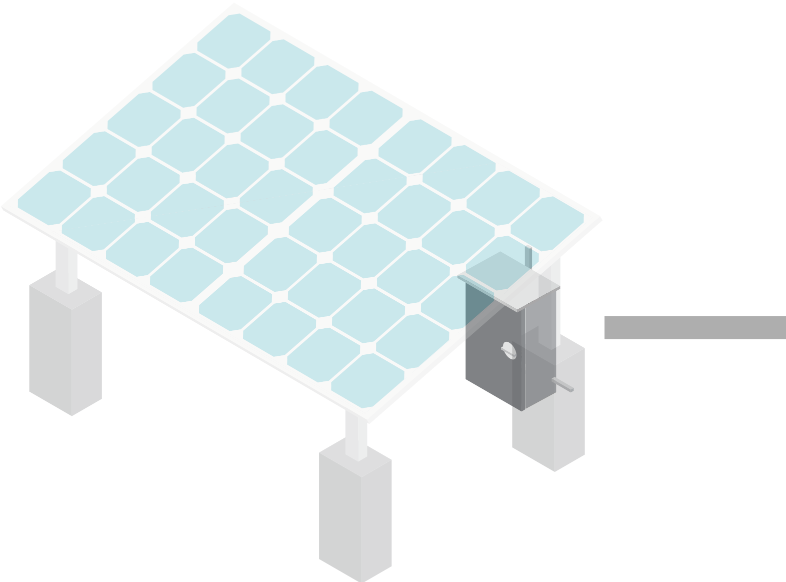


Unstable and poor installation, the cable ties may not be able to hold the load.

Cable ties must not be used to fix combiner boxes.

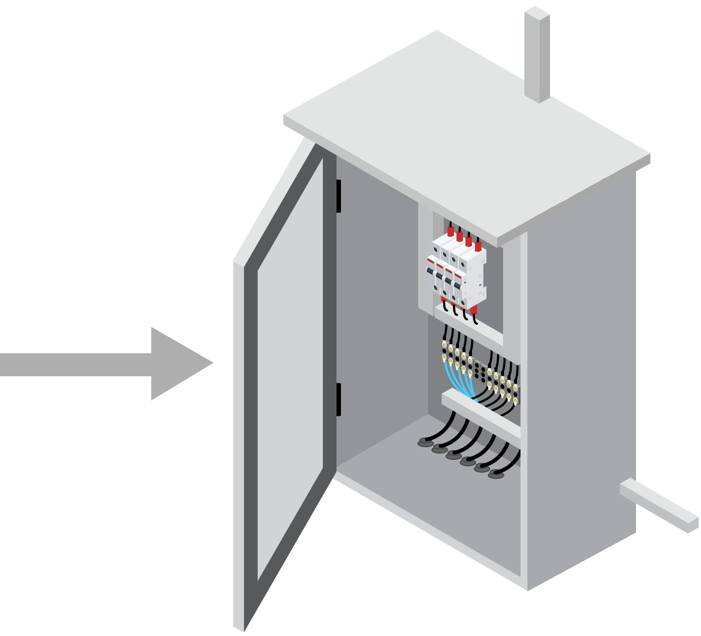
How to fix the installation?

- Relocate and install the combiner boxes under the PV modules. Ensure that there is no direct sun exposure at any time of the day.
- Re-positioned the box so that it does not reduce the IP Rating
- If relocation is impractical, provide a robust or fixed roof on top of the box.



Proper dimension of combiner box. The bigger internal space allows the electrical components to dissipate heat.

Very small combiner box considering the high number of installed electrical components.



Why the combiner box should not be too small?

- Spacious area inside combiner box provides better cooling of the internal components.
- Maintain sufficient space to work on the box during installation and maintenance. Very small combiner box is prone to unexpected mistakes.

SIGNS, LABELS, AND SAFETY PRECAUTIONS

High voltage DC may exist on the busbars or non-isolated live conductors inside the combiner box! Preventive measures before opening the box such as alerting technicians with warning sign of electrical hazard is strictly recommended.

The combiner is attached with a warning sign of electrical shock hazard.

Absence of a warning sign. Operator or technician may not be aware of the high risk of being electrocuted.

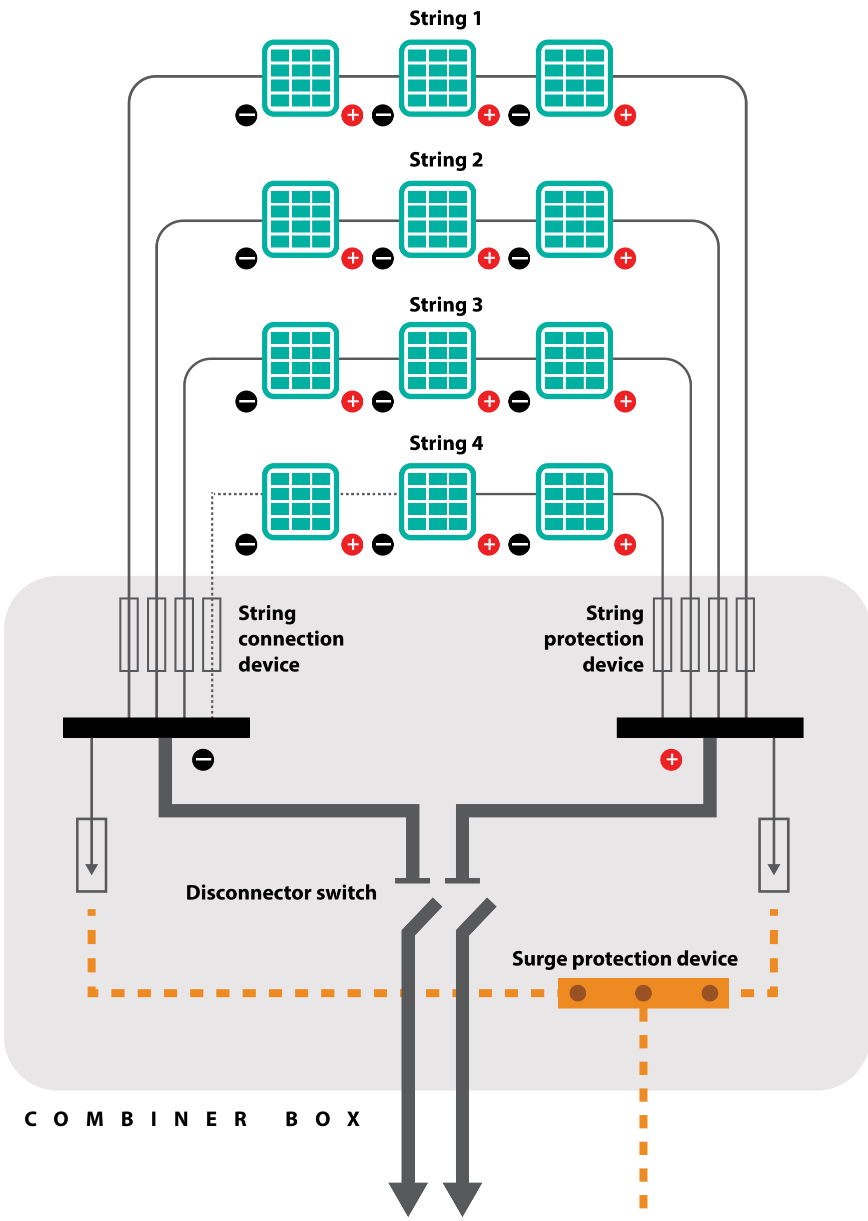
The box is equipped with lock to prevent access from an unauthorized person..

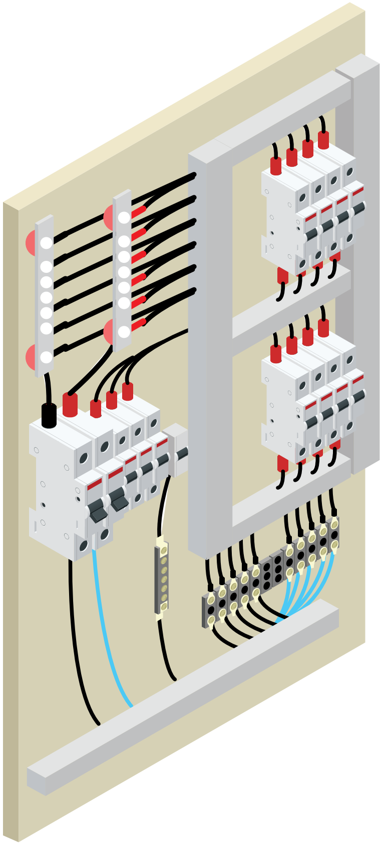
Combiner box is not equipped with lock and can be accessed by anyone.

3.3. ELECTRICAL COMPONENTS IN THE COMBINER BOX

The components inside the combiner box comprises string protection devices, busbars, surge protection devices, switch disconnector, and grounding bar. The electrical component should be selected and installed properly to achieve a proper operation and protection of the PV arrays.

▶ What is the typical electrical diagram of PV array installation?





▶ What to consider when installing the equipment?

- All components should be DC-rated and are able to accommodate voltage up to the maximum voltage of the PV strings.

- Ensure that the current-carrying conductors are correctly sized and secured by protection devices from being overheated caused by excessive current. Protection devices should also be properly sized to avoid unresponsive devices or unexpected trip

.

- Using protection device that can be reset, such as MCB, is recommended due to the limited spare parts in rural areas.

Electrical drawing is available and attached to the combiner box to easily identify the components.

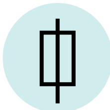
The installation is not provided with drawing. This may cause difficulty during service or maintenance.

STRING PROTECTION DEVICE

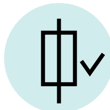
Each PV string has to be protected with a string protection device when a combiner box has more than two strings connected in parallel. The protection device will protect the connected cables and PV modules against overcurrent and reverse current in PV strings. It will disconnect the faulty string and keep the rest of the strings in operation.

What to consider when selecting string protection devices?

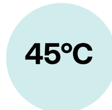
- Only consider protection devices that have proven DC switching capability.



- It is recommended to use MCBs than fuses. MCB is more sensitive, easy to identify faults, able to be reset, safer, and provides individual string isolation.



- If fuse is preferred, use PV type of fuse specifically designed for photovoltaic installation.

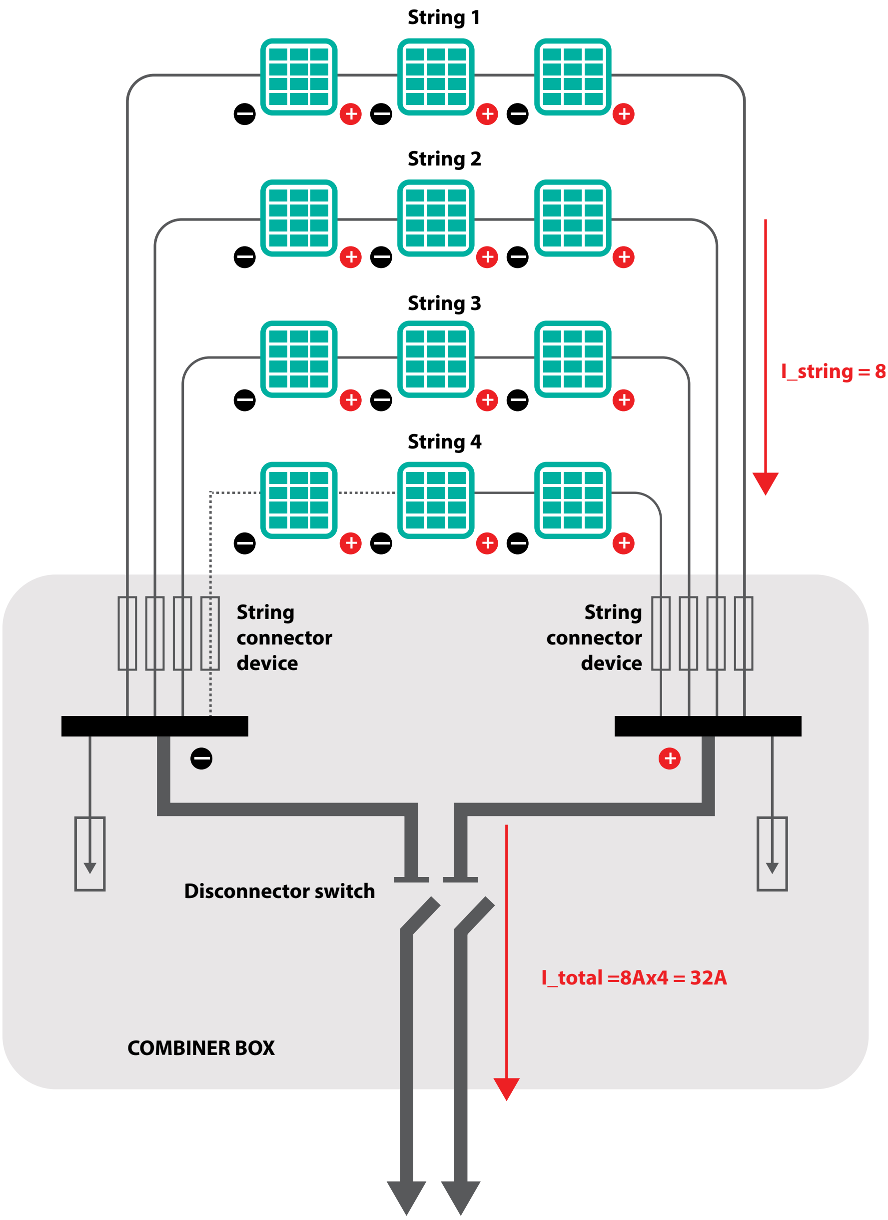


- The current capability of the protection device should consider derating factor in case of high ambient temperature. It is safe to consider derating factor at ambient temperature of 45°C.

Why string protection device is important?

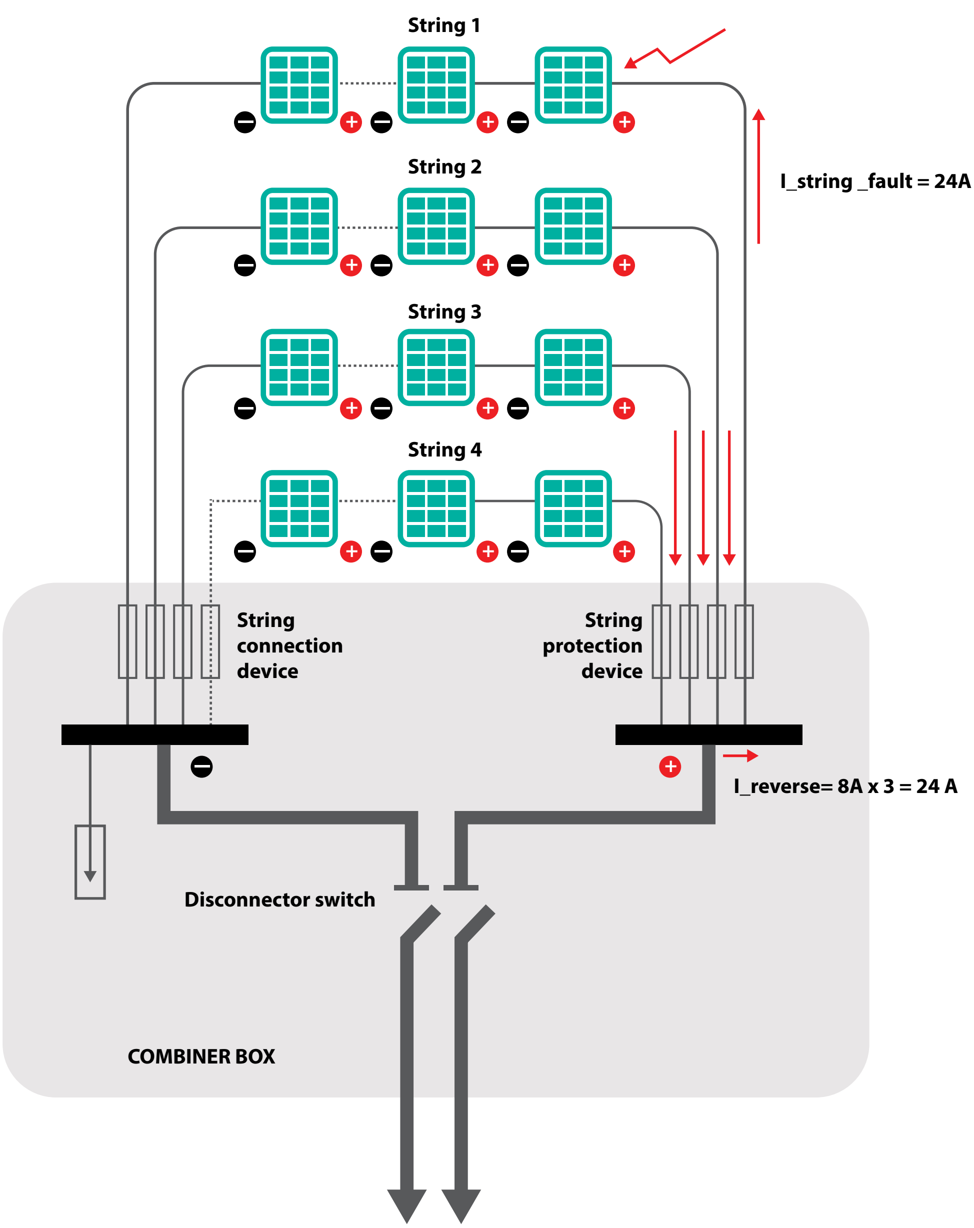
The reverse current in PV strings occurs in the event of faulty wiring or short circuit in a PV module. During normal condition, the current of each string is summed and feeding into the charge controller. Once electrical fault occurs, the voltage of the faulty string is significantly lower than the healthy ones. This results in flow of current from the healthy strings to the faulty one instead of to the solar charge controller. A considerable sum of current from the healthy strings may increase the temperature of the faulty PV module as well as the conductor. It is also possibly causing fire if no overcurrent protection is installed.

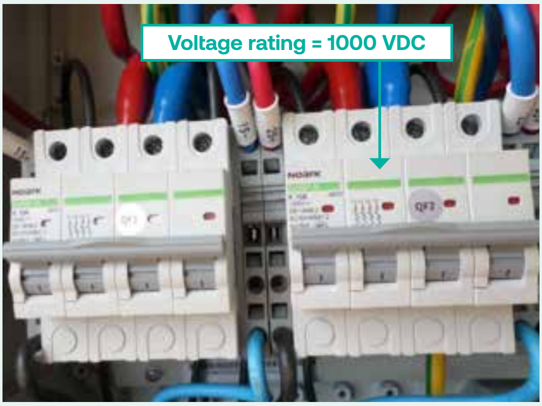
Normal condition



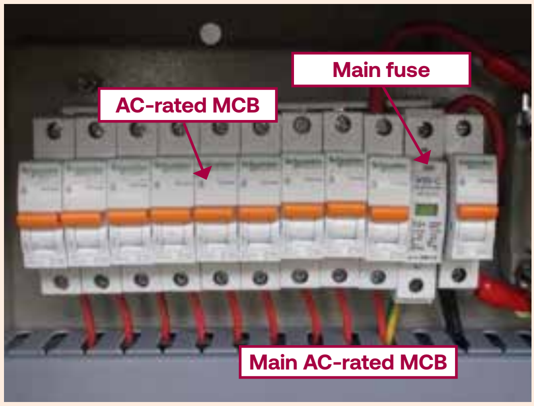
Never use an AC-rated circuit breaker in a DC circuit. Only use circuit breakers that have proven DC switching capability.

Faulty condition





DC-rated MCBs are used to protect PV strings.



Wrong type of circuit breaker is used. AC-rated MCB may not be able to extinguish the DC arc.

How to fix such installation?

- Main fuse is not necessary to be installed as there will be a small chance the fuse will burn. It is recommended to remove the main fuse and bypass the cable since the fuse will generate heat when current is flowing.
- Replace all AC-rated MCBs with DC-rated protection devices. Opt to use a string fuse instead of blocking diodes. Blocking diodes cause additional drop of voltage for about 0.5 to 1 V that leads to significant power losses. The function is better served by a string fuse.

How an AC switch and a DC switch extinguishes electric arc?

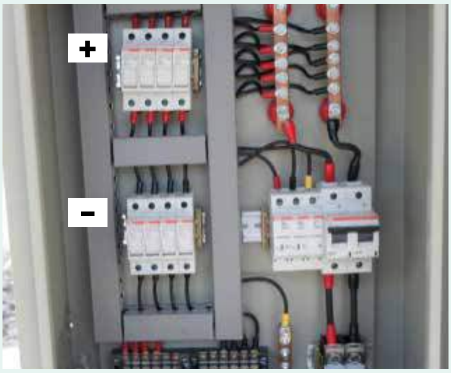
The function of a switch is to interrupt the circuit from/to power source, in this case PV array and the load. During the event of disconnecting, the internal contacts detach and an electric arc will be created as the current jumps across the air gap. In this period of time, the arc must be extinguished to stop the flow of current through the circuit. As the characteristic of AC and DC voltage is different, the AC and DC switches extinguish the arc differently.

• AC switch

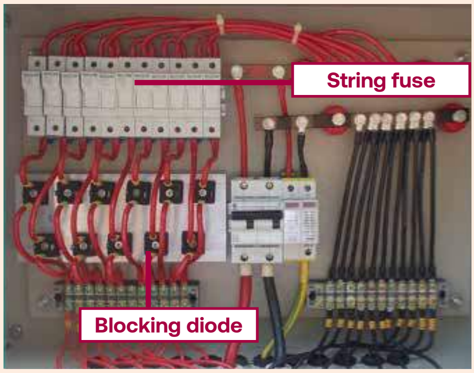
In the AC circuit, the voltage alternates in sinusoidal form 50 times per second (for 50 Hz grid) between +V and -V. Since there is a point at which the voltage is at 0 V, the switch will interrupt the connection as well as extinguish the arc particularly at 0 V.

• DC switch

Unlike the AC circuit, DC circuit is constant and does not alternate. Since there is no 0 V, the AC switch will not be able to interrupt a DC circuit. A DC switch uses magnet to attract the arc from the air gap and extinguish it. Therefore, never use an AC switch that is not equipped with magnet as it is unable to extinguish the arc.



Fuses are installed at both positive and negative sides. Spare fuses are also provided in the box.



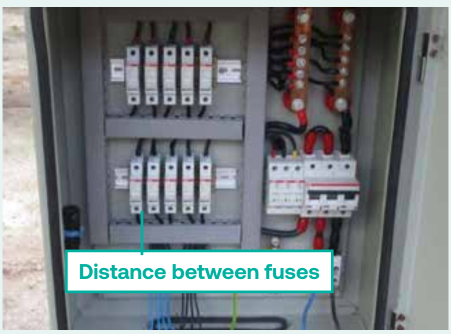
Negative side (see black cables) is not protected by any protection device. Fuses and blocking diode are used.

Opt to use a string fuse instead of blocking diodes. Blocking diodes cause additional drop of voltage for about 0.5 to 1 V that leads to significant power losses. The function is better served by a string fuse.

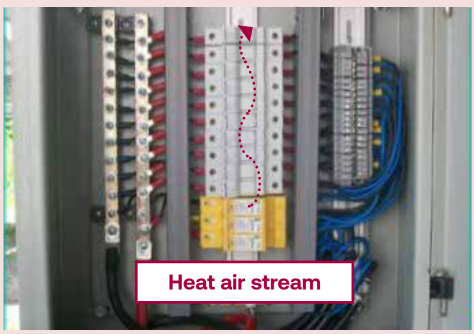
▶ Why the string protection device should be provided at both positive and negative sides?

- To protect the string cable in case of double ground fault. Double ground fault occurs when the negative and positive sides touch the ground at the same time. In this case, fault current path may still be existed if protection device is not provided.
- To provide isolation at both positive and negative sides.

! Consider ambient temperature, power losses and ideal temperature of the internal components when designing the layout of the installation.



Fuses are installed in horizontal arrangement with adequate distance between the fuses.



Fuses with vertical arrangement may cause unexpected trip on the top fuses during normal operation.

How to ensure proper operation of the protection devices?

- Use correct size of the protection device.
- Conduct inspection to regularly monitor the fuses condition. Burnt fuse or tripped MCB should be investigated immediately.
- Electrical fault has to be located and cleared before switching the MCB back on or replacing the fuse.
- Fuse holder should never be left empty. Insert a dummy fuse to avoid the spark gap.
- Provide a minimum of 20% spare fuses from the total fuses installed with similar size and rating inside the box.

Never open the fuse holders during operation or under load. Intervene the circuit during operational may lead to fire, due to electric arc and electrical shock hazards. Main switch disconnector has to be opened.

How to size string protection devices?

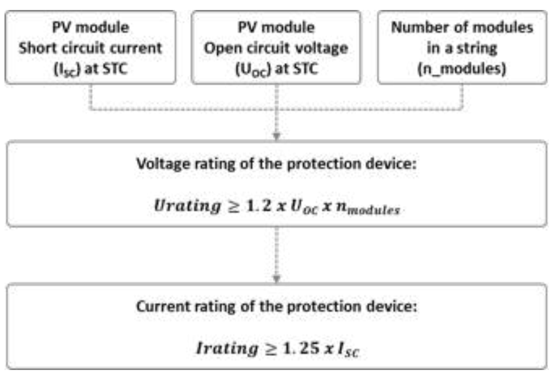
Example:

PV module specification:

- Short-circuit current (ISC) = 8 A
- Open-circuit voltage (UOC) = 25 V
- Number of modules connected in a string (n_modules) is 10.

Minimum voltage rating (Urating) is 300 V (1.2 x 25 V x 10).

Minimum current rating (Irating) is 10 A (1.25 x 8 A).

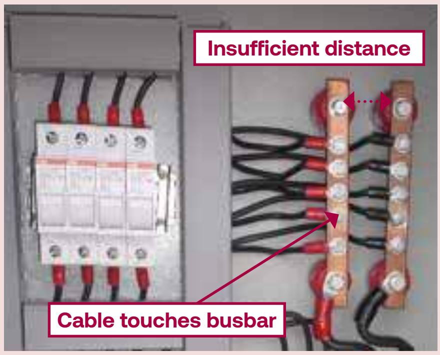


BUSBAR TERMINAL

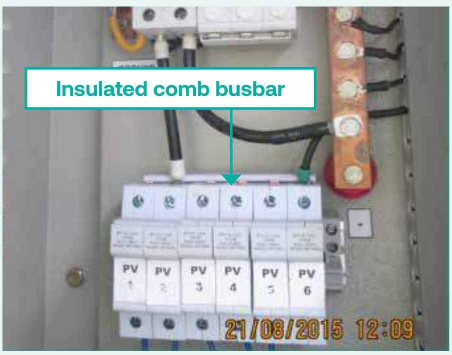
How to safely install positive and negative busbars?

- Keep sufficient distance between positive and negative busbars. It is recommended to install connections from different polarities on different sides.
- Ensure that there is no contact between cable conductors and busbars to avoid damage on the cable insulation which is prone to short circuit.
- If rearrangement is not possible, install a non-conductive separator between the positive and negative busbars.
- Heat-shrink insulation tube should be installed on the surface of the busbar to reduce the risk of having short circuit as well as reducing the clearance in between.

Positive and negative busbars are separated by cable tray.



Insufficient distance between positive and negative busbars.

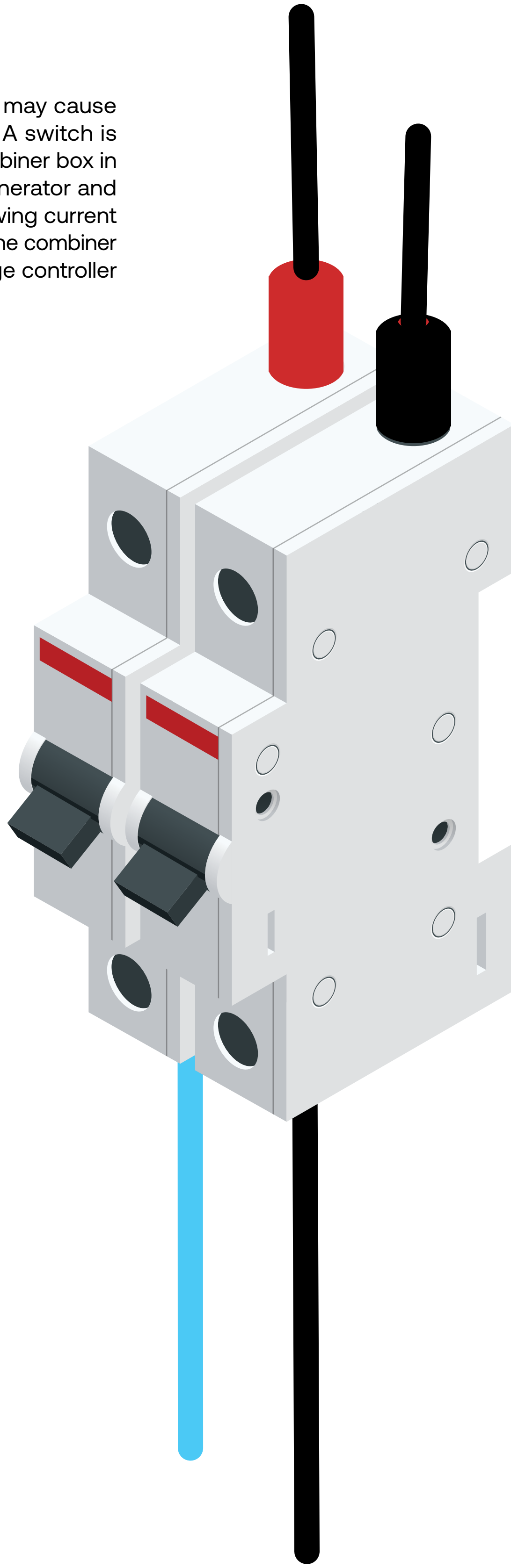


Comb busbar is covered by insulation material to avoid accidental short circuit.

Unisolated and bare live conductor or unisolated busbar is prone to have short circuit.

DISCONNECTOR SWITCH

Interrupting a relatively high voltage DC circuit may cause electric arc and possibly lead to fire hazards. A switch is required to be installed at the output of the combiner box in order to safely disconnect or isolate the PV generator and load. The switch will ensure the absence of flowing current and voltage during service and maintenance on the combiner box, wiring to the power house, and solar charge controller or grid inverter.

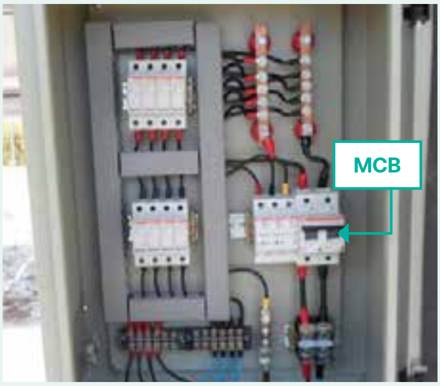


What should be considered when installing a switch disconnector?

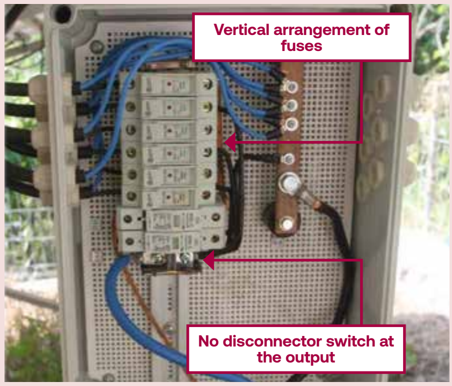
- The rated current of the switch should be 1.25 times higher than the total current of the connected PV string. For example, if five PV strings with short-circuit current of 8 A are connected in the combiner box, a switch disconnector rated at ≥ 50 A should be used (8 A x 5 strings x 1.25 = 50 A).

- The switch should be DC-rated and graded at maximum open circuit voltage of the PV array. In case the voltage reaches 1000 VDC, four poles in series are required to break the circuit.

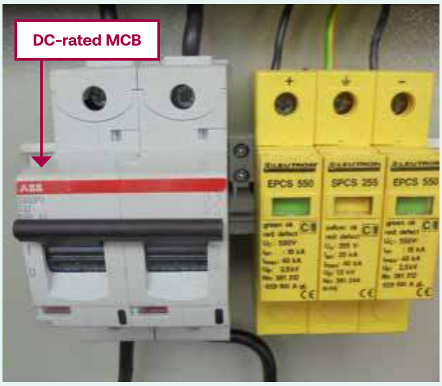
- Switch disconnector should allow safe disconnection. Prior to maintenance, it should easily be accessible by the operator or technician to disconnect the PV string.



DC-rated MCB is used as a switch disconnector to isolate PV strings from the load.



Single-pole AC MCB is used to disconnect DC circuit. AC MCB will not be able to estinguish the arc.



Double-pole DC MCB rated at 800 VDC is used to interrupt and isolate the circuit.

Single-pole AC MCB is used to disconnect DC circuit. AC MCB will not be able to estinguish the arc.

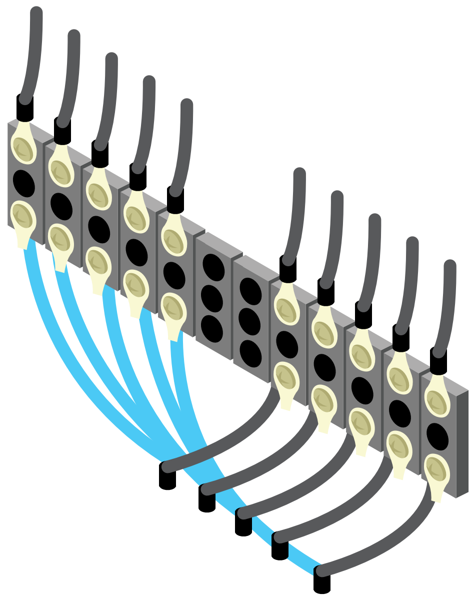
How to fix such installation?

- Install a double-pole switch disconnector at the output to isolate the PV array during service and maintenance.
- In case of unavailable DC switch disconnector, a double-pole DC-rated MCB with the correct voltage and current rating can be used.
- Rearrange the fuse installation to a horizontal configuration to avoid unintentional trip of the upper fuses.

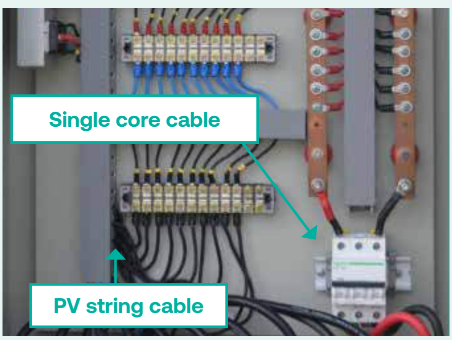
CABLE INSTALLATION

How to avoid poor cable installation?

- All cables should be terminated using the correct type and size of cable shoes. Always check the tightness of the crimping by slightly pull the cable.
- Inspection should be conducted in a regular basis. Use an infrared camera to identify loose connections. Poor connection can be indicated by warmer points.
- Ensure that all the screws and bolts are fastened. If necessary, re-torque all electrical connections in the combiner box.
- It is recommended to use preassembled and tested components to avoid unnecessary mistakes when performing assembly on site. Quality assurance e.g. continuity test may also be conducted in the factory to ensure a proper connection and ideal ambient temperature.
- Avoid using excessive cable terminals. Additional screw terminal will add new source of problems as well as additional resistance.



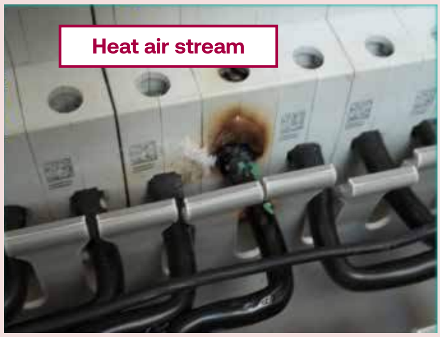
Never use an AC-rated circuit breaker in a DC circuit. Only use circuit breaker labelled as DC-rated for DC application.



Bigger size of the single core conductors are used. The cables can handle the PV array current.

Multi-core cable is connected in parallel to increase the capacity of the cable. The cable is not equipped with cable shoes either.

Poor cable crimping may risk the safety of the operator and may lead to ground fault.



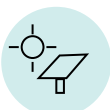
Burnt sign at the terminal of MCB. Possibily due to electric arc caused by loose cable connection.

Cables are well equipped with cable shoes and screws are properly fastened.

Melted screw terminals. The screw terminals are not designed to handle the string current.

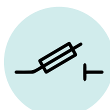
Cables must be terminated and properly tightened. Crimping and a bad connection can result in increased heat due to high-resistance connection and possible fire risk

What safety precautions should be taken into consideration before conducting an inspection?



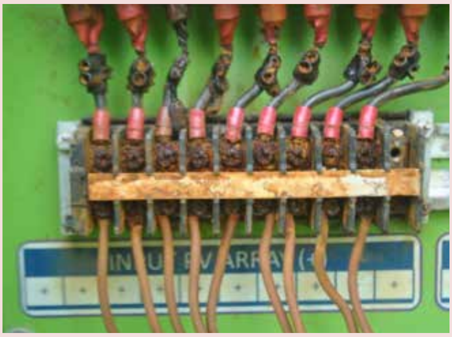
- PV modules always generate electricity when they are exposed to the sun. It is less dangerous to conduct the inspection during cloudy time.

- Always wear insulated rubber glove.



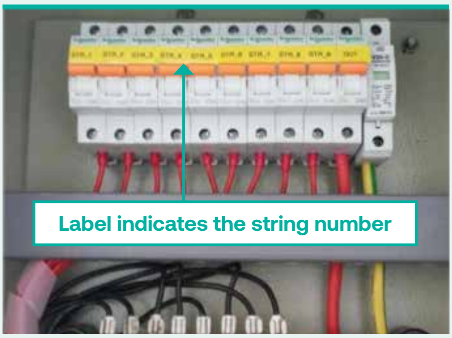
- Open the switch disconnector to break the load.

- Ensure that the enclosure is grounded or has good insulation.

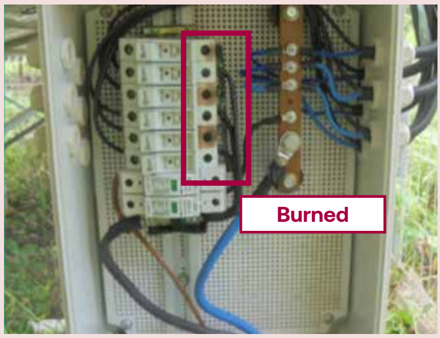


Corroded terminals. Ensure that the enclosure has high IP rating and replace the corrosive terminals.

Corrosion may increase the resistance of the terminals.



Poor cable crimping may risk the safety of the operator and may lead to ground fault.



Unlabeled components and wrong cables are used.

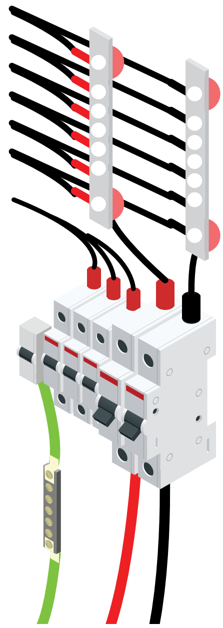
Difficulties in conducting service or troubleshooting are often found when tracing and finding the correct components. It is recommended to label all components and put the circuit diagram at the door of combiner box.

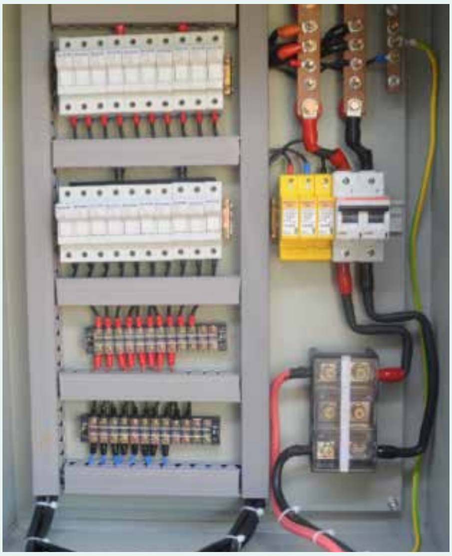
Why correct labelling is required?

- The operator can easily follow the instruction through the labels, if remote troubleshooting should be conducted.
- Provide safety precautions for the operator to be more careful when conducting activities.

What insulation colour of wire should be used?

(red swatch)	red	DC positive (+)
(black swatch)	black	DC negative (-)
(green swatch)	green	grounding





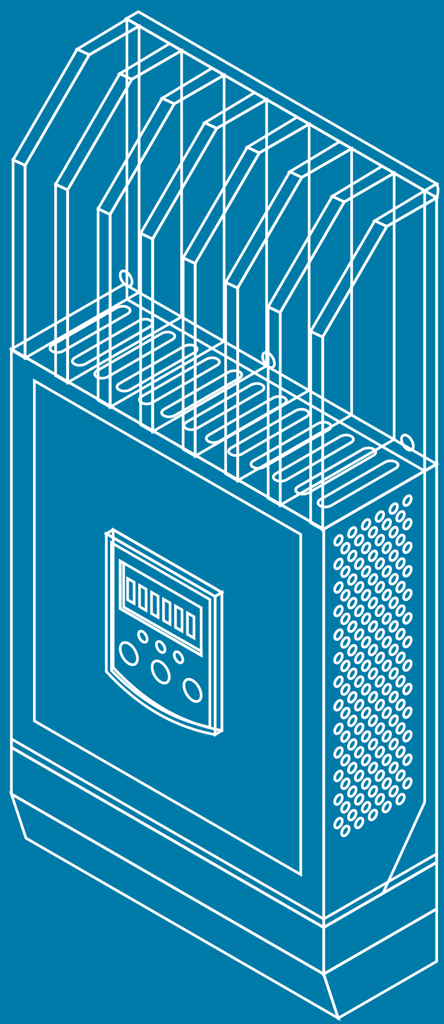
Cables are neatly wired and routed inside cable tray.

The cable is not installed in the cable tray and it has excessive cable length.

Cables should be arranged neatly and not too long. A very long cable will cause unnecessary voltage drop..

CHAPTER 4
Solar Charge Controller

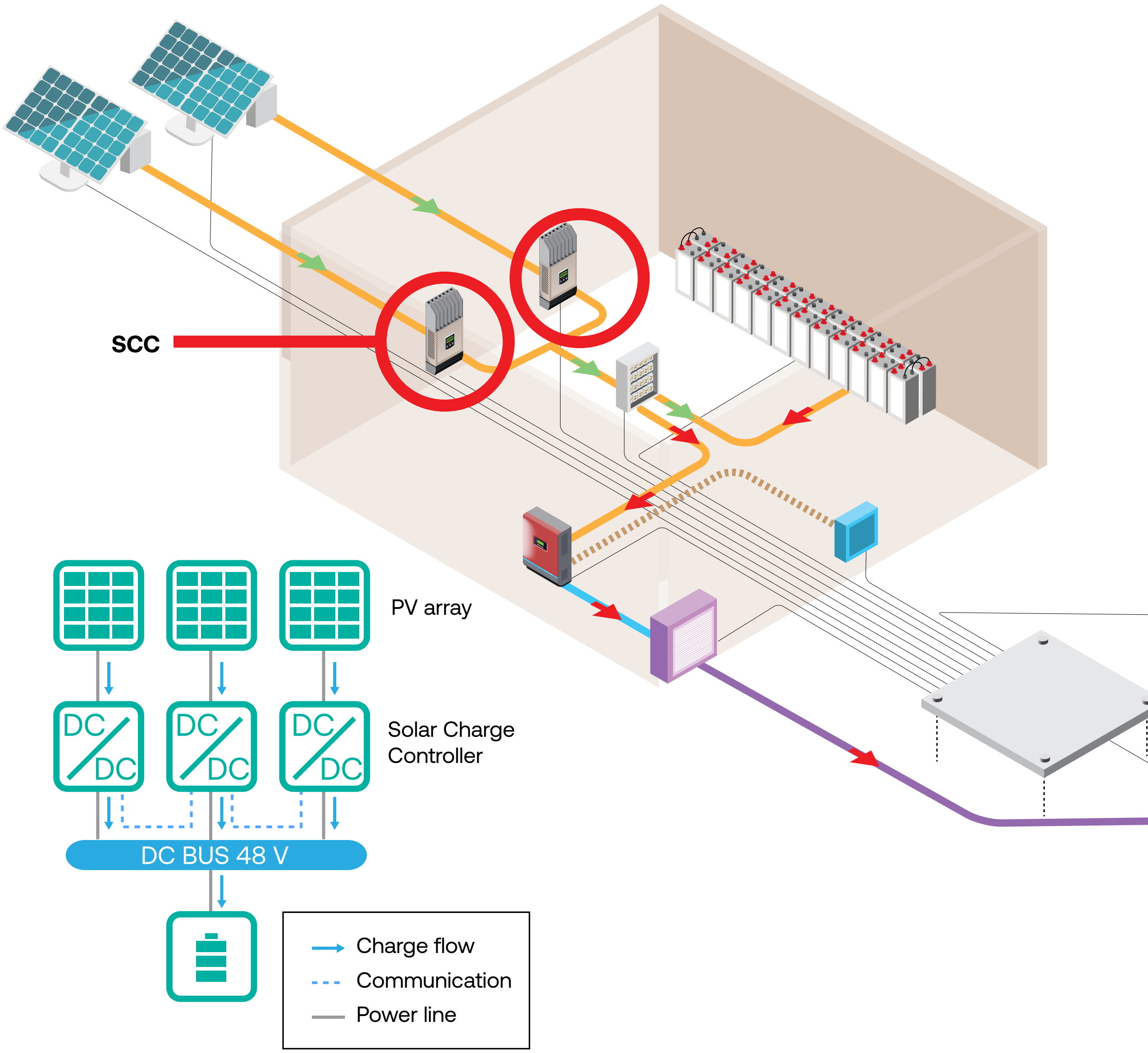
- ✓ What is solar charge controller?
- ✓ Good and bad installation of solar charge controller
- ✓ Things to consider when setting the parameters



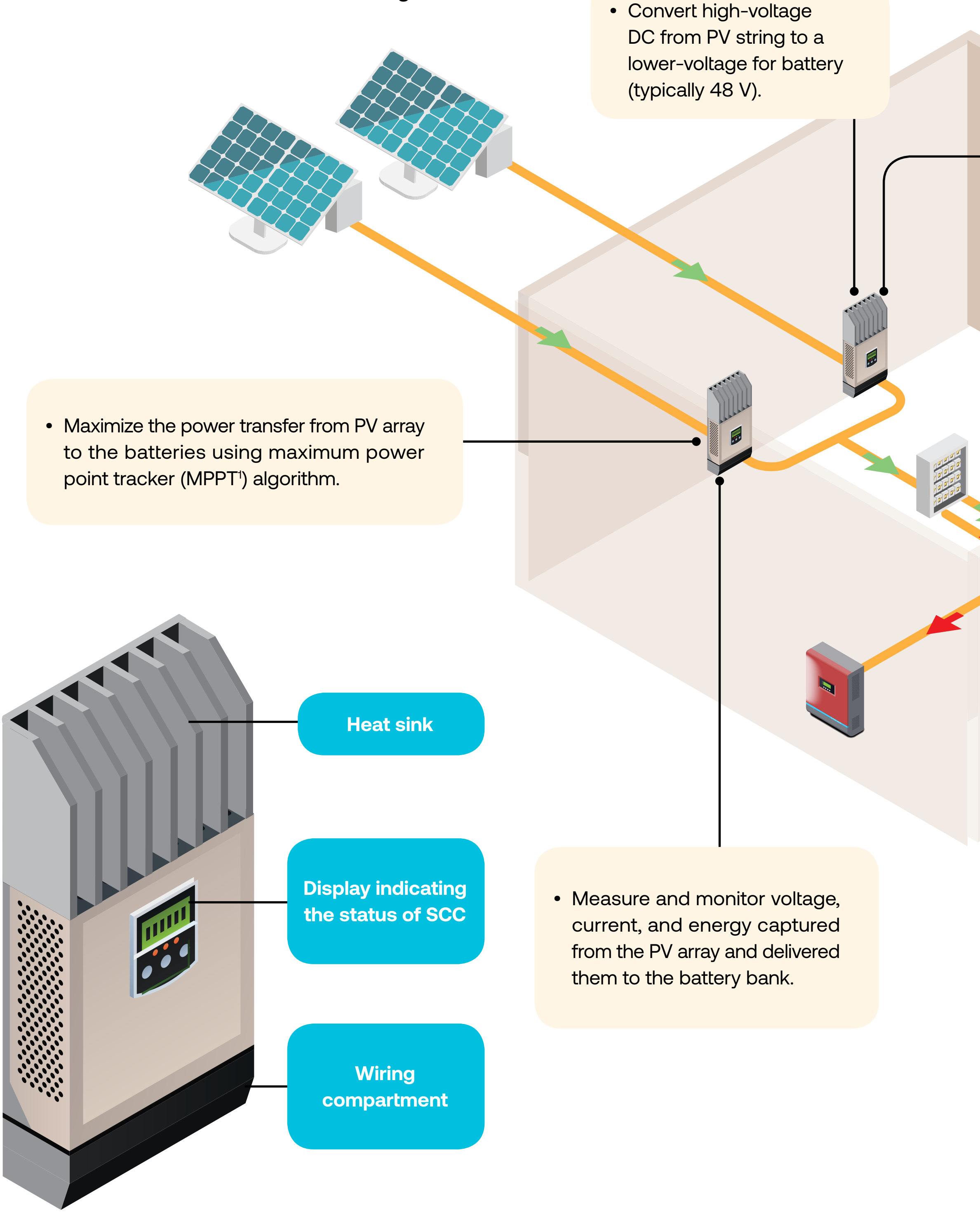
4.1. WHAT IS SOLAR CHARGE CONTROLLER?

Solar charge controller (SCC) or also known as battery charge regulator (BCR) or charge regulator is a power electronic component in a PV mini-grid to provide interface between the PV array and the battery bank to allow an optimal battery charging. It operates by regulating the charging voltage and current based on the available power from the PV array and the battery state of charge (SoC). To achieve higher charging current, multiple charge controllers can be installed in parallel on the same battery bank to combine the power from each PV array. In this case, data interchange between the devices is required.

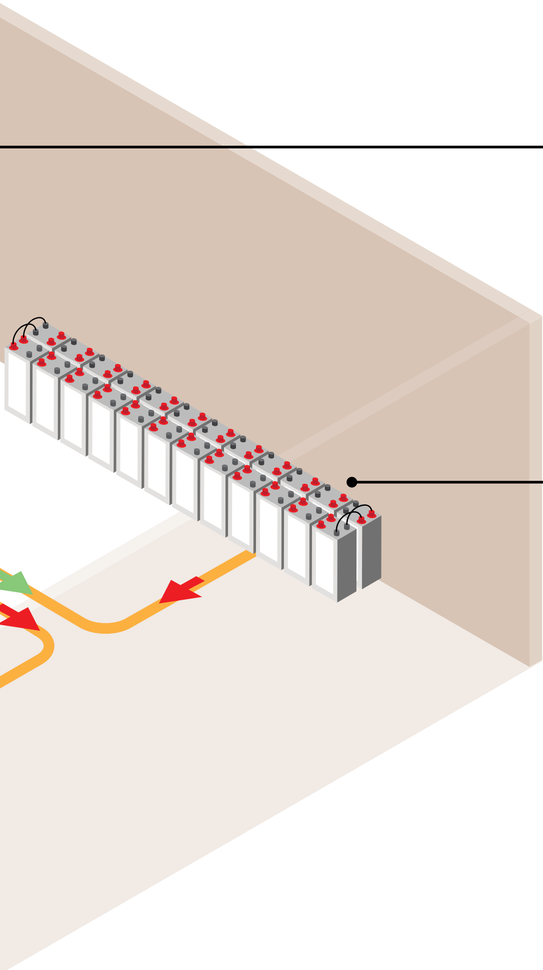
Typical installation of SCCs in the PV mini-grid system.



What are the functions of a solar charge controller?



1 Maximum Power Point Tracker is an algorithm or technique used by solar charge controller or grid inverter for tracking and extracting maximum possible power from PV array under certain conditions.



- Block reversing current from the battery banks during the time with insufficient solar irradiance or at night.

- Protect battery banks from overcharging by decreasing the charging current from PV array when the battery is already full. Overcharging the battery may cause gassing and explosion depending on the battery technology.

Schneider MPPT 60 150

SMA SIC 50-MPT

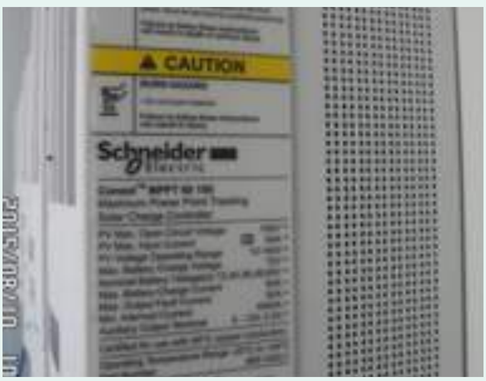
SOLAR CHARGE CONTROLLER SPECIFICATION

Selecting a proper type and design of SCC is important for the efficiency and life time of the PV mini-grid system, particularly for battery. SCCs are specified mainly based on the configuration of PV array, system voltage, and characteristic of the battery. Hence, it is crucial to understand the specification of the SCC to avoid harming the controller. The table below explains common terms used in the specification

Max. open circuit voltage [V]	Maximum input DC voltage of PV array at open circuit voltage (UOC)
MPP or operating range [V]	Range of voltage range for maximum power point tracker
Max. input current [A]	Maximum input DC current of PV array at short circuit current
Output voltage [V]	Nominal battery voltage
Max. battery charging current [A]	Maximum output current to charge the battery at certain voltage

Leonics SCB 48120

Morningstar TriStar TS-MPPT-60



Label attached on the SCC shows the electrical characteristics of the installed SCC. The information on the label is useful to identify the type and specification, especially during inspection or maintenance.

What is the ideal specification of a solar charge controller?

- **Maximum input voltage and current of the device must be higher than maximum voltage and current of the connected PV array at any condition**, as well as considering the PV modules temperature coefficient. Module temperature of less than 25°C will increase the output voltage whilst higher temperature will increase the output current. Safety margin of 1.25 for both input current and voltage should be considered.

Max. input voltage SCC > 1.25 x U_{OC} PV Array

Max. input current SCC > 1.25 x I_{SC} PV Array

- **High efficiency** (≥ 98%) at system voltage and featured with MPPT.
- **Equipped with the following protection systems:**
  a. Input reverse polarity, when accidentally make incorrect connection with the wires
  b. High-voltage disconnect, that automatically stops the charging process when the battery voltage reaches the defined limit to avoid overcharging the battery.
  c. Overcurrent protection, the device should be rated at least 125% of the PV array short circuit current.
  d. PV ground fault protection, to protect the cables when the conductors of the PV module touching the grounding system.
  e. Overvoltage protection, placed at the input from the PV array.
  f. Temperature-compensated battery charging is the ability of SCC in controlling the charging voltage based on battery temperature.

- **Suitable for the installed battery technology** (i.e. lead-acid, lithium-ion, zinc-air, etc.). Every battery has different characteristics, therefore appropriate configuration is required, especially when designing and installing the system. The nominal output current of solar charge controller should not be higher than the permissible charging current of the used battery. The cut-off limit or high-voltage disconnection threshold of the battery should be configured differently for each battery technology.

Max. charge current SCC ≤ 10C* rate battery (lead-acid)

Voltage at CV mode ≤ Maximum voltage of battery

*C-rate is the rate which defines duration of a battery to be charged or discharged at full capacity. The 10C rate means to allow the battery to charge or discharge within ten (10) hours, for example, 10C of 1000 Ah battery is 100 A. Battery with lower C-rate offers faster charge and discharge. Lithium batteries allow lower C-rate, hence higher current per hour.

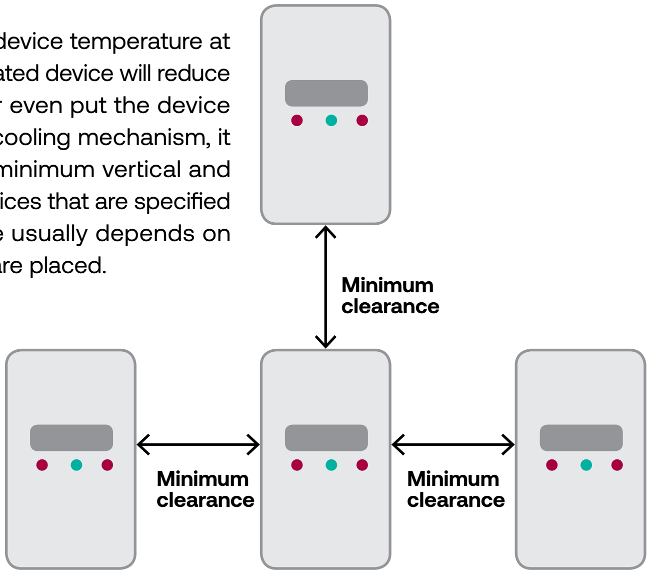
- **User friendly display that shows the status of SCC.** It will help operator or technician to easily monitor the system.
- **Tested and certified according to IEC 62509.** The standard comprises of information regarding battery charge controllers for photovoltaic systems as well as performance and functioning charge controllers.
- **Manufactured by a reputable company** that has good track record and clear warranty procedures.
- **Connect only the similar brand and type of SCC** in parallel when aiming a higher power.

4.2. SCC HARDWARE INSTALLATION AND WIRING

As the installation requirements are different between the products, this chapter will only cover general aspects of the installation. To access information that are specific to manufacturer or product, it is highly recommended to follow the user manual of the product.

LOCATION AND ARRANGEMENT OF THE UNITS

Good airflow is crucial to keep the device temperature at ideal operating temperature. Overheated device will reduce the output power of the system or even put the device into a faulty condition. For a good cooling mechanism, it is recommended to consider the minimum vertical and horizontal distance between the devices that are specified by the manufacturer. The distance usually depends on where the heatsink and ventilation are placed.



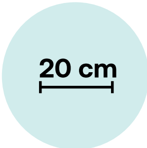
Configuration of SCCs with minimum clearance required by manufacturers. Check the user manual for the minimum clearances.

Perfect distance between the devices. The heat convection will not affect the equipment next to it.

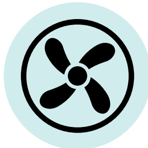
Insufficient distance between the devices will hamper heat dissipation of the device.

Sufficient distance between the SCCs should be provided to allow heat to dissipate. Rated performance may not be achieved if the clearances are below the requirement.

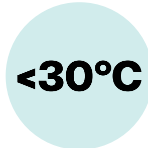
How to improve the heat management of the installation?



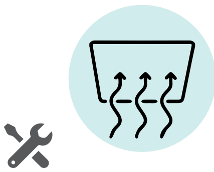
- **Re-arrange the position of the charge controllers** based on the recommended layout specified by the manufacturer. In general, 20 cm is an acceptable distance between the devices for both vertically or horizontally.



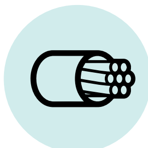
- **Power electronic equipment should not be installed inside an enclosure**, unless an adequate ventilation, such as active cooling, is provided. If the enclosure is not equipped with cooling fan, relocate the SCCs to an open area inside the power house to get natural cooling for the devices.



- **Make sure that the ambient temperature** of the room is below 30°C.

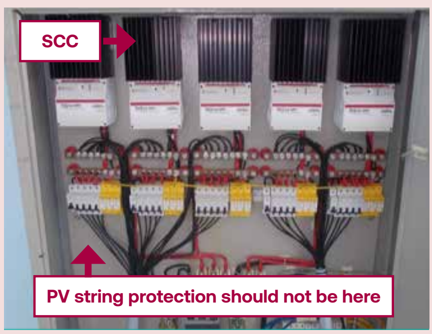


- **Regular cleaning for the ventilation** of the SCC using dry cloth to avoid accumulation of dust.



- **Install cable support to protect** and route the cables. Heat dissipation of the cables may also contribute to accumulated heat inside the panel.

Perfect distance between the devices. The heat convection will not affect the equipment next to it.



Untidy and very dense installation. Installing SCC inside an enclosure requires a good air ventilation.

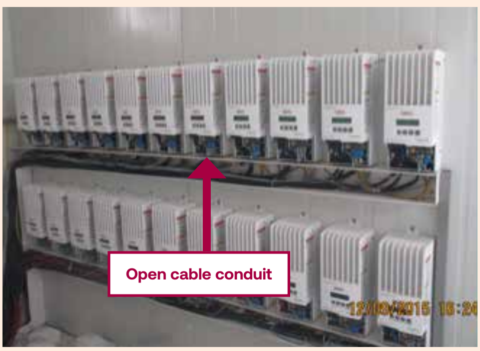
CABLE INSTALLATION OF SOLAR CHARGE CONTROLLER

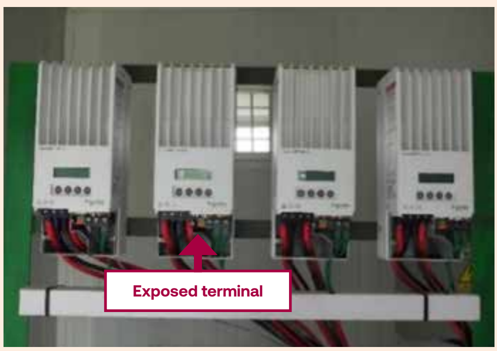
The cable installation of the solar charge controller includes power cable and communication cable. The power cable facilitates the distribution of power from the PV array and to the batteries, while the communication cable ensures communication between the SCCs to exchange information, providing control as well as data acquisition. It is highly important to install both cables in a proper way.

Why wiring of solar charge controllers should be done properly?

- Reducing the risk of having short circuit and electric shock hazard to the operator/ technician.
- Synchronising the charge states between the SCCs to obtain optimal charging of battery and sharing information of the temperature among the SCCs to activate the compensation.
- Avoid having high voltage drop that may cause premature charging termination.
- Collecting measurement data from the monitoring system.

The cable compartment of SCC should always be covered. High voltage DC may exist at the input terminal. Disconnector switch at the combiner box has to be switched-off prior working on the cable compartment.





Exposed terminal of solar charge controllers. High voltage DC may exist at the terminals and cause an electric shock. The network power cable should not be routed together to avoid noise in the communication.

Cable glands are used to protect the cable and prevent animal entering the compartment.

Cable glands are missing. Absence of rubber around the sharp edges may damage the cable insulation.

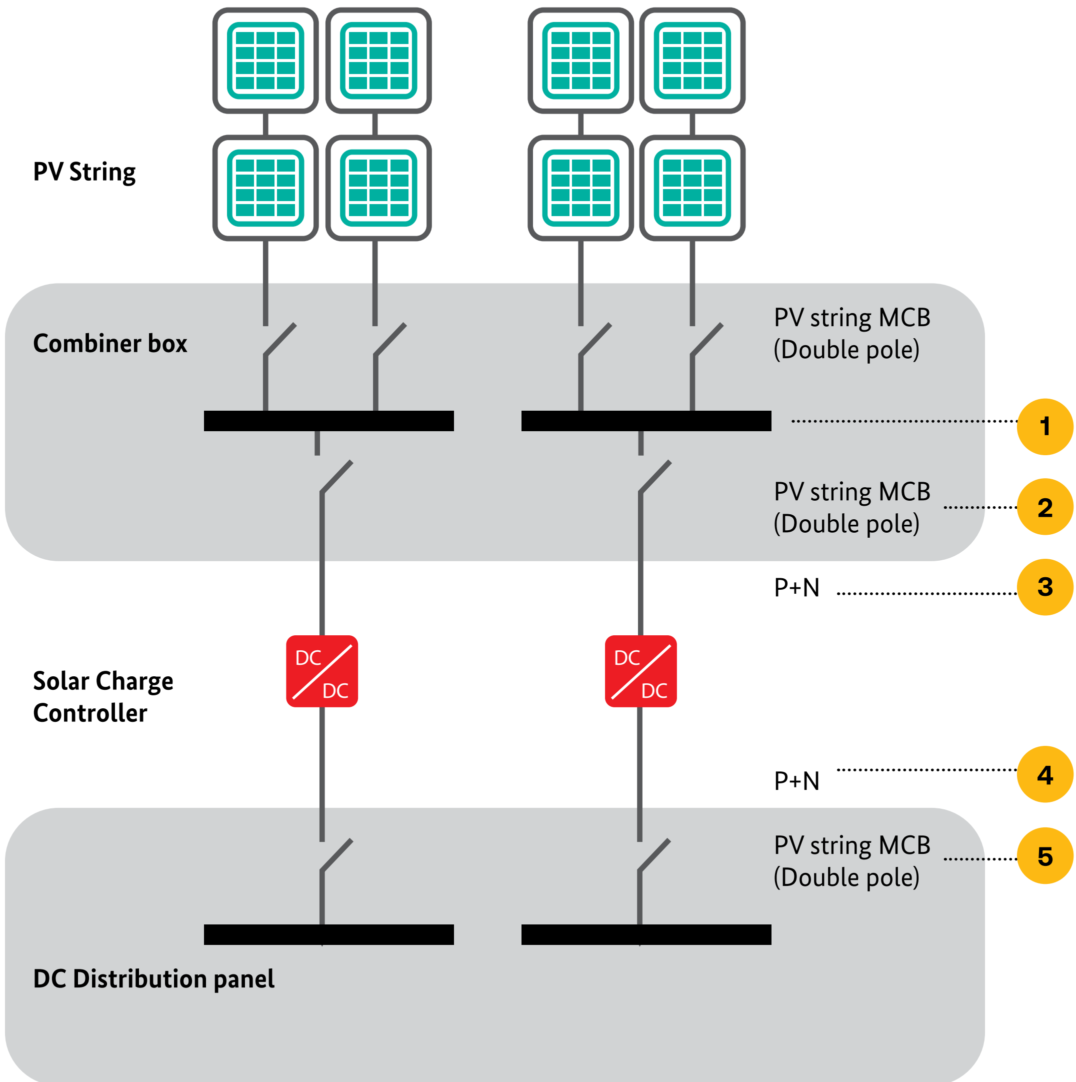
Power and communication cables are installed separately and protected inside cable conduit.

Untidy cable installation. Cables are installed on the mounting structure and fixed by cable ties.

How to install the power cable properly?

- **Choose correct type and cross-section** of the power cable according to possible amount of current flowing through, permissible voltage drops, recommended maximum and minimum cross section from manufacturer, and size of the protection device. Typically for low voltage DC, PVC-sheathed cables with the type NYAF, NYY, or NYF are used.
- **Install the correct size of cable glands** to avoid direct contact between cables and sharp edges. It will also prevent any objects entering the cable compartment.
- **Use cable conduit** to protect the cables from the environmental interferences. Install the communication cables and power cables in separate conduits. The signal might be disturbed when installing communication and power cables closely.

How is the recommendation to install multiple SCCs in parallel?



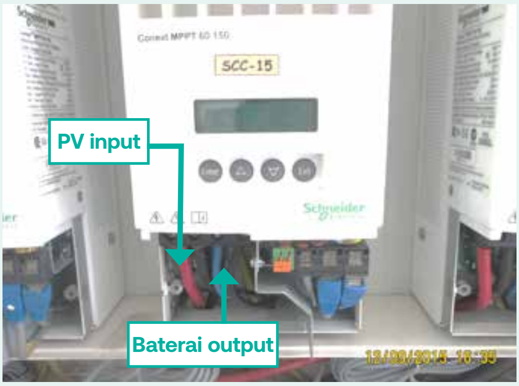
1	U_{input} SCC > $U_{open\ circuit}$ PV array I_{input} SCC > n x $I_{short\ circuit}$ PV string
2	I_{rated} PV array MCB ≥ n x $_{Irated}$ PV string MCB
3	I_{rated} PV array MCB ≥ n x Irated PV string MCB
4	Max. 1% voltage drop and I_{rated} array cable > I_{rated} PV array MCB
5	I_{rated} SCC MCB ≥ 1.25 x Irated SCC output current

Why using single cable is preferable than two cables in parallel?

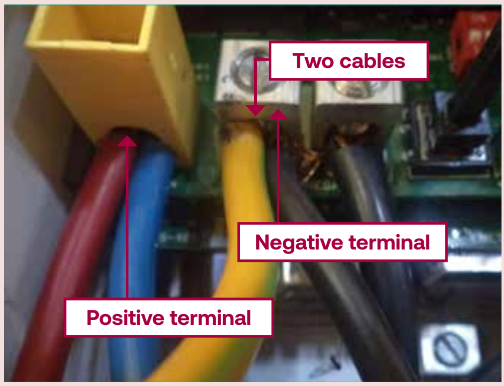
- Most terminal connection is designed for single cable, fixing two cables in one terminal may reduce the reliability of the connection.

- Protection device or MCB should be provided for each cable. MCB will prevent the cable from being overloaded especially when the current is not equally split.

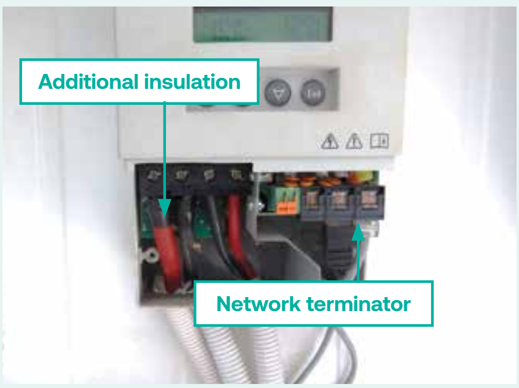
Ensure that the cables are fixed securely to avoid electric arc and possibly increase the temperature at the terminal.



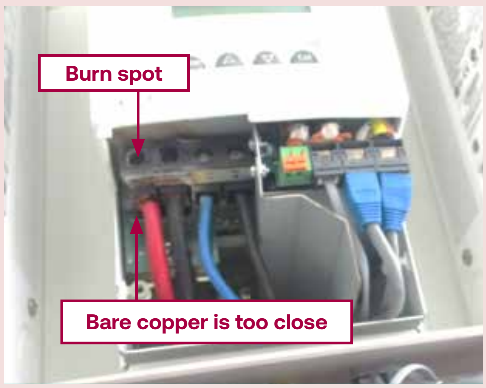
Single cable per terminal and correct cable insulation color is used for DC cable.



It is preferred to install single cable with higher rating than two cables in parallel. Wrong cable insulation color is used.



Neat cable installation with additional insulator to ensure that the stranded copper does not touch other terminal.



Burnt sign at the input terminal. This might be due to bad cable connection that creates electric arc.

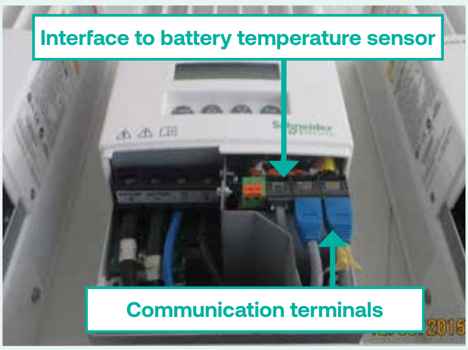
One SCC is not installed. Missing SCC will reduce the energy production from the PV thus limiting the energy supply to the load.

Fixed separation between positive and negative cables is required. Sign of electric shock hazard must be provided.

What to do when one of the SCC is not working?

- Disconnect the SCC electrically from the network by switching-off protection device at input (combiner box) and output (DC panel distribution).
- Secure the connected cable by separating the positive and negative cables to avoid them touching each other and conduct unintentional switching that may cause short circuit.

High voltage cable may exist on the cable end. Unattached conductor from the PV array has to be protected and disconnected at the combiner box.



Communication cable is properly connected. In this type, network terminator should be installed at each end to ensure signal quality

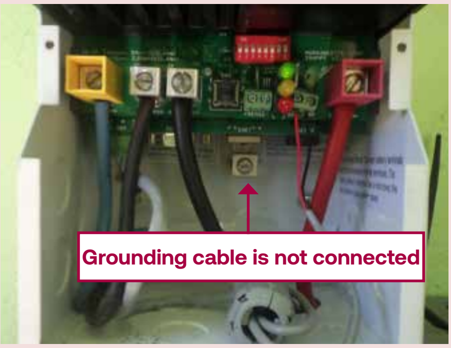
Communication adapter is not working. SCC with unworking adapter will not be read in the monitoring system.

Please refer to the manual for the recommended cable type. Some manufacturer allows only straight ethernet cable type instead of crossover. Using twisted 2 pairs cable for the signal connection may reduce the noise.

How to ensure that the communication is functioning well?

- Check the accumulation of power and energy on the SCC's display.
- All the connected SCCs should be presented in the monitoring system as well as the required monitoring parameters. Validate the connection by checking the recorded data of all SCCs in the monitoring system.
- Interface adapter must be supplied by required power and voltage

Devices are grounded in daisy-chain or series wiring. However, it is preferable to have star configuration or single-point grounding.



Solar charge controller is not grounded.

PROTECTION AND INSTRUMENTATION

- **PV ground fault protection**

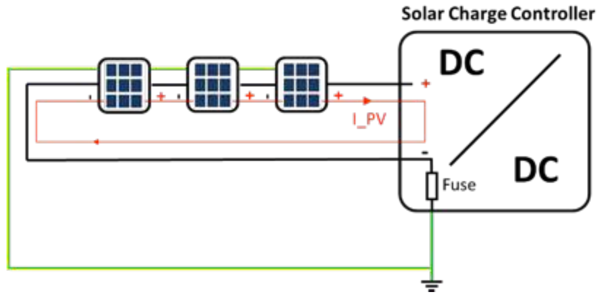
  Ground fault is one of the most common fault in PV mini-grid. The fault occurs when the positive conductor touches the grounding cable or grounded non-carrying conducting parts, i.e. module frame, mounting structure, etc. Ground fault can result in considerable fault current or electric arc that may increase the risks of electric shock and fire hazards.

  To mitigate the risk, grounding system and ground fault protection must be properly installed to avoid current flowing on any unintended path during ground fault. It is required to detect and interrupt circuit when ground fault occurs due to broken cable insulation or bad wiring.

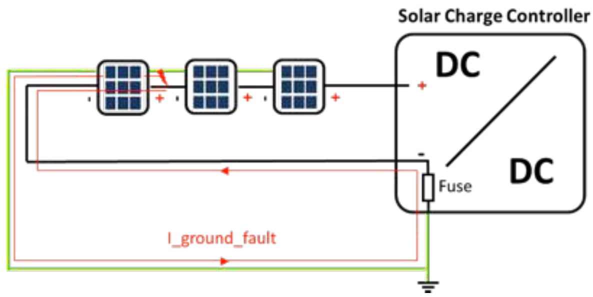
The ground fault protection is by default will ground the negative line of PV array to the ground. Therefore, do not ground the negative line of PV array separately. Use external ground fault protection in case the SCC is not equipped with the necessary protection. The support structure of the PV should also properly grounded.

▶ How does the ground fault protection work?

1. During normal operation, the current flows through the normal path and the PV power is delivered to the load.



2. Due to some reasons such as corrosion, melting insulation, insulation failures, and bad wiring, short circuit occurs between the exposed positive conductor and the ground. The current path changes and current flows through the grounding cable and internal ground fault protection fuse. The fuse will immediately interrupt the fault and report to the device that ground fault is detected.

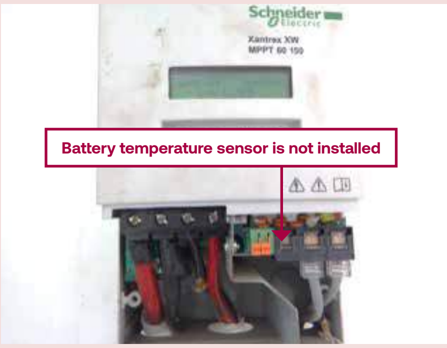


Integrated ground fault protection is installed in the SCC

Fuse is installed in each SCCs that are connected in parallel. Remove the fuse from each units and leave only one unit with fuse.

In case several solar charge controllers are installed in parallel and connected to the same battery bank, only one ground fault protection should be installed. For the SCC with integrated ground fault protection, remove the fuse from each unit and leave only one unit with attached fuse.

- **Battery temperature sensor**
  Battery temperature sensor (BTS) should be installed properly to have correct function of temperature-compensated battery charging. The compensation works by adjusting the charging voltage based on the changing in battery temperature. Charging voltage decreases when temperature reaches above reference temperature (typically 25°C) and vice versa, thus it prevents battery charging at high temperature. Cable interconnection from BTS to the SCC should also be maintained for its functionality unless the charging voltage will not be affected by temperature changes.



Battery temperature sensor is not connected.

Battery temperature sensor is connected but left hanging. The SCC will measure ambient temperature instead of battery temperature.

How to install the battery temperature sensor correctly?

- Install the sensor in the negative terminal of the battery or in between two batteries from the same bank. Use adhesive tape to attach the BTS to the side of the battery and bellow the electrolyte level.

- The BTS cable should not be installed in the same conduit as the power cable to avoid disturbance or noise.

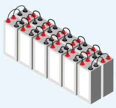
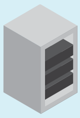
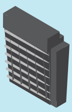
- Only one BTS is required per battery bank if multiple SCC are installed on the same communication network. All the SCC in the same network will share battery temperature information. In case that more BTS are installed in the same bank, the highest temperature will be used as an input to change the charging voltage.

4.3. SCC PARAMETER SETTINGS

Setting-up the parameter is a crucial step during installation to ensure a safe battery charging. Correct setting of the parameter will not only allow the SCCs to efficiently work in parallel but also to protect battery from overcharge and thus increase the lifetime of the battery. The parameter can be configured according to the recommended values from the battery manufacturer. All the basic parameters should be set properly prior to the commissioning.

▶ **What parameter should be considered when configuring SCC?**

- **Device number or Identification number (ID)** of each SCC in a network should be defined and must be unique.
- **Type of battery,** it is important to set the correct type of battery to ensure safety charging. Type of battery can be chosen between the lead acid battery (Flooded, GEL, AGM) or other type such as lithium ion, zinc air. The OPzV battery is specified as a GEL battery.
- **Nominal Battery bank voltage,** which mostly set at 48 V DC. Depending on the battery type, the system voltage should follow the nominal voltage of the battery.
- **Battery bank capacity in Ah (Ampere-hour).** The total capacity of the connected battery banks should be specified to be used as a reference to terminate charging process.
- **Charging current limit** defines the acceptable output current to charge battery.
- **Charging cycle** is either three-stages or two-stages charging process with no float. Three-stages cycle consist of bulk or charging-current phase, absorption or constant-voltage phase, and floating phase is normally used for lead-acid and two-stages for lithium.
- **Bulk voltage,** at bulk stage, batteries will be charged with the maximum-allowed set value of current until the absorption stage is reached. Considering that different battery has different setting, use the recommended values from battery manufacturer.
- **Absorption voltage**, in this step, the batteries will be charged with a constant voltage, which was set with the set value for absorption voltage, and the current will decrease.
- **Float voltage** is the voltage of the battery after absorption. During floating stage, the battery will stop charging, the power from PV will go directly to the load when needed. The stage will go back to bulk when the voltage reaches the defined voltage. The following table is the recommended values in case the values are not provided by battery manufacturer.

Battery technology	Nominal voltage [V]	Bulk voltage [V]	Absorption voltage [V]	Float voltage [V]	Charging rate [V]
Lead acid (OPzV) 	2 V	2.4 V	2.4 V	2.25 V	≤ 10C
Lithium-ion 	3.7 V	4.2 V	4.2 V	-	≤ 1C
Lithium Iron Phosphate 	3.2 V	3.65 V	3.65 V	-	≤ 1C

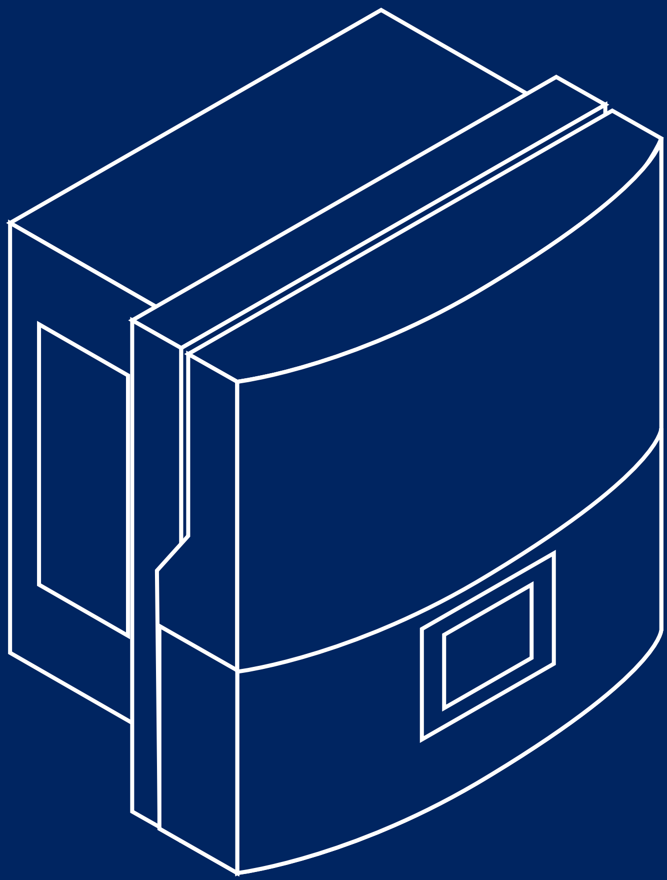
Ensure that the charging voltage is properly set. Improper setting of charging parameters may cause fire hazard due to overcharging (if it is set above the limit) or insufficient charge at the end of charging phase (if it is set below the limit).

ID number will help the operator or technician to identify the SCC. The number should correspond to the ID on the combiner box.

16 solar charge controllers are not equipped with ID number.

CHAPTER 5
Grid Inverter

- What is grid inverter?
- Good and bad installation of grid inverter
- Things to consider when setting the parameters



5.1 BASIC OF GRID INVERTER

The grid inverter or also known as PV inverter is a power electronic component which converts DC voltage from PV array into AC voltage for both direct consumption or storing excess power in the battery. Similar to solar charge controller, the device is also equipped with MPPT to optimize the power captured from the PV array.

As the inverter is unable to operate without grid voltage and frequency, the battery inverter should be kept in operation and maintain the battery bank at the specified state of charge. In particular case where grid voltage is available, the inverter will first observe the grid and synchronise with the grid's voltage and frequency to be able to join the network.

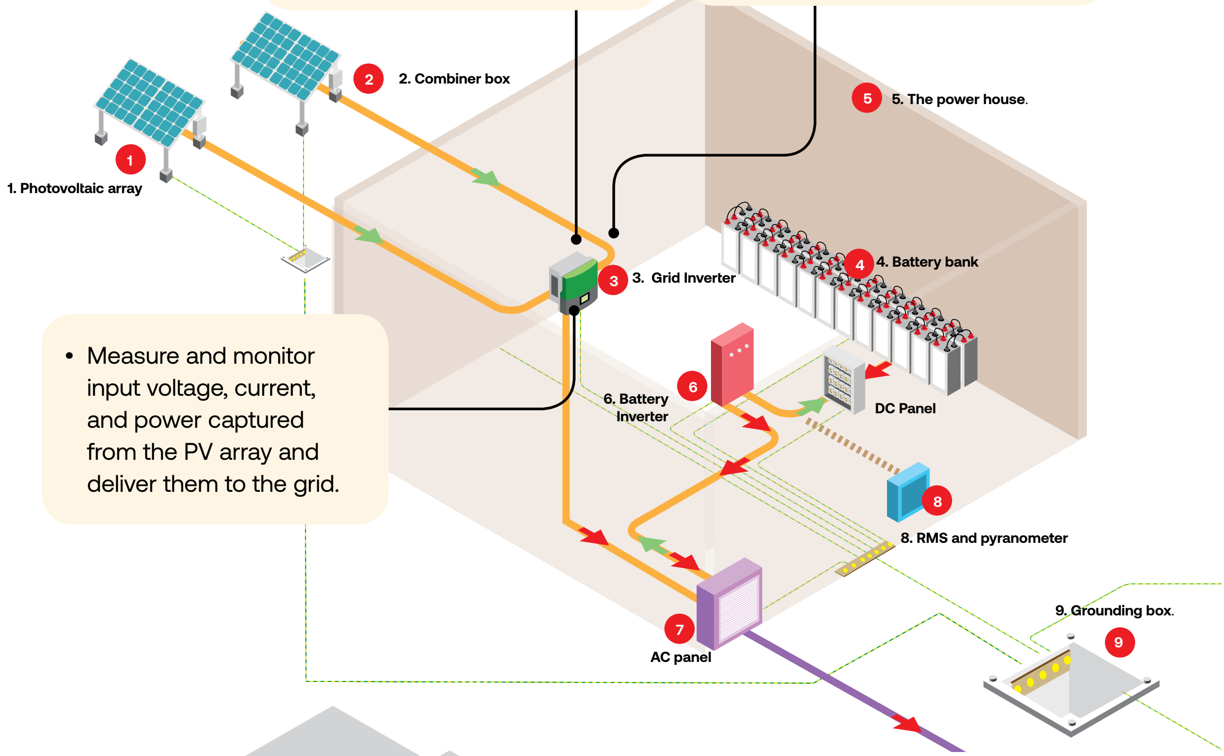
Typical installation of grid inverter in the PV mini-grid system.

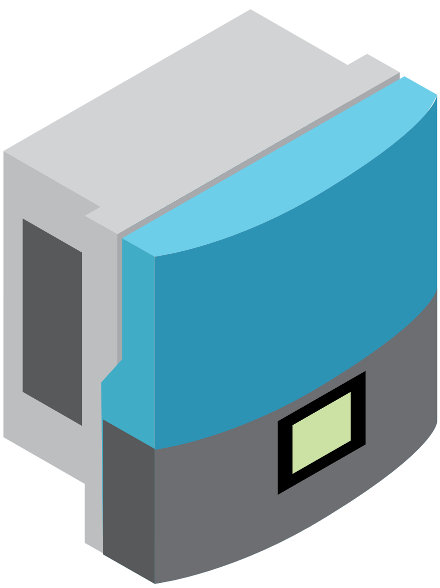
What are the other functions of a grid inverter?

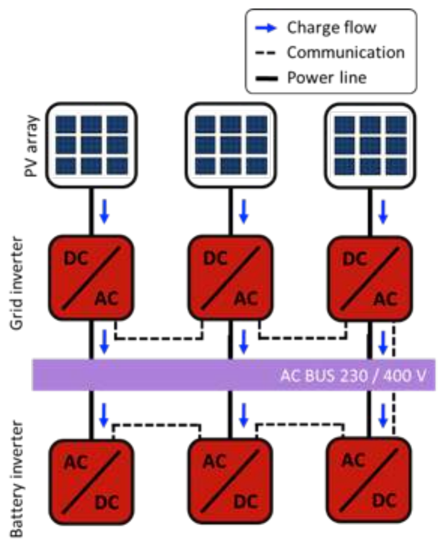
- Anti-islanding or automatic shutdown when the grid is not available to provide safety at the grid.

- Maximize the power transfer from PV array to the batteries using maximum power point tracker (MPPT) algorithm.

- Measure and monitor input voltage, current, and power captured from the PV array and deliver them to the grid.







GRID INVERTER SPECIFICATION

The output of the inverter can be fed into single phase (220 VAC) or three-phase (380 VAC) depending on the type and grid configuration. Some grid inverters typically have multi-string inputs to allow several strings to be connected without using additional combiner box. The grid inverters are specified based on the following parameters.

UDC max[V]	Maximum input DC voltage of PV array
UDC MPP [V]	Voltage range of maximum power point tracker (MPPT)
IDC max [A]	Maximum input DC current of PV array
UAC rated [V]	Output voltage (single-phase or three-phases)
PAC rated [W]	Output power at normal condition, typically at 50 Hz
S max [VA]	Maximum apparent power. Apparent power is the vector sum of active [kW] and reactive power [var].
IAC max [A]	Maximum output current at rated voltage

Label attached on the inverter showing the electrical characteristics of the installed grid inverter.

The written information on the label is useful to identify the type and specification, especially during inspection or maintenance

What should be considered when selecting a grid inverter?

The rated output power of grid inverter should be in the range of 0.9 to 1.25 of the installed capacity of connected PV array. However, it is recommended to use 1 to 1 ratio between PV capacity and inverter power for sizing to avoid inefficiency caused by an oversized inverter.

0.9 PDC PV Array < PAC Grid Inverter < 1.25 PDC PV Array

PAC Grid Inverter < 2 x PAC Battery Inverter

The voltage and current rating must be chosen based on maximum voltage and current of the connected PV array at any condition, upon consideration of PV modules temperature coefficient.

High conversion efficiency (≥ 98%) and featured with dual MPP Tracking.

Equipped with the following protection systems:

a. Input reverse polarity when accidentally connecting the wires wrongly.

b. Overcurrent protection at the DC and AC sides, the device should be rated at least 125% of the PV array short circuit current.

c. PV ground fault protection to protect the cables when the conductors of the PV module touch the grounding system.

d. Overvoltage protection at the input from the PV array.

It is preferred to have minimum of two inverters to increase redundancy when one fails. It is recommended to use only similar brand of grid inverter to maintain consistency in the communication protocol. Albeit the aforementioned consideration, if only aiming for functionality, it is still acceptable to use different brand with the same configuration and specification.

User friendly display that shows the status of grid inverter. It will help operator or technician to easily monitor the system.

Tested and certified according to EN 50530, that describes standard for overall efficiency of grid-connected utility inverters and IEC 62109, which outlines standards on safety of power converters for use in photovoltaic power systems.

Manufactured by a reputable company that has good track records and clear warranty procedures.

Equipped with multi-string inputs and communication module for monitoring purposes

! Grid inverter should comply and being tested according to EN 50530 and IEC 62109 to ensure the quality of the inverter. The inverter should also have warranty period for over five (5) years.

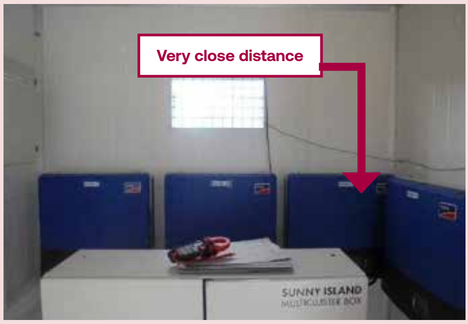
The German Energy Societz. (2008). Planning and Installing photovoltaic systems (Second edi). Earthscan.

5.2 GRID INVERTER HARDWARE INSTALLATION AND INTERCONNECTION

LOCATION AND ARRANGEMENT OF THE UNITS

The grid inverter can be installed both outside or inside a power house depending on the IP rating specified by the manufacturer. In both cases, distance between components is important to be considered to avoid overheating. Minimum distance of 30 cm should be maintained horizontally and 50 cm vertically to allow natural convection. Good ventilation should also be provided to obtain good air circulation thus gives natural cooling for the equipment.

Sufficient distance between inverters allows good air circulation and heat to be dissipated.



Insufficient distance between the devices will increase operating temperature of the devices

Installing grid inverter next to the PV array is more recommended to reduce the power losses as well as cost efficiency for the DC cables. Additionally, having inverter outside will also provide natural cooling for the component. However, several considerations concerning the weather protection should be taken into account.

Grid inverter is installed under the PV modules and protected from direct sun exposure.

Grid inverter is directly exposed by the sun. Add adequate roof to avoid overheating.

To avoid overheating components, grid inverter must be protected from direct sun exposure. Increasing temperature may reduce its performance and life expectancy.

What should be considered when installing grid inverter outside?

- Location of the installation should be under roof or PV array.
- IP rating of the inverter should be at least IP 54 protection.
- Suitable mounting support.
- Ventilation of the grid inverter should remain clean to improve the cooling. Clean with dry cloth to avoid accumulation of dust blocking the ventilation.
- AC cables should be rated for outdoor and protected from direct sun exposure.

Grid inverter is installed closed to the combiner box to avoid losses in the DC cable.

Bunch of long DC cables are used. Such installation increases the investment cost on the cable as well as increasing voltage drop.

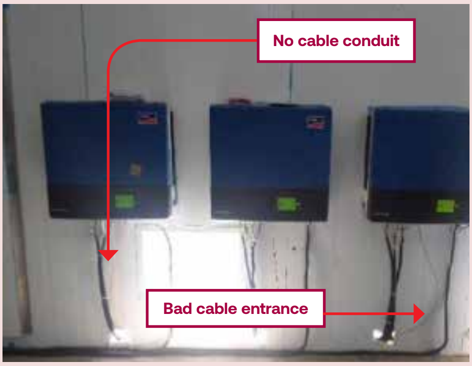
Good galvanized mounting support will ensure the quality of the installation.

Rusty inverter mounting support. Bad mounting support may risk the durability of the installation.

CABLE INSTALLATION OF GRID INVERTER

Interconnection of the grid inverter consists of power cables, communication cable for data transfer or data acquisition, and grounding of the component. The cables and their installation should be dimensioned and designed according to the national standard and recommendation from the manufacturer.

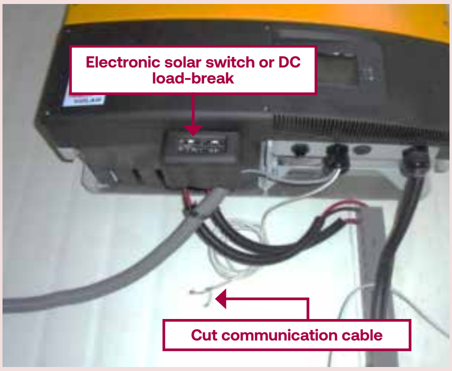
Neat cable installation. Be aware of derating factor of the cable and the separation between power and communication cable.



Bad cable entrance and cables are installed without cable conduit.

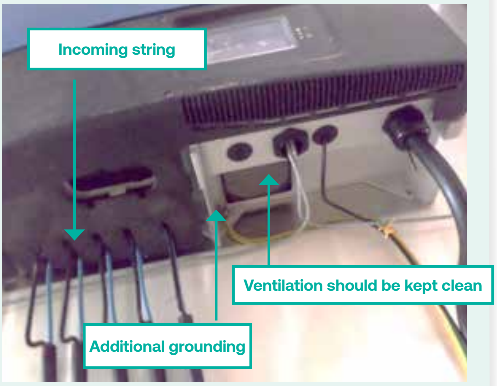
Power cable and communication cable should not be installed close to each other. Installing in the same conduit may introduce noise in the data transmission.

The communication of grid inverters are interconnected through RS485 in daisy chain configuration or in series



Communication cable is not connected to anywhere. Data cannot be acquired by data logger.

Additional grounding is required to protect the operator or technician from touch voltage or being electrocuted in case the grounding at the AC cable terminal fails. Ensure that the minimum and maximum cross-section are in accordance to the standard and manufacturer's recommendation. Typically, the cross section is between 10 to 16 mm2



Strings are connected individually to the grid inverter.

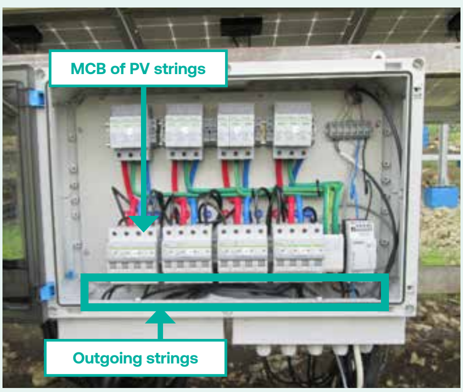
Strings are combined in the combiner box and split equally to be used as input of grid inverter.

How to fix the cable installations?

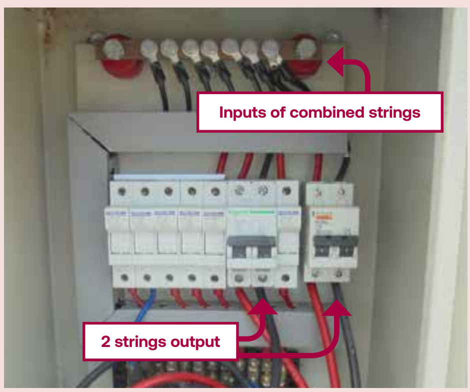
- Ensure that the communication cables are connected and functioning properly. Use the data cable specifically for inverters communication interface to increase performance and network flexibility.

- Reconfigure the PV string cables and connect the cables directly from the PV string to the grid inverter input. Reduce the number of strings and increase the string voltage if the input is insufficient.

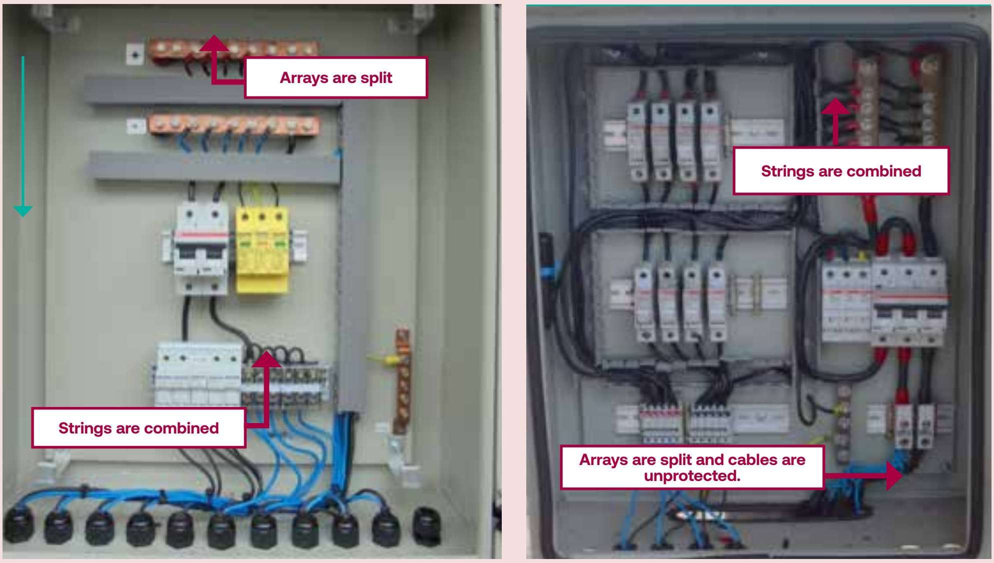
Keep in mind that the voltage of PV string may reach 1000 VDC. Always disconnect the MCB at the grid inverter output, PV input at the combiner box, and load-break switch sequentially when working on the grid inverter.



Strings are individually go to the grid inverter. MCB serves as overcurrent protection as well as diconnector.



Strings are combined in the combiner box and split equally to be used as input of grid inverter.



Strings are combined to become an array and then split back to individual "string" to adapt with the multi-input terminals of the grid inverter. Any outgoing cable from the combiner box to the grid inverter must be protected.

Why multi-string connection is preferred?

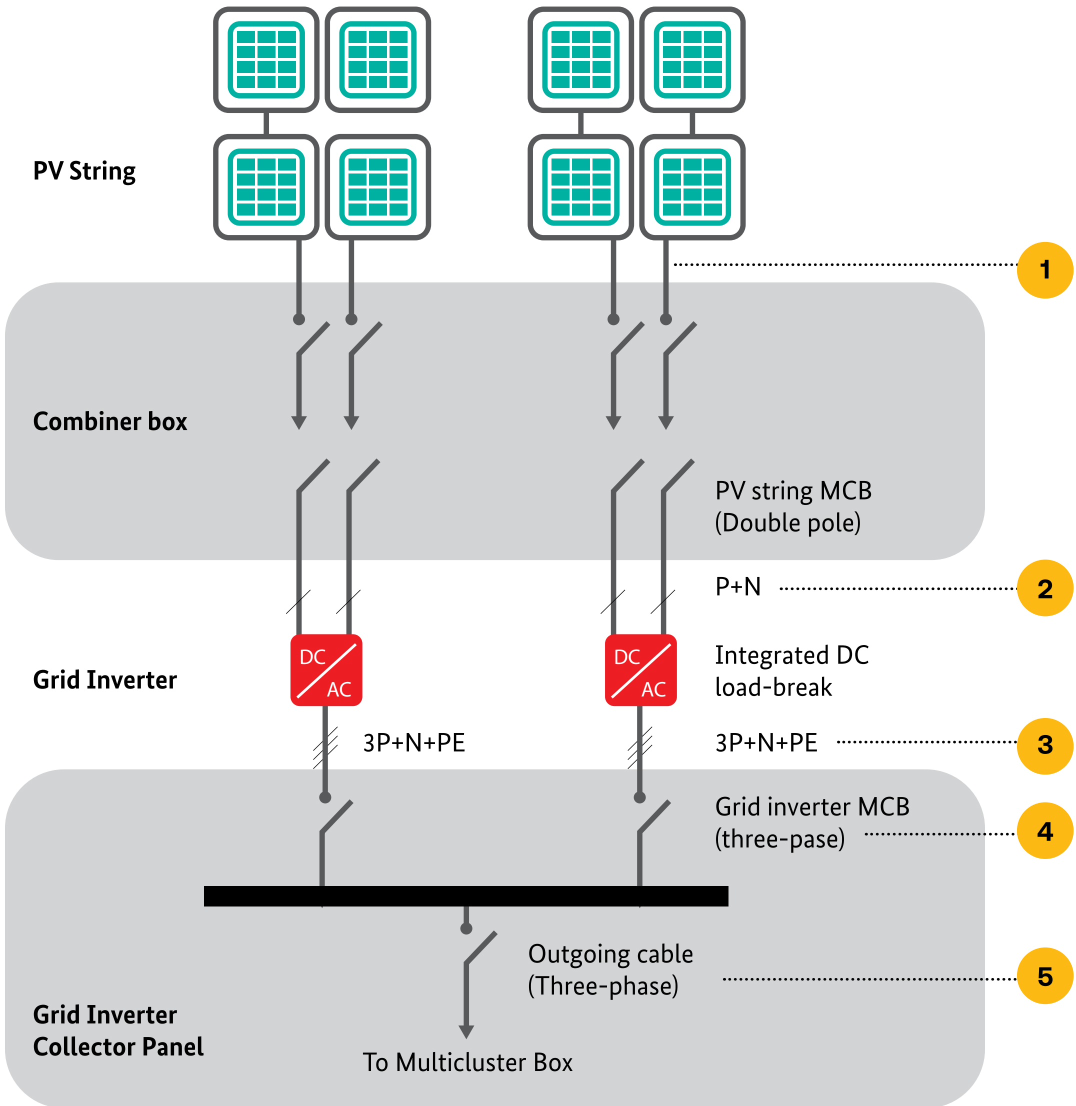
- Single input will only provide the array data, while multi-string input can show the performance of each string.

- Multi-string input usually comes with dual MPP-tracking. Dual MPPT will increase the system flexibility as well as the amount of harvested energy.

- Minimise the number of components in the combiner box such as busbar and main disconnector. Some grid inverters are equipped with integrated electronic fuse and surge arrester at the DC side. Maximum input current per string should be observed prior to the installation.

Keep in mind that the voltage of PV string may reach 1000 VDC. Always disconnect the MCB at the grid inverter output, PV input at the combiner box, and load-break switch sequentially when working on the grid inverter.

How is the recommended installation when multi-input string inverter is used?



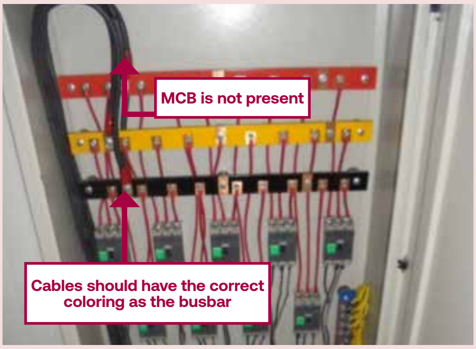
1. $U_{open\ circuit}\ PV_{string} < UDC_{max\ Grid\ inverter}$
   $I_{short\ circuit}\ PV_{string} < IDC_{max\ Grid\ inverter}$

2. Max. 1% voltage drop and I_{rated} cable > I_{rated} PV string MCB

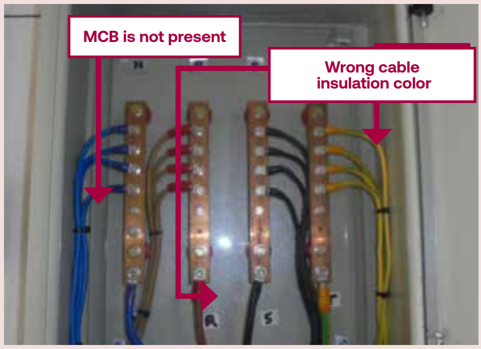
3. $I_{rated\ cable} > I_{rated}$ grid inverter MCB

4. I_{rated} Grid inverter MCB $\geq$ 1.25 I_{max} Grid inverter

5. Irated Outgoing cable MCB ≥ n x Irated Grid inverter MCB
   *n is number of parallel inverter



Outgoing cable is not protected by MCB. Leaving cable unprotected may increase the risk of having overcurrent in the cable.



Protection device of the grid inverters and outgoing cable are not installed. Grounding cable is used as phase cable.

Every grid inverters and outgoing cables must not be left unprotected. Proper type and size of protection device is crucial in providing safety in the installation.

5.3 GRID INVERTER PARAMETER SETTINGS

In principle, the grid inverter could be used in both off-grid or grid-connected system. The inverter works similarly by following the grid voltage and frequency. In grid-connected system, the inverter will keep providing power as long as the sun is shining and grid is capable handling the converted power.

On the other hand, when it comes to a PV mini-grid system, in which the operational is based on battery storage and demand, the grid inverter will have to be controlled by the battery inverter. The battery inverter must be able to communicate with grid inverter to limit their output power in case the battery bank is already fully charged and the PV power is higher than demand. This can be done by shifting the grid frequency hence the grid inverter reducing its output power. The magnitude of the output power depends on the changing in frequency using droop control.

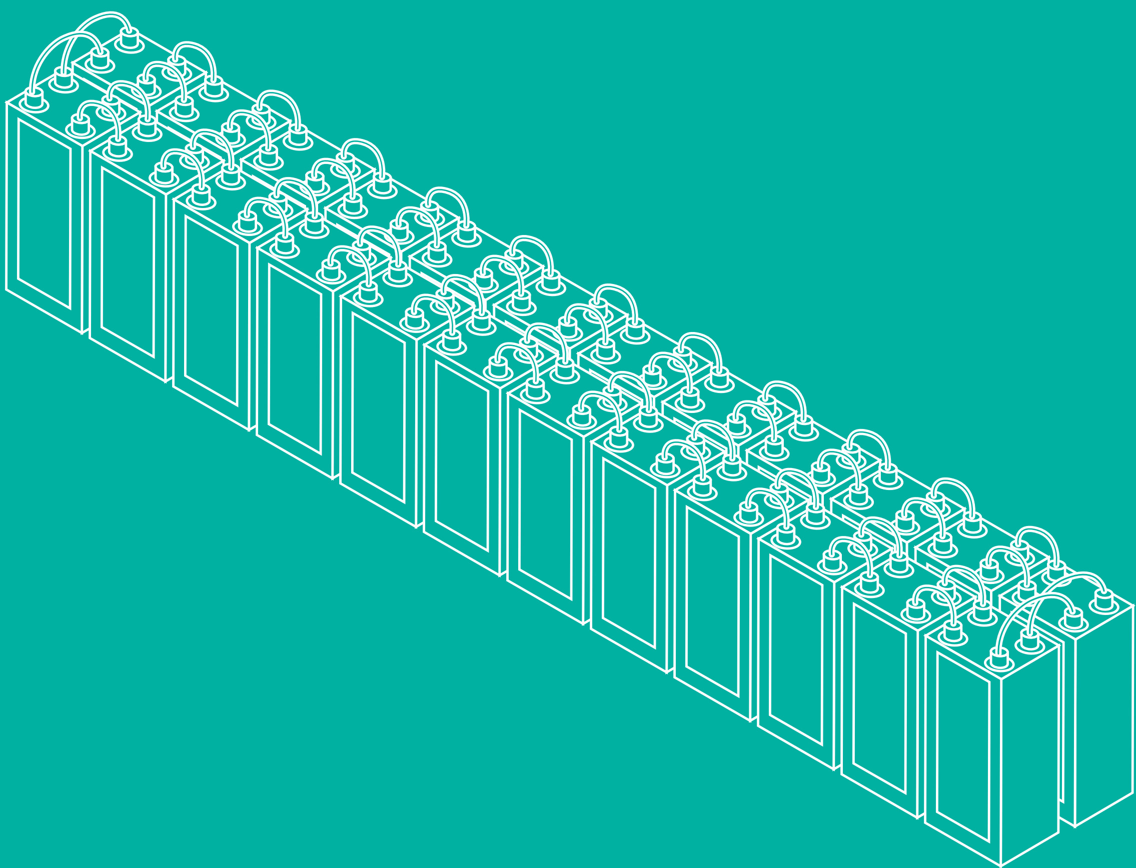
To achieve this, the setting of the grid inverter must be configured properly to an off-grid mode. Having off-grid mode will allow the inverter to set its reference values

What parameters should be considered when installing grid inverter?

- **Country data set** is to adjust the parameters to the required grid. For stand-alone system, off-grid or island mode should be chosen.
- **Base frequency** is the frequency of the stand-alone grid, which is 50 Hz.
- **Minimum AC** voltage is the minimum voltage of the system to operate. The value should depend on the battery inverter range.
- **Maximum AC** voltage is the maximum voltage of the system to operate.
- **Minimum AC** frequency is minimum frequency of the system to operate. Typically, it is defined in percentage from the base frequency (50 Hz).
- **Maximum AC** frequency is maximum frequency of the system to operate.
- **Start power** control frequency is the point where the frequency droop power control starts.

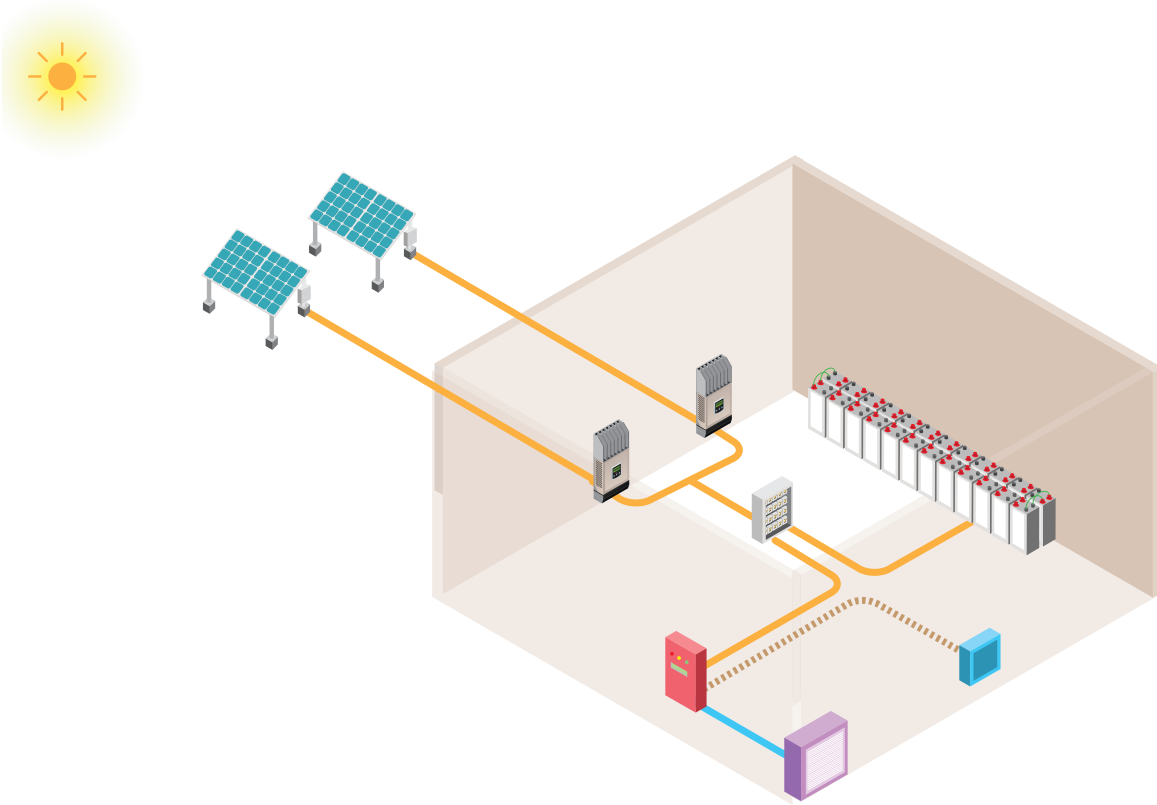
CHAPTER 6
Battery Bank

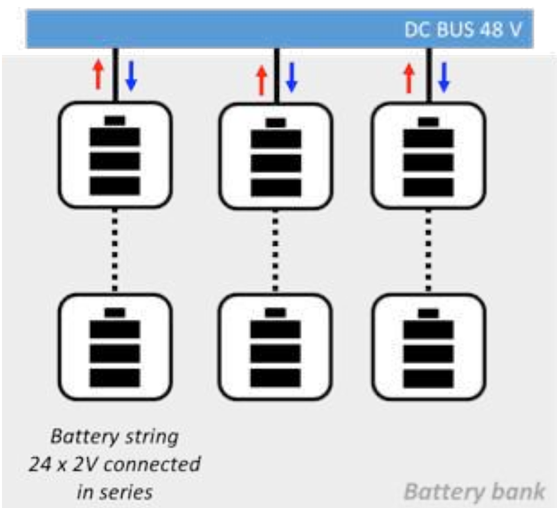
- Which type of battery is used in PV mini-grid
- Technical battery terminology
- Good and bad installation of battery bank
- Things to consider to prolong the battery lifetime



6.1 BASICS OF BATTERY

Batteries are used in PV Mini-grid systems to store energy produced by the PV array during the day, to supply it to the load during the night or in the periods of cloudy weather. The battery is act like a buffer to avoid mismatch between the PV supply and demand. Batteries are currently the most practical way to store electricity generated by the PV array through electrochemical reaction. It is considered as one of the most critical and vulnerable components in the system. Poor design or battery sizing may lead to reduction of lifetime expectancy, shortage of energy, or even permanent failure of the system. Batteries have a limited lifetime that depends on the usage behaviour as well as operating temperature.



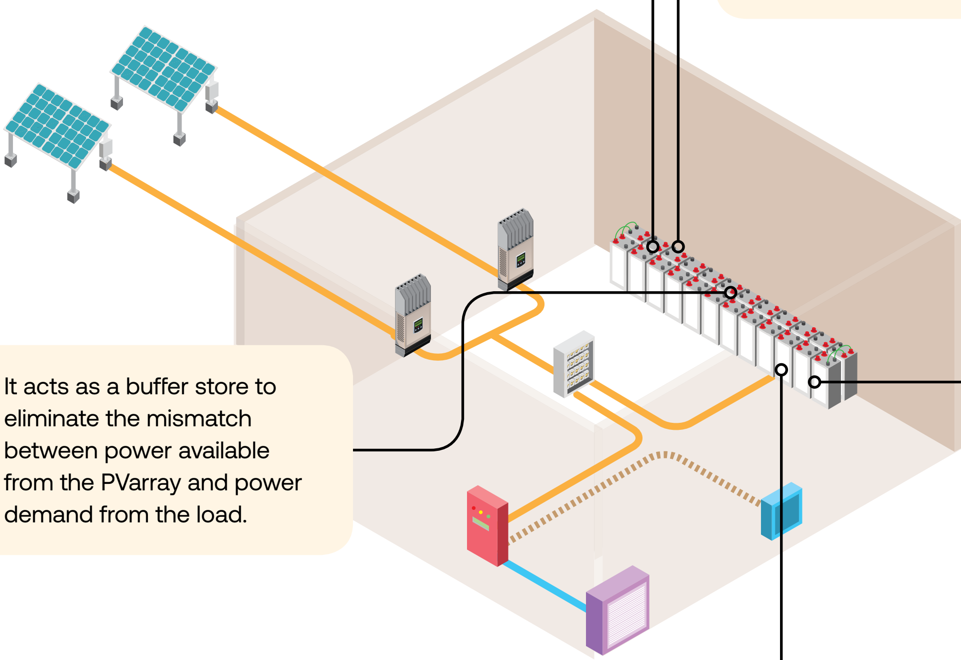


Typical installation of the lead-acid battery bank inside the power house. Battery bank is configured from several battery cells connected to series or parallel to achieve the intended system voltage and capacity.

What are the other functions of a battery bank?

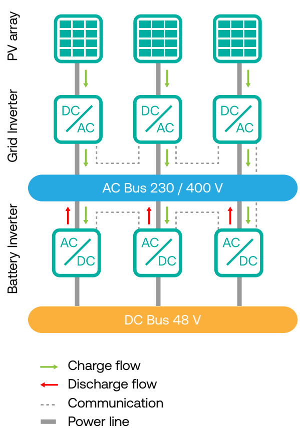
- Provide a back up energy that can be used on the days with very cloudy weather or during emergency situation. Battery is normally sized with define days of autonomy or the buffer days to fulfil the demand without being charged.

- Supply the power to load with stable voltage and current through battery inverter, also in the event of intermittent power from the PV array.



- It acts as a buffer store to eliminate the mismatch between power available from the PVarray and power demand from the load.

- Provide power to the power electronics such as solar charge controller and battery inverter grid voltage is available, the inverter will first observe the grid and synchronise with the grid's voltage and frequency to be able to join the network.



- to supply power to electrical loads at stable voltages and currents, by suppressing or 'smoothing out' transients that may occur in PV systems.

There are plenty of battery technology available for PV mini-grid systems such as lead-acid, lithium ion, Zinc air, Nickel cadmium, etc. However, due to the consideration if maturity of technology, performance, as well as safety, only some are chosen to be used in remote areas. Lead acid battery is the most common type of battery used in PV mini-grid systems, although, newer battery storage alternatives such Lithium-ion and Zinc air are started to be considered to achieve higher lifecycle. Both lithium ion and Zinc air battery require battery management system to ensure its safety and prolong the lifetime. These batteries are also having higher energy density (Wh/ kg) that is sometime more favourable for transporting to remote areas.

Lead acid OPzV battery arranged in vertical insallation.

Lead acid OPzV battery installed in horizontal arrangement

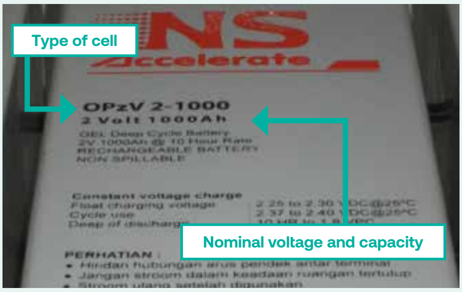
Zinc air battery banks. Each bank has capacity of 21 kWh at 48 V nominal voltage.

Lithium iron phosphate battery banks with parallel rack-mount battery. Each block has nominal capacity of 100 Ah at 48 V nominal.

Deep cycle lead acid type of battery is widely used due to their long lifetime reliability, safer, easy to use, and relatively lower cost. As the battery is located in remote areas and difficult to access, low maintenance type such as sealed type and long lifetime battery is essential. OPzV type or Ortsfest (stationary) PanZerplatte (tubular plate) Verschlossen (closed) of batteries is one of the mostly used battery type for PV mini-grid systems. It is a valve regulated lead acid (VRLA) battery that has tubular plate technology and immobilized gel as electrolyte to achieve higher performance. It is capable to reach at least 1500 cycles with 80% of depth of discharge which is ideal to use. **Only the installation of this type of battery will be shown in this chapter.**

BATTERY SPECIFICATION

Battery is typically specified by its nominal voltage and capacity. The nominal voltage is basically the mid-point voltage of the battery or the voltage measured when the battery has 50% state of charge. While the capacity is the amount of current that battery could provide for some amount of time (Ah). The nominal capacity is typically measured with discharging the battery within 10 hours with discharging current of 1/10 of battery capacity.



Label indicating the voltage, capacity, and float voltage of each battery cell should be on the visible side.

Sufficient distance between inverters allows good air circulation and heat to be dissipated.

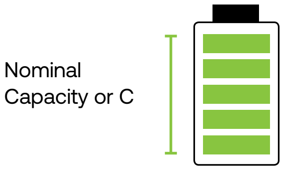
It is recommended that the battery should be tested according to IEC 60896-21 – "Stationary lead-acid batteries - Part 21: Valve regulated types - Methods of test", IEC 60896-22 – "Stationary lead-acid batteries - Part 22: Valve regulated types – Requirements" as well as IEC 61427 – "Secondary cells and batteries for renewable energy storage - General requirements and methods of test" to meet the minimum quality standard.

As the battery is still relatively expensive and take a relatively big portion of the capital cost in PV mini-grid, the selection and sizing should be done correctly to not oversize or undersize the battery. Undersize may lead to high depth of discharge thus reducing lifetime as well as insufficient energy during the night time. While oversize will be ineffective used of battery. Sizing can be done using hand calculation and later can be corrected using simulation software such as HOMER or similar to optimize the solution.

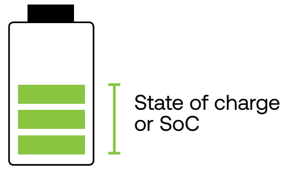
What factors have to be taken into consideration when sizing the battery?

- Required energy during night time and the load profile. Energy will determine the capacity, while the peak power will determine the maximum discharging current to maintain at the recommended level.
- The number of days that is expected to provide the energy to the load without any input from PV array or during cloudy days. Typically, two or three days is used.
- As there will be significant amount of losses in the battery, battery round-trip efficiency should be considered when sizing
- Allowable depth of discharge should be known to avoid deeply discharge of the battery. Depth of discharge will also affect the life cycle of the battery significantly.
- Number for cycles required to avoid frequent replacement of the battery
- Temperature effect to the battery lifetime and capacity.

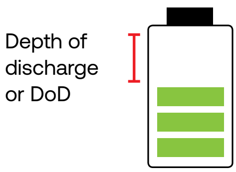
Terminology in battery



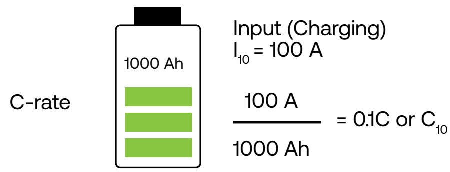
Nominal capacity or C
indicated the amount of charge that can be stored in the battery or that can be withdrawn from a fully charged battery cell under specific discharging rate. It is specified in Ampere-hour (Ah), or sometimes convertible to Watt-hours when system voltage is known.



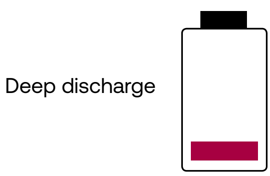
State of charge or SoC
is the current state of the battery or the ratio of residual capacity and nominal capacity expressed in percentage (%).



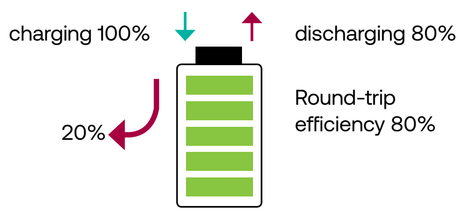
Depth of discharge or DoD is the amount of energy used from the battery. It is the opposite of state of charge. Therefore, when a battery specifies its lifecycle might be greater than 1500 cycles with 80% DoD, meaning it will only occur if the usage of energy is not higher than 80% of the nominal capacity.



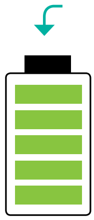
C-rate is typically expressed as the charge or discharge rate equal to the battery capacity divided by time. For example: a C10 discharging rate (or I10 for 1000 Ah would be 1000/10 or at 100 A.



Deep discharge is when the battery is discharged below the end-of-discharge voltage. End-of-discharge voltage itself is the voltage point of the battery when the battery has completely discharged or when its SoC is less than 20%

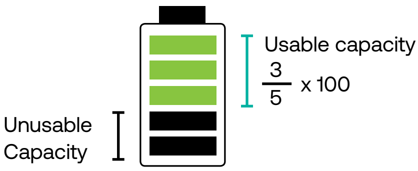


Round-trip efficiency is expressed as ratio between the energy used during discharging and energy to restore until its get fully charge. Efficiency includes the losses during discharging and charging. Lead acid battery typicaly has efficiency of around 85% or slightly lower than lithium ion which is up to 95%.

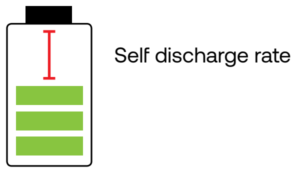


Overcharge is the situation when excessive current is applied to the battery at the end of charge. Overcharge leads to electrolysis and therefore development of gases as well as loses of water.

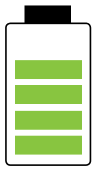
Cycle is one sequence of recharging and discharging. Battery lifetime is specified as cycle life or the number of cycles before the battery fails. Ideally, a good battery should have at least 2000 cycles or equivalent to 5 years of operation.



State of health (SoH) is the ratio of current condition of battery to the ideal or the capacity when it is new. It is expressed in percentage %. One of the reason of the reduction of SoH is due to increase of internal resistance of the battery that makes some part of battery capacity unusable



Self-discharge rate is the rate of loss battery capacity without any load connected or due to internal chemical activity. Lead acid is typically specified at maximum 2% per month at 20°C. This number will determine the requirement to charge the battery when it is not in used.



Open circuit voltage is the voltage of the battery without load.

How to size the battery bank capacity?

1. Daily energy required during the night time. Daytime load should be covered by the PV and partly by battery during the fluctuation. Peak load should be identified.

Estimated energy = 60 kWh
Estimated peak = 15 kW

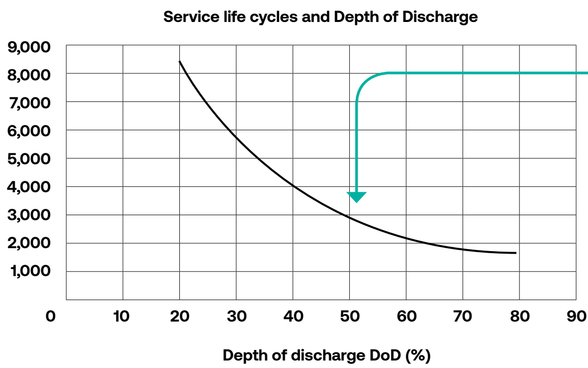
2. Energy required with consideration of days of autonomy.

Required days of autonomy = 2 days →
Required energy with days of autonomy > 60 kWh x 2 days = 120 kWh

3. Expected lifetime basded on ambient temperature. This can be seen from battery manufacturer. According to Arrhenius law, the battery lifetime is significantly reduced by half with every 10° C increase. 100% lifetime is typically at 20° C ambient.

Expected ambient temperature = 30° C ambien t→ 50% correction
Expected lifetime = 5 years → 365 days x 5 = 1,825 cycles
Required cycle life with temperature correction = 1,825 cycles / 50% = 3,650 cycles

4. Define the required depth of discharge to achieve expected lifetime based on the battery technology. Following is for OPzV type of battery.



Required cycle life = 3,650 cycles

Required minimum DoD = 45 (%)

5. Required capacity based on the required DoD and efficiency of the battery.

Battery efficiency = 85 %

$$\textbf{Required capacity} = \frac{\textbf{Required energy with days of autonomy}}{\textbf{Efficiency x Required DoD}} \quad \frac{\textbf{120 kWh}}{\textbf{0.85 x 0.45}} = \textbf{313 kWh}$$

6. Crosscheck with the peak load. The peak load should not be highre than the discharging rate of C10.

C10 rate = 313 kWh / 10 hours → 31,3 kW
Peak load of 15 kW < 31.3 kW

6.2 BATTERY OPERATION

DISCHARGING

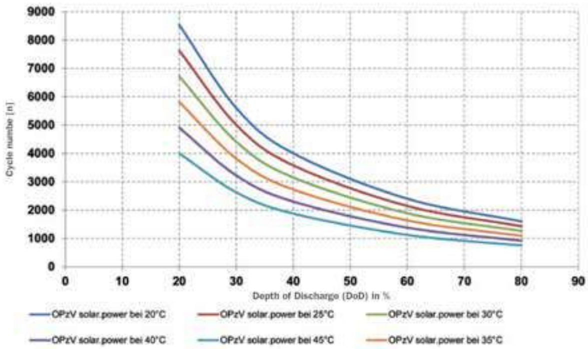
At the time of battery discharge, the closed-circuit voltage (CCV) of the battery experiences an initial reduction do to ohmic losses and the voltage gradually reduces depending on the characteristics until the low voltage disconnection (LVD) is reached. In this case, load should be disconnected to avoid deep discharge the battery that may lead to reduction of acid concentration in the electrolyte and sulphation on the battery terminal.

What to consider when discharging the battery?

- Avoid deeply discharge the battery. Minimum of 1.95 V per cell is recommended with discharging time of up to 24 hours. Meaning with 48 V system voltage, 46.8 V is the end of discharge voltage.
- Battery should not be charged at very high current. The higher the current the faster reduction of voltage, thus LVD is reached faster. The total energy that can be retrieved is also decreased. Battery manufacturer often stated the capacity in the function of C-rate. Typically, nominal capacity is obtained when the C-rate is not lower than C10.

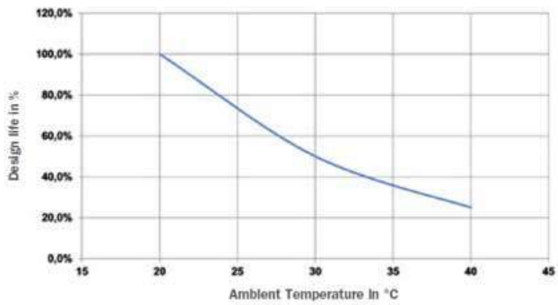
▶ What factors that influence the lifetime and capacity of battery?

- **Depth of discharge**
  The greater the depth of discharge, the fewer number of cycle life. In order to achieve minimum of 1825 cycles (5 years) at 20°C, depth of discharge of the battery should not be higher than roughly 75%.



Cycle lifetime of OPzV in the fucntion of DoD and temperature[1]

- **Ambient temperature**
  The higher the temperature, the fewer number of cycle life. The chart shows that lifetime is reduced by half by an increase temperature of 10°C.

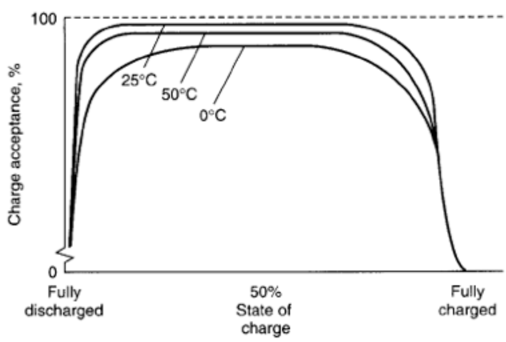


Design life of OPzV as a function of ambient temperature at floating stage[2]

- **Swallow discharge**
  or discharge the battery at very low depth of discharge may reduce the charge acceptance or efficiency of the battery. It is recommended to

- **Discharging current** ➔ The higher the discharging current the lower the usable capacity

- **Setting of constant voltage.** High constant voltage may cause battery to overcharge and increase the gassing process and thus reduction of water.



Charge acceptance of sealed lead acid battery[3]

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[1] Hoppecke, "Installation, commissioning and operating instructions for valve-regulated stationary lead-acid
[2] Hoppecke, "Installation, commissioning and operating instructions for valve-regulated stationary lead-acid batteries," 2013.
[3] D. Linden and T. B. Reddy, "Handbook of batteries," 2001.

CHARGING

During charging proses, in particular at absorption phase, there is development of gas inside the battery due to the split of water into oxygen and hydrogen due to electrolysis process. The gas is trapped inside the battery under low pressure and form a water. In some cases, when the pressure is increase significantly and reach the limit, valve will act to release the gas and therefore loss of electrolyte. In this case, the hydrogen concentration is increased inside the room and therefore good ventilation should be provided. It is also important to maintain the functionality of the battery valve to avoid the loss of unnecessary oxygen at lower pressure. The gassing effect will also lead to slow corrosion of the positive plate of the battery.

How to improve charging process to prolong the battery lifetime?

- Battery bank should be charged according to the specification with three stages charge method which is bulk, absorption, and float. Equalization should not be done for OPzV or GEL type of lead acid battery

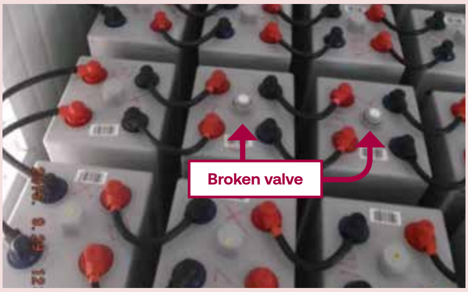
- Avoid charging the battery very high voltage above with maximum at 2.4 V during bulk and absorption phase. The charging current of the batteries should not be higher than C10 rate of the battery bank. Overcharge the battery may cause capacity loss, increase of acid concentration in the electrolyte, as well as overheating the battery.

- During the shipment and storage, the batteries lose some charge due to self-discharge. It is recommended during the commissioning to charge battery at minimum of 16 hours with constant voltage.

Valve is at good condition to avoid unnecessary loss of oxygen during normal operation.

Sign of battery active chemical leakage from the valve.

Sulfuric acid is corrosive and dangerous that can cause serious injury as well as blindness. Avoid any contact with skin and clean immediately with water when exposed to the liquid. Always use insulated gloves when cleaning up the liquid.



Broken battery valves will expel some the gasses easily to the atmosphere and reduces capacity of the battery

Plastic bag is used to cover the pressure relief valve. Broken valve should be replaced instead. Excessive pressure may damage the battery.

Why damage valve should not be installed?

- Damage of battery valve may lead to leaking of hydrogen gas and possibly electrolyte. Leaking of hydrogen and oxygen mixture may lead to explosion risk when the hydrogen content in the air reaches 4%, while ealectrolyte is very harmful and corrosive when spilled.

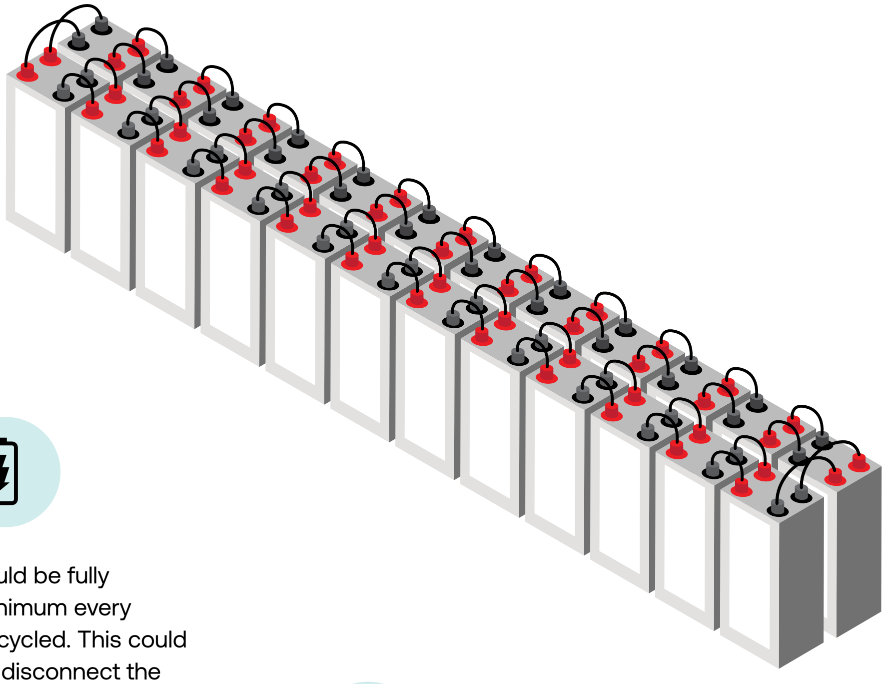
- Release of oxygen at low pressure will cause uninventable irretrievably lost

Ensure that the batteries are in a good condition without any damage before the installation. Battery should be packed properly during shipment. Do not install battery with broken valve or broken terminals.

Battery terminal is in good condition and is free from corrosion or sulphate flakes

Corrosion on the terminal reduces the surface on the lead and increase the internal resistance of the battery

▶ How to avoid corrosion on the terminals?



- Battery should be fully charged minimum every month and cycled. This could be done by disconnect the load to allow battery get fully charged and re-connect to discharge the battery. Never fully charge the battery and leave the battery undercharging may cause corrosion or sulphation on the negative terminals.

- Battery should not be stored in very long duration and left at low state of charge or undercharge.

- Avoid direct contact between lead alloy (battery terminals) and copper (conductor).

Sign of active chemical leakage dropped on the battery rack. This could be due to excessive release of gas (overcharging)

Sulphide flakes may cause corrosion to battery rack. Clean the battery and reduce the charging voltage if necessary.

TEMPERATURE LIMIT

The ideal ambient temperature of the battery room should be in between 20°C to 30°C. In some site, the outdoor temperature might be higher. In this case, the difference in temperature between indoor and outdoor should not be higher than 2°C.

Acceptable and ideal battery room temperature. Increase of 4°C from the nominal will only reduce 20% of the designed lifetime.

Very high battery room temperature leads to significant reduction of battery lifetime by more than 50%.

Temperature sensor from the charge controller is located in the middle of the battery's body.

Sensor is located on the lid of the battery. It will not sense accurately the tubular plate.

Temperature difference between the battery string location should not be greater than 3°C. Deviation of temperature will lead to different operating condition and cause lifetime to reduce differently.

How to indicate a bad battery?

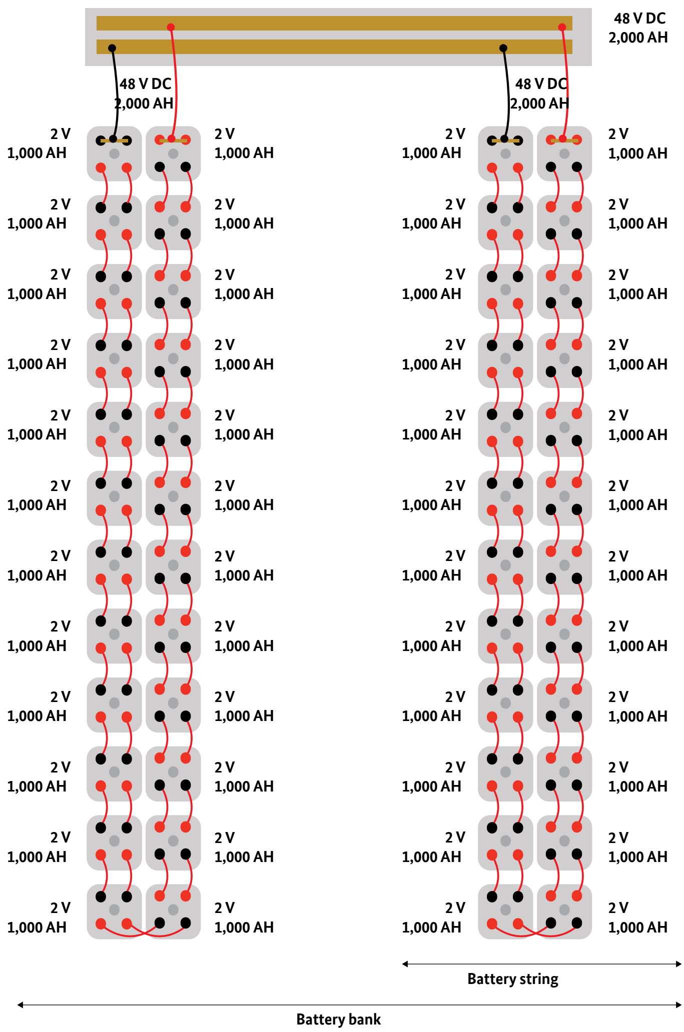
- Bad battery can be seen from the increase of temperature during charging or discharging due to high internal resistance of the bad battery.
- High internal resistance can also be seen from the significant increase or decrease of voltage during charging and discharging. Bad batteries tend to reach absorption phase faster or experiencing early charging termination and discharged faster.
- Deviation in open circuit voltage of larger than 0.5 V may indicate that the battery not at the same state of charge as well as state of health.

6.3 BATTERY INTERCONNECTION

A battery bank consists a single string or of several battery strings connected in parallel. A single string is composed of individual battery cells connected in series. Each of the cell produces a voltage of about 2.1 V for lead acid and is varied depending on the battery technology as well as the state of charge. The battery bank is then configured based on the desired system voltage (battery voltage) and capacity.

When a higher voltage is required, the battery with same capacity is connected in series until the battery string voltage reaches the required voltage, which is typically 48 VDC. While to increase the capacity, the battery strings with the same nominal voltage and characteristics should be connected in parallel.

How is the typical configuration of a lead acid battery bank?



What should be considered when connecting the batteries?

- It is recommended to only connect batteries with the same technology, manufacturer, type, nominal capacity, and state of health in a battery bank. Different characteristics may result in inefficiency during charging and discharging or possibly damage the batteries.

- Mismatch of battery capacity may cause bigger battery to never get fully charge and small battery to get fully charge and possibly overcharged. During discharge, small battery will be discharged faster and may be deeply discharged.

- It is recommended to not parallel more than four (4) battery strings. To avoid charging and discharging problem due to discrepancy of state of charge and state of health of each string.

- Over current devices must be installed on each positive and negative side of the battery string. The over current device should be specified based on 1.25 x battery voltage and 1.25 x possible charging or discharging current, typically I10-rate. Temperature compensation of maximum 45^{0}C should be applied in the calculation.

- Batteries in the battery bank should be at the same state of health and state of charge. The state of charge can be seen from the voltage of each cell during open circuit or no load. The voltage of each cell should not have difference of 0.02 V or specified by the manufacturer. State of charge should be adjusted accordingly before the installation.

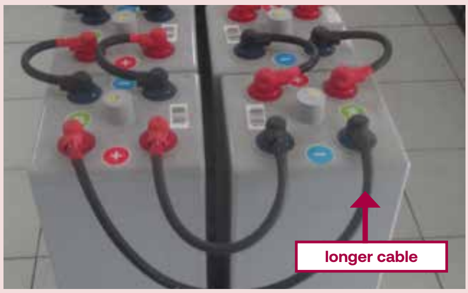
- The voltage, current, and temperature of the batteries should be checked in regular basis to take preventive action when the voltage and temperature of the batteries indicate the reduction of state of health.

BATTERY BANK WIRING

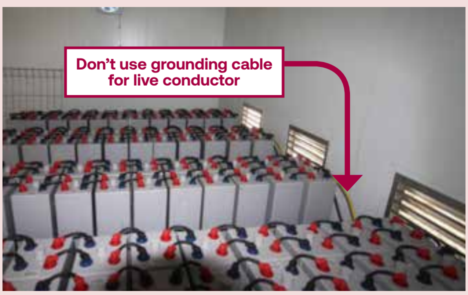
NYAF 50 mm² cable is used to handle maximum of 104 A. A correction factor due to ambient and grouping used is 0.75.

Undersized NYAF cable is used in the battery string that could be charged with higher current than the cable rating.

The interconnection cables between the battery cells have the same length and resistance



Paralel cables with different length leads to different cable resistance.



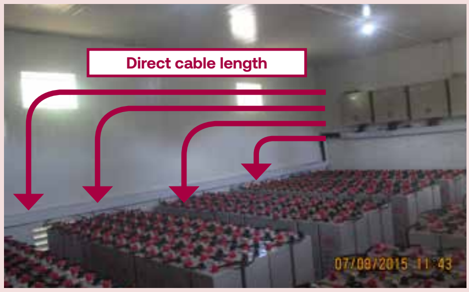
Although the type and cross-section ar similar. Cable with grounding color insulation should not be used for the live conductor.

Different color of the cables for the same terminal may cause confussion. Cable extension may introduce additional losses.

How to improve the wiring?

- The battery string cables should be sized to accommodate the possible current during charging and discharging and have rating above the relevant over current device. It is recommended that for each battery string to have minimum cross section of 50 mm², however, the actual value shoud be
- Use the same cable type, length, cross section, and cable arrangement to obtain similar electrical resistance and ensure the same voltage drop between the strings.
- Avoid to extend the cable with additional connector and use the whole cable. Bad quality of the connector and connection would increase the resistance.

DC distribution panels are placed distributedly to avoid differences in cable length between battery strings.



Different cable length between the battery strings. DC distribution panel should be located closer to the strings

The length of cable between the over current device and battery terminal must be as short as practicable to avoid unintended voltage drop that may cause early charging termination as well as early disconnection

Cables are installed neatly inside cable conduit. Correction factor of enclosed and grouping installation should be applied according to IEC 60364-5-52.

Cables are not installed inside conduit. Having cable inside the conduit will protect the cable as well as avoid operator trips over the cable.

Example on how to size a battery bank cable

1. Estimate the possible charging and discharging current to and from the battery bank. This could be done by checking the maximum DC current from the charge controller and battery inverter.

Battery inverter maximum power = 15,000 W
Solar charge controller maximum DC power = 15,000 W
Battery voltage = 48 V
Number of battery banks = 3

Charging current = 15,000 W / (48 V x 3) = 104 A
Discharging current = 15,000 W / (48 V x 3) = 104 A

2. Estimate the installation condition for temperature and cable arrangement.[4]

Installation method B1

Insulated single core conductors in condult on a wall
Estimated ambient temperature = 35° C
Number of grouped cable = 3

Size (mm²)	Current Rating for 2 x PVC Insulated Copper Conductors								
	Reference Installation Method								
	A1	A2	B1	B2	C	D1	D2	E	F
15	14.5	14	17.5	16.5	19.5	22	22	22	-
25	19.5	18.5	24	23	27	29	28	30	-
4	26	25	32	30	36	37	38	40	-
8	34	32	41	38	46	46	48	51	-
10	46	43	57	52	63	60	64	70	-
16	61	57	76	69	85	78	83	94	-
25	80	75	101	90	112	99	110	119	131
35	99	92	125	111	138	119	132	148	162
50	119	110	151	133	168	140	156	180	196
70	151	139	192	168	213	173	192	232	251
95	182	167	232	201	258	204	230	282	304
120	210	192	269	232	299	231	261	328	352
150	240	219	300	258	344	261	293	379	406
185	273	248	341	294	392	292	331	434	463
240	321	291	400	344	461	336	382	514	546
300	367	334	458	394	530	379	427	593	629
400	-	-	-	-	-	-	-	-	754
500	-	-	-	-	-	-	-	-	868
630	-	-	-	-	-	-	-	-	1005

°C	Ambient temperature derating factor	
	PVC	EPR / XLPE
10	1.22	1.15
15	1.17	1.12
20	1.12	1.08
25	1.06	1.04
30	1	1
35	0.94	0.96
40	0.87	0.91
45	0.79	0.87
50	0.71	0.82
55	0.61	0.76
60	0.5	0.71
65	-	0.65
70	-	0.58
75	-	0.5
80	-	0.41
85	-	
90	-	-
95	-	-

3. Apply correction factor due to ambient temperature and cable arrangement.

Correction ambient temperature = 104 A / 0.94 = 110.6 A
Correction factor number of grouped cable = 110.6 / 0.7 = 158 A
158 A < Rated current of 70 mm² B1 method (192 A)

4. Crosscheck with the MCB or fuse rating. The cable rating should be higher than MCB or fuse rating at the same correction factor. MCB or fuse should be rated at 1.25 of possible charging or discharging current.

Correction ambient temperature = 104 A / 0.94 = 110.6 A
Correction factor number of grouped cable = 110.6 / 0.7 = 158 A
158 A < Rated current of 70 mm² B1 method (192 A)

4 International Electrotechnical Commission, "Low-voltage electrical installations - Part 5-52: Selection and erection of electrical equipment - Wiring systems," 2009.

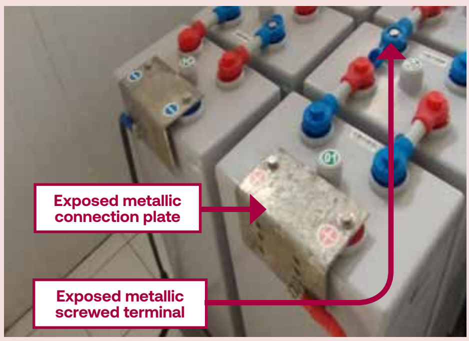
5. Calculate the possible voltage drop. The voltage drop should not exceed 1%

$$\text{Voltage drop} = \frac{2 \times \text{load current} \times \text{resistance} \times \text{length}}{1{,}000} \qquad \frac{2 \times 104 \times 0.272 \times 5}{1{,}000} \quad 0.28\ \text{V} \rightarrow 0.5\% \rightarrow \text{OK}$$

Resistance at 20°C		Current carrying capacity at 30°C max		Short circuit current of conductor at 1.0 sec max
Nominal cross sectional area	Insulation min	In Pipe	In Air	
Ω/Km	MΩ. Km	A		kA
13.3	50	15	24	0.17
7.98	50	20	32	0.29
4.95	50	25	42	0.46
3.30	50	33	54	0.69
1.91	50	45	73	1.16
1.21	40	61	98	1.84
0.780	40	83	128	2.88
0.554	40	103	158	4.03
0.386	30	132	197	5.75
0.272	30	165	245	8.05
0.206	30	197	290	10.93
0.161	30	235	345	13.80
0.129	30	-	390	17.25
0.106	20	-	445	21.28
0.801	20	-	525	27.60
0.641	20	-	605	34.50
0.0486	20	-	725	46.34

BATTERY TERMINAL CONNECTION

The battery terminals are covered with acrylic board and are labelled with voltage hazard sign.



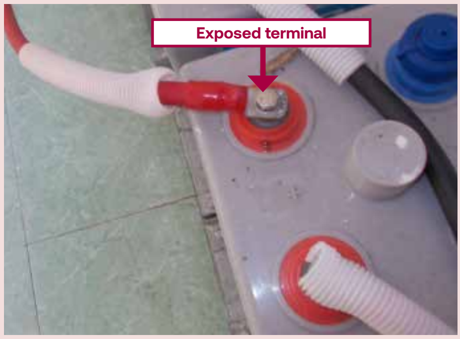
Exposed battery terminals, potentially battery short circuit that may cause spark and explosion

The terminals of the battery are always alive, therefore never leave the terminals unprotected. Metal parts may cause accidental short circuit. It is recommended to use insulated wrench when fixing the connection.

Battery terminals are well protected with insualtor material and the cables are installed neatly.

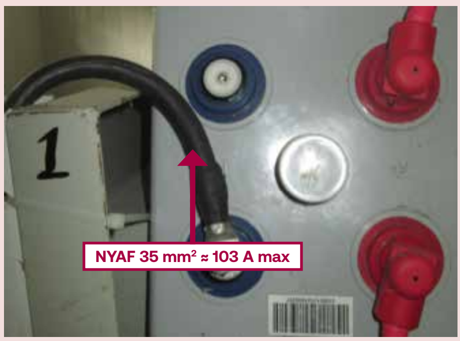
Cardboard is used to cover battery terminals. The makeshift solution is not adequate to isolate the terminals.

Terminal connector is equipped with rubber cap.



Inproper plastic hose is used to isolate the battery terminal.

Connector plate is used to connect the end terminal of the battery string



Only one cable is connected to the terminal. Connection plate should be provided.

Ensure that the batteries are always clean from any excessive dust and water vapor to increase the creepage distance between terminals. Only use wet cloth moistened by water to wipe the batteries. A dry one may cause electrostatic charge through friction and increase the explosion risk.

6.4 BATTERY INSTALLATION

What to consider when installing the batteries?

- Installation of the batteries including the arrangement, racking, and requirement of the battery room should be based on IEC 62485-2- Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries.

- Batteries can be installed in vertical or horizontal arrangement. However, special attention from the manufacturer should be made such as arrow indicator when installing battery in horizontal. Ensure that the internal plates are vertically arranged (same polarity in vertical arrangement)

- Batteries should be installed on the stable and proper rack to avoid the battery from falling as well as for better cooling.

- Battery room should have adequate ventilation to avoid high concentration of hydrogen in the room during charging. The lead acid batteries may produce hydrogen gas that could be ignited due to electric arc or fire.

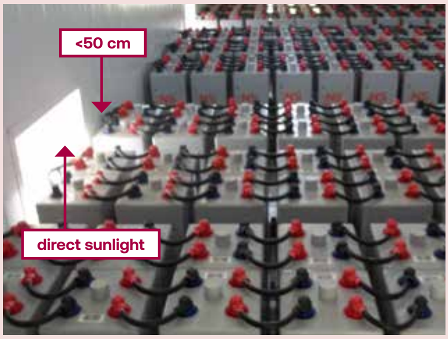
LOCATION AND LAYOUT

Battery strings are intalled in zig-zag configuration with the ventilation to avoid direct sun exposure.

Some batteries are exposed directly to the sun light. Long term heating may cause those specific batteries to fail earlier.

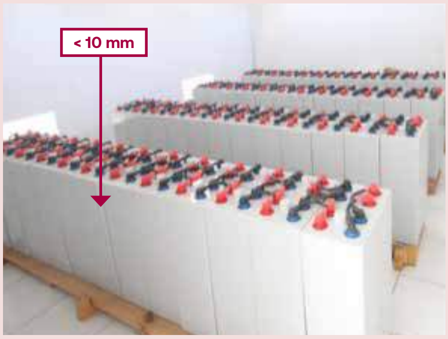
Battery banks should not be located close to the heat source or directly exposed to sunlight. High temperature may result in reduction of lifetime, leakage, or even explosion.

Sufficient distance between battery and wall. Such confguration provides better alirflow and large passageway.



Inadequate space between the power house wall and battery. Direct sun exposure may heat up the battery.

Battery cells are installed with sufficient distance for the battery to release heat.



Inadequate distance between battery cells. Minimum distance of 1 cm should be provided.

Battery bank is installed with adequate space between battery strings.

Very dense battery in a room may increase the source of heat and hydrogen concentration

How to improve such installation?

- Battery rack should have at least some distance to the wall to access the battery for cleaning. All the batteries should be easily accessible for the maintenance.

50cm

- Shift the battery rack away from the wall until the distance is 50 cm. Make sure that the battery is not directly exposed by the sun and enough space to conduct maintenance.

Battery room with natural lightning and warning signs are attached in the battery room

Very dark battery room with insufficient ventilation and low lumen. Difficult to conduct maintenance.

How to improve such installation?

- Number of the batteries inside a battery room should be calculated based on the available space and possible production of gas during charging. If the number of batteries is relatively high, make sure that the ventilation should provide required flow rate. Typically, flow rate of 6.8 m3/h is necessary for every 48 V /1000 Ah during boost charging. This leads to requirement of roughly minimum 200 cm2 ventilation opening.
- Provide natural lightning by adding additional ventilation. Additional ventilation will also improve the air flow in the room. It is recommended that the light intensity should be at least 100 lx.
- Attach the warning sign such as “No smoking” sign, risk of explosive gas, corrosive materials, and existence of live voltage should be clearly shown in the battery room.

Keep away the battery from sparking component might be the source of ignition such as: open flames, electrical arc, sparks, or electrostatic charge.

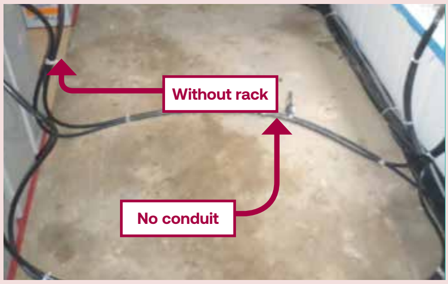
[5] North Star, “NSB OPzV Batteries - Tubular Gel Technology,” 2017.

BATTERY RACK

What should be considered from a battery rack?

- Ensure that the battery rack as well as the floor is able to support the weight of the battery
- All the material in the battery room must be corrosive proof to provide stable support to the heavy battery
- Avoid to use wooden especially in the place that plenty of termites.

Battery are installed inside th battery rack with edges to avoid the battery from faling.



Batteries are not installed properly on a rack or without sufficient support.

Strong battery rack with no sign of corrosion. Rack is equipped with side bar to protect battery from falling

Wooden rack material is prone to termites and risk of being rotten and may cause the entire bank to collapse.

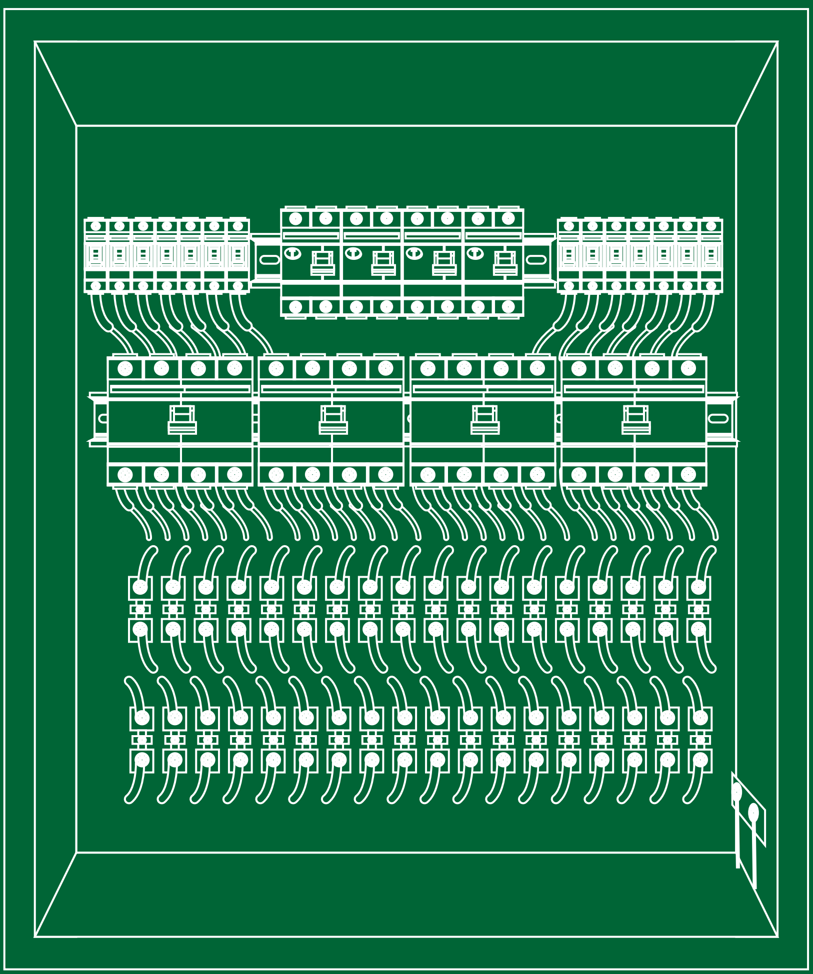
Horizontal battery arrangement on hot deep-galvanized steel rack structure with no sign of corrosion.

Corrosive rack will reduce the metal thickness resulting loss of mechanical strength.

As the weight of each battery cell is approx. 70 kg which makes in total 1,680 kg for the entire bank, a considerable weakening of material strength will cause structural failure or breakdown.

CHAPTER 7
DC Distribution Panel

- What is the function of dc panel distribution?
- What should be inside the panel?
- Good and bad installation of the panel



7.1 BASICS OF DC DISTRIBUTION PANEL

DC distribution panel is the place where solar charge controllers, battery banks, and battery inverters are connected together. The panel distributes the converted DC power from solar charge controllers to battery banks and from battery banks to battery inverters at typically 48 VDC. A typical DC distribution panel mainly consists of busbars as connection points and protection devices to protect the battery banks and cables to SCCs and battery inverters.

DC distribution panel consists of three batteries connected in parallel, as well as five SCCs, and three battery inverters

- Protection of outgoing cables to battery inverter protects the outgoing cable against overcurrent or short circuit.

- Protection of incoming cables from SCC serves additional overcurrent or short circuit protection to the SCC and incoming cable to the panel.

- Battery bank protection is used to protect individual battery bank against short circuit. MCB or fuse is typically used for this purpose.

- DC terminal or busbar is the interconnection point of battery banks, SCCs, and battery inverters. It aims to bring several devices into a common conductor. It is made of solid copper conductor and tin-plated for corrosion protection. Terminal block is also often used for this purpose.

- Enclosure houses the protection devices and busbars.

- Grounding bar provides grounding connection of the box (if metal box is used) and to divert voltage from surge protection device when overvoltage occurs.

What to consider when designing a DC panel distribution?

- Ambient condition and power losses of the components affect the heat inside the panel. Good heat management is required to avoid derating of the components caused by overheating.

- Separation between the positive and negative conductors must be maintained to prevent accidental short circuit. The battery banks contain high energy content, hence significant spark may occur.

- All cable connections should be securely tightened to prevent fire hazards.

- As the panel is located indoor, the ingress protection of the enclosure should be rated at minimum of IP 3X or protected against solid objects greater than 2.5 mm.

7.2 ENCLOSURE

What to consider from an enclosure?

- Polycarbonate, polyester, or painted steel material can be used for the enclosure.

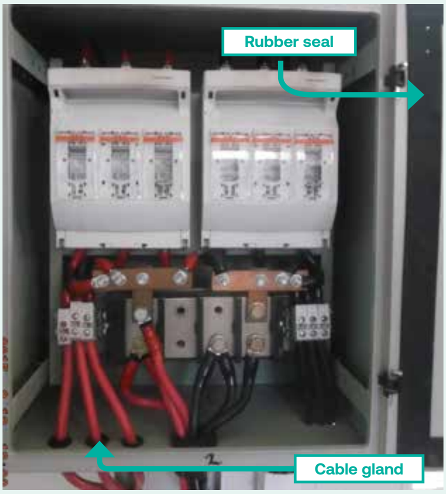
- Panel should have double insulation or protection class II. The enclosure has multiple layers of insulating material between the internal components and the box surface to protect operator or technician from touch voltage.

- Additional safety precaution such as label and protection from unauthorised personnel should be provided as the system is running at maximum 56 VDC which can be dangerous to touch especially in wet condition.

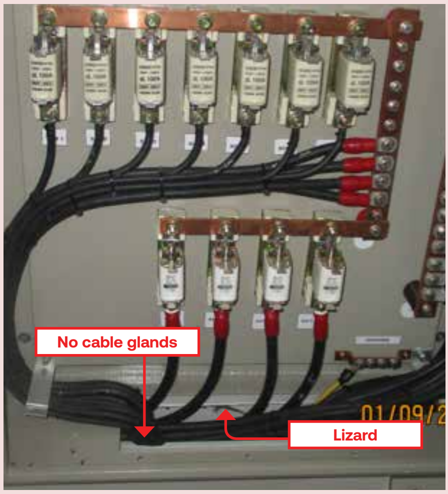
- Distribution panel should be properly sized in accordance to required number of SCC, battery inverter, and battery bank to be connected.

QUALITY OF THE ENCLOSURE

The panel should have minimum protection class of IP 3X or is protected against solid objects greater than 2.5 mm. In order to achieve this, the cable glands at the cable insertions should be used and ventilation of the box should not be too big to prevent animal entering.

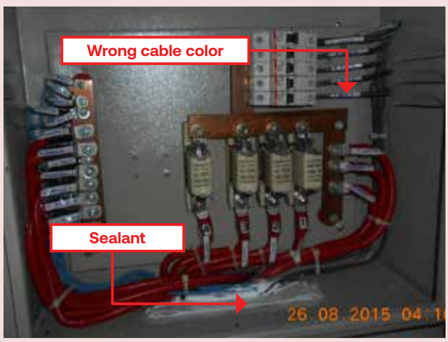


Cable gland is used to prevent animal enrtering the panel.



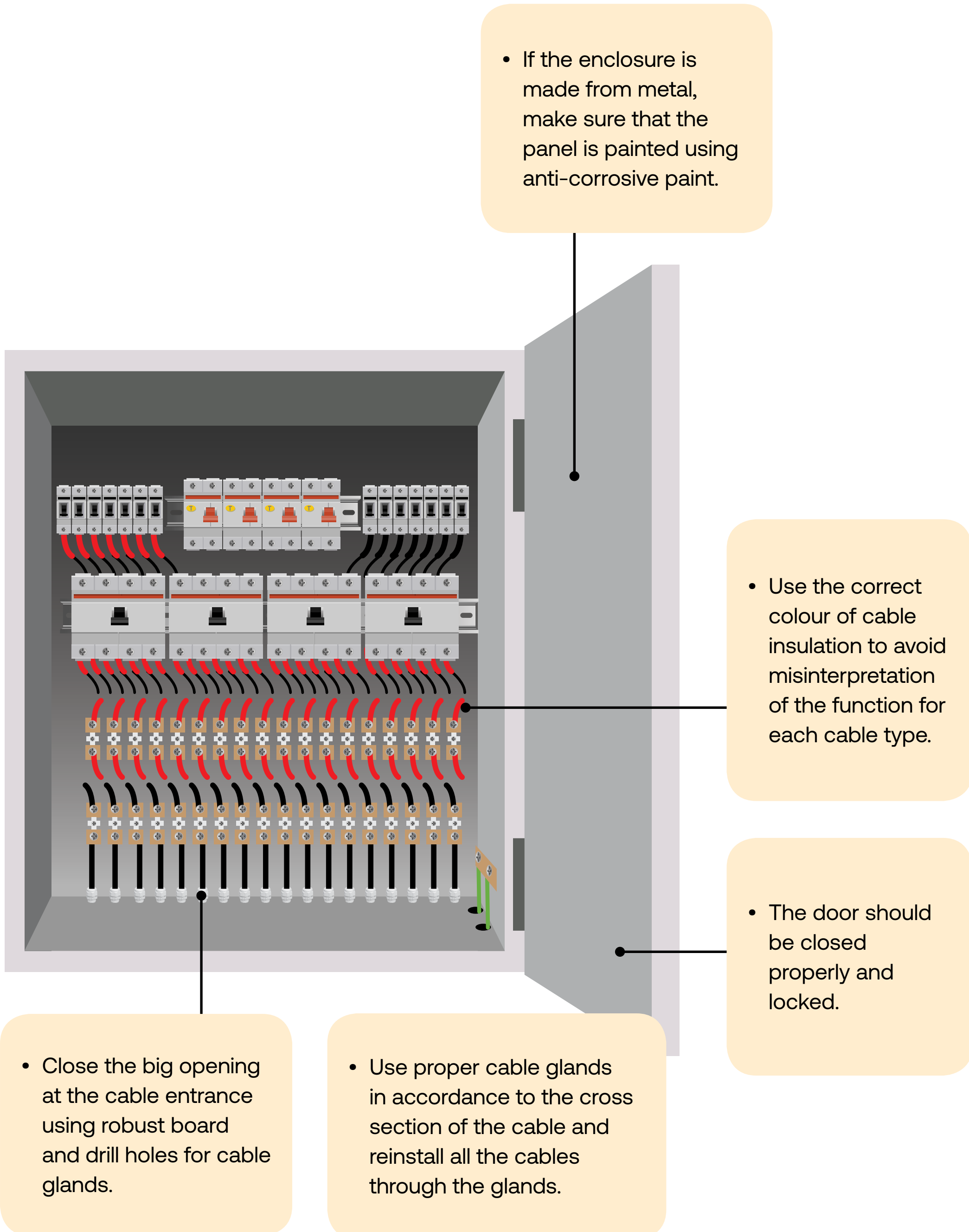
Big insertion at the cable entrance providing access to uninvited animal.

Enclosure is made from polycarbonate that provides good insulation and properly labeled with electrical shock hazard.



Ungrounded box and improper way to seal the cable insertion. Use of sealant will make cable installation become semi-permanent.

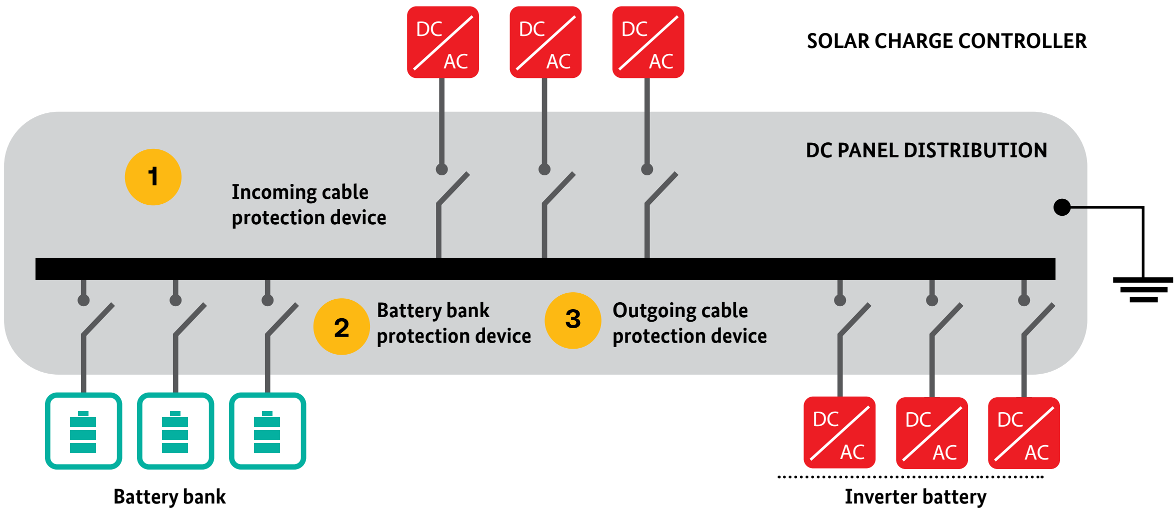
How to improve the quality of the panel?



The panel should be safe to touch at any condition. This could be achieved by having double insulation enclosure or grounded panel as well as its door, if metallic material is used.

7.3 ELECTRICAL COMPONENTS IN THE DISTRIBUTION PANEL

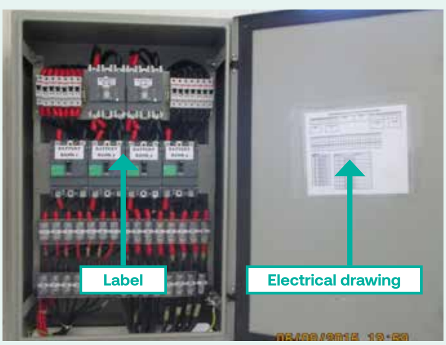
▶ How is the typical electrical diagram of DC panel distribution?



1 I_{rated} **SCC MCB ≥ 1.25 x Irated SCC output current**

2 I_{rated} **battery bank MCB ≥ (1.25 x** I_{rated} **inverter input current x number of inverter) ÷ number of battery bank**
I_{rated} **battery bank MCB ≥ Irated SCC MCB**

3 **Irated battery inverter MCB ≥ 1.25 x Irated inverter input current**

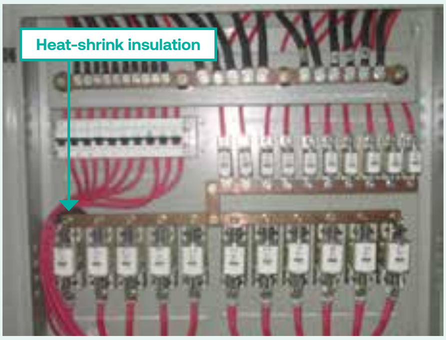


Electrical drawing and component labels are attached on the enclosure door

Neither drawing nor label is provided. This may cause difficulty during service or maintenance.

Knife type (NT) Fuse

Electrical drawing and labelling of all components should be available on site and possibly attached on the panel to help operator, technician, or inspectors to identify the installed components.



Adequate distance between the component and bigger internal space allows the electrical components to dissipate heat.

Neat but relatively dense installation. Dense installation may create difficulty to conduct measurement and maintenance.

PROTECTION DEVICES

The protection devices protect the cables and battery bank against overcurrent and short circuit. It will disconnect the faulty device or line in case of short circuit and keep the rest of the devices in operation.

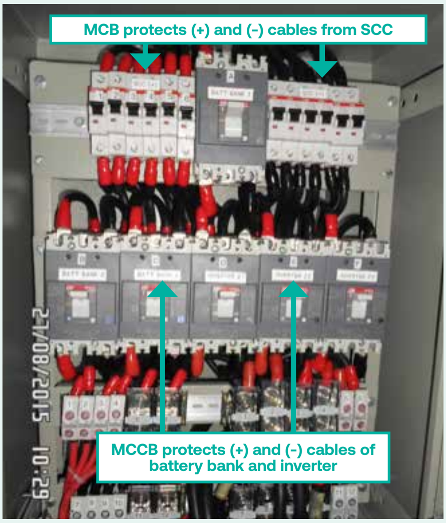
What to consider when installing protection devices?

- Only consider protection devices that have proven DC switching capability and are able to accommodate voltage up to the maximum battery voltage.

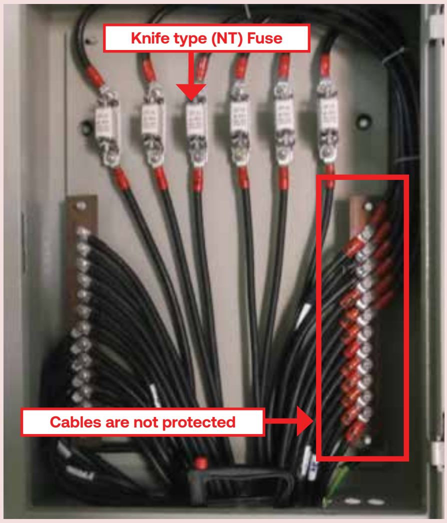
- It is recommended to use MCBs than fuses. MCB or MCCB (Molded-Case Circuit Breaker) is more sensitive, easy to identify faults, resettable, safer, and provides easy disconnection. Using fuse would require special tool and spare part which is often unavailable in rural areas.

- Selectivity of the protection devices should be considered to maintain the MCB, that protects battery bank, to be the last device to trip in case of fault.

- The current capability of the protection devices and cables should consider derating factor in case of high ambient temperature. It is safe to consider derating factor at ambient temperature of 45°C.



Battery banks, SCCs, and battery inverters are protected by MCB and MCCB on both positive and negative sides.



Cables from SCCs and to battery inverters are not protected.

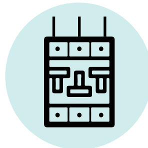
Two inverters are connected in one terminal of three pole MCCB.

One circuit breaker is used to protect three battery banks.

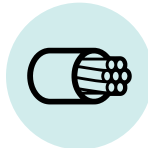
How to fix such installation?

- Install DC-rated MCB at each incoming and outgoing cable to SCC and from battery inverter, respectively.

- Do not combine the installation into one protection device. Combined protection will lose installation flexibility, such as unable to trip the faulty line only.

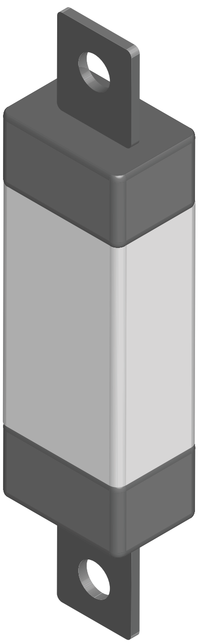


- Separate the connection and install an MCB for each line.



- Replace the cable size to the correct cross section. The current carrying capacity of the cable should at least be greater than the maximum possible current going in and out from the battery banks

What to consider when using fuses?



- Use only the fuse switch-disconnector type and widely available type across the country to ease maintenance and repair process, as well as, avoid difficulty in finding component replacement.
- Conduct inspection to regularly monitor the fuses condition. Measurement is needed when there is any burning sign.
- Electrical fault has to be located and cleared before resetting the MCB or replacing the fuse.
- Spare fuses amounted 20% from the total fuses installed with similar size and rating inside the box should be provided.

Never interrupt the circuit or take the fuse during operation or under load. The battery inverter and SCCs should be switched-off prior opening the fuse.

Fuse switch-disconnector is used. It provides protection, safety, as well as allowing easy fuse replacement.

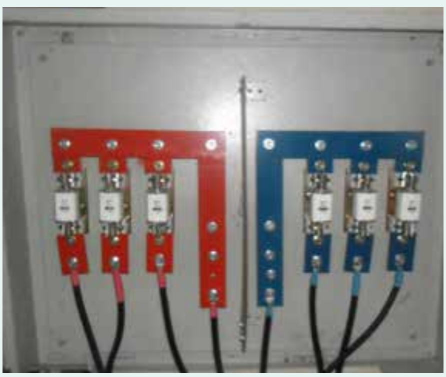
Standard fuse base is used. Using NT or NH type fuse without switch-disconnector requires fuse puller and may create arc when disconnecting.

Safety precautions to consider before conducting an inspection

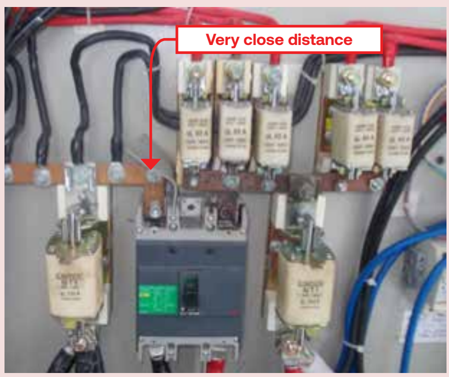
- Ensure that the solar charge controllers and battery inverters are disconnected prior disconnecting the battery

- Cables connected to the battery bank are always alive. Use insulated rubber glove to prevent getting electric shock.

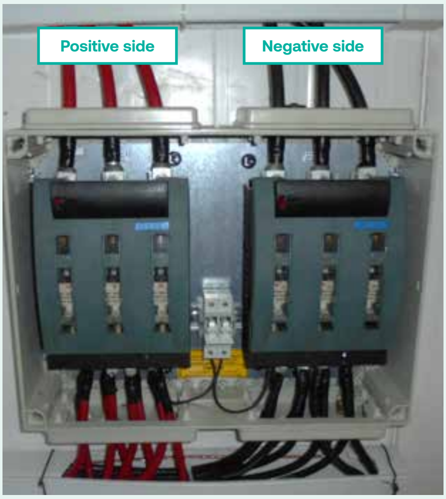
BUSBAR AND CABLE INSTALLATION



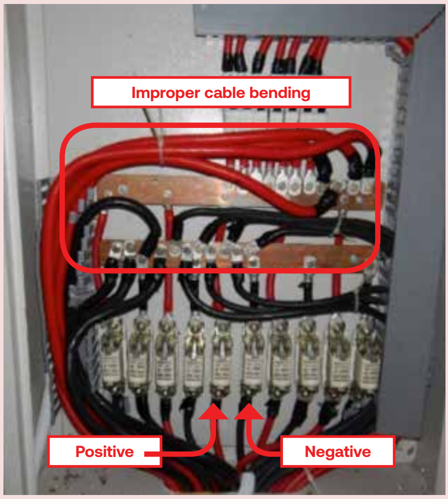
Adequate distance between the busbars. Separator is provided to avoid accidental short circuit during installation or maintenance.



Very close distance between positive and negative busbar. Rearrangement of components is required.

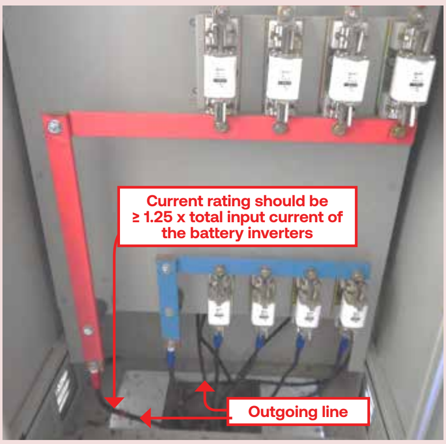


Preferable installation with horizontal busbar arrangement. It provides easier cable routing and clear separation.



Vertical busbar arrangement makes difficulty to arrange and route the cable. Some positive cables touch negative busbar and vice versa.

Adequate separation between positive and negative terminals is required to avoid unintended short circuit. It is easier to separate the connection if they are installed with left and right arrangement. See CHAPTER 3 *on how to safely install positive and negative busbar.*

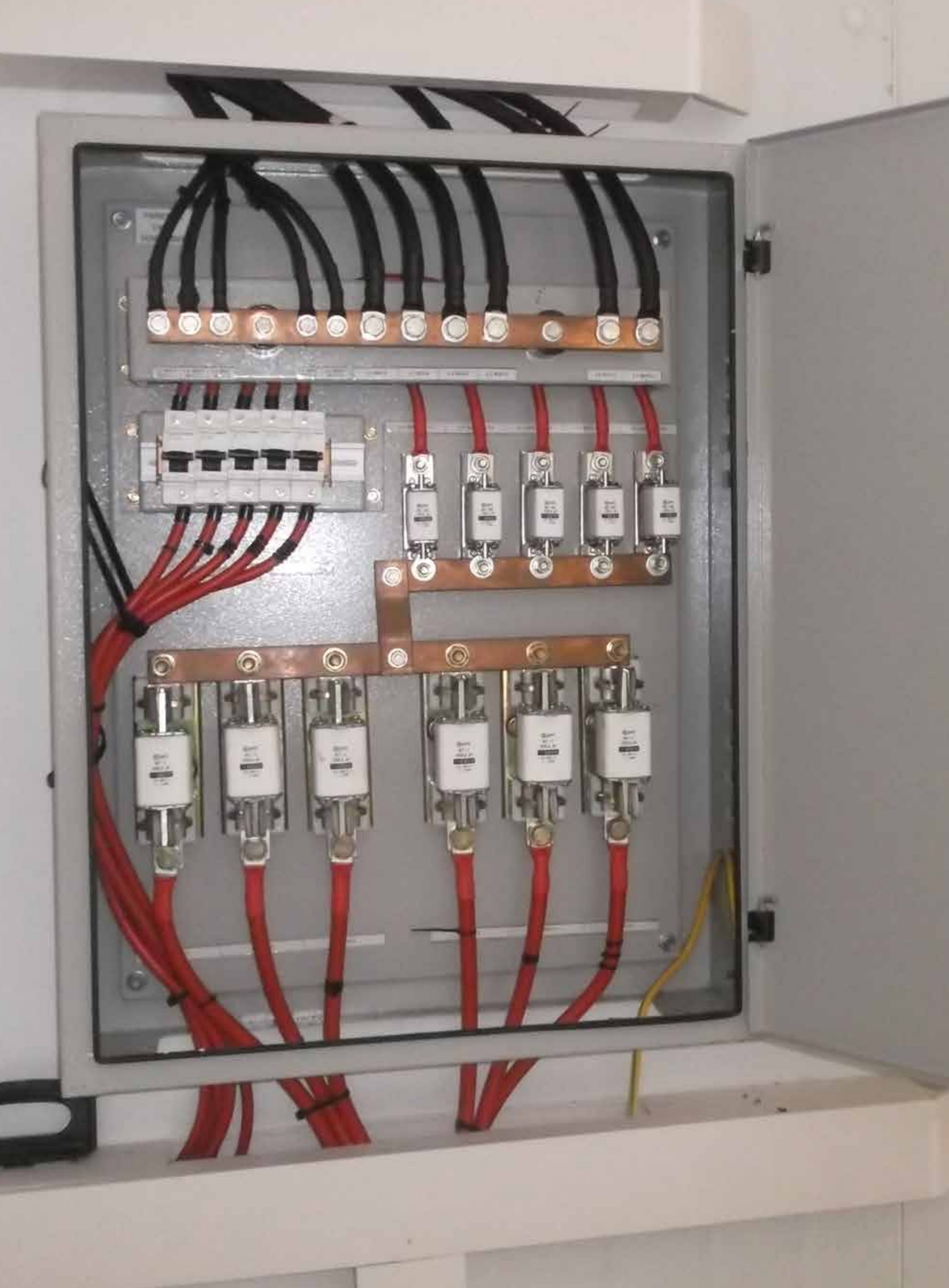


The outgoing line from four battery banks in parallel has the same size as individual battery and is not protected by an overcurrent protection device.

Vertical busbar arrangement makes difficulty to arrange and route the cable. Some positive cables touch negative busbar and vice versa.

Never leave cables unprotected and always use proper cross-section of the cable that is calculated based on the possible current passing through, as well as, the installation method[1]. See CHAPTER 3 page on how to avoid poor cable installation.

1. SNI 0225:2011 Persyaratan Umum Instalasi Listrik 2011 (PUIL 2011)



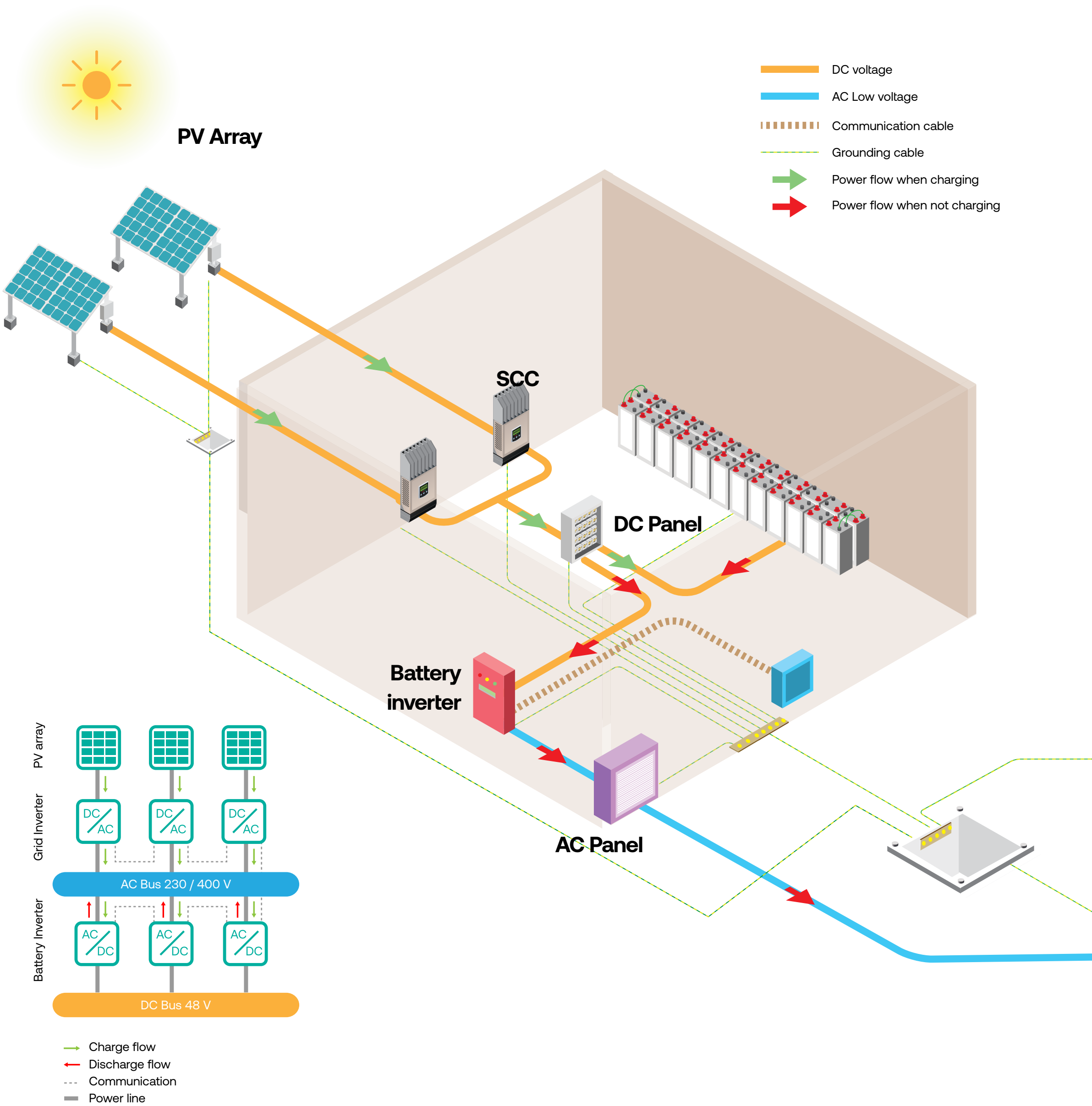
CHAPTER 8
Battery inverter

- What is a battery inverter?
- Good and bad installation of battery inverter
- Things to consider when setting the parameters

8.1 BASICS OF BATTERY INVERTER

Battery inverters or also known as stand-alone inverters is the brain of PV mini-grid system that form the AC distribution grid by regulating the voltage and frequency within allowable limit and maintain the energy balance in the grid. Battery inverters can typically be used bidirectionally or unidirectional depending on the system configuration. In AC coupling system, battery inverter works as an inverter (DC-AC converter) as well as a charger (AC-DC converter). If there is an energy surplus from the PV and the batteries are not fully charged, the battery inverter acts as a charger. And if there is shortage and battery still have energy left, battery discharges to fulfil the demand through inverter.

Several battery inverters can be expanded or interconnected modularly to achieve higher output. It can be configured in parallel as single-cluster in ¬¬single-phase or three-phase configuration as well as multi-clusters with additional panel distribution. In this case, if one cluster fails, the others are still in operation.



What are the functions of a battery inverter?

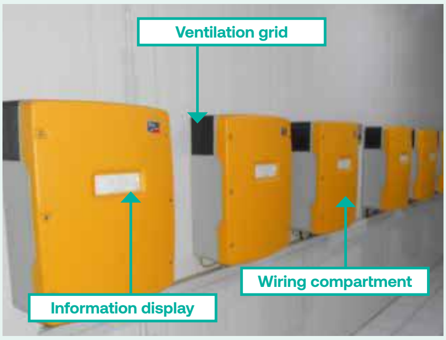
- Convert DC power from battery bank (typically 48 VDC) to AC power grid of 230 VAC

- Protect battery bank from overcharging by decreasing the charging current when the battery is already full. Overcharging the battery may cause gassing and explosion depending on the battery technology.

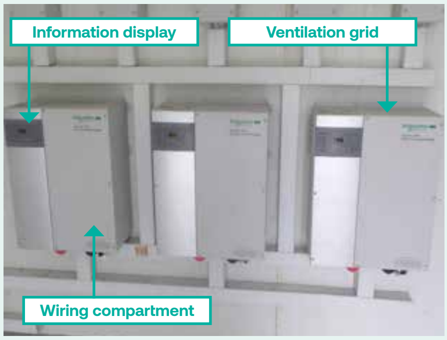
- Protect battery bank from deeply discharged by switching off the output when the state of charge of the battery falls bellow the threshold. As battery inverter requires battery to operate, deeply discharge of the battery can result in losing the grid.

- Measure and monitor the charging and discharging voltage, current, and energy to and from the battery bank and the AC output voltage and current.

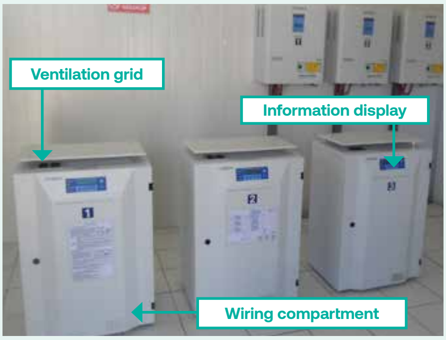
- Automatic transfer switch when the battery inverter is connected to other resources such as external grid or generator. External grid or generator can be used as a back-up when the battery is at low state of charge.



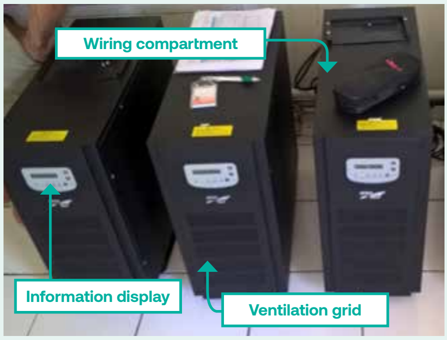
Six SMA Sunny Island 8.0H battery inverters installed in parallel to form 36 kW three-phase AC distribution



Three Schneider XW 6048 inverters are connected in parallel to achieve 18 kW continous output power.



Three Leonics Apollo S-219C inverters are connected in parallel result in 15 kW total output power



Three Kehua Tech DBX 12-5 kW inverters are installed to provide 15 kW output power to the load

WHAT IS THE IDEAL SPECIFICATION OF A BATTERY INVERTER?

- **Minimum of two battery inverters** should be used to increase redundancy in single-phase system and three inverters in three-phase system. It is preferable to use the same brand or type or any compatible inverters recommended by the manufacturer.

- **Battery inverters should be able to operate in parallel.** Control of grid inverter power is preferably done by adjusting the AC grid frequency or so-called frequency shift power control (FSPC). If the battery is fully charged, the grid frequency increases and power from other power sources such as the grid inverter is curtailed. Once the battery voltage decreases, the grid frequency also decreases and thus increases the allowable feed-in power of the grid inverter.

- **Flexible to be configured in single-phase or three-phase** and easily expandable with multi-cluster configuration. The inverter should also be suitable for TN configuration.

- **Sizing of the battery inverters should be according to the average load and peak load running for more than 30 minutes.** Estimated or measured load profile should be determined to identify the continuous and peak load. Battery inverters' rating should not be higher than the PV capacity.

Continuous rated power @ 25°C > Average load power

AC power at 25°C for 30 minutes > Peak load for more than 30 minutes

Continuous rated power @ 25°C ≤ PV capacity

- **High efficiency (≥ 94%) at peak system voltage and featured with MPPT.**
    - Equipped with the following protection systems:
    - Overcurrent and short circuit protection at AC side, the device should be protected against overload and short circuit during discharging.
    - High-voltage disconnect, that automatically stops the charging process when the battery voltage reaches the defined limit to avoid overcharging the battery.
    - Low-voltage disconnect, that automatically switches the inverter to standby mode or completely OFF when the battery voltage or SoC falls below the pre-set limit to avoid deeply discharge the battery.
    - Temperature-compensated battery charging is the ability of battery inverter in controlling the charging voltage based on battery temperature.

- **User friendly display that shows the status of battery inverter and SoC of the battery bank.** Battery management system should be based on precise determination of the SoC. It will help operator or technician to easily monitor the system.

- **Data acquisition or data logging to obtain the performance data** from the system directly from the inverter or via separated remote monitoring system.

- **Suitable for the installed battery voltage level and technology** (i.e. lead-acid, lithium-ion, zinc-air, etc.). The inverter should be able to operate with 48 VDC system voltage. The charging and discharging current and voltage of battery inverter should not be higher than the permissible value of the installed battery. The high-voltage disconnection and low-voltage disconnection threshold of the battery should be configured differently for each battery technology. If lithium-ion or zinc-air type of battery is used, battery management system of the battery should establish the communication with the inverter.

Max. charge current SCC ≤ I_{10}[1] battery (lead-acid)

Voltage at bulk/absorption mode ≤ Maximum voltage of battery

- **Tested and certified according to IEC 61000, IEC 62109, and IEC 61683.** The standard describes the electromagnetic compatibility (EMC) interference, safety of the power conversion unit, and guideline on how to test measure the efficiency of inverters used in stand-alone system.
- **Manufactured by a reputable company that has good track record** and clear warranty procedures.
- **IP rating of the battery inverter should be at least IP 40 for indoor used** to avoid the penetration of insects, dust, corrosive substances, moisture or water.

IP54 rating provides protection against dust and splash of water that may cause harm

Low IP rating may cause small objects as big as 12.5 mm to enter the compartment

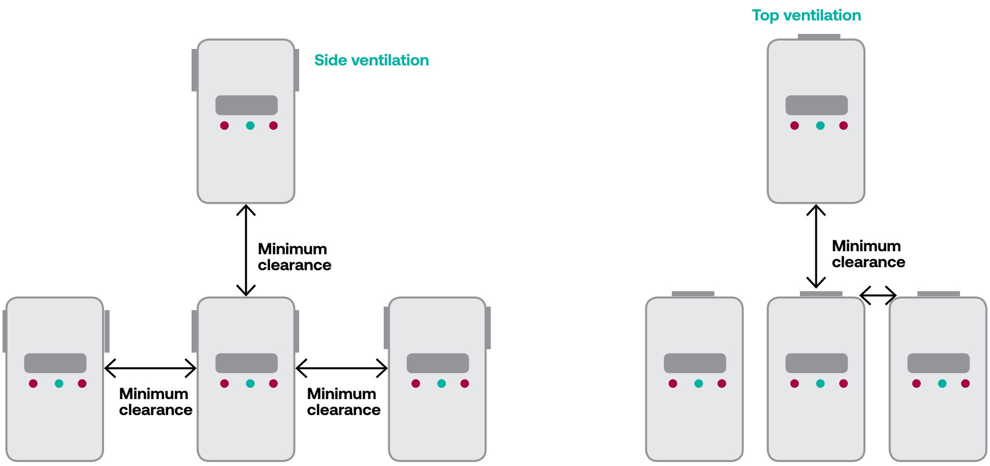
The information on the label is useful to identify the type and electrical characteristics of the installed battery inverters, especially during inspection or maintenance. Label should be attached and easily visible.

1. I_{10} or charging current rate in 10 hours (Capacity [Ah]/10 hours)

8.2 BATTERY INVERTER HARDWARE INSTALLATION AND INTERCONNECTION

LOCATION AND ARRANGEMENT OF THE UNITS

The battery inverter should be installed inside a power house to protect the device from direct sun exposure and harsh environment. Good heat management inside the room should be considered by providing good air flow circulation. Adequate distance between battery inverters should be maintained to allow heat dissipation.



Installation arrangement of battery inverters with minimum clearance for ventilation opening and cable installation. Check the manufacturer instruction for the minimum clearances.

Adequate clearance between the inverters to ensure air supply and allow heat convection.

Battery inverters are installed very close to each other. Ventilation is blocked by the cable conduit.

Ventilation opening is free from objects allowing the warm air to escape

Ventilation opening of the battery inverter is obstructed with foreign objects

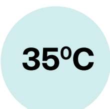
Ventilation opening of the battery inverter should never be blocked by any object to avoid unnecessary increase of heat. Increasing of heat will reduce the output power. Battery inverter ventilation openings must regularly be cleaned from dust deposits

The front of the battery inverter have greater than one meter of clearance

Insufficient front clearance may cause difficulty when conducting service and maintenance.

How to improve the inverter arrangement?

- Position of the battery inverters should be rearranged based on the recommended layout specified by the manufacturer. Depending on the location of ventilation, minimum clearance of 30 cm should be maintained around the inverter to allow natural convection and proper cable installation and 1 meter from the front side of the inverter.



- Ensure that the ambient temperature of the power house is not exceeding 35°C due to excessive number of inverters installed in the room.

- The ventilation of the battery inverter should be cleaned in regular basis from dust accumulation.

Wooden base is used to elevate the installation of the inverters.

Battery inverters are installed on top of free-standing concrete blocks.

How to fix such installation?

- As wood is susceptible to wet damage, replace the mounting base with anti-corrosive metal structure. If the power house is not prone to flooding, install directly the inverters on the floor.

- Free-standing concrete blocks are not very stable. Small movement on the inverter may easily cause the entire installation to collapse. Use a more stable structure to elevate the inverters.

CABLE INSTALLATION OF BATTERY INVERTER

Electrical connection in the battery inverter includes the battery and AC power cables, different type of communication cables, and equipment grounding.

The importance of correct battery inverter

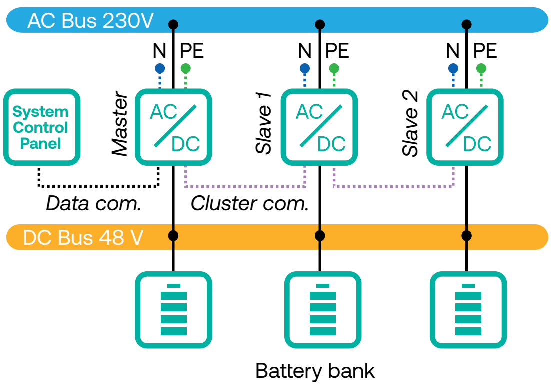
- To mitigate the risk of having overheated cable, electric fault, and possibly electric shock hazard to the operator or technician.
- To establish parallel operation between master and slave battery inverters as well as between the main cluster and extended clusters.
- To obtain the measurement data from the battery inverters via remote monitoring system.

Battery inverters and the cabling are neatly installed and routed inside the cable conduit.

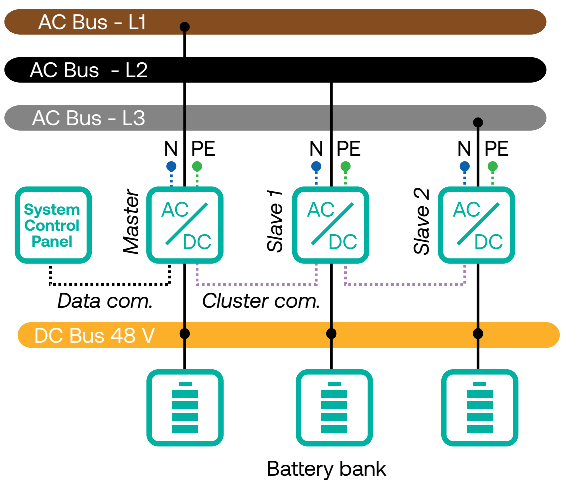
Very long cable reduces the efficiency of the system due to unnecessary voltage drop.

How to configure multiple battery inverters in parallel?

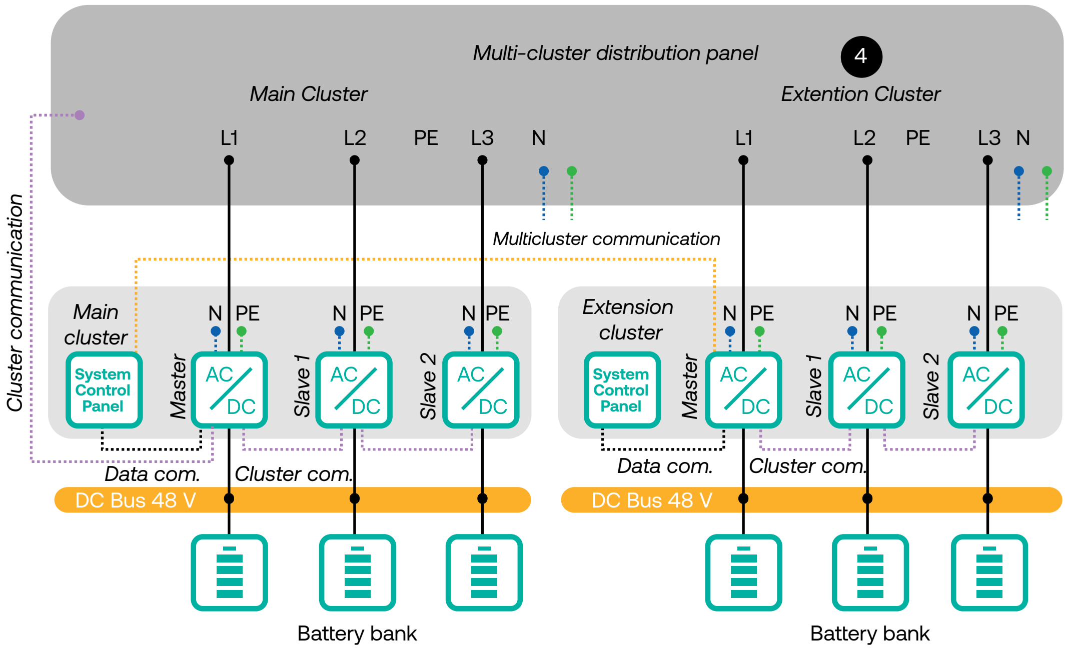
- **One cluster, single-phase**
  In this configuration, up to three or four battery inverters (depending on manufacturer) are connected to a battery bank forming a cluster. The AC output of battery inverters are connected in parallel on a single-phase line conductor. Cluster communication or AC synchronisation network should be established between the inverters within the cluster.



- **One cluster, three-phase**
  Three battery inverters are connected in parallel at the DC bus and forming three-phase distribution system. Each of the battery inverter represents one phase of the three phases and operates at phase shift of 120° or 240° between each other



- **Multi-cluster, three-phase**
  A multi-cluster system consists of multiple clusters connected in parallel. The output power of the multi-cluster system increases with the number of clusters. As multi-cluster system is intended for three-phase configuration, the number of installed battery inverters should be divisible by three. Depending on the brand, a multi-cluster box is required to connect the clusters as shown below. Multi-cluster communication should be established between the masters.



- Master is set to act as a control and monitoring centre and communicate with the slaves within the same cluster and to other masters. The master regulates the frequency and voltage to be followed by the slaves. It also controls the battery operation and connect or disconnect of the slaves as well as monitors the battery state of charge.
- Slave follows the configuration setting and commands from the master within the cluster. The slaves operate based on the commands issued by the inverter and provide the feedback to its master.
- Main cluster has the highest cluster level in the multi-cluster system. The master of the main cluster is superior than masters of the extension cluster. The task of the master is to communicate with multi-cluster box, start and stop the entire system, and control as well as monitor the other masters.
- Extension cluster is additional cluster in multi-cluster system that is under the main cluster control. The master of the extension clusters has to follow the signal sent by the master of main cluster. The extension cluster is independent to the operational of the entire system, which means

Source: SMA[2] and Schneider[3]

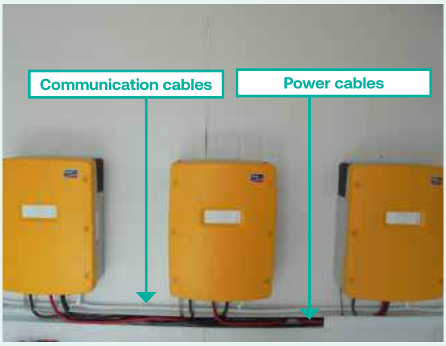
2. SMA, "Installation - Quick Reference Guide Off-Grid Systems," 2014.
3. Schneider Electric, "Conext XW Multi-Unit Power Systems Design Guide," 2016.

Power and communication cables are protected inside cable conduit.

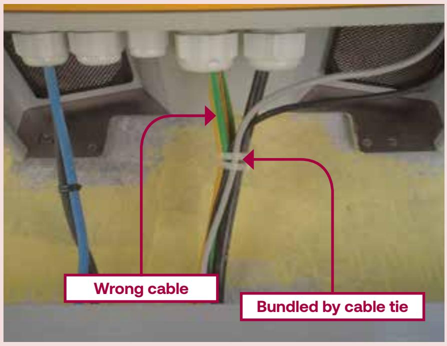
Tangled power and communication cables. Bad cabling can be dangerous and affecting performance.

How to improve the cabling of battery inverters?

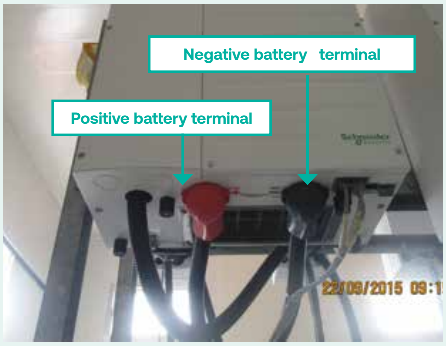
- Re-route the cable and cut the unnecessary length of the cable. The length of power cable within a cluster should be identical.
- Install cable conduit to route and protect the the cables and preventing high mechanical load on the cables by not leaving the cables hanging.
- The cable length between the battery inverters and battery bank and AC distribution in a cluster should be identical to avoid unsymmetrical operation.
- Use proper cable type based on the operating voltage, maximum charging and discharging current, and AC output current. The cross-section of the cable should be calculated based on IEC 60364 or PUIL and should not be less than 70 mm2 for DC and 10 mm2 for AC or as per manufacturer instruction. The peak AC output current should be considered when sizing the cables and protection devices (Cable rating > MCB rating > Peak AC output current).
- Battery inverters should be installed closely to the connected battery bank. The cable length between the battery bank and battery inverters should not exceed 10 meters. And the total length of the communication network should not exceed 40 meters.
- Power cable and communication cable should be not be installed close to each other or bundled in the same conduit.
- Label each power and communication cable for easy identification of the cables



Power and communication cables are protected inside cable conduit.



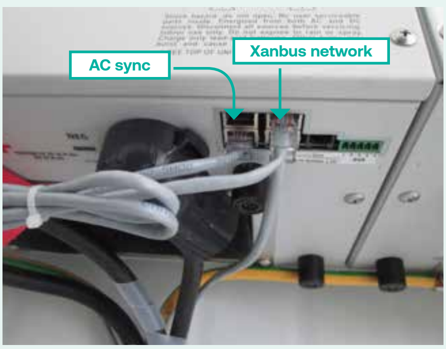
Bundling of communication and power cable may introduce unintended noise in the signal



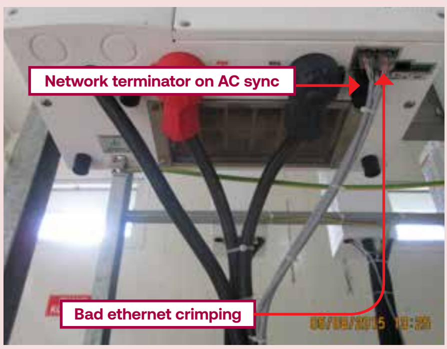
Battery terminal connection is protected with insulator material from direct touch and being shorted.

Absence of terminal boots can lead to an accidental short circuit to the battery.

The battery terminal connection is always alive and should never be left unprotected. Metal parts may cause accidental short circuit and potentially creating sparks.



Ethernet cables for sycnronsation between battery inverters and communication network are properly installed.

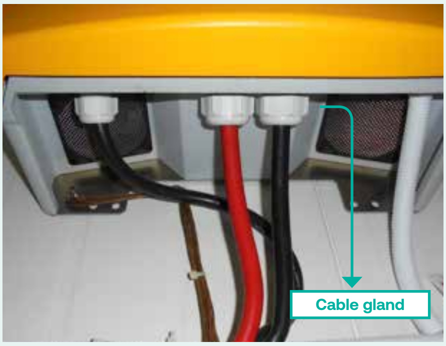


Low quality self-made ethernet cable is used. The outer jacket is not securely crimped inside the connector.

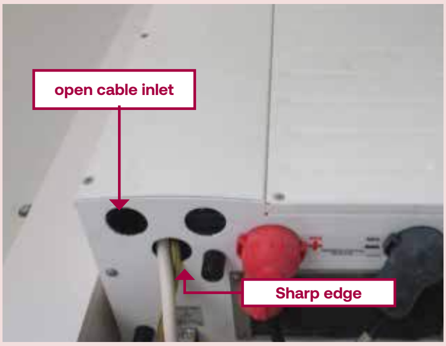
Network terminator is normally used to terminate the first and the last devices of the communication chain. Cross-check with the manufacturer instructions for the necessity to terminate the connection.

How to fix such installation?

- In battery inverter type above, the cluster network for AC synchronisation should not be terminated with network terminator. Network terminator should only be installed on the first and last device of the data communication network.
- Please refer to the manual for the recommended communication cable type. Some manufacturer only allows straight-thru Category 5 (CAT 5 or CAT 5e) cable type with RJ45 connector. Using twisted pairs cable for the signal connection may reduce the noise
- Replace the ethernet cable with higher quality crimping or use the cables provided by the inverter manufacturer. The tiny wires may not be able to hold the mechanical load when plugging in and out the cable. Excess wires should be cut and the connector should hold the outer jacket by squeezing it into the connector.
- Use strain relief boots around the connector to avoid cable snags



Power and communication cables are protected inside cable conduit.



Absence of cable glands may damage the cable insulation due to sharp edge and also causing IP rating degradation.

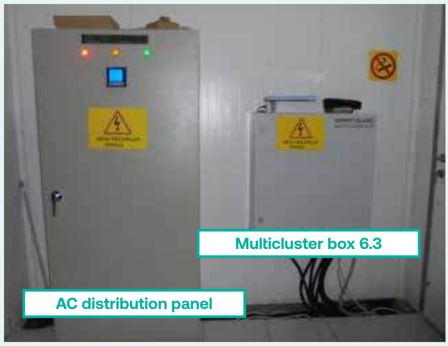
Grounding connection of the exposed conductive case is provided to prevent electric shock.

Chassis of the battery inverter is not grounded. Ungrounded metal case may lead to electric shock hazard.

MULTI-CLUSTER BOX

Some manufacturer requires additional distribution panel to establish multi-cluster system and to connect between the battery inverters (clusters), grid inverters, and the load. The panel is often prewired and contains all the switching and monitoring devices. The panel is available according to the required number of inverters to be connected.

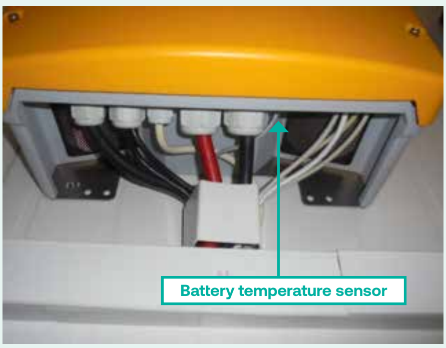
SMA Multicluster box 12.3 is used to connect three clusters consisting nine battery inverters.

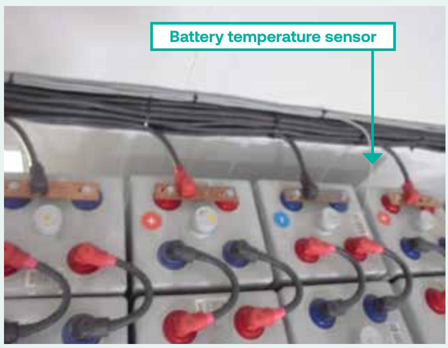


SMA MC box 6.3 is used to install six battery inverters in parallel before being distributed to the grid via AC distribution panel.

BATTERY TEMPERATURE SENSOR

Similar to the solar charge controller, the information on battery temperature is required to prevent battery charging at high temperature. The charging compensation is done by adjusting the charging voltage based on the increase of battery temperature.





Battery temperature sensor is connected to the battery inverter (master) and installed on the battery for charging compensation feature.

Battery temperature sensor should only be installed on the master battery inverter of each cluster. See chapter 4 on how to install the battery temperature sensor correctly.

8.3 BATTERY INVERTER PARAMETER SETTINGS

Setting-up the battery inverter parameter is an important step during installation to ensure the parallel operation of multiple inverters and safe battery operation. The parameters should be configured according to the manufacturer instruction and recommended values from the battery manufacturer. All the basic parameters should be set properly prior to the commissioning. The configuration of the battery inverters can be done using a system control panel that is connected to the master inverter through data communication network.

Four SMA Sunny Remote Controls are installed to configure and monitor each cluster

Conext System Control Panel are instaled to set up and monitor the battery inverters.

What parameters should be considered when configuring battery inverters?

- **Basic configuration**
  - **Device type** to identify the master and slaves
  - **Operating mode** should be set to stand alone or off-grid mode
  - **Type of battery** can be selected between the lead acid battery technologies (valve regulated or flooded) or other type such as lithium-ion. The OPzV battery is specified as a valve regulated (VRLA) battery.
  - **Nominal Battery bank voltage**, which is typically set at 48 V DC. The battery voltage should be within the range of the nominal battery voltage.
  - **Battery bank nominal capacity** in Ah (Ampere-hour) based on the C10 capacity of the battery bank. Sum the capacity of all battery strings if multiple strings are connected in parallel.
  - **Line voltage and frequency** of the grid is set to 230 VAC and 50 Hz.
  - **Number of line conductors** is ether single-phase or three-phase configuration.
  - **Single cluster or multi-cluste**r to determine configuration of the system.
  - **Type of cluster** differentiates between main cluster and extension cluster.
  - **Cluster address** and type of distribution panel is to identify the address of extension cluster and the product specific box is used
  - **Connected energy sources** such as PV with grid inverter, generator, or external grid

- **Additional configuration for AC output is only done at the master**
  - **Nominal AC voltage and frequency** of the stand- alone grid. The default value is 230 V / 50 Hz
  - **Frequency droop function** is to set the rate of frequency change per kW
  - **Minimum and maximum inverter voltage** is the operating range of inverter AC voltage
  - **Minimum and maximum inverter frequency** is the operating range of inverter frequency

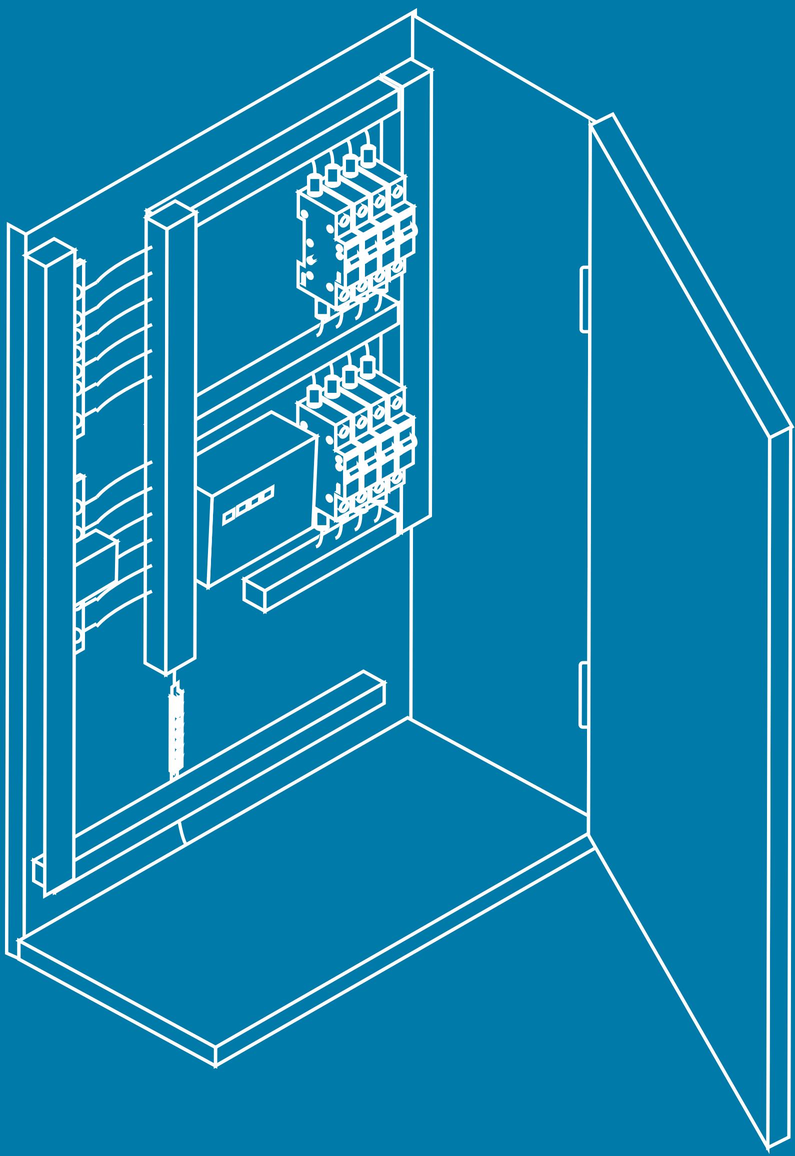
- **Additional configuration for battery configuration is only done at the master**
  - **Low voltage disconnection** is the cut-off limit of battery voltage that the inverter should stop
  - **Charging current limit** defines the acceptable output current to charge battery. The value normally depends on the maximum charge that can be applied to the battery.
  - **Charging cycle** is either three-stages or two-stages charging process with no float. Three-stages cycle consist of bulk or charging-current phase, absorption or constant-voltage phase, and floating phase is normally used for lead-acid and two-stages for lithium.
  - **Charging voltage setting** to ensure proper battery charging. See Chapter 4 for the recommended values for the voltage setting. The recommended voltage for lead acid OPzV is 2.35 2.4 V for the bulk and absorption stage, and 2.25 - 2.3 V for float charging or consult with the battery manufacturer for the allowable limit.
  - **Battery temperature compensation** is the adjustment required per increase of temperature specified in mV per °C.

Battery inverters are labelled with ID showing the device type and phase connection

Absence of label on the inverters can cause difficulties when carrying out inspection or maintenance

CHAPTER 9
AC Distribution Panel

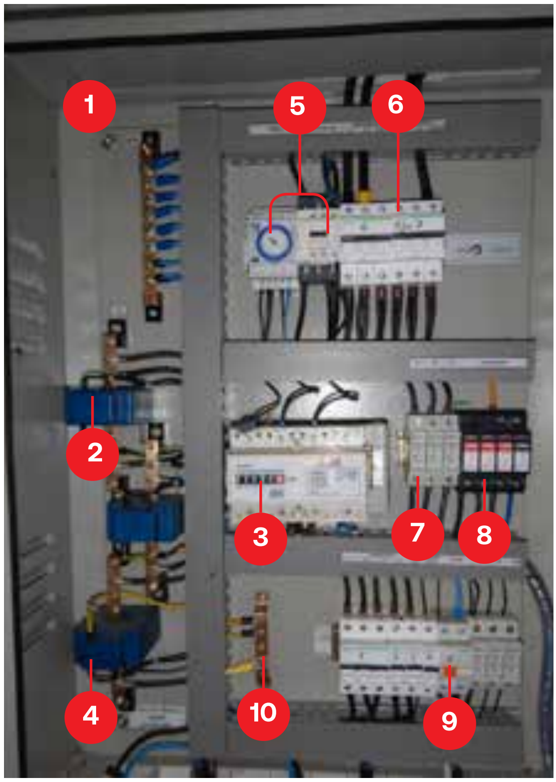
- ✓ What is the function of AC distribution panel?
- ✓ What are the components inside the panel?
- ✓ Good and bad installation of the panel



9.1 BASICS OF AC DISTRIBUTION PANEL

Alternating Current (AC) distribution panel or also known as AC panel distribution box (ACPDB) is used to divide and distribute the power from battery inverters to feed several loads or feeders. It is the place where the battery inverters are connected in parallel to combine the output power as well as the housing of protection devices of all feeders. A typical AC distribution panel consists of busbars, incoming and outgoing feeders, protection devices, and local monitoring system. Depending on the system capacity and topology, AC panel distribution might be configured in 1-phase or 3-phase arrangement.

1. **Enclosure houses** the protection devices and busbars
2. **Busbar is the interconnection point** between battery inverters, grid inverters and output feeders. Typically, four busbars consisting of three lines and one neutral are used for three phase configuration while two busbars consisting of one line and one neutral are used for single-phase configuration.
3. **Energy meter** acquires the voltage and current from each phase, calculate the power and accumulate the energy.
4. **Current transformer** is used as a current input of the energy meter. It measures the current on each phase and converts it to a lower current that is readable by the energy meter.
5. **Timer and contactor control** operational hour of the streetlight. Usually the streetlights operate only for five hours.
6. **Miniature circuit breaker (MCB)** protects the incoming feeders (battery inverters) and the outgoing feeders to the grid distribution.
7. **Fuse** to interrupt the voltage measurement from the busbars in case of sudden short circuit or damaged energy meter.
8. **Surge protection device (SPD)** is used to limit voltage in the event of overvoltage and lightning strikes.

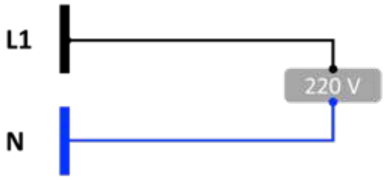


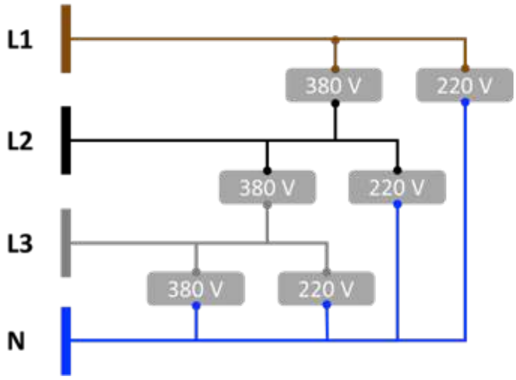
30 kW AC distribution panel with three-phase configuration

9. **Earth-leakage circuit breaker (ELCB)** prevents human from electrical shock due to dangerous voltage on the metal enclosure. The device will interrupt the load when considerable voltage is detected. Residual current device (RCD) is also often used for this purpose.
10. **Grounding bar** provides grounding for the enclosure, surge protection devices, as well as current transformers.

▶ How is the cable insulation colour in 1-phase and 3- phase system?

All components in the AC distribution panel are operating in AC voltage that may reach up to 380 to 400 V for three-phase configuration. PV mini-grid with capacity bigger than 15 kWp is usually configured in 3-phase. While system smaller than 15 kWp is normally operated in 1-phase or 220 to 230 V.





The insulation colours are according to PUIL[1] 2011 and SNI[2] IEC 60445. Previous insulation colours are red for phase 1, yellow for phase 2, blue for phase 3, and black for neutral.

▶ What is good installation of a panel?

- Enclosure should be safe from touch voltage in case of fault. This could be done by having good grounding of the enclosure or using double insulation panel.
- Additional safety precaution such as marking and label should be attached to raise awareness that dangerous voltage is existing in the system.
- Good heat management is required to avoid significant derating of the components.
- Meters and light indicators should be available on the door and clearly visible.
- Panels should be properly fixed and easily accessible.

Panels are mounted on the wall and cables are installed neatly.

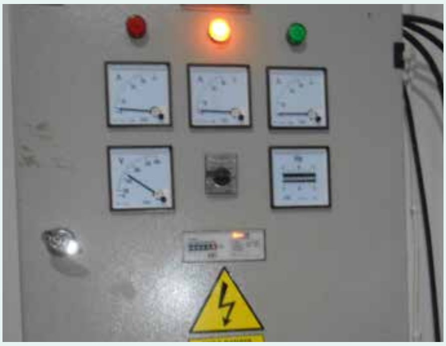
Free standing AC distribution panel may lead to instability and cause the panel to fall.

[1] General Requirements for Electrical Installation - Indonesian Standard
[2] SNI - Indonesia National Standard

9.2 ENCLOSURE

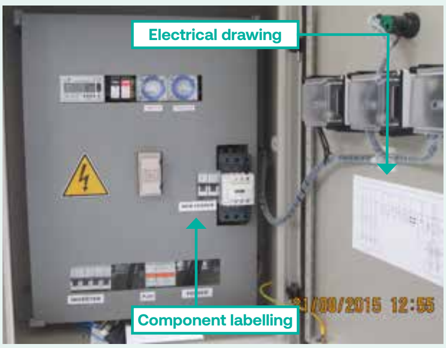
QUALITY OF THE ENCLOSURE

It is important that all the active electrical components have clear warning label to alert the operator or technician with the existence of live busbars and connectors in the panel. Apart from label, the panel should also be provided with key lock to prevent unauthorized person from accessing the installation.

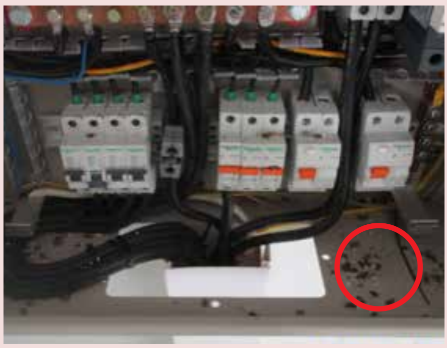


Panel is labelled with electrical shock hazard.

Absence of labels reduces the awareness of the dangerous voltage existence.

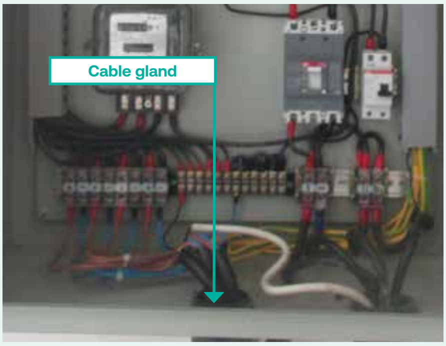


Additional board to protect the installation from direct touch. As built electrical drawing is available on the panel.



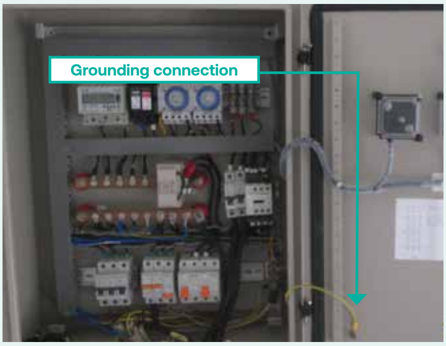
Sign of animals in the panel. Panel should have at least IP3x to avoid animal entering the panel.

Ensure that all the components and cables are attached with relevant label. All the labels should be corresponded to the available electrical drawing on the panel.



Cable gland is used to prevent animal entering to the panel. It is preferred to have individual gland for each cable.

Improper sealant is used at the cable insertion. Cable glands should be used instead.



The enclosure including its door is well grounded.

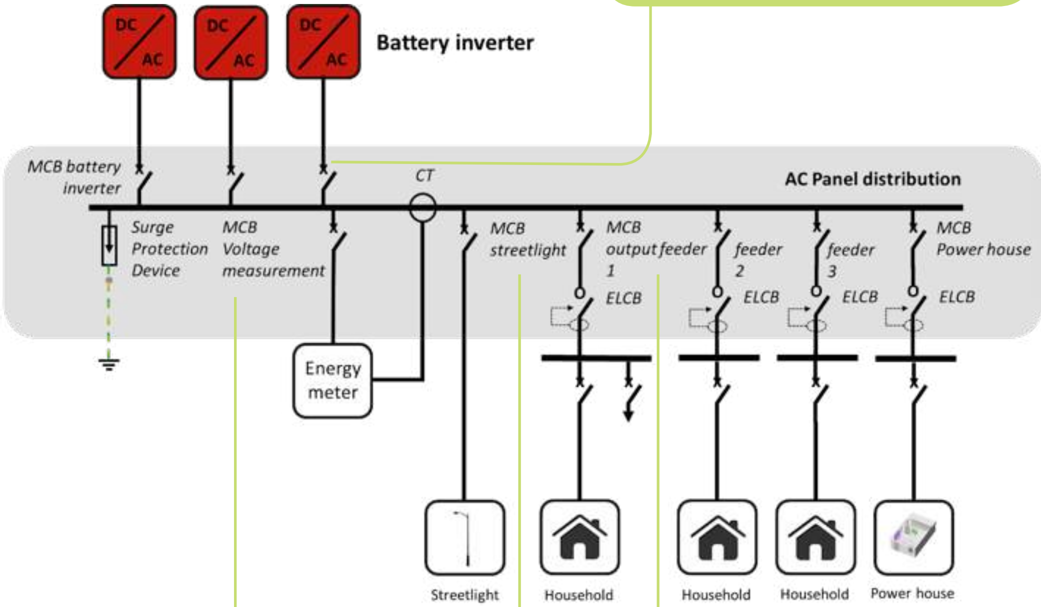
Ungrounded door may lead to electric shock when there is fault or cable insulation failure.

There is no guarantee that the door is conductively connected to the box. Attaching grounding cable to the door will reduce the risk of having electrocuted when fault occurs.

9.3 ELECTRICAL COMPONENTS IN AC DISTRIBUTION PANEL

How is the typical electrical diagram of a single-phase AC panel distribution?

Irated Battery Inverter MCB ≥ 1.25 x Irated inverter output current



I_{rated} voltage measurement MCB ≥ 1.25 x I_{rated} energy meter

I_{rated} street light MCB ≥ 1.25 x Irated energy meter

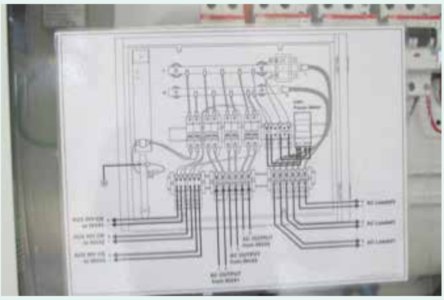
I_{rated} output feeder MCB ≥
I_{rated} households MCB x number of households
Irated battery inverter MCB ≥ Irated output feeder MCB

Irated power house MCB ≥
1.25 x I_{rated} appliances in the power house

It is recommended that the output feeders should be at least equal to the number of installed battery inverters. This will enable protection coordination which avoid having feeder's MCB (downstream circuit) rating higher than the MCB of the single battery inverter (upstream circuit).

Why protection coordination is required?

- To ensure that the protection devices operate with the necessary reliability.
- To disconnect only the faulty line from the system.
- To avoid unnecessary disconnection of upstream protection device when overload or short circuit occurs.



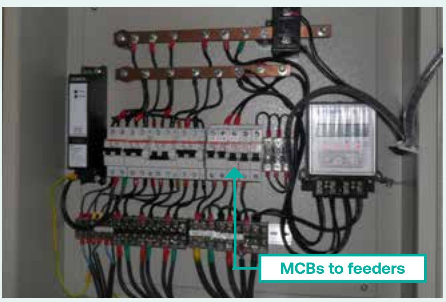
As built electrical drawing is available on site to indicate the location and interconnection between components

Panel without drawing and label on the cables and components causing the possibility of having incorrect connection.

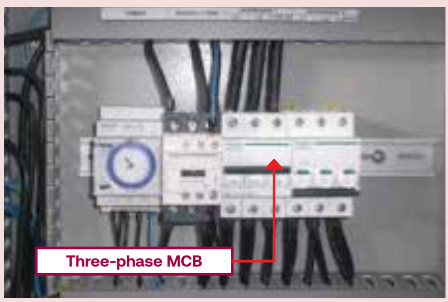
PROTECTION DEVICES

What to consider when installing protection devices?

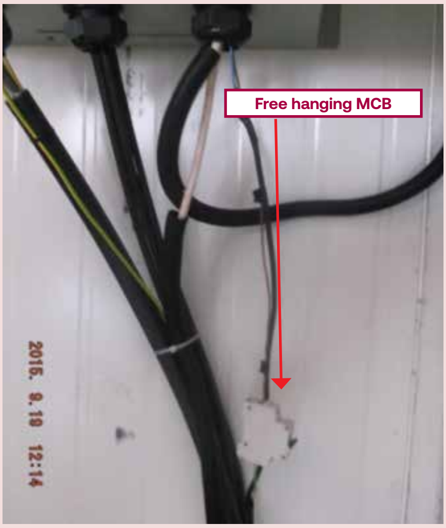
- It is recommended to use MCBs than fuses. In case of fault, MCB is reusable and has higher availability in the rural areas compare to the fuse.
- Protection for the feeders must be specified and installed according to the requirement of the relevant standards (PUIL 2011 and IEC 60364)
- Always check that the MCB or fuse rating is higher than the load current and lower than the rating of the protected cable.
- All the devices should be AC-rated and has voltage rating equal or greater than the operating voltage (220VAC / 380 VAC)
- Ambient temperature of the panel should be taken into consideration in the sizing of devices. Correction factor must be estimated in case of high ambient temperature. It is safe to consider derating factor at ambient temperature of 45°C.



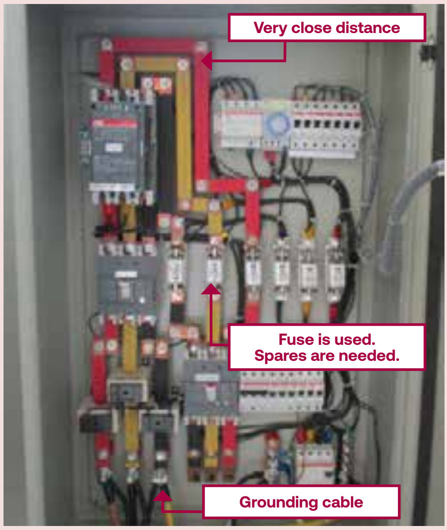
Single phase MCB is used to protect individual feeder.



Three-phase MCB is used for three different feeders. Fault in one feeder will unecessarily disconnect all feeders.



Unsafe installation of MCB. MCB should be mounted and protected inside the panel.

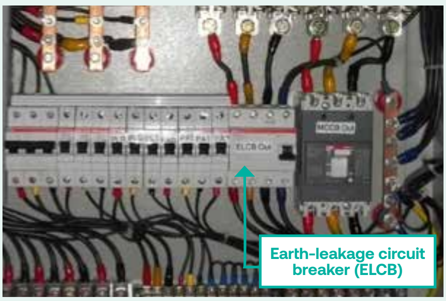


Busbars are used to interconnect the components. Grounding cable is used as line cable.

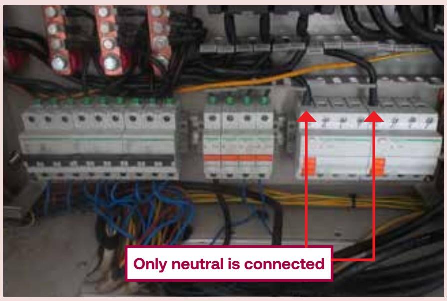
How to ensure proper operation of the protection devices?

- Verify during commissioning that the protection devices are functioning correctly and are using proper rating (not underrated).
- Conduct inspection to regularly monitor the fuses condition. Burnt fuse or tripped MCB should be investigated immediately.
- Electrical fault has to be located and cleared before switching the MCB back on or replacing the fuse.
- If fuses are used, provide a minimum of 20% spare fuses from the total fuses installed with similar size and rating inside the box.

Always make sure that the system is off or the panel is free from voltage when conducting troubleshooting or inspection.

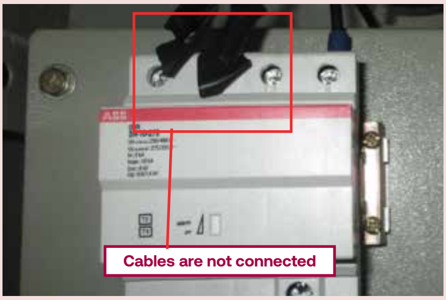


Correct installation of the ELCB. All the phases and neutral are connected to the ELCB.

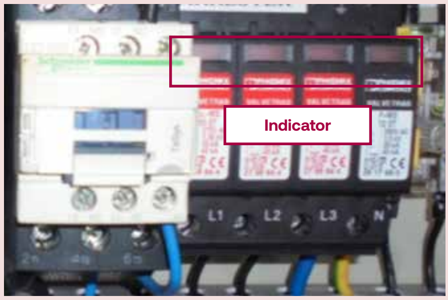


ELCB is not installed correctly. All the phases should also be connected to the protective device.

All phases and neutral cables should be connected to ELCB to have complete protection. ELCB can only be used in the following earthing systems: TT, TN-S, or TN-C-S. See Chapter 14 – Grid distribution for different earthing arrangement or systems in PV mini-grid.

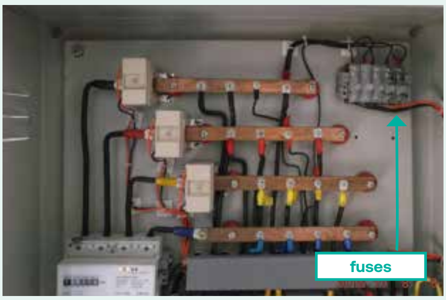


Cables are not connected to the surge protection device. The system may not be protected from voltage spike.

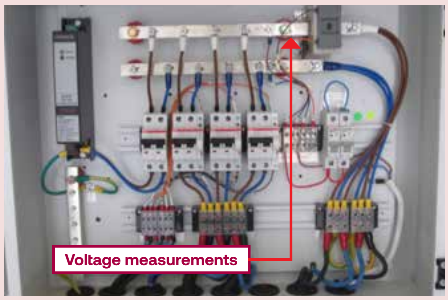


Replacement of surge protection device (SPD) is needed as shown with red indicator on the SPD.

Induced voltage may occur in all phases, therefore, all the phases including neutral and ground should be connected to the surge protection device (SPD).



Voltage measurements are protected by fuses.

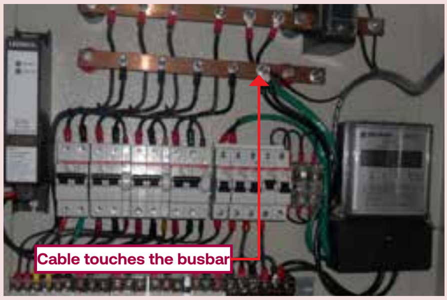


Voltage measurement is not protected by any protection device. Energy meter is not installed.

Cable connection from the energy meter to the busbar for voltage measurement should not be left unprotected. Faulty energy meter or wrong connection may cause overload or short circuit.

BUSBAR TERMINAL

Line cables do not cross the neutral busbar. Avoid direct contact between cable and busbar from different line.



Direct contact of phase cable and neutral busbar. Insulation may be damaged overtime due to the sharp edges and vibration.

Adequate distance between line and neutral busbars.

Busbars installation of the phases are too close and separation is not provided.

All the busbars should be identified with labels and are separated using isolated material to avoid direct contact or accidental short circuit.

LOCAL MONITORING SYSTEM

Local monitoring system is required to provide basic information such as instantaneous voltage, current, frequency, power, and the total energy delivered to the load. The monitoring unit can be in the form of digital or analogue meter. It consists of energy meter, voltage measurement and current transformer as input of the meter.

Energy meter is provided to monitor the energy used by the load

Digital meter on the panel provides better visualization and precision of the measurement values.

What to consider when installing an energy meter?

- Energy meter should be calibrated prior the shipment
- For better accessibility, it is preferable to have energy meter installed on the door of the panel.
- Verify correct reading of the meter during commissioning to avoid invalid or unreliable reading of the data.

Energy meter is working properly and all phases are connected to the measuring device.

The meter is not functioning and the third line is not connected to the meter. Fuse might be blown.

Ensure that all the phases and neutral are connected to the energy meter for correct reading. The ratio of the current transformer should match with the input current of the energy meter.

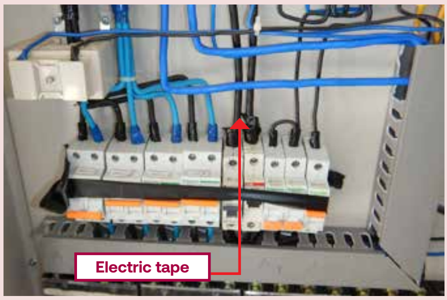
Current, voltage, and frequency of the electrical system are shown on the panel.

The output current is not measured by the panel. Output current is needed to identify the power consumption of the load.

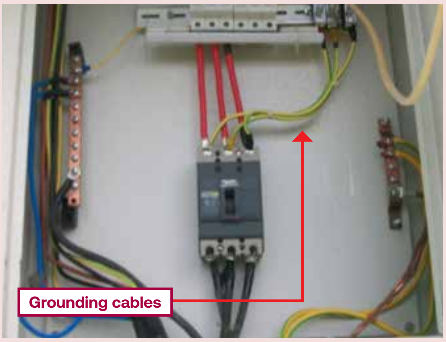
Voltage and current measurement of the output should at least be installed on the panel to display the power delivered to the loads. The information is useful for the operator or technician to see the instantaneous power as well as to detect faults.

CABLE INSTALLATION

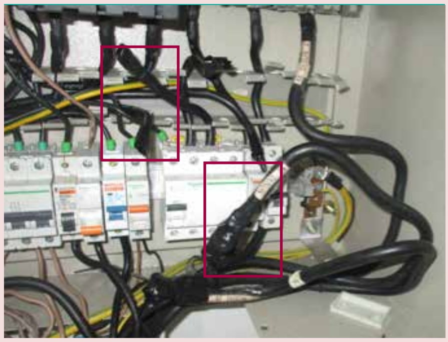
Neat installation and proper cable shoes are used.



Cable is not installed with proper cable shoes. Eletrical tape is used as insulation and to fix the MCBs.



Wrong insulation colour (grounding cable) is used for the line phase. Correct colour should be used instead.



Improper cable connection and insulation. Replace the cable with the whole cable.

Cables must be properly terminated and fastened. Bad crimping and connection can lead to increase of heating, losses in wiring, and rising possible risk of being electrocuted and fire. Always check the tightness of the crimping by slightly pull the cable.

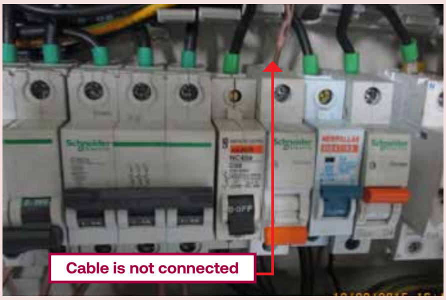
How to avoid bad installation?

- Use pre-assembled AC panel distribution. Pre-assembled panel is more reliable as the panel is tested to assure the quality of the installation. Continuity test is usually conducted in the factory to ensure a proper connection and normal ambient temperature.
- Verify during commissioning that there is no overheated cables or connectors. Verification can be done visually, mechanically by checking the tightness of connection, electrically by checking the voltage and current, as well as verified thermally.
- Thermal imager can be used to spot the abnormal heat due to undersized cable or bad installation. Inspection is required when there is a significant difference in temperature between the overheated component and its neighbours.
- Conduct inspection and maintenance regularly to make sure there is no loosen bolts, screws, or cables due to vibration or temperature variation. Re-torque the bolts when needed.

Cables are neatly wired and routed inside cable tray. Colour codes and labels are used to identify phases and components.

Unnecessary cable length and messy installation. Re-routing of the cable installation is required.

Cables should be arranged neatly and not too long. A very long cable will cause unnecessary voltage drop and higher cost. Bad installation may increase the risk of having fault due to damaged cable insulation and causes difficulty to quickly identify the fault.



Improper connection may lead to an electric arc. MCBs are not equipped with labels.

Conductors of two core cable are connected in parallel and not protected individually.

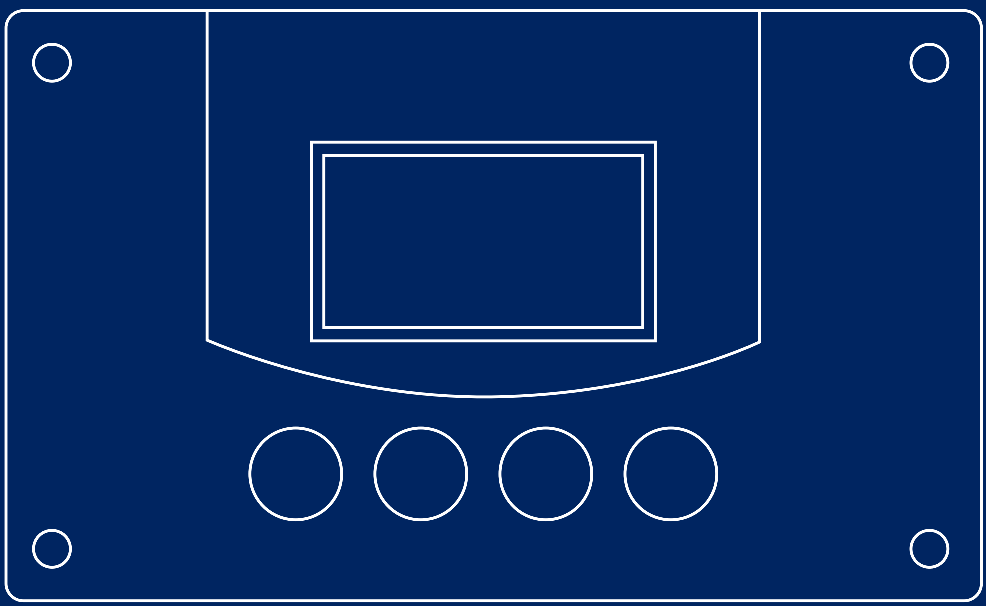
Only use one conductor in multi-core cable for each line. Connecting in parallel two different insulation colours may lead to short circuit.

How to fix the installation?

- Avoid using double core cables connected in parallel to increase the current flow use bigger single core cable
- rewire messy cable installation. Cut unnecessary cable length and use cable conduit to arrange and protect cable insulation

CHAPTER 10
Monitoring System

- ✓ Good and bad installation of monitoring system
- ✓ List of parameters to be monitored
- ✓ Things to consider when setting the monitoring system

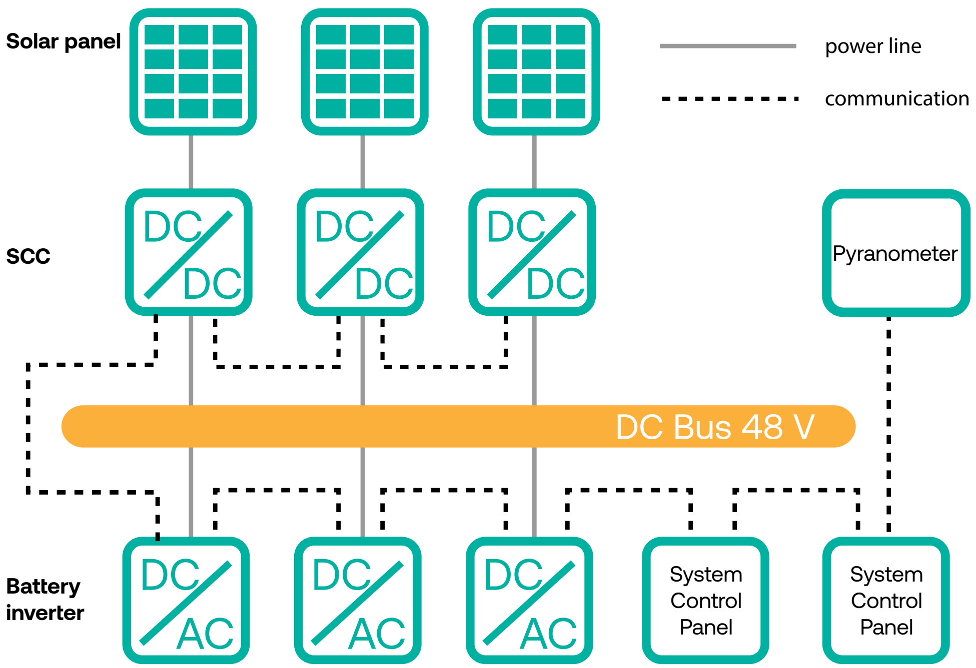


10.1 BASIC OF MONITORING SYSTEM

Alternating Current (AC) distribution panel or also known as AC panel distribution box (ACPDB) is used to divide and distribute the power from battery inverters to feed several loads or feeders. It is the place where the battery inverters are connected in parallel to combine the output power as well as the housing of protection devices of all feeders. A typical AC distribution panel consists of busbars, incoming and outgoing feeders, protection devices, and local monitoring system. Depending on the system capacity and topology, AC panel distribution might be configured in 1-phase or 3-phase arrangement.

What are the main functions of monitoring systems?

- Evaluate whether the production meets the demand of the consumers
- Understand the system performance including its efficiency and reliability
- Provide support to the local operator in conducting troubleshooting
- Provide substantial information for further improvement on the system design which optimise the components used in the system



Typical installation of the monitoring system. Cable communication is connected in daisy chain[1].

PV mini-grid must be equipped with monitoring device to keep an eye on r its condition and to initiate maintenance when needed. A typical remote monitoring system comprises monitoring device as a data hub from individual devices and system control panel. The monitoring is conducted by acquiring data such as voltage and current from each power electronic device, irradiance from pyranometer then transfer the data to the monitoring device through communication cable. Further, the data can be directly visualized, stored in data logger, or transmitted to the data cloud when GSM/GPRS signal is available.

1. Daisy chain: a series of interconnected or related things

What are the requirements of a good monitoring system?

- Featured with data logging function using SD card. Data logging interval of at least in hourly period.
- Accessible from personal computer through web browser.
- Compatible with the type and brand of the installed power electronics and pyranometer. Compatibility means an ability to communicate easily with the available interface and protocol.
- Featured with communication interface through ethernet and RS485.

Sunny WebBox, communication and monitoring device for SMA

Conect ComBox, communication and monitoring device for Schneider

SMA Sunny Remote Control to control and monitor Sunny Island battery inverter

Schneider XW System Control Panel (SCP) to control and monitor all connected power electronics

How to monitor a PV mini-grid system?

1. Manually check the system

Monitoring is conducted by the operator in daily basis. It is performed by manually check the data on the local monitoring system in AC distribution panel and on the system's control panel. The operator should visit the power house and write the basic data such as energy output, battery voltage, input energy from the PV, etc. The checklist should be send regularly by the operator to the owner of the system. See operation and maintenance guideline published by Directorate General for New, Renewable Energy, and Energy Conservation (DG NREEC) for the maintenance checklist.

Energy meter

Battery inverter

No	Frequency	Activity	Component
1	Daily	Output energy from AC distribution panel [kWh] - Morning (06:00 - 07:00)	AC Panel Distribution
2		Daily energy usage [kWh]	Calculation
3		Battery voltage [V] - Morning	Batery Inverter
4		Check that the charging indicator is lit - Morning	Solar Charge Controller / Batery Inverter
		Measuring time - Morning	
5		Energy production from PV array [kWh]- Night (19:00 - 20:00)	Solar Charge Controller / Grid Inverter
6		Battery voltage [V] - Evening	Batery Inverter
7		Check that the discharging indicator is lit - Night	Batery Inverter
		Measuring time - Evening	
8		Check that the solar charge controller, battery inverter and grid inverter is in operation (no alarm or warning sign)	Solar Charge Controller / Batery Inverter
9		Weather condition during the day - Sunny = "S", Cloudy = "C", Rain = "R"	Solar Charge Controller / Batery Inverter

Solar Charge Controller

2 Monitoring system using data logger

Data is collected by the monitoring device and stored in an SD card with defined interval. All the required parameters for the analysis should be registered during the installation of the monitoring system. When reporting is needed, SD card should be sent to the owner. Notice that the length of data stored in the SD card depends on the variety of parameters being recorded and the size of the SD card used for the system. New data will overwrite the old data if the SD card is full.

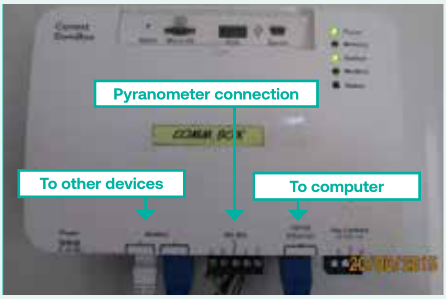
3 Monitoring system using GSM/GPRS network

Monitoring system using GPRS is recommended due to the remote location of the site. With this method, the owner can access to the data remotely without coming to the site. Firstly, it collects the registered parameters then transmit the acquired data to the data storage of the owner.

Each of the above-mentioned method has its advantages and disadvantages. It is clear that the manual check is the most robust way to monitor the system as the operator will directly check the system and report in the form of log book. However, only limited details can be obtained from the manual check method which is unfavourable for further analysis. Implementation of monitoring system depends on the situation on site. Data logger is always considered as an option since there are plenty of sites that do not have good mobile network. However, when mobile network is strong enough and reliable, transmitting real time data with GPRS should be an option. In this case, monitoring device should have

10.2 INSTALLATION OF MONITORING SYSTEM

HARDWARE INSTALLATION

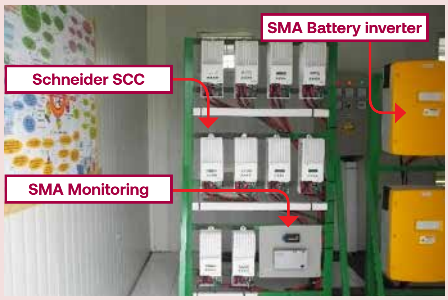


Functioning monitoring system with connection to the other devices through Xanbus and RS485 for pyranometer.

Monitoring system is installed but not connected to anything.

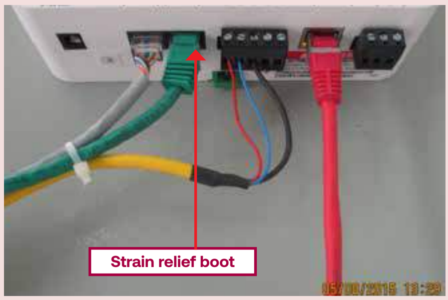
Ensure that all the monitored devices are connected to the bus. There is a maximum number of connected devices on a single monitoring device that should be taken into account. Consider having additional monitoring device and creating multi-cluster configuration when maximum number is exceeded.

Solar charge controllers and battery inverters from the same manufacturer are monitored in the same network.



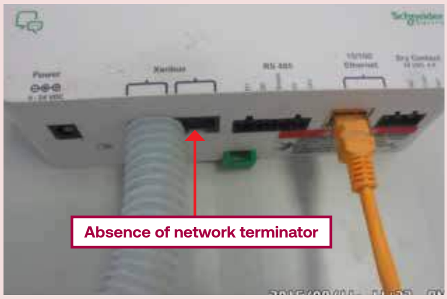
A mix of two different manufacturers leads to communication problem between the components

Ethernet cables with strain relief boots are used as cable communication aiming for more robust connection.



RJ45 strain relief boots is not equipped on the grey cable.

Network terminator is installed to the remote monitoring. the component is the first component of the system that connects to the network



The communication network is not terminated by network terminator.

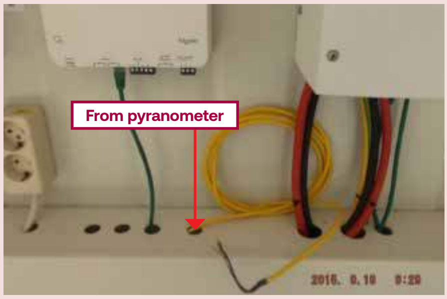
Neat cable installation of monitoring device and system control panel. Router will only be used when remote monitoring via GSM/ GPRS is possible.

Pyranometer is not connected properly to the device. Data may not be readable.

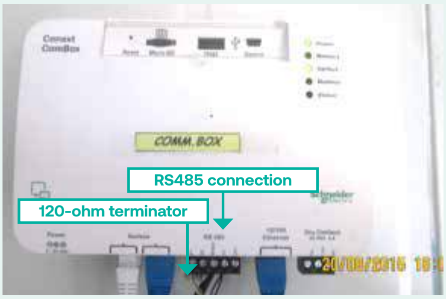
What to consider when installing the communication cable?

- Ensure that the communication cable is connected properly.
- High quality ethernet cable with strain relief boot should be used to reduce conductor stress which may cause network failure.
- Straight-through cable type is often used for connecting different types of devices. Please refer to the user manual from the manufacturer for the recommended cable type.
- When the network is connected in daisy chain, network terminator should be available at both ends.

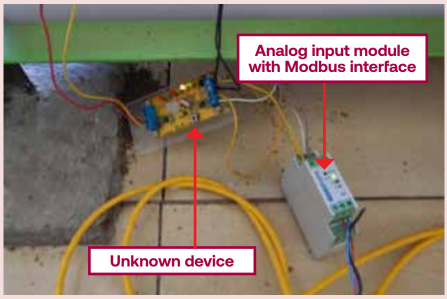
Pyranometer is connected to monitoring device via RS485 interface



Pyranometer is installed but not connected to the monitoring device. Avoid installing communication and power cables in the same conduit.



Pyranometer is connected to Modbus RS485 terminal. Modbus network is terminated by 120 Ω resistor.

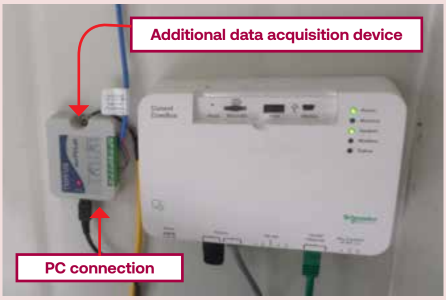


Messy and unsafe installation of analogue input module from pyranometer.

Pyranometer should not only be installed correctly but also connected properly to the monitoring device. Availability and reliability of data should be validated from the monitoring device. For the system that does not equipped with internal resistor terminator in RS 485 network, additional 120 Ω resistor should be installed.

How to fix such installation?

- Connect the pyranometer to the monitoring device based on the available input of the monitoring system.
- When Modbus RS485 interface is available in the monitoring device, make sure that the pyranometer has the same communication protocol and interface to avoid additional data conversion module.
- Reinstall the analogue input module and reroute the cables.
- Install termination resistor at the end of the Modbus network.



Pyranometer is connected to additional data acquisition device. The data can only be acquired and monitored in a PC.

Instantaneous measurement of the irradiance. The device will only show the instantaneous data without recording them.

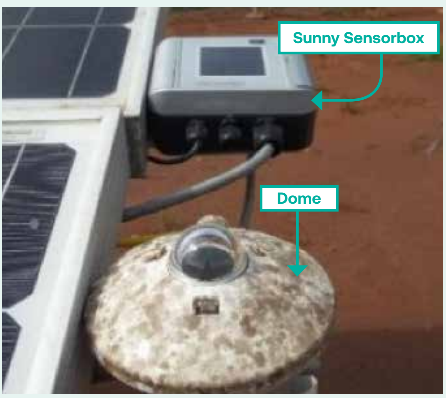
What to consider when installing solar irradiance meter?

- The pyranometer should be installed in the same plane as the PV array to represents the actual irradiance received by the PV array.

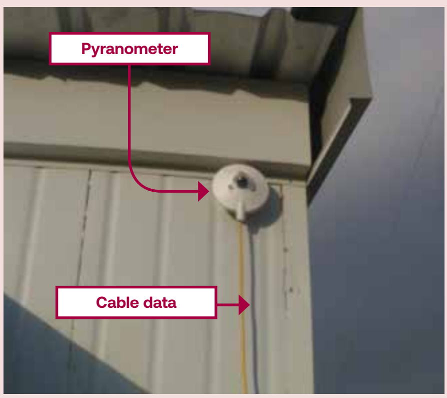
- Similar to PV module, the pyranometer should be free of shade and with no potential shading in the future.

- Ensure the validity of the irradiance data during commissioning. Data can be retrieved from the SD card in the monitoring device.

- The dome or glass surface of pyranometer should always be cleaned and free of cracked to improve the light transmission into the sensing element.



The pyranometer is straightly hit by the sunlight and in the same plane as the PV array. Sunny sensorbox is installed as additional sensor.



The pyranometer has probablity of being shaded and thus providing unreliable global irradiance data.

Pyranometer is free from shade but installed in-plane with the roof. The tilt angle may follow the angle of the roof.

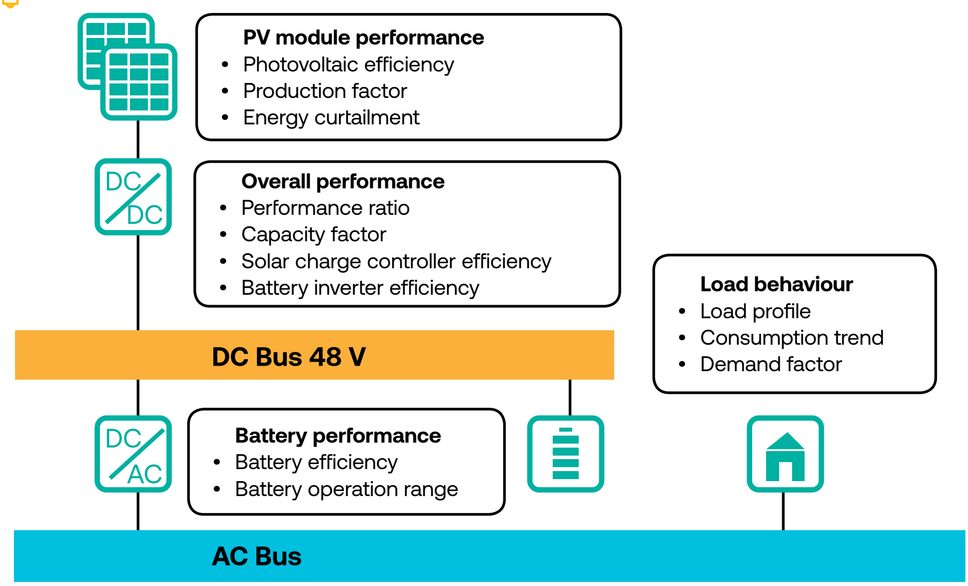
Pyranometer is installed below the PV module plane. The shadow from the PV module can cover the sensor.

Installing pyranometer in plane with PV module will allow the performance analysis of the PV modules at particular tilt angle and position. It is recommended to install the pyranometer on top of the PV array structure to avoid shading of the PV module from any angles.

10.3 MONITORING PARAMETERS

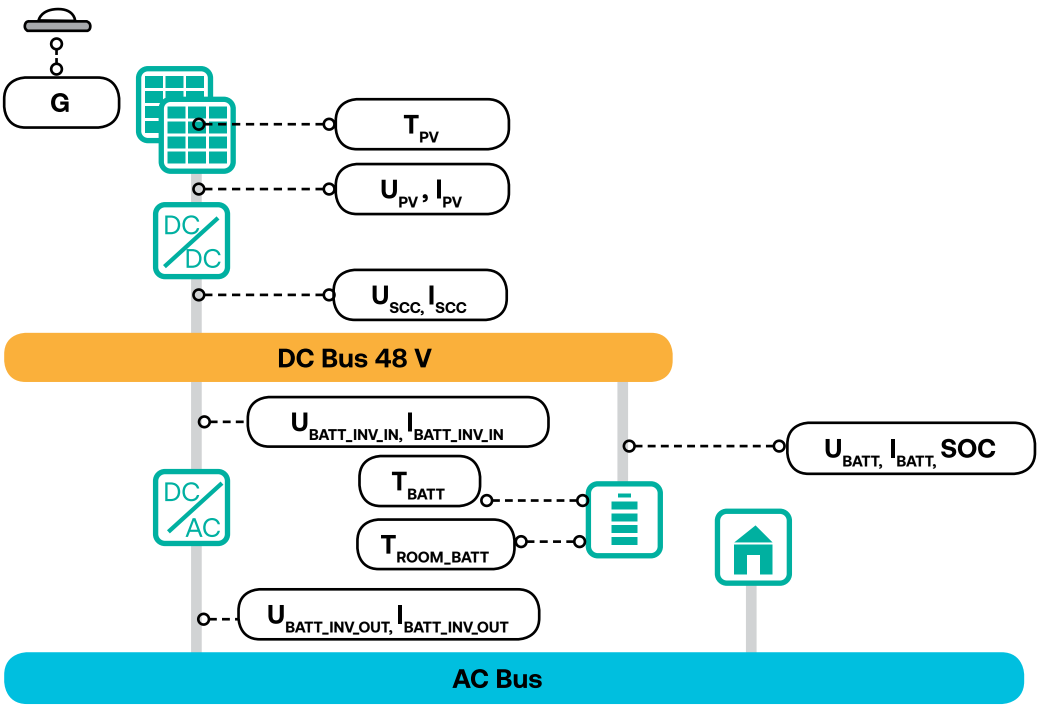
Monitoring is not only about possessing and maintaining the components but also establishing data processing and evaluation methods for further use of the data. Monitoring will only be essential if the acquired data are analysed and used for improvement. Data needs to be stored, pre-processed, and analysed in a proper way to obtain reliable information from the system such as system performance and efficiency. However, there are limitation in the monitoring device in storing all data from each component. In order to evaluate the system correctly, performance indicators of a PV mini-grid have to be defined prior to configuration setting. Following is an alternative option to evaluate a PV mini-grid with DC coupling configuration.

What to analyse from a PV mini-grid?



The evaluation comprises not only the performance of the entire system such as performance ratio, but also the performance of each individual component. It aims to improve the design or take preventive action facing loss of performance, for example, battery efficiency, cycling behaviour of the batteries, energy losses in PV modules due to dirt and temperature, etc. Performance Analysis of Photovoltaic Mini-grid for Rural Communities in Indonesia[2] can be referred for a detailed evaluation method and for AC-coupling system. The study was based on IEC 61724 – *Photovoltaic system performance* and combined with several literatures. In this case, there are parameters that should be measured and recorded in the data logger to perform the evaluation.

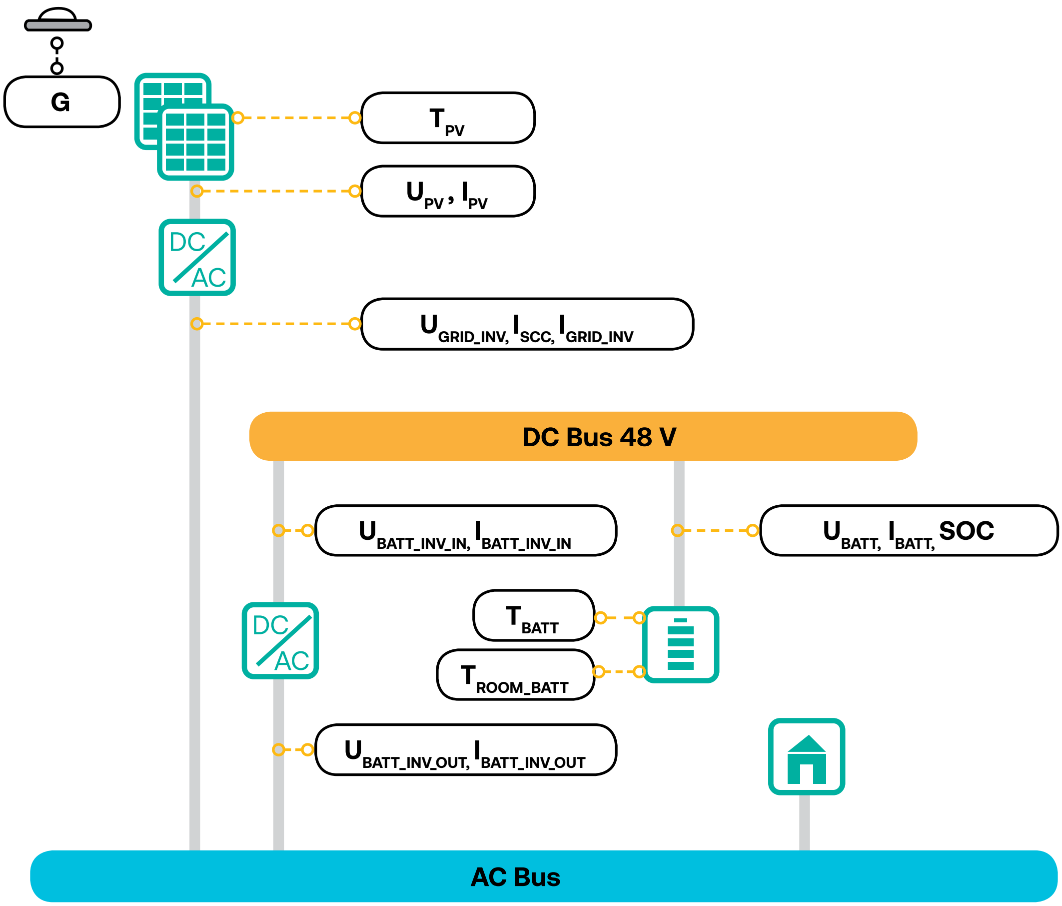
Which parameters should be measured in DC-coupling system?



No	Parameter	Symbol	Unit	Component
1	Irradiance	G	W/m²	Pyranometer
2	PV module temperature	T_{PV}	°C	Temperature sensor
3	PV array output voltage	U_{PV}	V	Solar charge controller
4	PV array output current	I_{PV}	A	Solar charge controller
5	SCC output voltage	U_{SCC}	V	Solar charge controllers (combined)
6	SCC output current	I_{SCC}	A	Solar charge controllers (combined)
7	Battery temperature	T_{BATT}	°C	Solar charge controller
8	Battery voltage	U_{BATT}	V	Battery inverters (combined)
9	Battery current	I_{BATT}	A	Battery inverters (combined)
10	Battery room temperature	T_{ROOM_BAT}	°C	Temperature sensor
11	Battery inverter input voltage	$U_{BATT\_INV\_IN}$	V	Battery inverters (combined per cluster)
12	Battery inverter input current	$I_{BATT\_INV\_IN}$	A	Battery inverters (combined per cluster)
13	Battery state of charge	SOC	%	Battery inverters (combined per cluster)
14	Battery inverter output voltage	$U_{BATT\_INV\_OUT}$	V	Battery inverters (combined)
15	Battery inverter output current	$I_{BATT\_INV\_OUT}$	A	Battery inverters (combined)

[2] Fadhilah, A., Ramadhani, B., “Performance Analysis of Photovoltaic Mini-grid for Rural Communities in Indonesia”, Jakarta, 2017.

Which parameters should be measured in AC-coupling system?



No	Parameter	Symbol	Unit	Component
1	Irradiance	G	W/m^2	Pyranometer
2	PV module temperature	T_{PV}	°C	Temperature sensor
3	PV array output voltage	U_{PV}	V	Grid inverter
4	PV array output current	I_{PV}	A	Grid inverter
5	Grid inverter output voltage	U_{SCC}	V	Grid inverter
6	Grid inverter output current	I_{SCC}	A	Grid inverter
7	Battery temperature	T_{BATT}	°C	Battery inverter
8	Battery voltage	U_{BATT}	V	Battery inverters (combined per cluster)
9	Battery current	I_{BATT}	A	Battery inverters (combined per cluster)
10	Battery room temperature	T_{ROOM_BAT}	°C	Temperature sensor
11	Battery inverter input voltage	$U_{BATT\_INV\_IN}$	V	Battery inverters (combined per cluster)
12	Battery inverter input current	$I_{BATT\_INV\_IN}$	A	Battery inverters (combined per cluster)
13	Battery state of charge	SOC	%	Battery inverters (combined per cluster)
14	Battery inverter output voltage	$U_{BATT\_INV\_OUT}$	V	Battery inverters (combined)
15	Battery inverter input voltage	$I_{BATT\_INV\_OUT}$	A	Battery inverters (combined)

There are parameters that is not directly measured by the equipment but essential to be included in the monitoring system, which is module temperature and battery room temperature. These data should be measured using additional data acquisition device and connected to the monitoring device with available protocol or typically using RS485 Modbus.

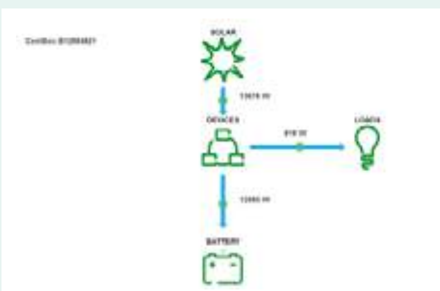
All the required parameters must be registered and logged in the data storage or SD card. Some manufacturer only allows limited number of data to be stored in the data logger. In this case, combined or aggregated data from several components with the same function is preferable as the data to be stored instead of individual component which is not possible due to system limitation.

How to ensure that the data is valid and reliable?

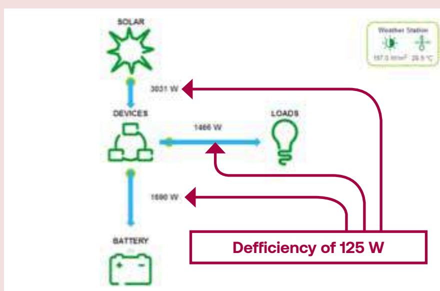
- Ensure that the data storage card or SD card is formatted and inserted to the monitoring device. Size of the SD card should at least be sufficient for one (1) year with one (1) minute logging interval. Minimum of 2 GB SD card should be provided.
- Data in the SD card should be verified during commissioning for the interval, the logged parameters, and the accuracy of the values. One week of measurement data should be provided as part of the commissioning report.
- Simple performance analysis should be conducted during commissioning to validate the data by using at least one-week measurement data. Having this process may reduce the data anomaly in the measurement, hence avoid erroneous analysis afterward.

Data logging information showing that the 4 GB SD card will be fully utilized in more than 10 years with 1 minute interval.

Memory card with size of 128 MB may not be sufficient to store complete data for one year.



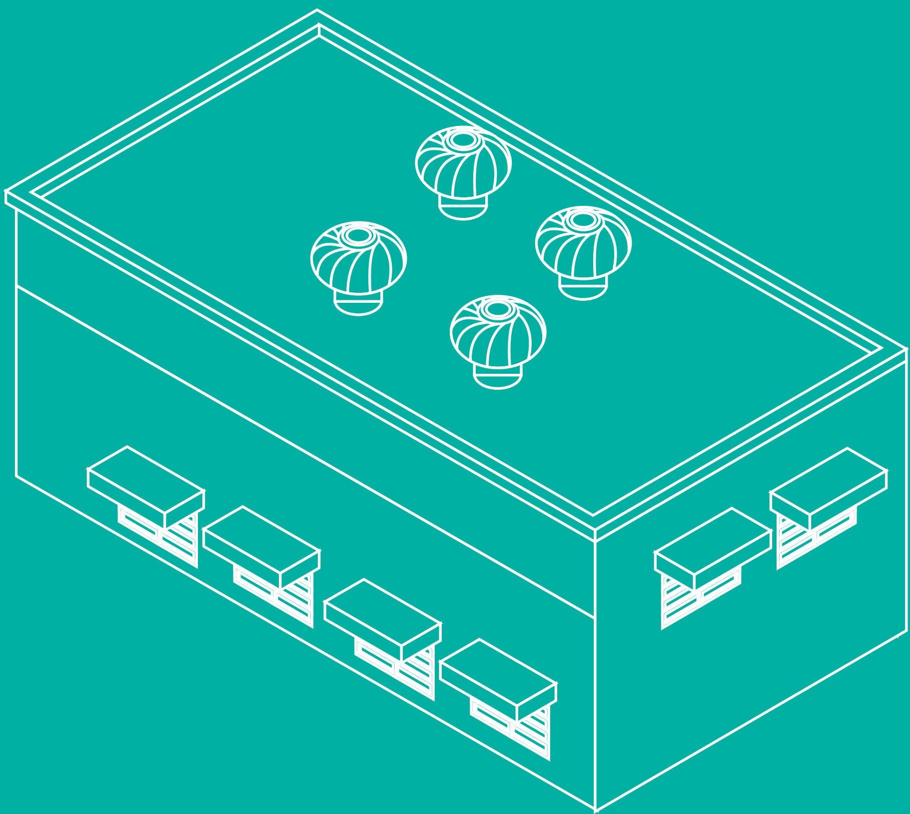
Web interface of the system showing correct power flow from PV modules to battery banks and loads.



Unrealistic power flow with input power value less than the output. This is caused by one inverter that is disconnected from monitoring device.

CHAPTER 11
Power House

- Things to consider when designing a power house
- Good and bad construction of power house and protective fence
- Cable installation inside the power house



11.1 BASICS OF POWER HOUSE

Power house is the place to protect all the devices, especially sensitive electrical equipment, from harsh environment and unauthorized access. The house is typically separated into two rooms, consists of battery room with battery banks, and a room for DC panel distribution and controller that comprises of solar charge controllers, battery inverters, monitoring system, AC panel distribution and tools. The house can be made from concrete or polyurethane shelter depending on the available materials. Dimension as well as the layout should give flexibility for the operator or technician to operate the system and perform maintenance or repair measures.

Typical power house in Indonesia.

[1]Daisy chain: a series of interconnected or related things

Power house made of concrete and painted. Power house is located under the tree to shade from direct sunshine and keeping the temperature low.

Power house made of lightweight pre-painted galvanized steel with polyurethane foam as insulation material.

What should be taken into account when constructing power house?

- Power house should be designed to have sufficient ventilation, light, and safe from water as well as animal intrusion. Good heat insulation should be provided to reduce rising temperature inside the powerhouse as an impact from sun exposure.
- Land should be free from risks of natural disasters such as flooding or land slide. Risks of having faulty components due to natural disasters have to be mitigated.
- The entire power plant has to be protected from animal intrusion and unauthorized person by using protective fence.
- The power house should be located close to the households aiming to reduce electricity losses in the grid.
- Warning sign from apparent risks in electrical works such as electrocution as well as explosion should be available in the power plant to raise awareness of the operator and visitors.

Power house is installed at higher level to avoid water from entering the power house during flooding.

Flooding in power house may cause electrical faults, damaging the electrical components and endanger the operator due to electric shock.

Power house and PV array are installed on top of the wooden patform to avoid disturbance caused by water.

Landslide on site that resulted in burried power house.

Power house including all electrical components should be installed higher than the surveyed flood level. The flood level and other historical information should be obtained from the local people before construction.

How to avoid flooding and risk of having landslide?

- Conduct a flood hazard mapping and ground assessment during feasibility study to choose the most proper place to build the power plant.
- Avoid building power plants nearby steep slopes and natural erosion place.
- If the chosen location is still prone to flooding, survey the cause and source of flooding, its frequency of flood occurrence, and the possible height of flood to be used as a reference to design the support structure and foundation.
- Provide sufficient drainage system to accommodate the water balance on site.
- Build retaining walls and plant ground cover to reduce the landslide hazard.

Well-constructed pathway to access the PV arrays

PV mini-grid installed on muddy and watery land with inadequate pathway to access power house and PV array.

Clean and neatly installed power house with attached warning signs.

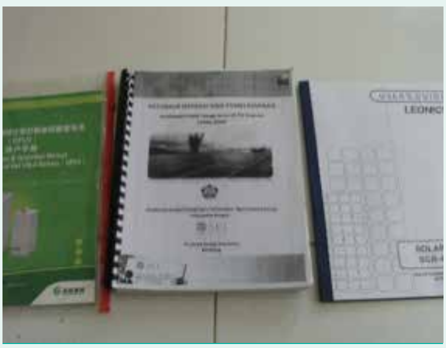
Power house should not be used as warehouse. Only components, spare parts and tools are allowed.

First aid kit is available in the power house in case of an accident happens. Temperature monitoring is provided in the power house.

Fire extinghuiser is available on site for emergency case. Needle showing the pressure should be within green area and has to be checked regularly.

▶ What kind of tools should be available in the power house?

- Safety equipment such as safety shoes and insulation glove class 0 up to 1000 VA/1500 VDC.
- Screwdriver sets and insulated wrench or socket wrench sets.
- Digital clamp multi-meter to measure AC/DC voltage and current.
- Ladder to conduct service or maintenance at higher location such as cleaning PV modules, etc.
- Digital thermometer, preferably infrared laser gun.
- Operation and maintenance manual of the PV mini-grid as well as user manual of the components in understandable language by the operator.



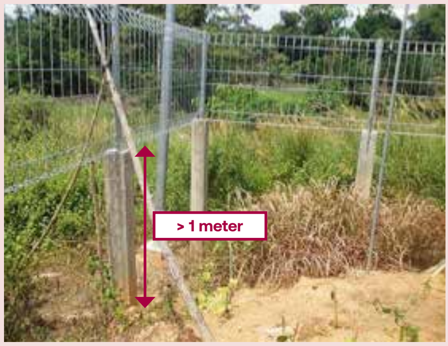
Operation and maintenance guideline for operator. The books must be understandable for the operator.

Wrench sets and multimeter

11.2 PROTECTIVE FENCE

PV mini-grid should be equipped with protective fence around it to protect the entire installation from unauthorized person and wild animals. It will ensure not only the operationalisation of the system but also a safety measure to keep some distance between live components and the people outside the power plant area. Therefore, it is important to have a robust and correct installation of the fence.

Power house made of concrete and painted. Power house is located under the tree to shade from direct sunshine and keeping the temperature low.



Very high gap between the fence and ground will allow animal and human entering the power plant area.

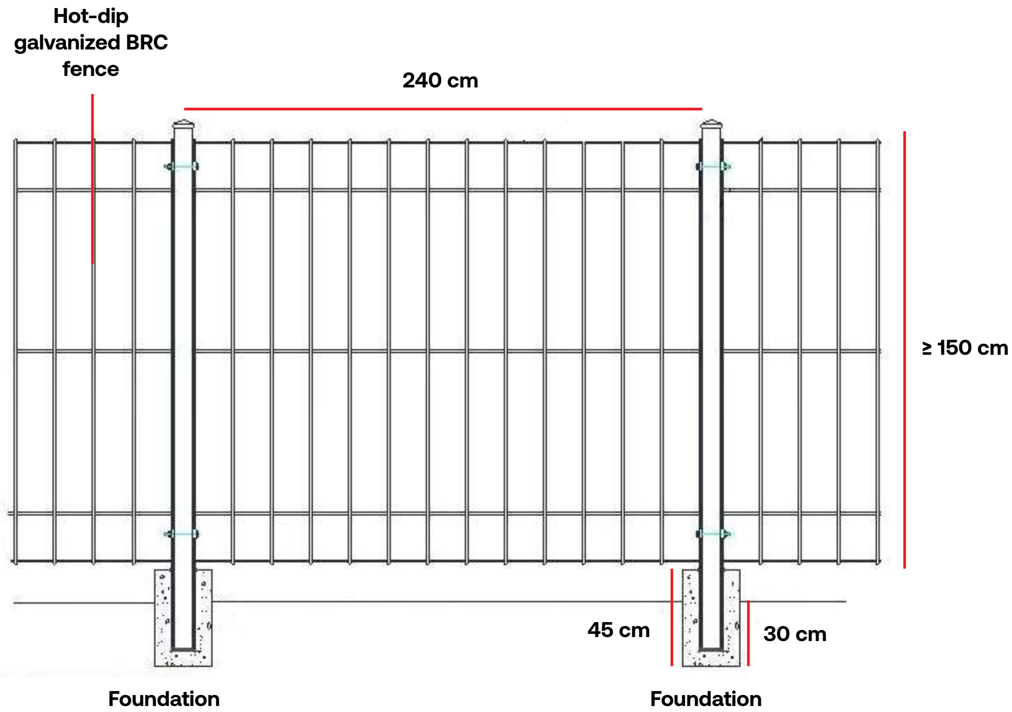
Fence foundation is constructed in a perfect shape with a good height. The two third (2/3) of the foundation height should be burried.

Foundation is not burried and not in a complete beam shape. Wood mold is still attached to the concrete.

How to fix such installation?

- Install additional fence to cover the gap. The gap between the fence and the ground should not give allowance for human and animals to enter that may harm the installation.
- Alternatively, reconstruct the foundation or shorten the height to only 15 cm from the ground if the soil contour allows.
- Patch the foundation with a good mixture of concrete (one cement, three parts sand, and three parts gravel. Ensure that the foundation has sufficient height (45 cm) and install the concrete at 30 cm depth and 15 cm of visible part.

▶ **How height the protective fence should be?**



Rusty gate hinges. Bad hinges quality may lead to broken gate.

Soil erosion around fence foundation may cause instability. Repair the foundation, compact the soil and create drainage system.

BRC fences have to be coated with zinc (hot-dip galvanized) to avoid rusting especially if installed in the place with high-salinity air.

A good installation of protective fence with adequate height. Additional foundation is installed for sandy soil .

Leaning fence is hold by support pole. Repair the foundation and align the fence.

11.3. CONSTRUCTION OF POWER HOUSE

The construction of the power house should consider foundation quality, adequate size of the power house, ventilation, and construction of its foundation should accommodate water diversion or drainage system. The size of the power house should be based on the number of components installed and give sufficient space for the operator to operate and perform maintenance.

FOUNDATION OF THE POWER HOUSE

Very good foundation with perfect apron concrete distance from the wall.

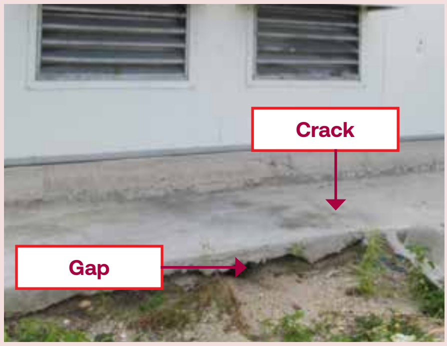
Cracked foundation due to bad mixture of concrete. Patch the concrete with a better mixture.

Foundation area of the power house should at least be bigger than the power house building with 70 cm distance from the wall at the front side and 20 cm for the other sides. The foundation should be constructed with minimum depth of 50 cm.

Good quality power house with good foundation and apron.

Apron concrete is not provided. Inadequate foundation size.

Cracked foundation due to gradual slide of power house.



Eroded power house foundation. Further erosion may lead to floated foundation and resulted in cracking of the foundation.

How to fix such installation?

- Patch the gap with a good mixture ratio of concrete.

- Retaining wall should be constructed when the power house is located on a slope.

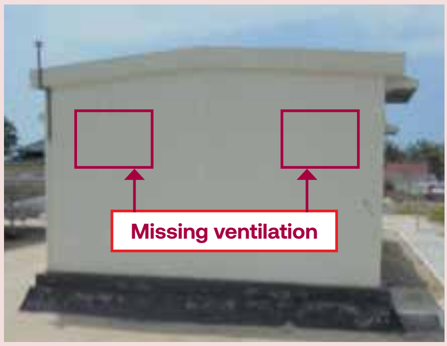
- Drainage system must be built separately to avoid water flows close to foundation that may lead to erosion.

Canopies are provided to shade the ventilation from direct sunshine.

Power house window is not equipped with canopies. Incoming sunlight from a certain angle may direcly hit the component inside.

Canopy should be installed to provide shade for the window from weather condition such as rain and direct sunlight.

Cross-ventilation combined with exhaust fans to extract heat inside the room.



Insufficient ventilation to provide air circulation inside the battery room and to keep the room temperature low.

Why power house should be equipped with sufficient ventilation?

- Battery room temperature should not be too high to ensure the expected lifetime of the battery. Ambient temperature of 30°C may significantly reduce battery lifetime.
- Hydrogen concentration inside the room may increase during charging process of lead acid battery thus provision of adequate ventilation is vital. Hydrogen is very explosive and even a small spark may cause explosion.
- Room temperature should be checked regularly and cooling initiative should be conducted when temperature exceeds the safe limit.
- During commissioning, room temperature has to be validated within the acceptable limit.

The power house should have sufficient ventilation to maintain the ambient temperature at maximum 30°C. Ventilation should not be blocked by any components.

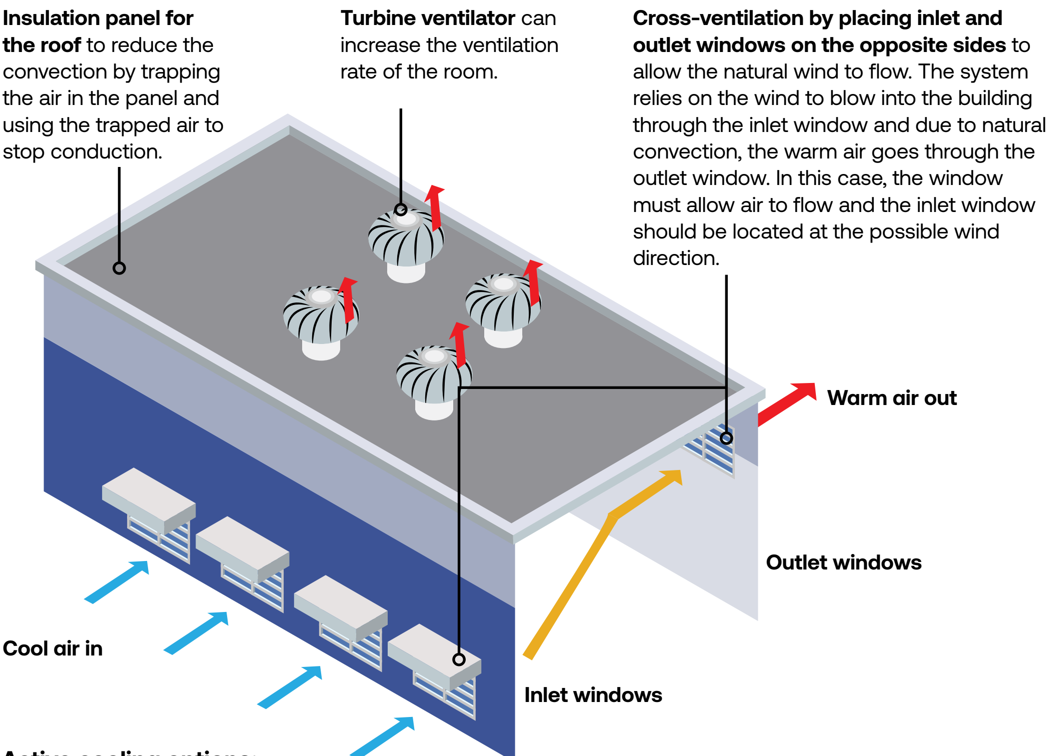
▶ How to improve cooling of the power house?

Cooling of the power house can be done using both passive or active cooling methods. Passive cooling is the method using the building design to control the heat dissipation inside the building with no energy consumption or also called natural convection. While active cooling force the air to move or enhance heat transfer using additional energy or device such as fan or air conditioner.

▶ How to improve cooling of the power house?

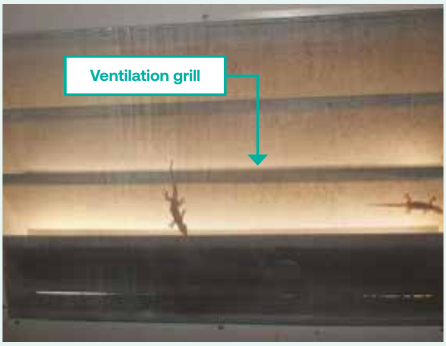
Passive cooling options:

- Cross-ventilation by placing inlet and outlet windows on the opposite sides to allow the natural wind to flow. The system relies on the wind to blow into the building through the inlet window and due to natural convection, the warm air goes through the outlet window. In this case, the window must allow air to flow and the inlet window should be located at the possible wind direction.
- Turbine ventilator can increase the ventilation rate of the room.
- Insulation panel for the roof to reduce the convection by trapping the air in the panel and using the trapped air to stop conduction.



Active cooling options:

- Exhaust fan or blowing fan can be used when passive cooling or natural convection is not sufficient to extract the heat or blowing in cool air. Fan should be controlled by a thermostat.
- Air conditioner can significantly keep the room temperature cool. However, the device may consume electricity of at least 10 kWh per day. It can be a favourable option when the energy consumption of the air conditioner per day is less than energy lost due to reduced battery lifetime. A smarter energy management system should be considered when using air conditioner.



Ventilation opening is covered with insect net to prevent animals from entering the power house.

Broken insect net provide entrance for uninvited animals. Cable should not pass through the window.

Ventilation should always be covered with ventilation grill and insect net or screen to improve the air flow and protect from animal.

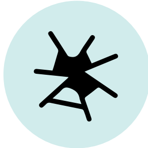
Poor ventilation opening. Smaller net should be used instead. Grill should be provided to ensure the security.

Broken glass window. Open window with insect net should be used instead of glass window.

How to fix such installation?

- Patch the hole on the net or if possible re-route the grid distribution cable. The feeder cable is preferably installed underground.

- Install ventilation grill and insect net on the window



- Replace the broken glass window with grill and insect net.

Installation of cable entry points

Cables from combiner box are installed undergrond and protected inside PVC pipe.

Cables are installed on the ground without any protection from sun exposure. Cement is used to seal the cable entry.

Never use cement to seal cable entry. The use of cement may degrade the cable insulation properties and cause losing the cable flexibility due to permanent installation by cement.

Outgoing cables to the grid pass through foundation and protected inside pipe.

Ventilation should not be used for the outgoing nor ingoing cables.

Puddle and dirt inside the tunnel due to unsealed cable tunnel. The uncovered tunnel may become the entrance gate of rodents and reptiles.

Cables should not pass through power house wall. Absence of cable gland may lead to damage insulation.

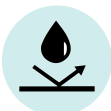
Sharp edges of the steel wall and friction with the cable may cause the insulation to peeled off and resulted in short circuit. Shelter has to be grounded.

11.4 CONSTRUCTION AND INSTALLATION INSIDE POWER HOUSE

Very organized and neat installation of power electronic components. Cables are installed neatly inside cable trays.

Unfinished floor and untidy cabling. The floor should be added with white ceramic tiles. All the cables should be installed inside cable conduit.

Why using ceramic flooring tile?



- Ceramic is resistance against water or stain.

- Easy to maintain by wiping or mopping the dirt, water, or stain.

- More durable and hard to crack.

TV is installed in the power house. Power house should not be used for public place or entertainment.

Refrigerator consumes the electricity without limitation inside the power house.

Devices other than components of the PV mini-grid should not be installed inside the power house. PV mini-grid is intended for community and not for personal use. Entertainment should be installed in the public place to avoid unauthorized people from entering the power house. Having additional electronics may contribute heat inside the power house and consume more energy than it was designed.

Grounding and cables are installed neatly with direct laying method.

Untidy cable installation may lead to complication when problem or fault occurs.

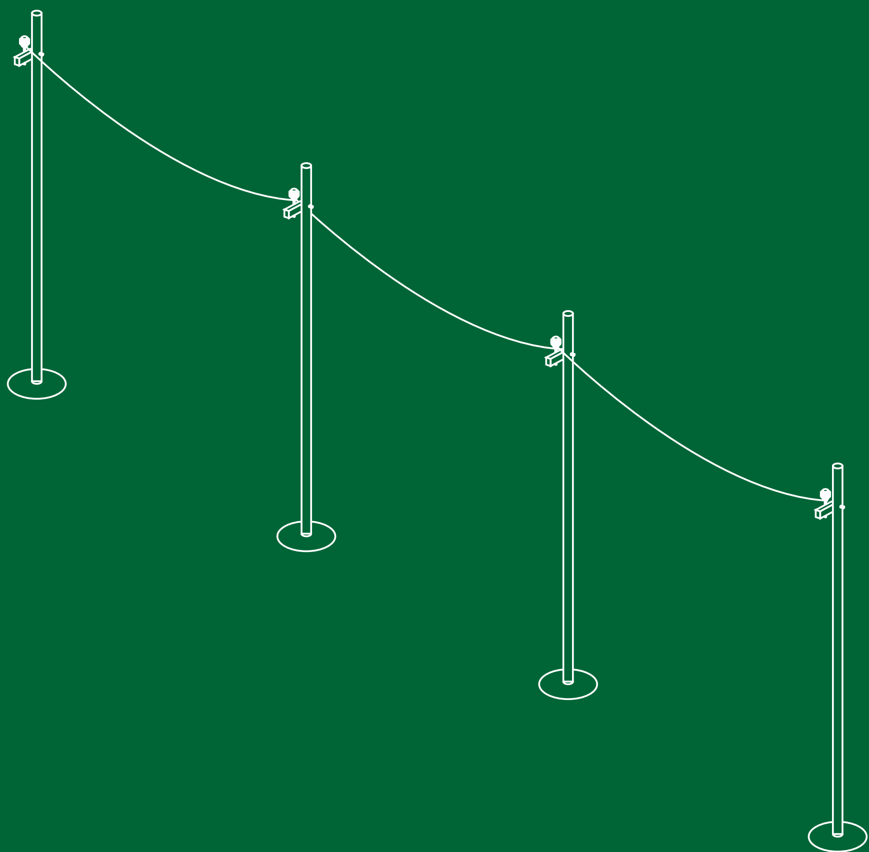
Cables are protected inside cable duct and covered.

Messy internal wiring. Underground cable duct should be covered.

Cables should be neatly installed with direct laying method. Correction factor due to grouping and underground installation should be taken into consideration when sizing the conductor.

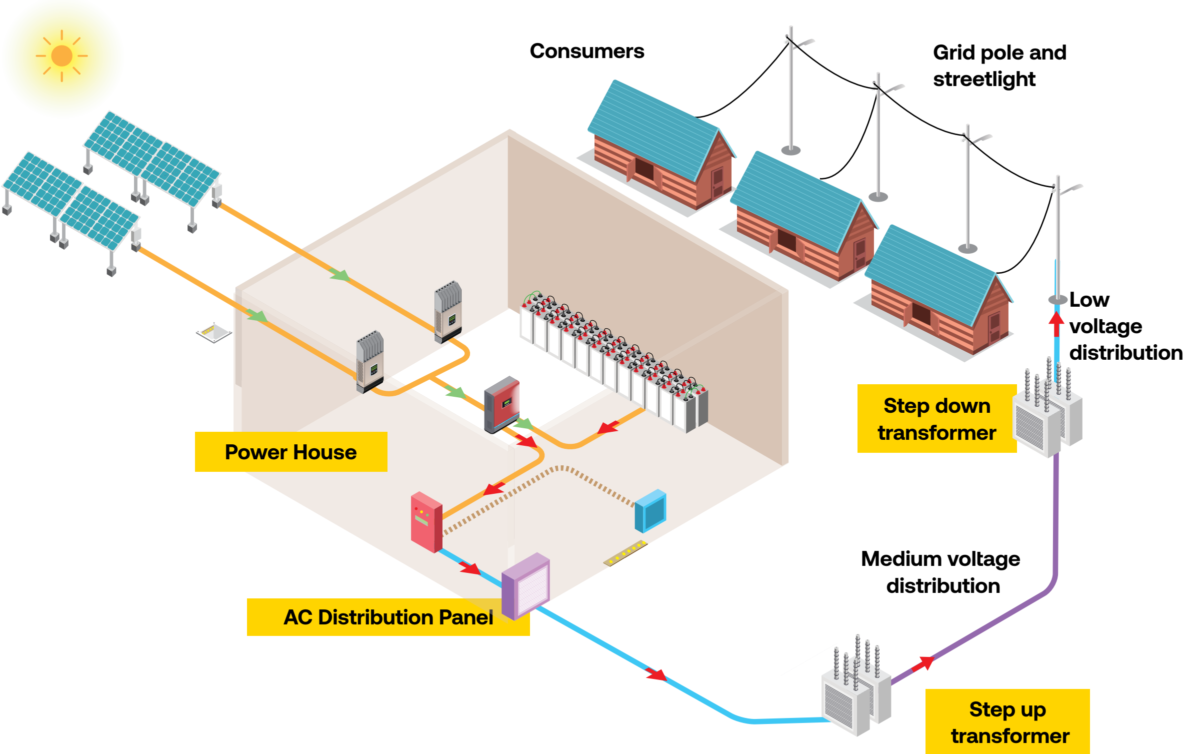
CHAPTER 12
Distribution Grid

- How is the ideal configuration of a distribution grid?
- Good and bad installation of distribution grid and its components
- Recommended installation of the streetlights
- Medium voltage distribution



12.1 BASICS OF DISTRIBUTION GRID

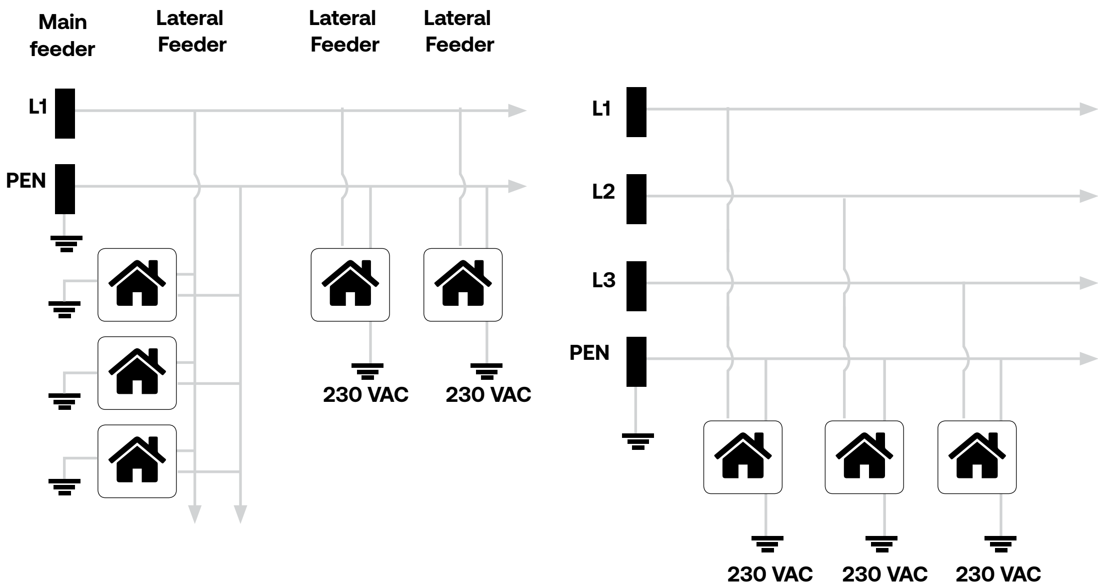
Distribution grid delivers the electricity from the power house to the households through low-voltage (LV) system as single-phase (230 V) or three-phase system (400 V). The design of line configuration is basically dependant on the capacity of the PV mini-grid and number of consumers. A system with the capacity equal or greater than 30 kWp typically uses three-phase configuration, while a smaller system runs single-phase configuration.



Typical distribution grid in PV mini grid

In a single-phase distribution grid, power is divided into several feeders in the AC panel distribution. The number of output feeders is based on the location and number of the consumers or households connected to the grid. In three-phase system, feeders are connected to different phases and should be equally distributed to avoid unbalance voltage.

The main components in a distribution grid are grid poles, overhead cables, and cable supports. Streetlight is included in this chapter because it uses the same grid pole and attached on the same distribution line though streetlight is not the main component in the distribution system. The grid distribution may include medium-voltage (MV) line when there is a high-demand and lengthy distance between power house and households which may cause high-voltage drop. In this case, the distribution grid shall use three-phase step-up transformer to 20 kV and step-down transformer.



A typical configuration of distribution grid in a village with TN-C earthing system.

Distribution grid transmits electricity from the power house to households and installed along the street which make it exposed closely to the consumers. Hence, quality for safe and reliable installation must be assured to prevent injury, fatalities, or system damage. Poor installation quality may result in electric shock and possibly death.

▶ What should be considered when designing and constructing distribution grid?

- All installation must follow best practices and local construction standards for low-voltage distribution, medium-voltage distribution, as well as substation distribution.[1, 2, 3, 4] The standards should describe in detail the minimum clearances between ground and overhead cable, acceptable cable span, appropriate cable supports, etc.
- Overhead cable should be robust and weatherproof. It should use aerial twisted cables with the specification of NFA2X-T twisted cable 3x35 mm^2 + 1x25 mm^2 + 1x16 mm^2 for the feeders on the household connections as well as streetlights.
- The grounding scheme of the distribution should follow the applied local regulation. The TN-C network system is being used in Indonesia which is also a standard for local utility. TN-C is a configuration where the neutral conductor and grounding conductor are combined (PEN).
- Geographical location of the households. Mapping of the households should be done prior to construction to identify and design the route of the distribution grid, location of the poles, and the total length of the grid.
- The acceptable voltage drop on the grid should not be greater than 10% from the nominal voltage.

1 For Indonesia, PT. PLN (Persero), "Buku 1 – Kriteria desain enjinering Konstruksi Jringan Distribusi Tenaga Listrik," 2010.
2 For Indonesia, PT. PLN (Persero), "Buku 3 – Standard Konstruksi Jaringan Tegangan Rendah Tenaga Listrik," 2010.
3 For Indonesia, PT. PLN (Persero), "Buku 4 – Standard Konstruksi Gardu Distribusi dan Gardu Hubung Tenaga Listrik," 2010.
4 For Indonesia, PT. PLN (Persero), "Buku 5 – Standard Konstruksi Jaringan Tegangan Menengah Tenaga Listrik," 2010.

1. Estimate the peak load by using the nominal power of the total battery inverter.

Estimated peak load or total battery inverter capacity = 6 units x 5 KW =30 kW

2. Check the electrical properties of the selected cable size such as resistance and reactance from the datasheet.

NFA2X-T 3X35MM^2 + 25mm^2 → R= 0.868 Ohm/km | x = 0.098 Ohm/km

3. Estimate the power factor of the loads. Power factor of 0.9 can be used as most of the loads are LED lamps, unless more inductive loads identified.

Power factor = 0.9
ϕ = accross (0.9) =25.84

4. Calculate the nominal load current based on the estimated peak load.

$$\textbf{Load current} = \frac{\text{Estimated peak load}}{\sqrt{3} \times \text{Nominal voltage}}$$

$$\frac{30{,}000\ \text{W}}{\sqrt{3} \times 400\ \text{V}} = 43\ \text{A}$$

5. Measure the distance between the power house to the load or houeholds. Consider the path for the distribution grid. This will determine the cable length.

Cable length = 500 m

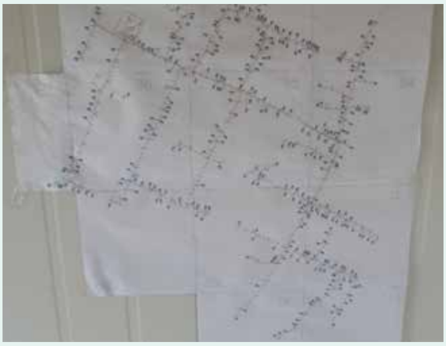
6. Calculate the voltage drop on the distribution line

$$\textbf{Voltage drop} = \frac{\sqrt{3} \times \text{load current} \times (\text{R.cos}\,\phi + \text{X.sin}\,\phi) \times \text{length}}{1{,}000}$$

$$\frac{\sqrt{3} \times 43 \times (0.868 \times 0.9 + (0.098 \times 0.43)) \times 500}{1{,}000} = 30.6\ \text{V} \rightarrow 7.7\%$$

7. Calculate the voltage drop percentage

$$\%\ \textbf{Voltage drop} = \frac{\text{Voltage drop}}{\text{Nominal voltage}} \qquad \frac{30.6\ \text{V}}{400\ \text{V}} = 7.7\%$$



Low-voltage grid layout in a village determines the type of cable installation on top of the pole

Typical installation of lowvoltage distribution of a PV mini-grid.

Recommended steps to perform study for designing distribution grid?

- Conduct households mapping in the village and measure distance between power house and the households, especially the farthest connection.

- Study environmental condition, land topography and type of soil in the village to select the grid pole, design foundation, and the required pole support.

- Design the shortest possible route for distribution grid and define location for the grid poles. GPS handheld can be used to register the household locations as well as the possible location for the pole. The data should comprise of GPS coordinates, altitude, and possibly photos of the location. Seek for an easy terrain, adequate distance from trees, and sufficient ground clearance for the cables.

- Draw the grid layout with projected pole top construction. Pole top construction is designed based on the angle from one pole to its subsequent pole in the distribution path.

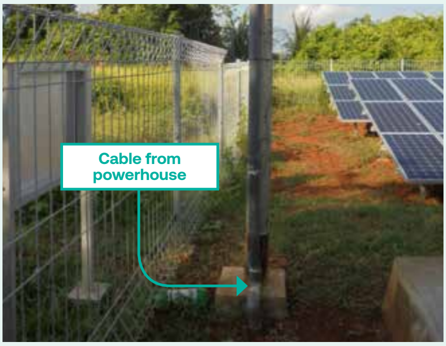
- Inform local authorities or trees owners that the trees may disturb the distribution network. therefore, they need to be cut regularly.

- Estimate the expected peak power consumption by the households on each feeder.

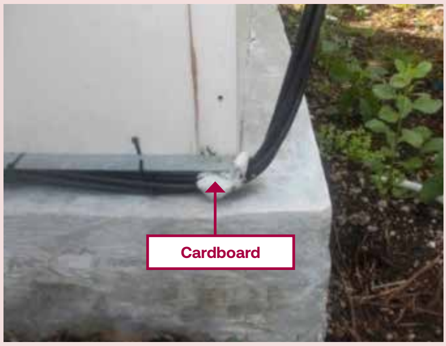
12.2 LOW VOLTAGE DISTRIBUTION GRID

Low-voltage distribution line in PV mini-grid is typically placed overhead and installed at an adequate height above the ground. It aims to keep the safe distance between the line and the villagers. Good installation of grid poles and pole top cable construction is essential and should be designed in accordance to the specified clearance, pole function and working load.

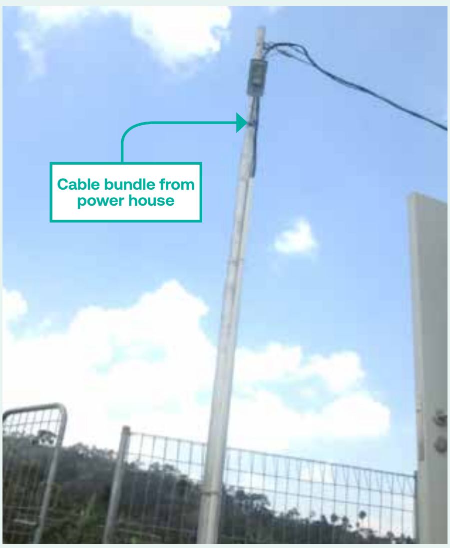
DISTRIBUTION LINE



Cables from the power house are installed underground and well protected.



Cables are in contact with sharp metal edge and protected with inadequate layer.



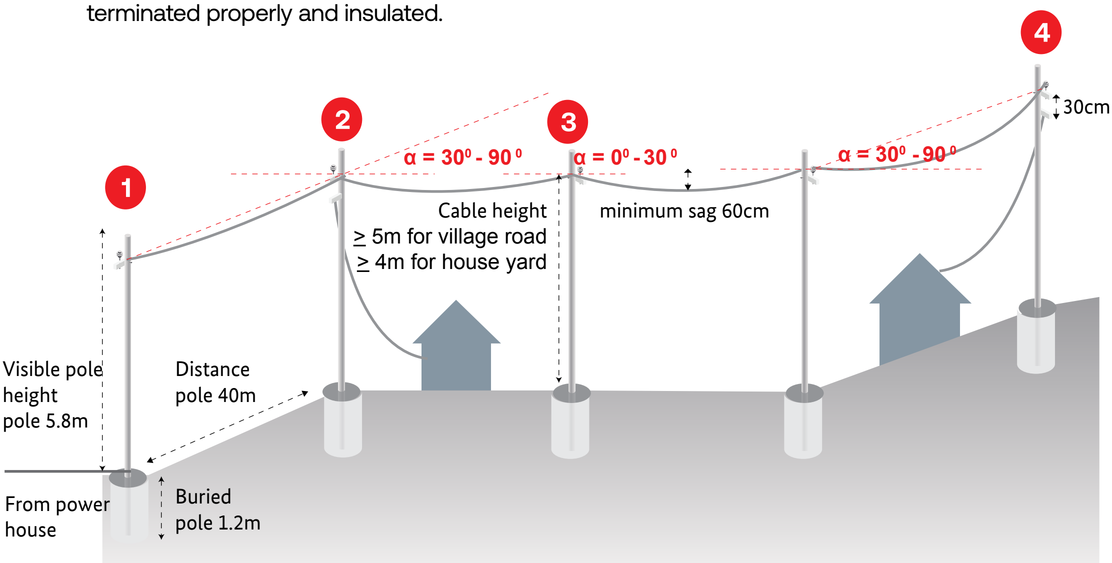
Good construction of the first grid pole. Cables are neatly installed inside PVC pipe.

Aerial bundle conductor should not be freely hanging and exposed to sharp metal edge of the power house.

Overhead cable must be distant from physical contact or adjacent to sharp metal edge to prevent the insulation from damage. Damage insulation may increase the risk of having electric shock as well as short circuit.

Recommended construction of low-voltage distribution grid

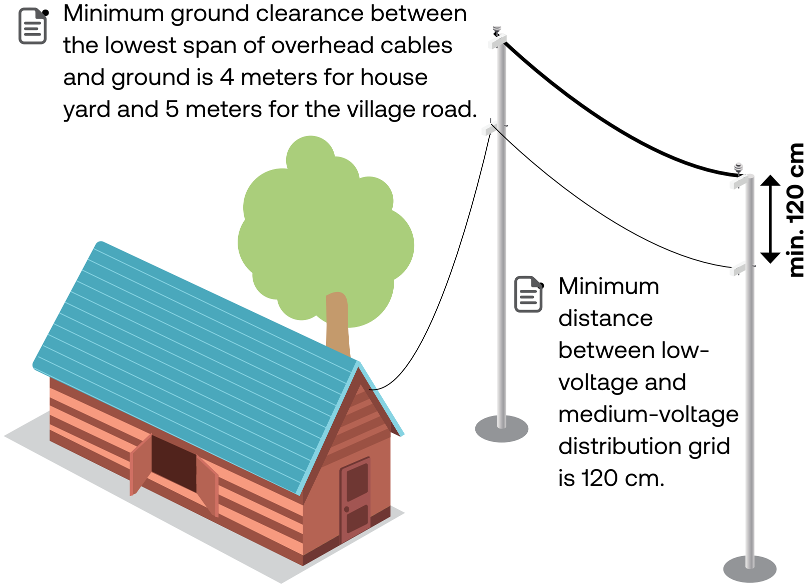
1. First pole is located right after the power house. The pole top is constructed using fixed dead-end configuration that supports the twisted cable from the power house to the next pole.
2. Large angle assembly (α > 30°) is constructed using fixed or adjustable dead-end construction. Dead-end construction is also used on the tension pole to adjust the tension of the overhead line. A tension pole is needed in every 10 poles.
3. Small angle assembly (0° - 30°) is constructed using suspension construction. In this case, the suspension clamp holds the neutral wire.
4. End pole with adjustable dead-end construction with turnbuckle. The cable end has to be terminated properly and insulated.



What are the requirements for right of way and safety distance in low voltage distribution grid?

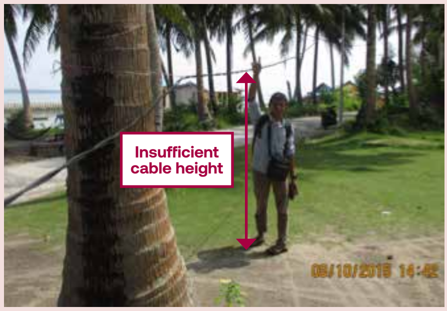
Distribution grid must not be too close to any objects that potentially disturb the installation. Minimum of 50 cm distance must be maintained between the line and buildings or trees. Verification of this requirement should be done during commissioning.

Minimum ground clearance between the lowest span of overhead cables and ground is 4 meters for house yard and 5 meters for the village road.



Minimum distance between low-voltage and medium-voltage distribution grid is 120 cm.

Cables are installed at a safe distance from the ground with clearance higher than five meters.



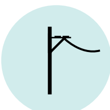
Insufficient cable height across the road. Potential for electric shock hazard.

Overhead cable is fimly mounted on the tree.

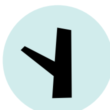
A cable is passing through a tree. The cable tension may increase when the tree grows bigger.

The overhead cable should not be easily reached by the human. Sag distance should not be lower than 60 cm to avoid higher tension on the cable.

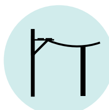
How to fix such installation?



- Pull the cable at the pole top construction through strain clamp and adjust the ground clearance of the cable accordingly.

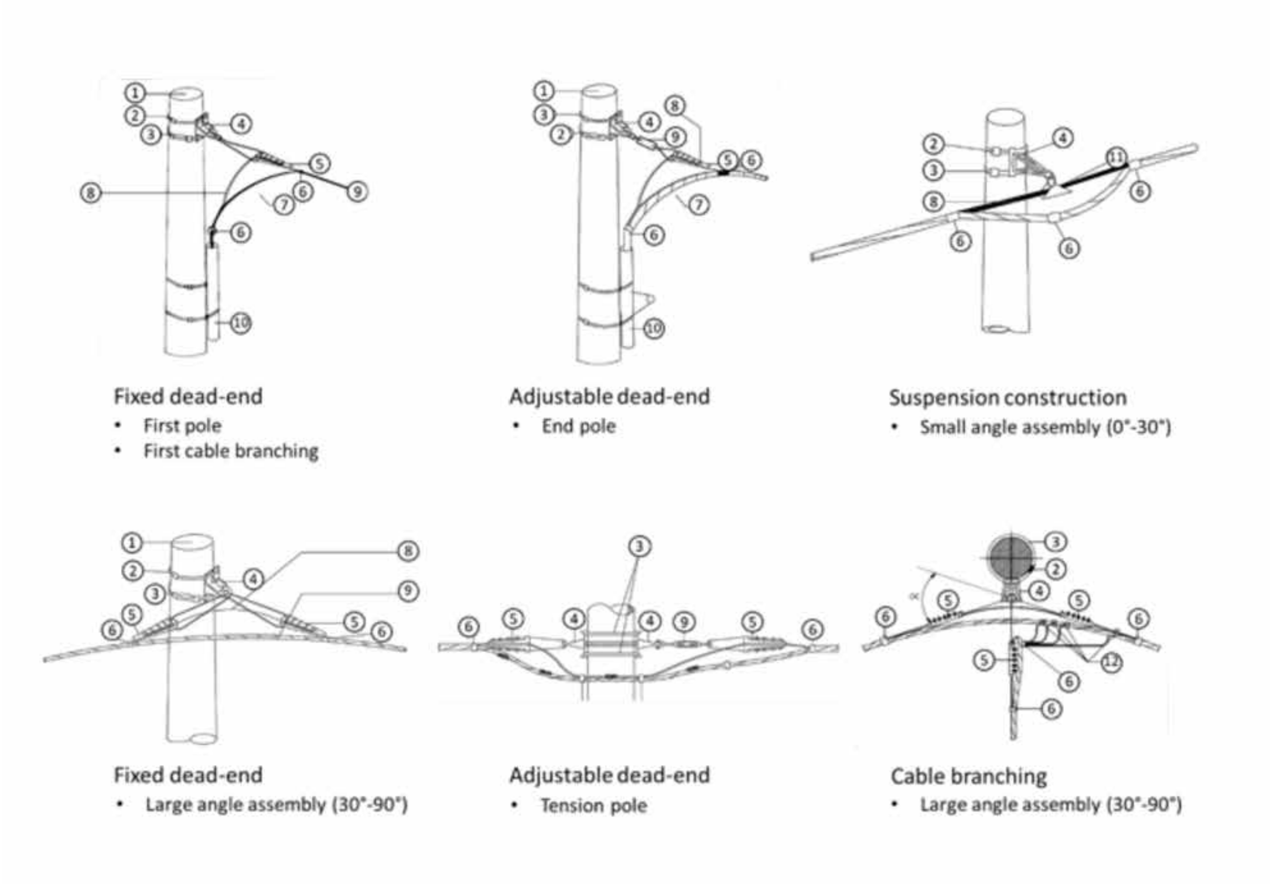


Trees or branches has to be cut when the branches are getting closer to the distribution line. Operator should perform scheduled maintenance to regularly check the potential disturbances to the line from the existing objects in the neighbourhood.



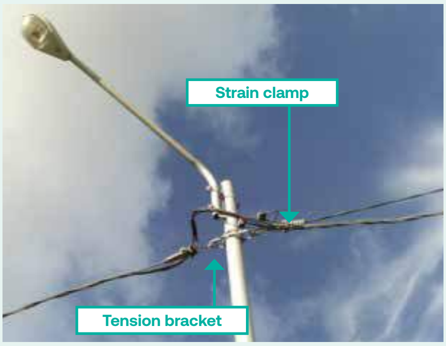
- V-shape branch of a tree should not be used for overhead cable support, install additional grid pole to support the overhead cable instead.

Types and when to use pole top construction[5]



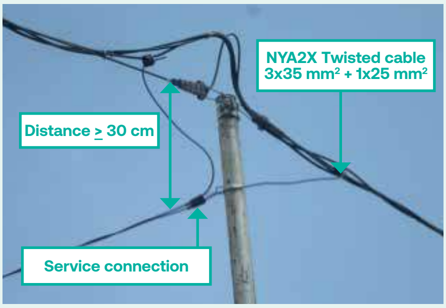
1 Pole
2 Stainless steel strip
3 Stopping buckle
4 Tension bracket (up to 1000 daN)
5 Strain clamp
6 Plastic strap
7 Twisted phase cables
8 Neutral cable
9 Twisted Phase + Neutral
10 PVC pipe
11 Suspension bracket (up to 700 daN)[6]
12 Suspension clamp
13 Connector

[5] For Indonesia PT. PLN (Persero), “Buku 3 – Standard Konstruksi Jaringan Tegangan Rendah Tenaga Listrik,” 2010.
[6] 1 Dekanewton (daN) = 10 newtons (N)

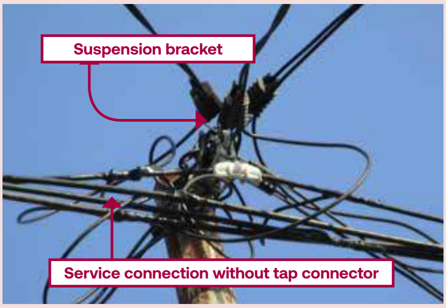


Strain clamps are used to hold the overhead cables. Certain length of cable should be remained to adjust the cable tension.

Overhead cable is hanged freely on suspension bracket. Suspension clamp should be used to hold neutral conductor of the cable bundle.

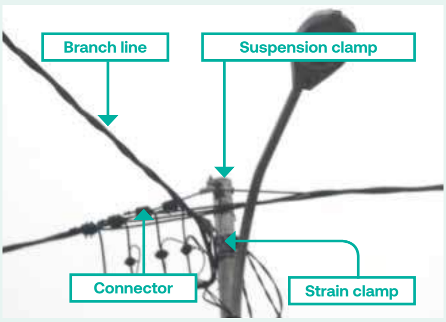


Service connection and main distribution line are installed on different bracket. Adequate distance should be provided.



Many clamps are hooked on a suspension bracket. Service dead-end clamp should be hooked on different bracket under the main line.

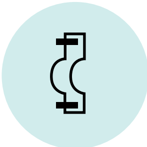
Always use standard cable supports and appropriate pole top construction such as fixed dead-end, adjustable dead-end, and suspension, based on the position and function of the poles. Bracket may be damaged if too many clamps are hooked.



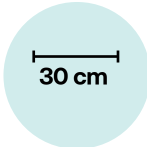
Neat installation of cable branching on small angle assembly. Proper accessories and connectors are used.

Messy installation of the pole top construction. Many of the service drop is not equipped with service dead-end clamp.

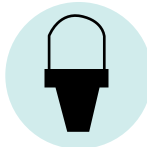
How to fix such installation?



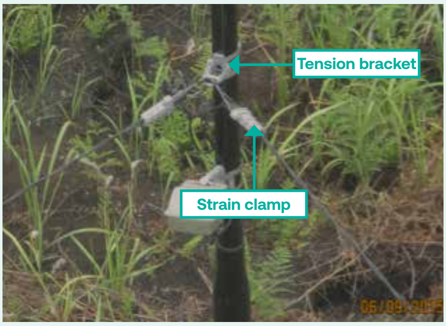
- Overhead cable should not be hanged without any support. Add suspension clamp and hook neutral wire on it.



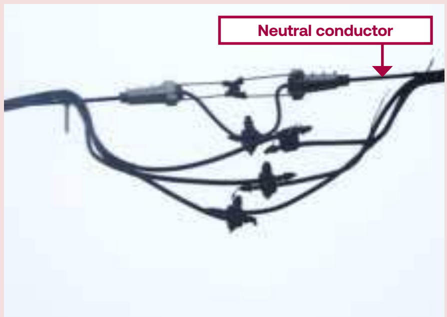
- To avoid overloading on the bracket, add another tension bracket under the existing bracket with minimum distance of 30 cm.



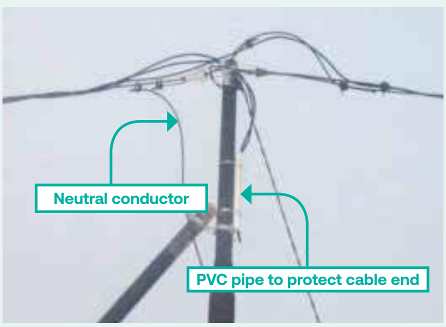
- Install service dead-end clamp on each service drop and hook neatly on separate bracket.



Good construction of large angle distribution pole with tension bracket and strain clamp.



Overhead cable is used as counter mast support between grid poles. Steel wire with cross-section area of 50 mm^2 should be used instead.



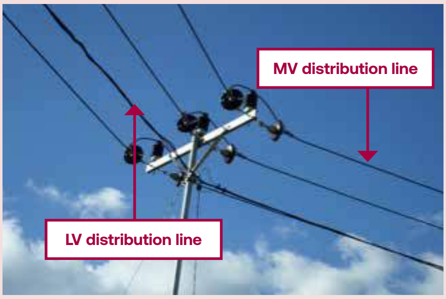
End conductors are installed inside PVC pipe. Neutral conductor is grounded to maintain the TNC[7] system.

Conductors are exposed without any insulation. Conductor may touch metal pole and cause fault.

Never left live conductors without proper insulation. The end conductors should be cut at different length and insulated using plastic strap to avoid short circuit between the conductors.

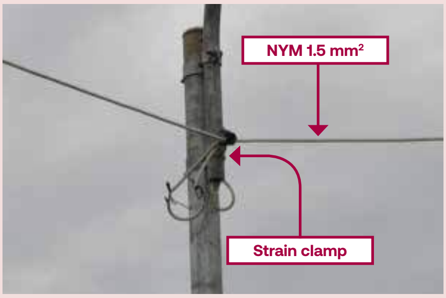
[7] TNC system is a grid configuration for distribution system where the neutral conductor and grounding conductor is combined.

Safe distance between medium voltage and low voltage line.



Medium voltage and low voltage lines are installed close to each other.

Melted cable insulation due to fire for land opening close to the cables. Damage insulation may lead to short circuit.



NYM cable is used as overhead distribution line. Cable with cross-sectional area of 1.5 mm^2 is too thin to resist against mechnical forces.

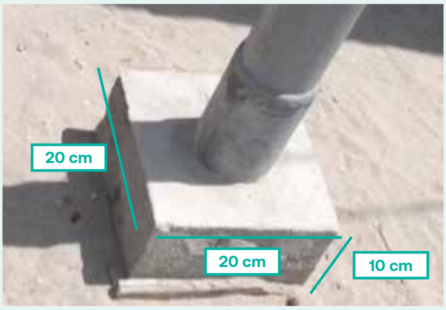
Never use small conductor for overhead line. The use of small cable may overstress the cable and lengthy span may cause fatigue at the connection points due to mechanical forces.

How to improve such installation?

- Distance between low-voltage and medium-voltage distribution should not be less than 120 cm.
- In the planning, ensure that the distribution grid route will not pass the location which may exposed the cable insulation to fire risks such as forest burning, etc.
- Only use appropriate components in accordance to the location and angle of grid distribution. Bad installation may lead to system blackout and safety hazards to the human.
- NYM cable should be replaced with appropriate cable type NFA2X-T 3x35mm2+N for overhead cable or NFAAX 2x10 mm2 for service drop cable.

GRID POLE

The grid poles must be strong and robust enough to maintain the distribution line installation as well as preventing the risk of electric shock to the villagers who might be unintentionally touch the conductors. The poles should be designed at a height complies to the local standard. It has to be constructed with concrete foundation and, possibly, guy wire to resist the forces due to the weight of conductor, tensile stress due to temperature change, and the wind.



Perfect shape of grid pole foundation. 20x20x60 cm concrete foundation is used with 50 cm buried and 10 cm visible.

Grid pole is not supported by concrete foundation. Depending on its depth and soil structure, the pole may not be able to stand and resist the force.

Grid poles have to be supported by concrete foundation to reinforce its strength. Type and size of the foundation depend on pole locations and soil condition.

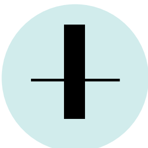
Gap between concrete foundation and the ground. Concrete foundation is constructed without any functional use.

Unburied and poor grid pole foundation. High forces may cause instability or even collapsed grid pole.

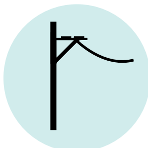
Galvanized steel poles are used and installed with acceptable distance in between.

Low-voltage distribution cable is hanged on the thin wooden pole due to the extended distance between metal poles.

How to improve such instalations?

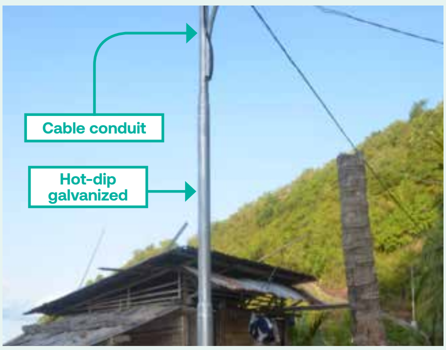


- Improve the foundation construction and bury the foundation and the pole in the ground at least 1/6 of the lengthlean angle is greater than 5° degrees.



- Wooden pole with V shape without additional clamp must not be used as supporting pole for air cable. As replacement use designated distribution pole for small angle construction

Distance between grid poles should not be longer than 50 meters. It should be considered during planning of the distribution grid path in the preliminary phase of the project.



Very good quality pole is used. Pole is made of hot-dip galvanized steel with bigger diameter at the bottom.

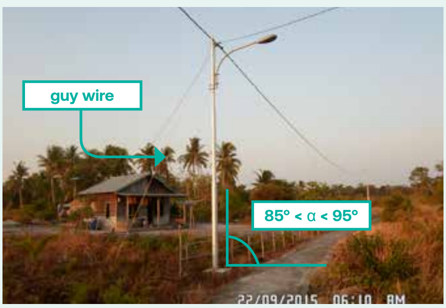
Rusty pole due to poor coating quality. Corrosive pole may lead to reduction of pole strength.

Grid pole is installed with acceptable tilt angle. The tilt angle of the pole should not be greater than 5°

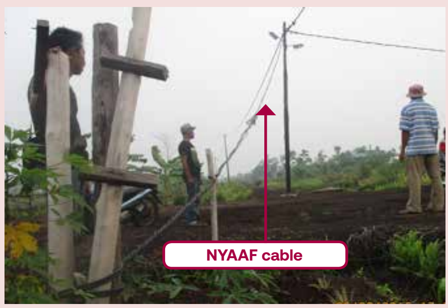
Leaning grid distribution pole due to excessive force at large angle assembly and bad foundation structure.

How to avoid leaning pole?

- Make sure that the working load of the pole is calculated properly in accordance to the cross-section of the cable, the pole position, and the soil condition within a range of 200 daN, 350 daN, and 500 daN.
- Use additional pole support such as guy wire, strut pole, or span guy wire to strengthen and stabilise the pole.
- Assess the soil type and construct the most suitable foundation for the poles.
- Ensure that 1/6 of the total length of the pole is buried. In this case, if the length of the pole is 7 meters, 1.2 meters of the pole should be buried.
- Perform maintenance regularly to check the pole condition and conduct correction when the lean angle is greater than 5° degrees.



Pole is installed firmly and stabilised with guy wire.

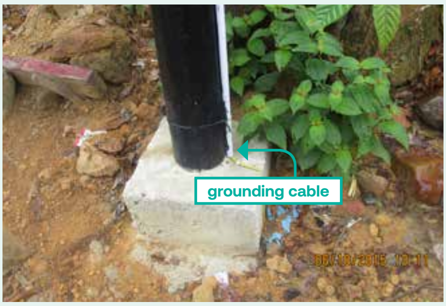


Improper use of LV distribution cable as a guy wire to support the pole.

Only use proper steel wire with minimum cross section of 50 mm2 as a guy wire. Make sure that the angle of the guy wire is not smaller than 60°.

How to perform maintenance on the distribution grid pole?

- Ensure that MCB of the feeder is switched off. Measure the voltage of the feeder and make sure that there is no voltage on the line. Ground the feeder if possible. Close the panel to make sure that nobody can operate the MCB.
- Check stability of the pole and use proper safety equipment before climbing up. Proper ladder should be used and fixed at bottom.
- Check pole top construction, cable connection and cable tension.



Pole and neutral conductor are grounded with sufficient grounding cable to maintain the TN-C configuration.

Grounding cable is too small. Size of grounding conductor should at least half of the cross section area of the phase conductor.

Grounding of the pole and neutral conductor should be done on the first pole, last and every 200 meters (5 poles) from the first pole. When the same pole carries medium- voltage and low voltage distribution, grounding must be done every three poles. Grounding resistance should not be greater than 10 Ω.

12.3 STREETLIGHT INSTALLATION

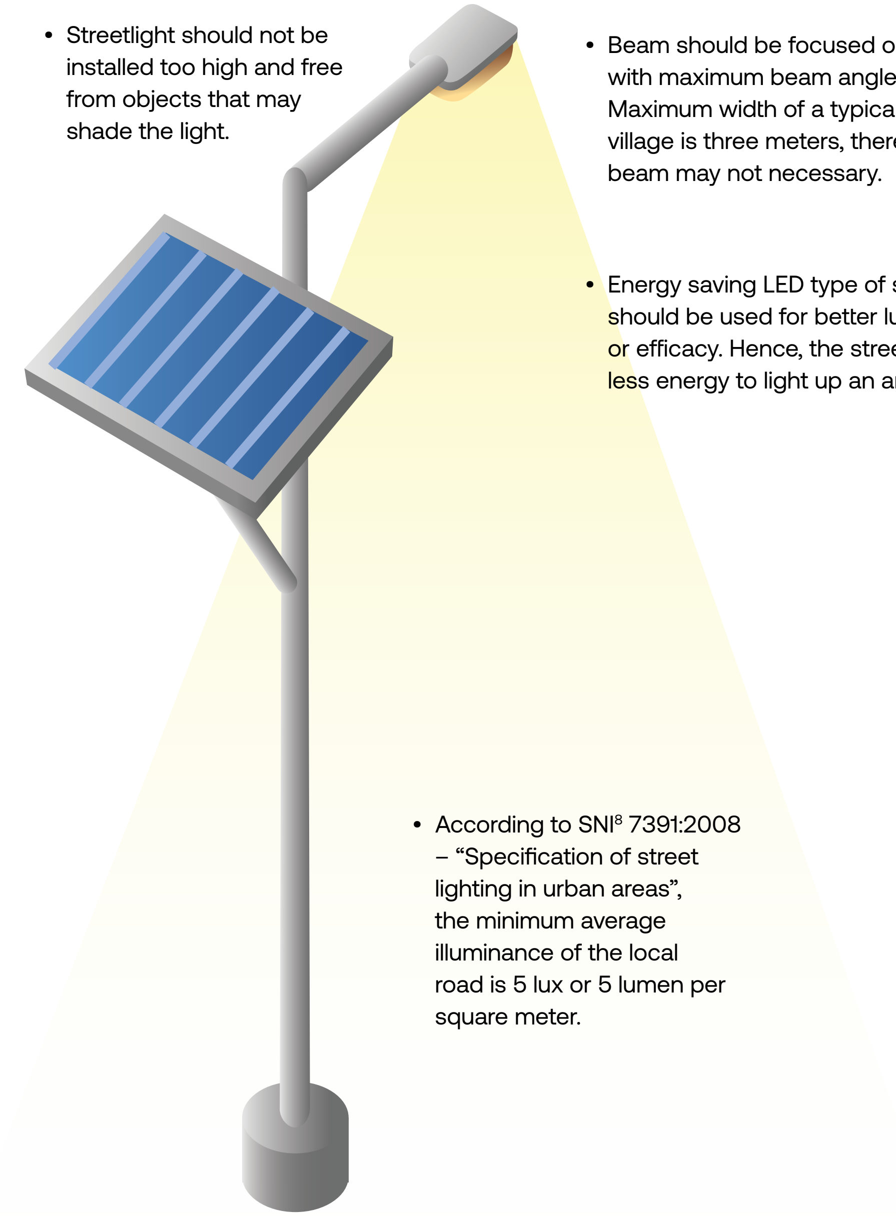
Streetlight is installed in every two grid poles with additional mounting arm to fix the streetlight head. The streetlight is typically controlled by a timer or light sensor to automatically switch on and off the light based on the availability of sunlight. To have the centralised control of all units, the streetlights are powered by a separate feeder.

▶ What to consider to have a good lighting from the streetlight?

- Streetlight should not be installed too high and free from objects that may shade the light.

- Beam should be focused on the street with maximum beam angle of 120°. Maximum width of a typical street in a village is three meters, therefore higher beam may not necessary.

- Energy saving LED type of streetlight should be used for better lumen per watt or efficacy. Hence, the streetlight requires less energy to light up an area.



- According to SNI[8] 7391:2008 – “Specification of street lighting in urban areas”, the minimum average illuminance of the local road is 5 lux or 5 lumen per square meter.

[8] Indonesian National Standard

Waterproof LED streetlight with IP 65 rating is used.

Inappropriate type of lamp is used for streetlight. The streetlight does not have sufficient IP rating.

High failures of streetlights can be in part ascribed to inappropriate products used. Ensure that the streetlight is waterproof and tested according to IEC 60598 for luminaires ingress protection (IP) rating. For example, IP 65 enclosure is rated as "dust tight" and protected against water projected from a nozzle.

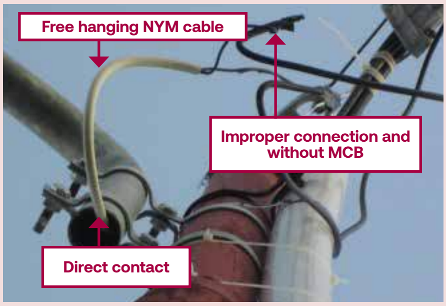
The streetlights are installed on the same pole without mounting arm and not focusing on the street.

Dysfunctional streetlight because it is installed in the middle of a tree thus its light is blocked by the leaves.

Streetlight installation is facing at the correct direction with acceptable mounting height, boom length and tilt angle.

Streetlight is facing to the wrong direction. Streetlight should provide lighting to the street.

Streetlight installation is facing at the correct direction with acceptable mounting height, boom length and tilt angle.



Streetlight is facing to the wrong direction. Streetlight should provide lighting to the street.

MCB must be installed to only disconnect individual streetlight in case of short circuit due to faulty device. A combined type 1 and 2 surge protection devices must also be installed on the streetlight pole that has grounding installation.

How to improve such installations?

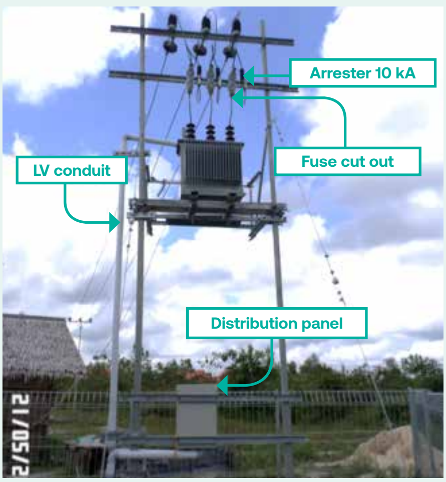
- Trees or branches that is potentially shade the lamp should be cleared. Check in regular basis that the streetlight is still in operation and is not blocked by anything.
- Move the mounting arm to the right direction.
- Use only cable that is designed for outdoor use. Replace the NYM cable with NYY type.
- Cable should not be freely hanging. Install the cable inside a cable conduit or pipe and mount it on the pole using metal strip.
- Add weatherproof junction box with MCB and surge arrester at a reachable level to protect the streetlight as well as the entire feeder.

Free hanging streetlight because of bad installation of streetlight housing to the mounting arm.

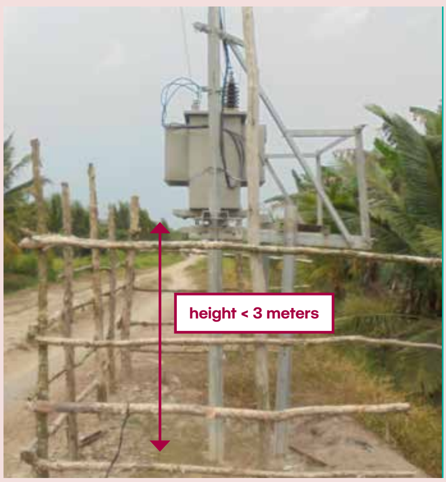
Bamboo is used as pole for lighting inside the power plant area. Light fixture is exposed to sun and rain.

12.4 MEDIUM-VOLTAGE DISTRIBUTION

In order to reduce the voltage drop on the distribution line due to long distance between power house and households, voltage is transform to medium-voltage (MV) at 20 kV using a step-up transformer and a step-down to 400 V AC when reaching the households. Depending on the length and load in each phase, MV distribution should be initially considered when the distance is greater than 1 km. It is because with distance longer than 1 km, the voltage drop may reach more than 10% or violating the standard. The MV distribution consists of step-up and step-down transformers, panel distributions, protection elements such as lightning protection, disconnector, overcurrent protections, and 20 kV cables.



Step-up transformer is installed neatly and at a safe distance from the ground with lightning arrester and panel.



Very low installation of transformer inside inadequate fence. High risk of injury due to electric shock.

What should be considered from the installation of medium-voltage distribution?

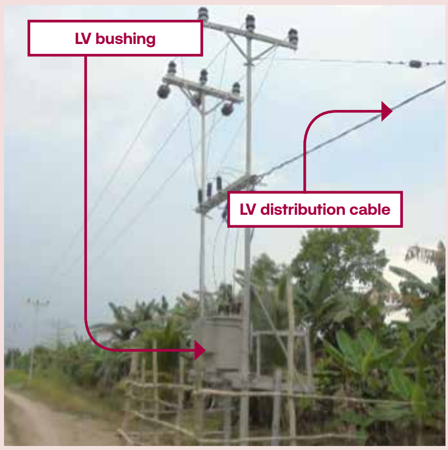
- Power transformer is installed at elevated level according to local regulation or at minimum four (4) meters to avoid access from unauthorized personnel.
- Install adequate protective fence with minimum height of 2 meters and protection from climbing to prevent human or animal reaching high voltage area. Sign of electric hazard is attached.
- Overhead line should have minimum height of six (6) meters from the ground and 2.5 meters from any objects such as roof, trees, antenna, etc.
- Ensure that the following components are grounded: neutral conductor of secondary side, body of the transformer, lightning arrester, and exposed conductive parts. Each should be grounded using individual electrode and connected using minimum copper conductor of 50 mm^2.

Transformers are attached with sign of existence of 20 kV voltage. It helps to raise an awareness to the people about the potential risk.

Power transformer is mounted inside easily accessible wooden fence without any warning sign.

Transformer should be mounted securely to avoid any significant movement due to vibration or any mechanical forces.

Panel distribution is installed to distribute power to feeders and protect low-voltage side of the transformer.



LV distribution cable is not protected by any protection device. Cables from LV bushing is directly connected to the LV distribution line.

Never leave outgoing low-voltage cable from the step-down transformer without any protection. Correct size of MCB should be provided inside panel distribution.

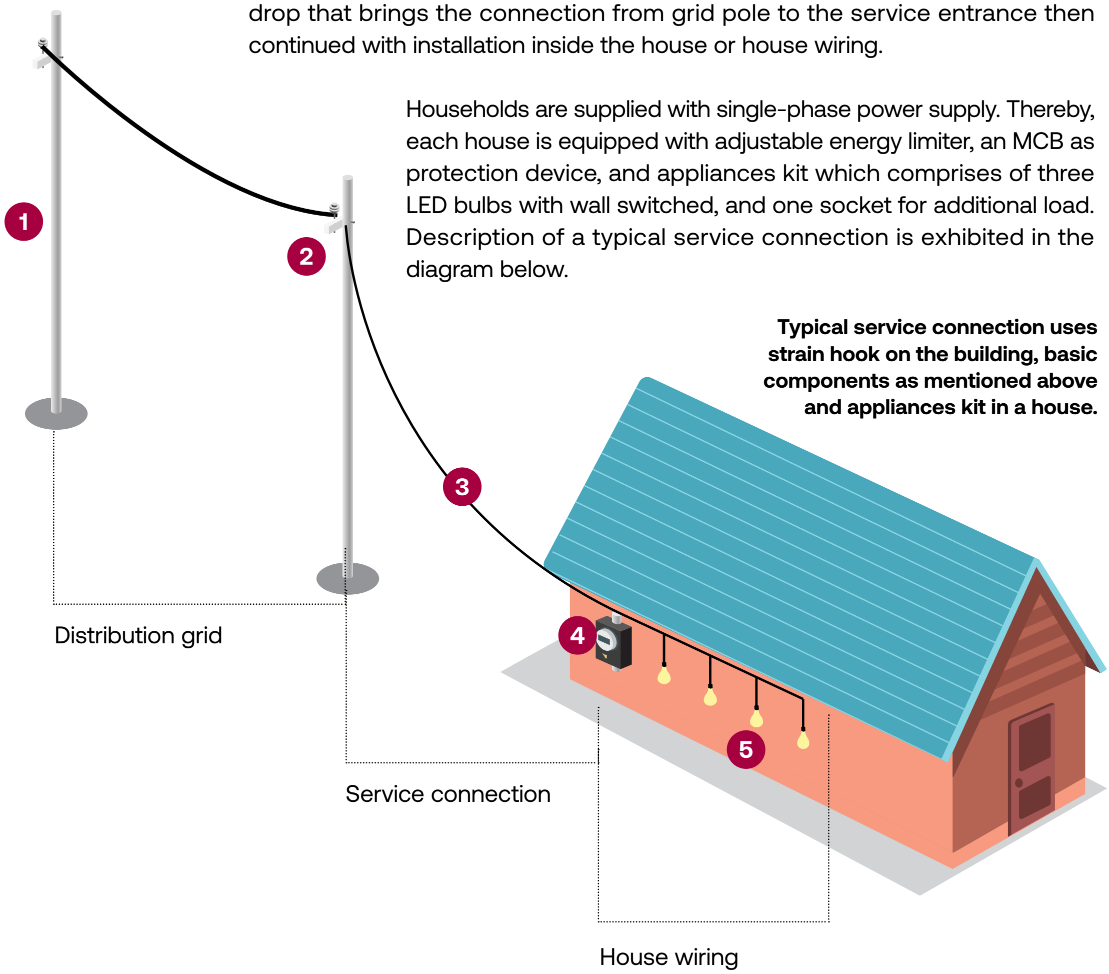
CHAPTER 13
Household Connection

- Good and bad examples of service connection installation
- How to safely install electrical connection in the house
- Awareness to use energy efficiently

13.1 BASICS OF HOUSEHOLD CONNECTION

Household connection includes service connection from low voltage grid distribution line to electricity installation inside the house. Starting from the service drop that brings the connection from grid pole to the service entrance then continued with installation inside the house or house wiring.

Households are supplied with single-phase power supply. Thereby, each house is equipped with adjustable energy limiter, an MCB as protection device, and appliances kit which comprises of three LED bulbs with wall switched, and one socket for additional load. Description of a typical service connection is exhibited in the diagram below.



Typical service connection uses strain hook on the building, basic components as mentioned above and appliances kit in a house.

1. **Grid distribution pole** holds and supports the main distribution line
2. **Service dead end clamp** or wedge cable clamp to hold the service drop
3. **Service drop** is the electrical service lines than run from main distribution line into the service entrance of the house.
4. **Service entrance** consists of energy limiter and MCB as protective device.
5. **House wiring** is the internal wiring of all appliances inside the house such as wiring between appliances and the wall socket.

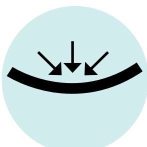
[1]Daisy chain: a series of interconnected or related things

Safety of the users and better utilisation of energy are the main things that should be carefully considered from the household connection. Household installation should be at a very good quality and the safest possible to reduce the safety risk to the end-users who are unfamiliar and have limited knowledge in electricity. It is very important to ensure that all installations are not harmful to the users during their activities and no possibility of damaging the system due to short-circuiting. In this case, it is important that the household installation comply with the requirement of the national regulation and installed by professional.

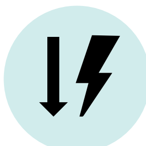
What are the risks that should be considered in the household installation?

- Electric shocks due to both direct and indirect contact with live conductors. Indirect contact happens when there is an insulation failure and live conductor touches metallic parts or liquid.

- Fires due to overheated element or electric arc. Overheated element occurs when the equipment is not sized correctly according to the load. Electric arc sparks when there is bad connection between conductors.



- Mechanical stress that may harm the installation as well as the human. Installation should be fixed and mounted properly.



- Under-voltage connection due to voltage drop in the grid may potentially cause damage to some sensitive household appliances.

Apart from the safety issues, users need to understand the basics of utilising the energy. It comprises of how to conserve the energy, using the energy efficient appliances, as well as using electricity for productive activities.

13.2 SERVICE CONNECTION

Service connection is a set of components including overhead conductors that connect the household electric installation with the low voltage grid distribution. It consists mainly service drop and service entrance.

SERVICE DROP

Service drop is the overhead cable that connects the main low voltage distribution cable to the energy meter by using a tap connector. It brings the electrical service to the house. The cable is attached to service dead-end clamp at both ends to adjust the tension.

How to install a good service drop?

- All installations should comply to local utility standard in connecting electrical service (2nd Book PLN – Construction Standard of Electrical Service Connection)[1].
- Avoid using very long conductor that may cause unnecessary voltage drop. Voltage drop should not be greater than 1%.
- Although the household load is very small that requires only thin cable, twisted cable with 10 mm^2 should be used to increase the cable strength.
- Use service dead-end clamp on both ends to hold and adjust the tension of the cable.

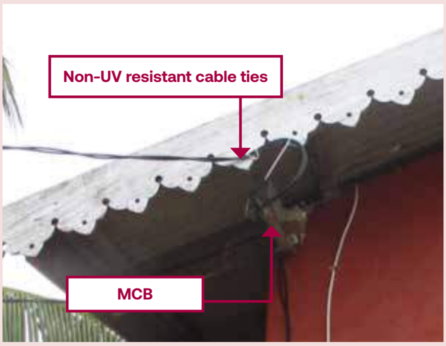
Service drop cable is under tension and cable is well installed on the wall using cable clamp.

Unnecessary long cable to the household without any proper cable support. The longer the cable, the higher the losses.

[1] Indonesia: PT. PLN (Persero), "Buku 2 – Standard Konstruksi Sambungan Tenaga Listrik," 2010.

Strain hook is installed to hook the service dead end clamp. The type of strain hook depends on the surface material.

Incorrect use of service dead end clamp. The clamp should be hooked on the strain hook.



Standard cable tie is used to fix the service drop cable. MCB should not be installed at the roof.

Distribution cable should not touch the sharp edge of the roof. Temperature increase and friction may cause damage in cable insulation.

Always use service dead-end clamp when the distance between the pole and the house is greater than 3 meters. In this case, installing tap connector in the middle of cable span is acceptable. However, the cable should be fixed on the wall to avoid service drop connection failure due to wind motion

How to fix such installation?

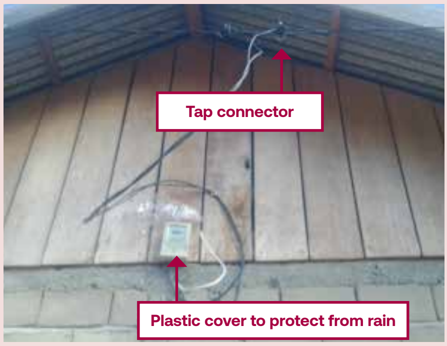
- To minimise losses, reduce the length of the cable and adjust the service drop accordingly. The distance between overhead service drop to the ground should not be less than 4 meters.
- Installation of the main MCB to the grid should be reachable by the users.
- Try to avoid using cable ties to fix the installation. Install service dead-end clamp and hook the clamp to the provided strain hook.
- Add hard layer between cable and sharp edge roof. Alternatively, re-route the service drop to the location that is free from sharp side of the roof.

SERVICE ENTRANCE

The service entrance provides the function of connecting household appliances to the grid. In this case, the service entrance is in the form of energy meter box that consists of energy limiter, MCB, and grounding connection. Energy limiter serves to limit the usage of the energy per day for each of the connected household. Daily energy quota is set by the operator based on the available energy from the PV system and the number of households with typical quota up to 600 Wh for each household.

As the box is accessible by the owner, it is important that the box is provided with protection against direct touch. This is to avoid people with insufficient knowledge in electricity access the components.

Energy meter box is installed at a good height from the ground and shaded. Energy meter is easily being monitored.



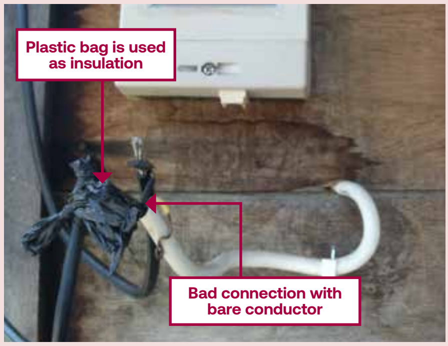
Energy meter will not be readable if installed at the gable (more than 3m from the ground). Long cable should not be hanging to avoid connection losses.

The energy meter box should be accessible both visually and physically by the owner and installed at safe location with minimum 150 cm from the ground.

Where and how to install energy meter box?

- Energy limiter and MCB has to be installed inside the box with outdoor rating or minimum IP 45.
- Energy meter box has to be installed at height in between 150 cm to 200 cm. Very high installation may cause difficulty to read the display while lower height might be dangerous for children.
- The box should be installed under the roof to protect from direct sunlight and rain.

Energy limiter is not installed at the service entrance. Absence of limiter allows unrestrained energy to the owner.

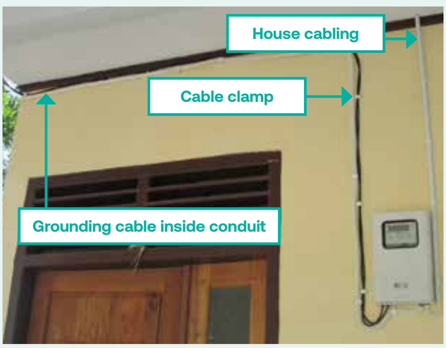


Unsafe bypass connection. Service drop is directly connected to the housewiring.

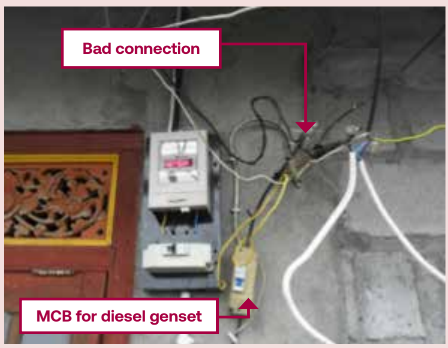
Installation without energy limiter and MCB or so-called bypass connection is considered to be an illegal connection. Bad bypass connection may lead to electric arc and fire especially if it is installed in wooden house.

Why an energy limiter and MCB are essential to the house installation?

- Energy limiter is used to avoid excessive use of energy by the consumer that may consume all the available energy from the PV system.
- Connection without energy limiter leads to unfair energy allocation among the users.
- MCB protects the installation against over-current and short-circuit that may lead to fire.
- During the service in the house, MCB can be used to isolate the house wiring from the grid by switching it off manually.



Energy meter box is fixed firmly on the wall with very organized cable installation inside cable conduit and clamp.

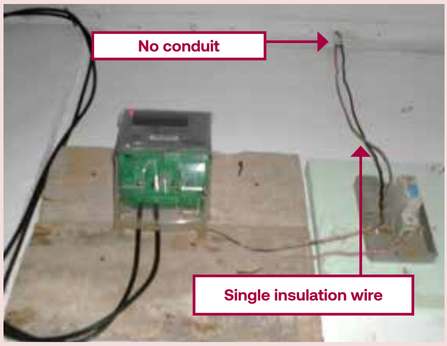


Poor and dangerous installation. Cable connection shall comply to local standard and fixed to the wall .

Energy meter with IP 54 is used and sealed. MCB is accessible by the user.

Installing equipment inside a box with low IP rating will not significantly protect the equipment from the rain or moisture.

For security and safety reason box should be locked and only operator has access to the box. However, MCB should not be installed inside the box.



Energy limiter and MCB are not installed inside a weather proof enclosure. Wires are fixed on the ceiling without conduit.

How to fix such installation?

- Reorganize the cables, install inside cable conduit and fix to the wall.
- Use junction connection box to protect the cable connection from direct touch.
- Never connect the household diesel genset in parallel to the PV mini-grid. Use changeover switch between PV mini-grid and genset if wanting to use the same household installation.

Direct weather exposure on the energy meter with low IP rating may cause energy meter to fail, especially in coastal area. Energy meter and MCB should be installed inside a secure and weather proof box for outdoor installation or at least rated at IP 4x and higher.

How to calculate the possible number of the new connections?

Due to limited number of energy limiter and MCB in a village, sometimes new household connection has bypass connection that may risk the household installation as well as the PV mini-grid. For this reason, it is recommended to provide at least 10% spares of energy limiter and MCB or for the remaining possible connection to the PV mini-grid.

Maximum number of connection is determined by the available energy from the PV array and maximum power that can be handled by battery inverter. Following is simple calculation on how to calculate the possible new connection:

Energy based

1. Check the capacity of the PV mini-grid

PV capacity =30,000 Wp

2. Check the number of huseholed connection and public facility. It is assumed that the energy allocation for public facility is the same as energy quota for household.

Existing connection = 110 household + 5 public facilities

3. Check the energy quota per household per day.

Daily energy quote = 450 Wh

4.Check the average global horizontal irradiation in the location using satellite data. The irradiance can be obtained from global Solar Atlas or similar database. Optionally, the average irradiance in Indonesia can be assumed at 4.5 kWh/m²/day.

Irradiation = 4,500 Wh/m²/day

5. Calculate the maximum household connection based on energy available with assumed total efficiency of 60% including the distribution losses.

$$\text{Maximum connections} = \frac{\text{PV capacity x irradiation x efficiency}}{1000\ \text{W/m}^2 \text{ x } 450\ \text{Wh}}$$

$$\frac{30{,}000\ \text{Wp x } 4{,}500\ \text{Wh/m}^2\text{/day x } 0.6}{1{,}000\ \text{Wh/m}^2 \text{ x } 450\ \text{Wh}} = 180 \text{ connection}$$

6. Calculate the maximum household connection based on energy available with assumed total efficiency of 60% including the distribution losses.

Remaining connections = Max. connection - existing connection

180 - 115 = 65 connections

Power based

1. Check the capacity of the totl batter inverters

Battery inverters capacity = 30,000 W

2. Check the number of huseholed connection and public facility. It is assumed that the energy allocation for public facility is the same as energy quota for household.

Existing connection = 110 household + 5 public facilities

3. Calculate the possible peak power based on MCB installed in household

MCB rating = 1 A

4. Calculate the maximum household connection based on energy available with assumed total efficiency of 60% including the distribution losses.

$$\text{Maximum connections} = \frac{\text{Battery inverter capacity}}{\text{MCB rating x grid voltage}}$$

$$\frac{30{,}000}{\text{! A x } 230\ \text{V}} = 130 \text{ connections}$$

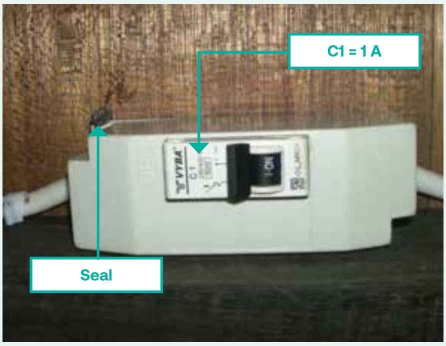
5. Calculate the possible remaining household connection.

Remaining connections = Max. connection - existing connection

130 - 115 = 15 connections

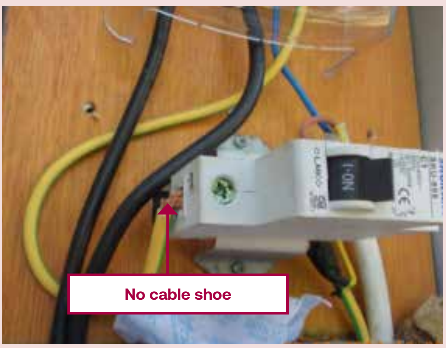
Additional of 15 households can be supplied by the PV mini-grid

From the result, the PV system is capable in delivering the energy to another 65 connections but it will not survive during peak load. Therefore, by calculating based on power allocation, there are only 15 additional households which can be connected by the system. In this case, spares of energy limiter and MCB should be provided to the local operator to anticipate new connection. When connecting the new connection to the feeder, it is important to check the existing current of the feeder (refer to Chapter 9 AC Distribution Panel to conduct the checking). The new household connection should be connected to the low loaded feeder.

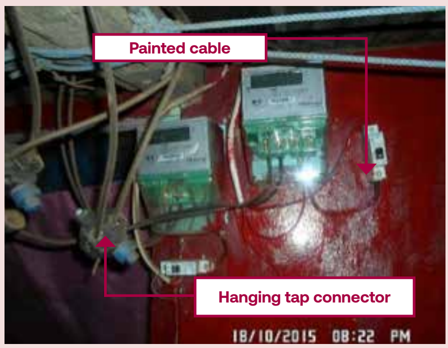


An 1 Ampere MCB is used to protect household installation. This equal to roughly 230 W of power consumption.

Higher rating (4 A) of MCB is used. High rating may lead to overcurrent at the power house MCB.



Cable for grounding is used for line connection. The possibility to wrongly connect the cable to the ground is very high.



Unsafe and untidy household connection with hanging cables and tap connection. Cable should not be coated with paint.

Always use the correct colour of cable insulation. Yellow-green should only be used for grounding. Misperception on the colour may lead to electric shock or short circuit.

13.3 HOUSE WIRING AND INSTALLATION

House wiring starts from the MCB in the energy meter box, then distributing power from the grid to all appliances in the house. The wiring includes the installation of light sockets, socket outlet, wall-switch, cables, as well as grounding. It is crucial that the installation should be at very good quality and safe from any electric shock or fire hazard.

How to increase safety in the household installation?

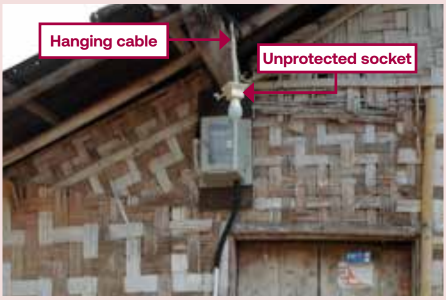
- Installation should be according to IEC 60364 – Electrical Installations for Building as well as PUIL (General Requirement for Electrical Installation) for Indonesian standard.
- Safe installation should be assured by professionals during commissioning. Sampling check could be done to validate the commissioning result.
- All electrical appliances that requires grounding or typically with metal box should be grounded. Grounded appliances will reduce the current flow to the body in case of somebody is in contact with faulty appliance.
- Use residual current device (RCD) to protect the users from electric shock when touching live conductor. Live conductors should not be left unprotected.
- Use double-insulated appliances to avoid leakage or faulty current on the housing.
- Local operator should check the cable and grounding installation of every household in regular basis. It is recommended to perform the inspection twice a year.

Grounding is provided for appliances grounding

Grounding cable is not connected to the ground

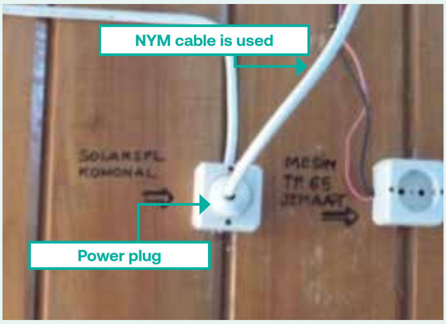
The main grounding installation as well as the appliances grounding should always be maintained to reduce the risk of electric shock on faulty appliances.

Lamp is installed on the beam and protected under the roof.

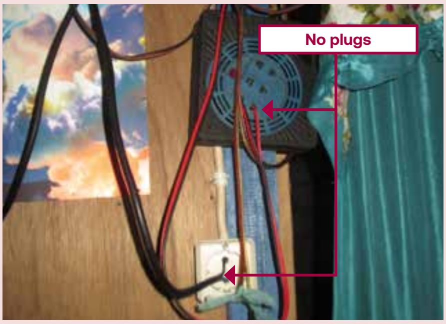


Socket bulb is not precisely installed under the roof. Showery weather may cause short-circuit.

All appliances that is not weatherproof or has low IP rating should always be protected from rain and moisture.



AC power plug with correct cable type is used. Grounding terminal and cable must be connected when the device requires grounding.



Extremely dangerous installation. Cabel should always be equipped with power plug. Single insulation cable should not be used.

Never connect wires directly to the socket. Bad connection will lead to electric arc and increase of temperature. Always use appropriate power plug to connect appliances. Reliable extension cord should be carefully selected indicated by at least SNI certified.

Lamp fixture is mounted on the beam and switch are installed at reachable height. Cables are well mounted on the wall and without tension.

Lamps are hanging and not mounted properly. Cables should not be under tension.

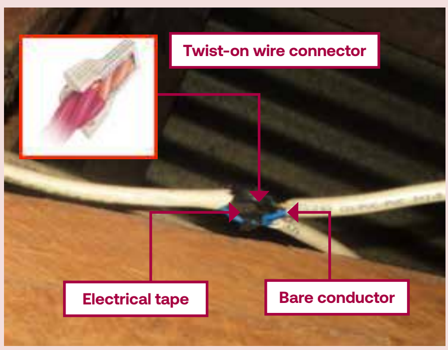
How is a good house wiring installation?

- Always use cable with double insulation such as NYM or NYY. Three-core cable for phase, neutral, and protective conductor with minimum cross section of 1.5 mm^2¬ should be used. The current carrying capacity of NYM 1.5 mm^2 is 18 A if it is installed at 30°C.
- Cable should be routed inside cable conduit to protect the cable insulation from damage. PVC pipe or flexible conduit can be used. It is a must to install single insulation cable inside cable conduit.
- Bulbs should be installed in socket with screw base instead of free-hanging bulbs.

150 cm

- Socket outlet should be featured with protective earthing terminal. The terminal should be connected internally with grounding wire to provide grounding for the appliances.
- For safety reason, wall switches and socket outlets should be installed with minimum 150 cm from the ground and easy to reach.

Neat installation of house wiring Junction connection box is provided to house the cables interconnection.

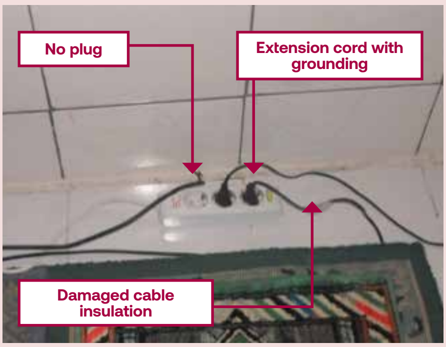


Junction connection is not installed inside box. Twist-on wire connectors should be used to fasten the conductors instead of electrical tape.

> **Connecting two or more conductors should be done by twisting the conductors and fasten with twist-on wire connector. Avoid using electrical tape as the thin tape may be damaged by the conductor and leave the live conductor unprotected. Unprotected live conductor may cause electric shock as well as short circuit. Junction box must be provided.**

Neat cable installation and junction. NYM cable and conduit is used for household appliances.

Very messy house wiring. Hanging cables all over the wall.



Extension cord should not be placed on the floor. Splash of water might cause very dangerous situation.

Socket outlet is installed at very low height. Socket should be kept away from the kids.

How to fix such installation?

- Re-route the wires and install inside cable conduit to reduce the tension on the cable.
- Use extension cord with grounding terminal to ensure that the grounding connection is always available.
- Avoid installing socket outlet or putting extension cord at very low height that is reachable by kids. All type of electrical connection should be installed with minimum of 150 cm from the ground.

Voltage is within the acceptable range.

There is 14.4% voltage drop on the line distribution. The voltage level is violated from the acceptable voltage range.

The voltage at the latest connection should not be less than 10% or greater than 5% from the nominal voltage. In this case the voltage should not be lower than 207 V or 198 V for 230 V and 220 V, respectively.

Why high voltage drops or under-voltage grid is not acceptable?

- Low voltage will cause appliances to draw more current and thus increase of heat and harm the cable insulation as well as damaging home appliances.
- Reduce of current will also cause the MCB to trip unintendedly due to the increase of current.
- Motor or fans will not work efficiently as not enough torque being produced to the load. This will heat up the winding and reduce the lifetime of the motor.
- For CRT (Chatode Ray Tube) type of TV, the colour may change when the voltage is low.

13.4 UTILISATION OF ENERGY

Sun radiation is abundance and free but the energy that can be captured and stored is limited. Therefore, it is important to save the energy by using electricity wisely only when needed and use energy-efficient electronic components. Saving the energy will not only secure the availability of energy at the power plant but also prolong the life time of battery.

The utilisation of electricity should not be limited only to lightning and entertainment. Electricity should be used also for productive activities such as lighting for small shop, refrigerator for cold drinks, bakery, small workshop, etc.

The use of referigerator in a small shop showing the productive use of energy.

Manual way of mixing the dough and processing the food is replaced by electric mixer and blender.

As the power and energy consumption might exceed the common limit for households, regulation or special installation should be made by local operator and village management team. Energy security in the power house and safety of the installation should be considered when giving permission and choosing the appliances.

What should be considered when some entrepreneur proposes productive use activities?

- Understand the load behaviour of the appliances. The consumption of appliances should not exceed 1000 W when connected to single-phase household connection. Meaning some small motors such as sewing machine, mixer, and blender are still acceptable for single-phase.
- Higher load or motor greater than 1000 W should consider three-phase connection. In this case, special connection should be designed. Make sure that regulations regarding the electricity usage for productive use is made within the villagers, such as for tariff and time allocation to operate the higher load appliances.
- Calculate the possible energy used of the appliances and time. Energy for household lighting should be prioritised before fulfilling the energy for productive activities by using excess energy. It is preferred to have productive activities which use high load appliances to operate during day time.
- For the motors with high starting current, soft starter has to be considered in the facility to avoid disturbance on the grid.

ENERGY CONSERVATION

Energy conservation means the behaviour to reduce the amount of energy service such as turning-on the light only when people are around, switch-off the TV after use, not using fans when the weather is cold, or using simple sound system when there is an event. Unnecessary energy consumption may lead to waste of quota in the energy limiter.

A single lamp is used to provide lighting for the learning process.

Excessive use of lamps in an empty mosque. Lamp should be lit only when the public facility is in used.

Lamp is unnecessarily lit during the day time. Approximately 60 Wh energy is wasted during day time for a single bulb.

Streetlight is installed in the public building without adequate support and lit during day time.

Unnecessary waste of energy during the day time will lead to lower energy quota for night use. Forgetting to turn-off a 5 W LED bulb during day time will already reduce the quota up to 60 Wh within 12 hours which is equal to one fifth of the typical daily quota 300 Wh.

Lamps are installed with sufficient distance to provide better light distribution

Lamp installation should not be too close to each other. It is preferable to change the lamp with higher lumen to increase illumination.

Make sure that the lamp has wide beam angle with minimum of 300°. Some of conventional LED bulb can only distribute light with angle of 120°. Lamp with narrow beam angle should not be installed horizontally.

All appliances are switched-off when the owner is not using them.

Exaggerated sound system for a limited energy source. One passive speaker may consume 400 W.

Additional efforts to reduce the use of electricity

- Lighting for public facility can be equipped with motion sensor, timer, or light sensor to switch-off automatically when nobody is in the room or when the sun is set.
- Paint the wall with reflective colour like white will help to increase the illumination.
- Always Install the lamp in vertical position with head lamp facing down to improve the illumination

ENERGY EFFICIENCY

Saving energy through using energy-efficient appliances will significantly contribute to reduce the energy consumption in a household. Energy efficiency is a way of using technology that consumes less energy to achieve the same output or service, for example replacing incandescent lamp and cathode ray tube (CRT) TV with LED technology. The prices of energy-efficient components might be slightly more expensive than the conventional ones. However, the higher price comes with lower energy consumption and longer life time that makes the appliance is cheaper in the long run.

What to consider when buying new appliances?

- Preform simple analysis on the cost benefits of different kind of options. Choose the most efficient appliances for the best price.
- Always look at the power consumption of the appliances before buying electronic item. This is to avoid non-optimal use of appliances due to overload of the MCB or insufficient quota.
- Calculate the estimated daily energy usage to be match with the daily energy quota.

How to calculate power and energy consumption in a household?

1. List all the household appliances.
2. Check the power consumption of each appliance in watt. Power consumption is shown the label attached on the appliances.
3. Check and estimate the operation hours of the appliances per day. Example: LED bulb is running 12 hours during the night from 18:00 to 06:00.
4. Calculate the energy use of each appliance in watt-hour per day.

Energy per day = Power x hours/day

5 W x 12 hours	**Energy per day = 60 Wh**

5. Calculate the total power of all appliances

Power 1 + Power 2 + ...+ Power appliance N^{th}

5 + 5 + 5 + 10 + 40 + 15 + 5	**Total power = 85 W**

6. Calculate the total energy per day of all appliances

Energi 1 + Energi 2 + ...+ Energi appliance Nth

60 + 60 + 60 + 40 + 120 +60 + 10	**Total energy per day = 410 Wh**

7. Crosscheck with the MCB rating. Total power of all appliances should be less than maximum power of MCB.

Maximum power MCB > Total power

Maximum power MCB = 1 A x 230 V	**230 W > 85 W**

Existing appliances

No.	Appliances	Power (watt)	hours/day	Energy/day
1	LED bulb	5	12 hours	60 Wh
2	LED bulb	5	12 hours	60 Wh
3	LED bulb	5	12 hours	60 Wh
4	LED bulb	10	4 hours	40 Wh
5	LCD	40	3 hours	120 Wh
6	Fan	15	4 hours	60 Wh
7	Phone charger	5	2 hours	10 Wh
	Total	90 W		410 Wh

<230 W **<450 W**

8	Rice cooker	300	0.5 hours	150 Wh
	Total	390 W		560 Wh

<230 W **<450 W**

8. Crosscheck with the energy limiter. Total energy consumption per day should be less than daily energy quota (if using energy limiter).
9. Add the item to be purchased into the calculation to check whether the appliance can be used with existing configuration.

High efficacy LED lamp is used. LED needs only 5 W to emit 400 lumen.

Less efficient fluorescent tube lamp is used for terrace lighting. Fluorescent lamp is not recommended to use because of excessive energy use with shorter lifetime.

Which type of lamp should be selected?

Instead of only looking at the cost and power consumption or wattage of a lamp, one should look at the right lumen when installing new light point or replacing broken bulb. Efficacy or lumen per watt as well as lifetime should be considered when choosing the right lamp. The higher the efficacy means more efficient lamp and the when the cost per lifetime is lower meaning it is actually cheaper price in a long run. Following is the comparison of different lamp technology installed on site. The price for fluorescent tube lamp includes the housing and the ballast.

Technology	LED bulb	CFL lamp	Fluorescent tube
Watts	9 W	10 W	10 W
Lumens	800 lm	590 lm	390 lm
Cost[2]	34,000 IDR	22,000 IDR	36,000 IDR
Est. Lifetime	15,000 hrs (3-4 years)	6000 hrs (1.4 years)	5000 hrs (1.1 years)
Efficiency	89	59	39
Cost / lifetime	10,000 IDR / year	10,000 IDR/ year	32,700 IDR/ year

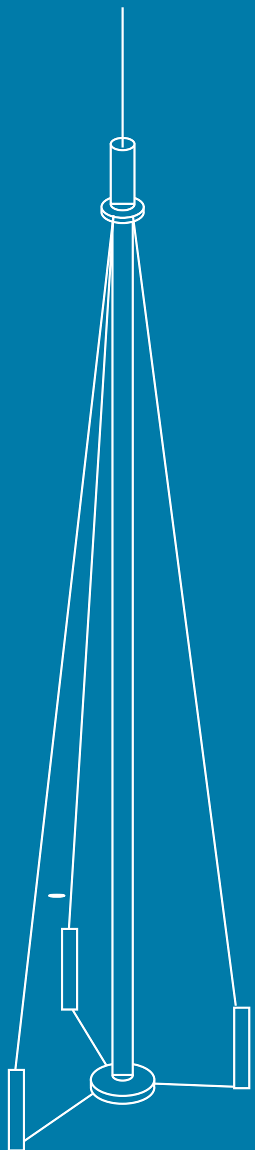
LED TV with lower power consumption is preferable despite its expensive cost.

CRT TV is used. CRT TV is cheap but less efficient compared to LCD or LED TV.

[2] Indonesian currency

CHAPTER 14
PV System Grounding and Lightning Protection

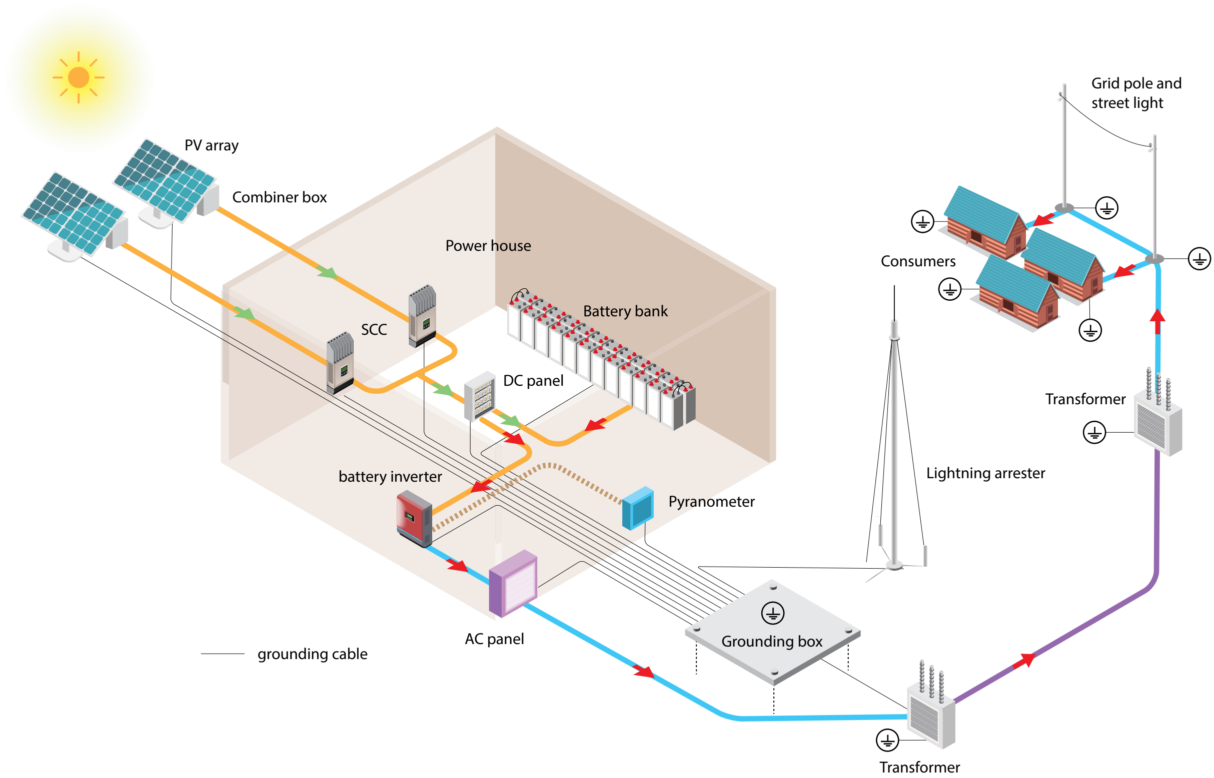
- How is the ideal configuration of a distribution grid?
- Good and bad installation of distribution grid and its components
- Recommended installation of the streetlights
- Medium voltage distribution



14.1 BASICS OF GROUNDING AND LIGHTNING PROTECTION

Grounding is a technique to electrically connect the conductive material of an equipment to the earth. It aims to provide safety of the installation from the unexpected fault current. Grounding includes the connection of current-carrying conductor to ground as well as connection of non-current carrying conductive equipment such as PV module frame, support structure, metal enclosures, and other conductive equipment. The absence of grounding will not only cause electrical shock hazard in the installation but also introduce potential damage of the installation especially during lightning strikes.

Grounding scheme in PV mini-grid system



▶ Why grounding is strictly required?

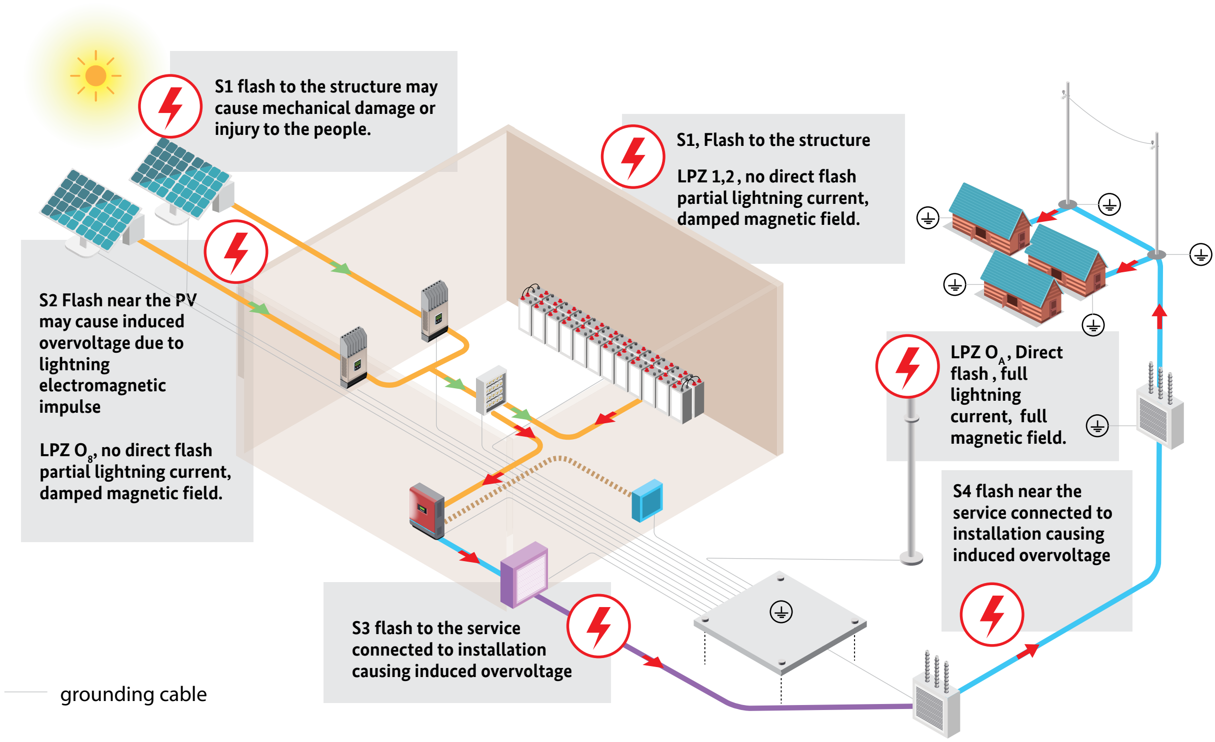
- To protect the electrical installation and equipment due to fault current and lightning strike
- To avoid different potential on exposed conductive parts through equipotential bonding
- To ensure safety for human and animals from electrical shock through both direct (directly touching the live conductor) and indirect contact (i.e. touching the electrified conductive equipment due to insulation fault)
- To provide safe path to dissipate lightning surge to the ground

Lightning strike is one of the threats to PV mini-grid systems due to location of the system which is in open area and far from high conductive structure. Unexpected failures of the systems and insulation damage may occur if preventive measures such as installation of a proper lightning protection system and grounding system are not considered. The damage to the electrical installation might be caused by both direct strike (direct strike to the structure) and indirect strike (lightning striking near to the structure) that may cause overvoltage on the line.

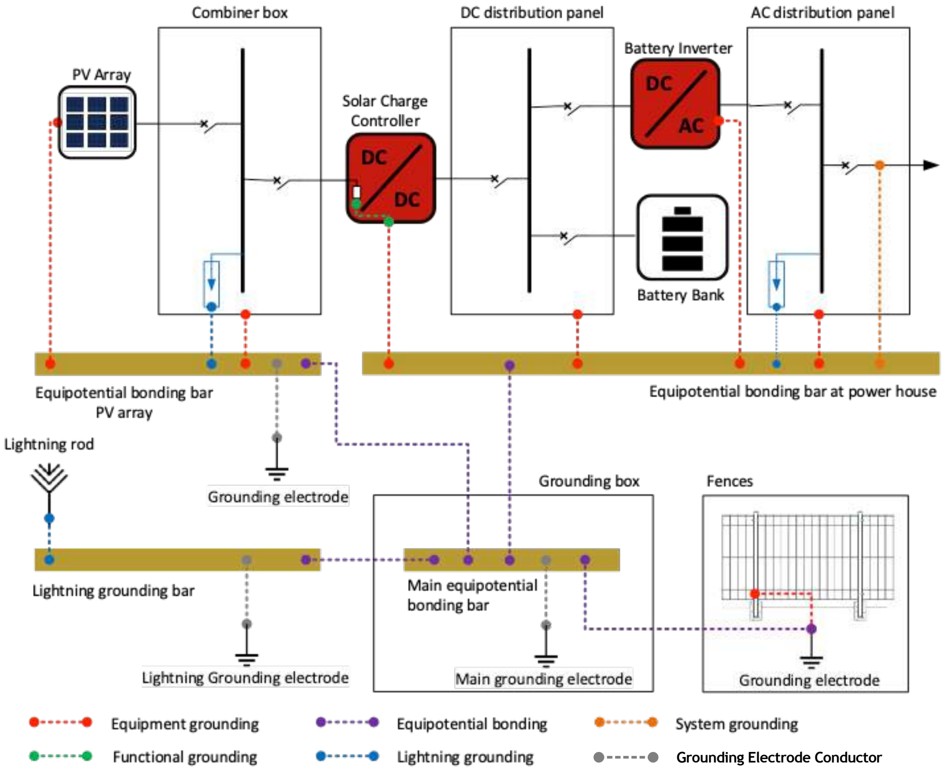
Lightning is high current electric discharge between cloud and ground and between positive and negative charges in the cloud. The rapid discharge occurs when the insulating capacity of air breaks down when the charges grow large enough. Cloud to ground type of lightning is the type that occurs most often and causing damages. The possible damages due to lightning strikes are explained in IEC 62305-1 and distinguished as S1, S2, S3, and S4 depending on the location of the strikes. depicted in the following figure. The expected damages are broken PV module frame and glass, failures of the power electronics or other sensitive equipment due to overvoltage, broken cable insulation, and electric shock hazard due to touch and step voltage caused by lightning electromagnetic impulse.

In order to determine the required protection measures against lightning strikes, the concept lightning protection zone is often defined. The zone is divided into external zone which are LPZ 0A that is susceptible to direct lightning strike with full lightning current, LPZ 0B with risk of partial lightning current, and internal zone which is LPZ 1 and LPZ 2.

In order to avoid the damage, lightning protection system (LPS) should be installed to protect the system from direct as well as indirect lightning strike. LPS is classified into external and internal LPS. The external LPS namely air termination system, down conductor and earth termination system which is mainly to provide the protection zone against direct strike on the structure in PV mini-grid. The internal LPS are to prevent any dangerous flashover and damage caused by surge. The internal LPS consists of equipotential bonding, separation distance, and surge protection device.



Components in grounding system



Equipment grounding connects exposed non-current carrying conductive parts of the component to the ground

- **Grounding system** provides grounding connection to the live electric part.
- **Functional grounding** is installed to ensure the proper functionality of PV systems such as avoiding potential induced degradation[1] (PID) in the PV modules by connecting the negative pole of PV to the ground. The grounding is typically done in the power electronics.
- **Lightning grounding** provides the current path to the ground during lightning strikes.
- **Equipotential bonding** bar ensures that all the conductive parts are on the same voltage level and at zero potential. The bonding prevents the current flow through the conductive parts that may cause electric shock.
- **Grounding electrode conductor** connects the bonding bar to the grounding electrode using grounding electrode clamp
- **Grounding electrode** is the conductor that connects the grounding of PV systems to the soil

Design, size, and installation of earthing conductor and boding must follow local standard or international standard such as IEC 60364-5-51 and IEC 60364-7-712

1 PID or Potential Induced Degradation is a phenomenon that normally affects crystalline silicon-based PV module. PID is caused by the leakage current and voltage potential in the module between solar cell and other parts of the module such as grounded frame, glass, etc. The phenomena lead to a significant reduction of performance gradually over the years and accelerates with humidity and temperature.

How to prevent PID?

- Grounding the negative pole of the PV array to avoid having negative voltage relative to the surrounding
- Discharge the charged on the modules by inverse the voltage on the PV array during the night time. This can be done using special device with automatic night-time discharging of PV module such as PV offset box.

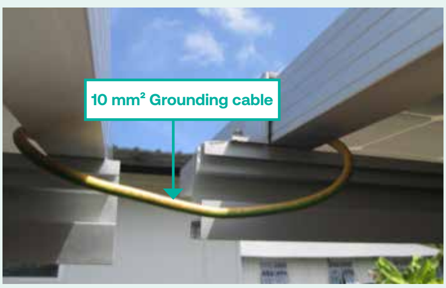
The grounding of negative pole of PV array is permitted as long as there is a galvanic isolation between AC and DC side, or when the grid inverter with galvanic isolation is used. Grounding the negative pole in the system with transformer-less inverter may lead to a short circuit between PV plant and the grid when ground fault occurs.

What to consider when installing functional earthing?

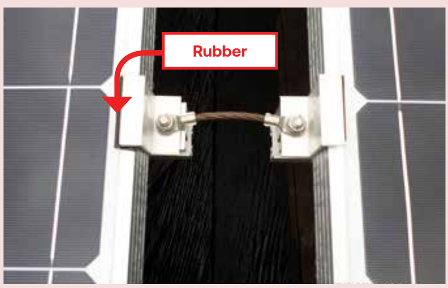
- Ground fault protection device and overcurrent protection device should be installed when the negative pole of the PV array is connected to the ground to avoid any fault current flowing in the functional grounding conductor.
- Functional grounding should be installed in between switch disconnector of the PV array and the grid inverter or solar charge controller. Some of the manufacturer provides grounding connection through ground fault detection interruption (GFDI) with fuse to interrupt the connection when ground fault occurs.

EQUIPMENT GROUNDING

Equipment grounding is required to ensure that the exposed non-current carrying conductive parts in the PV mini-grid system such as PV module frames, mounting structures, metal conduits, metal enclosure of junction boxes and distribution panels, and chassis of the power electronics, and fences are on the same voltage and zero potential to earth. A good grounding protects the users or operator from touch voltage, especially during faulty condition or when the live conductor get in touch with metal chassis.



Each of PV module frame is grounded by having interconnected grounding cable directly on the frame.

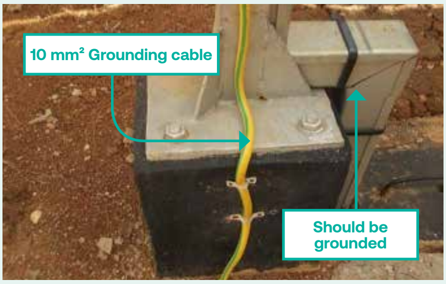


Bonding between PV modules is done on the clamp. The clamps may have rubber that prevent direct contact.

PV module frame must be grounded to prevent floating potential especially in the system with transformer-less inverter. Inverter contains high frequency switching components that may cause small fluctuation in the array cable. Since the PV cables are capacitively coupled to the module frame, the fluctuation induces voltage on the frame.

Mounting structure is bonded to the PV module frame and neatly grounded.

Grounding conductor is detached from the cable lug cause loss of protection.



Good grounding of PV mounting structure with proper size and routed nicely. Metallic conduit shoule also be physically grounded.

Poor grounding connection and installation. Insufficient conductor size and absence of cable lug.

The equipment grounding conductor should not be less than 6 mm2 for copper, 16 mm2 for aluminium or 50 mm^2 for steel.

How to improve such installation?

- Grounding of the PV module frame should be done by connecting the grounding cable directly to the frame. Ensure the direct contact between modules since special coating or layer may isolate the connection.
- Visual inspection and performance verification by performing grounding continuity test on all grounding connection should be done in regular basis to ensure the grounding connection.
- The mounting structure of PV array should be bonded to each other by connecting it to the bonding grid of PV array. Connection should be made underground with cross connector.

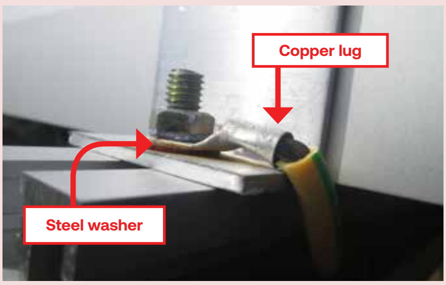
Makeshift solution using nails to fix the earthing electrode on the mounting structure

Cable lug is not properly mounted on the anchor bolt of the mounting structure. Small movement may cause the connection to lose.

Chassis of the battery inverter is grounded through lay-in grounding lugs.

None of the solar charge controllers (SCC) are grounded. Chasis of SCC should be grounded individually in star configuration

Avoid of connecting equipment grounding in daisy-chained configuration. Grounding continuity can break-off easily when the first connection is removed and resulting the increase of electric shock hazard.



Corrosion on the washer may increase the connection resistance. Avoid direct contact of dissimilar metal that has different anodic potential.

Wrong cable insulation color may cause confusion and lead to misplace of cables.

Fence is grounded to protect persons or animals from electric shock due to indirect contact.

Ungrounded metallic raceway leads to electric shock hazard when the tray become live under fault condition

Door of the enclosure is connected physically to the equipotential bonding bar

Absence of bonding conductor may lose the protection against indirect contact as well as protection from lightning strike

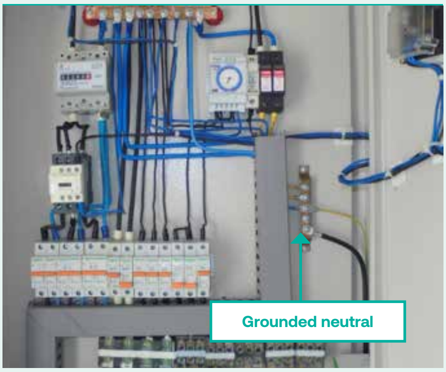
How to fix such installation?

- To prevent galvanic corrosion, avoid of having direct touch between copper and aluminium frame or copper and hot dip galvanized steel. Bimetallic washer or bimetallic joints can be used to prevent direct contact.
- Use different cable insulation to distinguish between power cable and grounding conductor. Yellow/green cable insulation colour or bare wire should be used only for grounding purposes.

14.2 GROUNDING SYSTEM

Grounding system or also known as earthing arrangement is the connection of the grounding conductor to the parts of the installation for safety purposes. One of the most common grid configuration and used by local utility is TN system that stands for Terre Neutre. In this configuration the neutral line is combined with protective earth conductor. There are three types of TN system that can be implemented namely: (1) TN-C or combined protective earth and neutral (PEN), (2) TN-S or separated neutral and grounding conductors, (3) TN-C-S in which hybrid of TN-C and TN-S.

TN-C networks are commonly used for low distribution grid as it is the most cost-effective earthing arrangement. The grounding system does not require additional conductor for protective earth (PE) connection, although it is the least safe arrangement with highest risk of broken neutral.



Neutral cable is combined in the grounding bar to achieved combined PEN conductor.

Neutral cable is grounded to maintain the combined PEN conductor at the distribution grid pole.

What should be consider from sizing of protective conductor?

- Protective earth conductor should be the same as the phase conductor for the phase conductor of up to 16 mm^2, as mentioned in IEC 60364-5-54 "Electrical installations of buildings – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements, protective conductors and protective bonding conductors".
- For the phase equal to or greater than 35 mm^2 the conductor should be half of the phase conductor.

Ensure that the neutral conductor is grounded along the distribution line. Grounding should at least be done on the first pole, last and every 5 poles from the first pole with maximum grounding resistance of 10 Ω.

PROTECTIVE EQUIPOTENTIAL BONDING

Equipotential bonding is electrically connecting grounding conductors except for functional grounding (if transformer-less inverter is used) together to the equipotential bonding bar to achieve the same potential. It ensures that no current will flow on through the conductive parts that may cause electric shock during electric fault condition or lightning strike.

▶ What should be consider when installing equipotential bonding bar?

- Equipotential bonding should be located closed to the entrance of grounding conductor that connects to the main equipotential bonding bar.
- Grounding should be labelled with the grounded equipment according to the as built grounding diagram
- Ensure that the connection between grounding conductor, equipotential bonding bar, and grounding electrode has low resistance path. Perform ground continuity test to verify that the grounding connection has low resistance

Grounding and bonding conductors from other bar is connected properly to main quipotential bonding bar

Excessive number of conductors are bonded in a grounding electrode clamp.

Combined grounding installation of several equipotential bonding systems in the main equipotential bonding bar

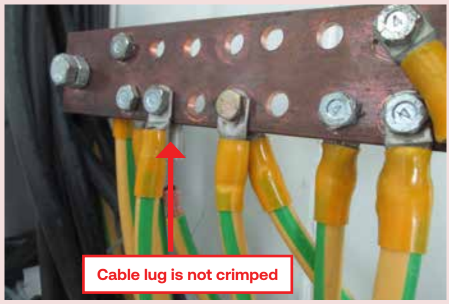
Separated grounding installation lead to possible potential difference between the grounded equipment.

How to improve such installation?

- It is preferred to use bonding bar as main equipotential bonding rather than connecting on the grounding electrode clamp for a better connection resistance
- Never left the grounding system separated. Combine the grounding electrode by having copper conductor of minimum of 6 mm^2 between the electrodes.

Ensure that all the grounding rods must be bonded together including the grounding electrode of PV array, power house, and lightning protection. It is recommended to use equipotential bonding conductor of at least 6 mm2 for copper or 16 mm2 for aluminium.

Equipotential bonding bar is installed properly with secure connection of grouding conductors.



Grounding conductor is detached from cable lugs. Ensure that conductor is pressed over the entire length of cable lug

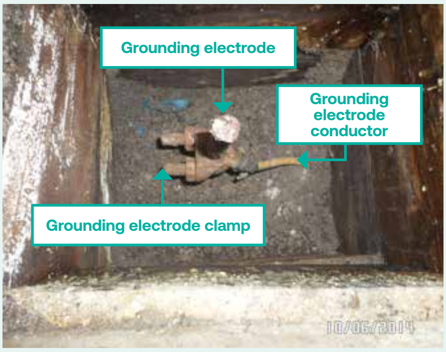
Install equipotential bonding bar near the cable entrance to prevent partial lightning current from entering the power house

GROUNDING ELECTRODE

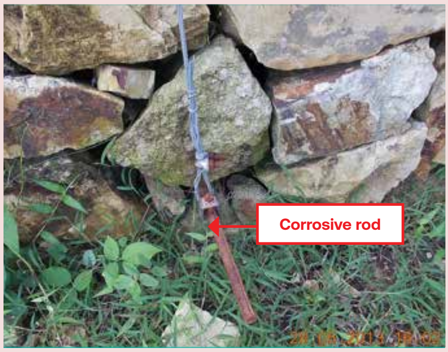
The grounding electrode is the conductor that provides connection to the ground and determines the grounding resistance PV mini-grid system to earth. The grounding electrode chain consists of:

1. Grounding electrode conductor that connects the main equipotential bonding to the electrode
2. Ground electrode clamp to securely attach grounding conductor and electrode
3. Grounding electrode. It is important to obtain low grounding resistance by having a proper grounding electrode material, length, proper installation, and low soil resistivity.

Soil resistivity is one of the key factors to determine the design of grounding system such as length of electrodes or grounding electrode material to achieve low grounding resistance. Soil resistivity means ability of earth to conduct electricity. It depends on the type of soil, humidity, and temperature.

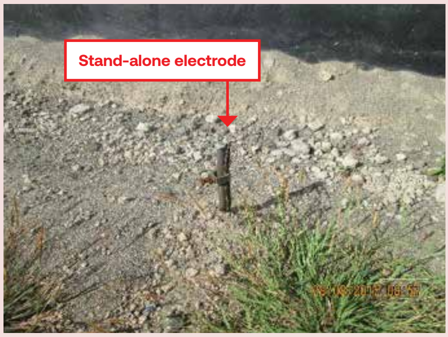


Proper installation of grounding rod. Well-attached grounding electrode and located inside the grounding box.



Poor installation of the grounding rod inside pile of stones. The unburied rod does not provide any intimate contact with earth.

Grounding electrodes are connected in parallel to reduce the grounding resistance. However, the distance should not be too close



Grounding electrode is not connected to any cable and located outside the grounding box.

What to consider when installing grounding electrode?

- The lower the soil resistivity, the higher the corrosiveness. The grounding electrode should be made from corrosion-resistant, highly conductive, and low resistance material such as copper.
- Ensure that the length of the electrode is sufficient to have contact with surrounding soil, and thus lowering the resistance of grounding system. Minimum of twometer electrode length with cross section area of 25 mm2 should be used for copper-based conductor. The soil resistivity is reduced steeply up to four meters depth and after there is no significant change

The grounding resistance should be kept as low as 5 Ω for the main grounding, PV array, and lightning rod. Grounding resistance should be frequently measured at least once a year and corrective action is required when the resistance raises above the limit.

Grounding electrode is installed in moist soil. Higher moisture content may increase significantly the soil conductivity.

Concrete is very poor in handling high current. During fault condition, water will turn to steam and causing cracks

Clamp is used to provide better grounding connection or low resistance path.

Poor installation of grounding electrode. Very thin electrode conductor and no clamp is used.

Connection of the grounding electrode conductor to electrode should be in a good contact to maintain electrical connection. Connection should be visible and easily maintained.

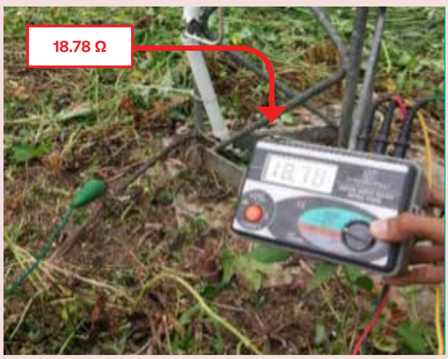
Good quality and corrosion free U-bolt clamp for burrial condition is used. It is preferrable to keep the connection above the ground

Non standard grounding electrode clamp is used. Corrosion may not only cause resistance to increase but also break the connection

How to improve such installation?

- Increase the distance between grounding electrodes to at least be equal to the depth of the grounding rod to achieve higher influence in soil resistance. Installing the rods close to each other will cause an intersect of resistance area of the electrodes and therefore the resistance will not be significantly reduced.
- Ensure that the resistance of the connection is low. It is recommended to keep the resistance not more than 1 mΩ.
- Corrosion protection layer or anti-corrosive tape could be applied to isolate the grounding clamp and protect the bonding connection from corrosion. Especially when the connection is located underground.
- Use proper grounding electrode clamp such as G5 type or U-bolt clamp

Low grounding resistance at the main grounding electrode.



Relatively high grounding resistance of lightning rod.

The grounding resistance for the main grounding electrode, PV array, and the lighting protection should not be greater than 5 Ω. Grounding resistance should be frequently measured at least once a year and corrective action is required when the resistance raises above the limit.

Good installation of grounding electrodes and equipotential bonding bar with adequate distance from the ground.

Equipotential bonding bar should not be install on the ground. Submersed bonding bar may speed up the corrosion process.

What should be considered from grounding box?

- The grounding control box is made from stone masonry that is in casted cement and smoothened. The height and cover (with handle) of the box must be designed to be easy for maintenance
- In order to keep the soil wet, salt and coal can be added to the existing soil to keep the soil wet and increasing the conductivity of the soil. As rule of thumb, 8 kg of salt per 1 M3 of soil is sufficient to significantly increase conductivity.
- Minimum of 20% of moisture should be maintained to achieve low resistivity. Lower concentration will rapidly increase the resistance. Soil should be watered regularly to maintain the resistivity low, especially during dry season.
- Grounding box in a hilly area or sloping landscape may have a dryer soil due to the fast drain of water table. Always choose location for the box that is not very easy to get drained.

Ensure that the grounding pit is composed from porous soil to absorb the water and maintained at wet condition. It is preferred to keep the any connection (clamp) above the ground.

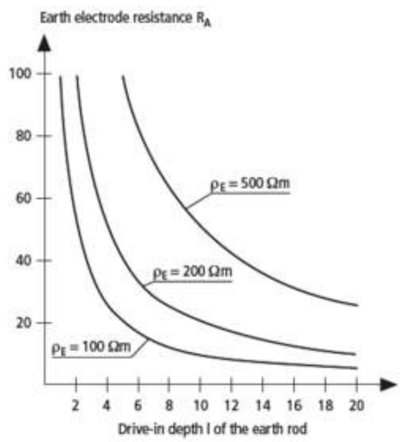
Good installation of grounding electrodes and equipotential bonding bar with adequate distance from the ground.

Improper construction of grounding box. Corroded and almost covered bonding bar. Absence of ground electrode.

How to improve the grounding resistance?

- Measure the existing grounding resistance using earth ground tester for base reference
- Prior the installation, perform soil resistivity test to obtain the best possible location for grounding installation and to identify the drive-in depth of the grounding rod to achieve low grounding resistance
- Calculate the required length of the electrode to achieve 5 Ω resistance. To reduce the resistance, increase the rod length or install several rods in parallel. From the following graph, at least 20 m drive-in depth of electrode is required for concrete soil to achieve 5 Ω. Other solution is to install several rods in parallel.
- Measure the existing grounding resistance using earth ground tester for base reference
- Prior the installation, perform soil resistivity test to obtain the best possible location for grounding installation and to identify the drive-in depth of the grounding rod to achieve low grounding resistance
- Calculate the required length of the electrode to achieve 5 Ω resistance. To reduce the resistance, increase the rod length or install several rods in parallel. From the following graph, at least 20 m drive-in depth of electrode is required for concrete soil to achieve 5 Ω. Other solution is to install several rods in parallel.

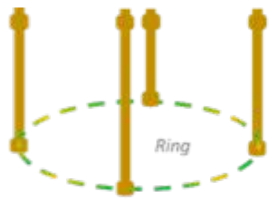
Type of soil	Resistivity in Ωm
Concrete	100 – 500
Boggy soil	20 – 40
Farmland	90 – 100
Humid sandy soil (dry)	200 – 400 (1000 – 1100)
Rocky soil	100 – 3000
Gravel	200 – 1500
River water (sea)	10 – 100 (0.3)



Resistance (R_A) of grounding electrode vs its length[2]

- Alternative to paralleling the grounding electrodes, it is preferable to use buried ring grounding system. Bare copper cable or copper clad cable of at least 25 mm^2 could be buried around the power house or PV array.

Grounding rods in parallel



Buried ring grounding system

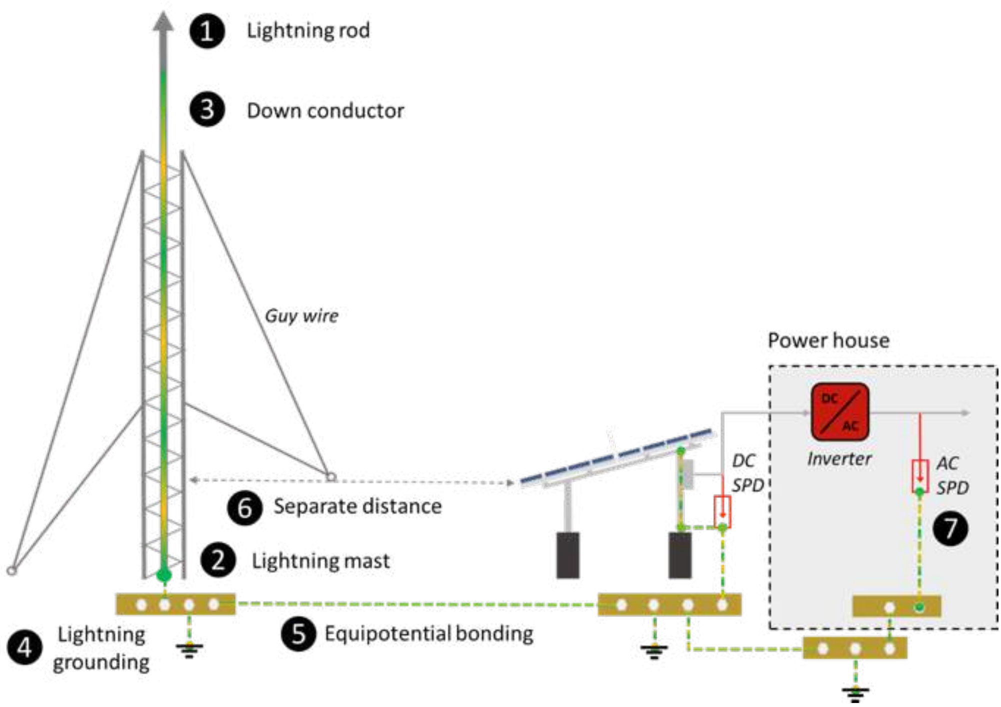
- Build grounding box to maintain the grounding connection as well as the soil condition.

[2] Lightning Protection Guide, 3rd updated version, 2015, Dehn, Neumarkt, Germany

14.3 LIGHTNING PROTECTION SYSTEM

Lightning protection system provides a protective zone to ensure the safety of the PV system as well as the people and animal against direct and indirect strikes to PV systems by using air termination system, down conductor, low resistance grounding termination, equipotential bonding, adequate separation distances and surge protection devices. It is important to conduct risk assessment, possible damage, and the required protection against lightning strike in the PV mini-grid system according to IEC 62305-2 and IEC 62305-3

How is the typical lightning protection system in PV mini-grid?



1. **Lightning rod** provides path to ground that can be used to conduct the high lightning currents when lightning strikes occur or to intercept the lightning flash.
2. **Lightning mast** supports the lightning rod to achieve the targeted tip height. It is also supported by guy wire to provide stability to the mast.
3. **Down conductor** provides the safe path for the lightning current to be discharged by the grounding electrodes
4. **Lightning grounding** or earth termination system is responsible in discharging the lightning current through the ground.
5. **Equipotential bonding ensures** that there is no potential difference or potential drop between the grounding electrodes
6. **Separation distance** is the distance between the air termination system or the down conductor and the metallic components in the installation.
7. **Surge protection device** protects the electrical equipment from the lightning surge.

▶ How to prevent damage from lightning strike?

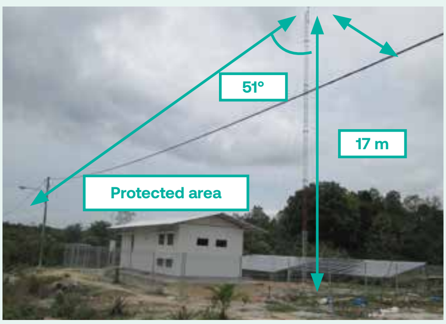
- Install a proper air termination system. PV arrays and power house should be in the protection zone of the air termination system.
- Down conductor and grounding electrode system should be properly sized and installed
- Separation distance between air termination system and any conductive parts such as PV modules frame should be maintained to avoid spark
- All the grounding electrodes such as lightning grounding, PV array grounding, and main grounding electrode should be connected together through the main equipotential bonding
- All the electrical and electronics devices have to be protected against overvoltage on DC and AC sides using surge protection device (SPD).
- To protect against overvoltage, avoid loop in the cable installation. The positive and negative cables should be installed closely. Protect the long cable inside earthed metallic conduit that is connected to the equipotential bonding to shield the cable from inductive surge.

The lightning protection system should be designed according to IEC 62305 – Protection against lightning.

AIR TERMINATION SYSTEM

Air termination provides protection by attracting the electric charge and discharge it to down conductor. The location and design of the air termination system should be defined properly to obtain the full protection of the power plant from direct lightning strike. Several methods such as rolling sphere or protective angle to position the air termination system can be used to estimate the protected area.

Free standing lightning mast with air termination rod that is designed using protective angle method is typically used in PV mini-grid system. Protective angle is the angle between the rod and the line projected to the ground. The protected area is in three-dimensional concept forming a cone. The protective area depends on the height of the air termination rod from the ground and the class of LPS as defined in IEC 62305-3.

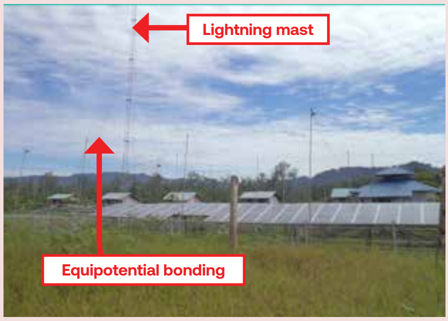


PV arrays and power house are inside the protected cone of the air termination system.

Some PV arrays are in the unprotected zone and at risk for direct lightning strike.

The tip height of the lightning mast should not be lower than 15 meters to achieve 20 meters radius of protected area, considering LPS class III for PV system bigger than 10 kWp. Extending the height will only increase radius of up to 2 meters.

Air termination system is installed at the perfect location to cover the PV arrays and power house.



Massive installation of lightning rods may cause additonal shading on the PV modules.

How to improve such installation?

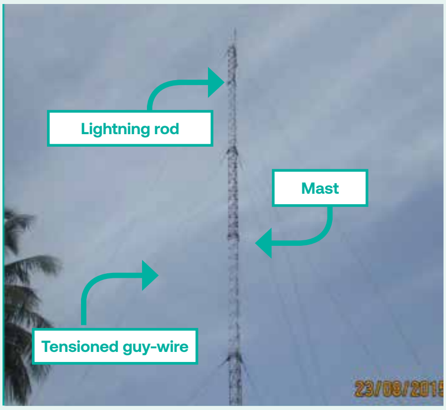
- Increase the protection radius by replacing the conventional franklin rod with early streamer rod or install additional lightning rod. Rolling sphere method can be considered when positioning multiple rods.
- It is not necessary to install lightning mast and multiple lightning rods. For relatively small ground mounted PV arrays, optimizing the lightning mast is preferable than installing multiple rods to increase the protection area.
- Equipotential bonding of the lightning rods should be installed underground using meshed earth termination system

Early streamer emmision (ESE) rod is used to enlarge the protection radius and improve the precision using additional ionization system.

Simple rod or franklin rod is used. The metal rod conducts passively when struck by lightning.

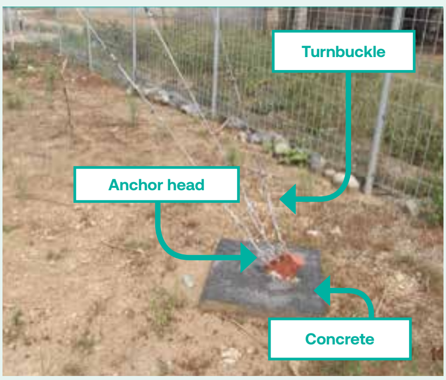
Why ESE rod or active lightning rod is preferred over the passive one?

- ESE rod provides bigger protection radius. The ionization system of the rod is activated by the electromagnetic field produced by the storm and leads to the creation of upward streamer. The early initiation of the streamer increases the efficiency of lightning attraction and protection radius.
- ESE rod is less expensive in comparison to the installation of multiple franklin rods to protect bigger area.
- ESE rod has a better precision in forming a discharge channel through the rod.



Very good construction of lightning mast with guy-wire to add stability on the free-standing segmented mast.

Bent lightning mast due to wind force and absence of guy-wire to support the structure.



Guy-wires are anchored securely using turnbuckle hooked on the anchor head. Turnbuckle is used to adjust the tension.

Corrosive single guy-wire. Additonal anti-corrosive wire should be installed to support the segmented mast.

DOWN CONDUCTOR

Down conductor is well protected inside PVC pipe and fixed to the lightning mast

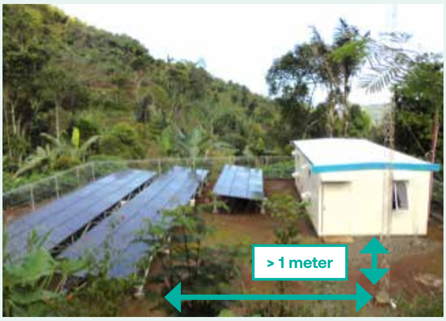
Undersized down conductor (16 mm^2) may lead to the increase of lightning path resistance.

50 mm^2 cable is used as down conductor to safely discharge the lightning current to the ground.

The down conductor is connected to ordinary cable sealed with tape. This connection is unsuitable to withstand high current.

Since the down conductor provides the link between lightning rod and the grounding electrode, the down conductor should have at least cross-section area of 35 mm^2 for copper to be able in handling temperature rise due to lightning current

Separation distance between lightning mast including the down conductor and conductive parts in the power plant such as PV modules frame and power house should be maintained to prevent induced overvoltage and electric arc. Overvoltage can be created due to large electromagnetic field caused by high current passing through the down conductor of lightning mast. Separation distance is the electrical isolation between the air termination system including the down conductor and other conductive parts



Separation distance is kept between the down conductor and PV modules frame and power house.

Lightning rods are installed very close to PV array.

▶ **How to fix such installation?**

- Increase the separation distance between lightning rods and PV array to avoid any flashover or induced voltage by relocating the lightning rods.
- The actual required minimum separation distance should be calculated based on the formula in IEC 62305-3 by considering the class of LPS, insulation material, circulating current through air terminals and down conductor, and the distance between the level where the separation distance is measured to the ground. Typically, the distance should not be less than 1 meter.

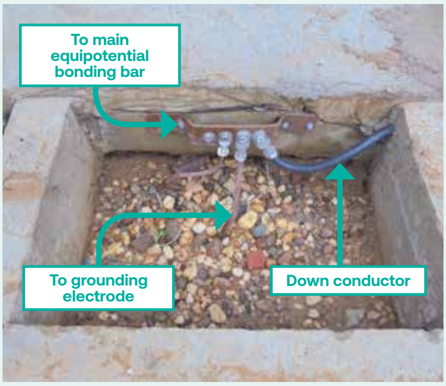
LIGHTNING PROTECTION GROUNDING

Grounding electrode of lightning protection is burried and installed inside a grounding box.

Grounding electrode should not be installed directly in the concrete. As its temperature may rise and cause concrete to break.

What should be considered from lightning grounding?

- Lightning grounding should have low impedance path to efficiently divert the lightning current into the ground and avoid unexpected mechanical damage, heat, or sparks.
- Grounding connection should be as short as possible and installed close to power cable to avoid loop that may introduce induced voltage.
- Lightning protection grounding should have low resistance between grounding electrode and earth. Ensure that the grounding resistance is not greater than 5 Ω. It is recommended to use two grounding electrodes in parallel for lightning protection grounding



Equipotential bonding bar to connect between lightning grounding electrode and main grounding system.

Grounding electrode is not connected to down conductor.

How to improve such installation?

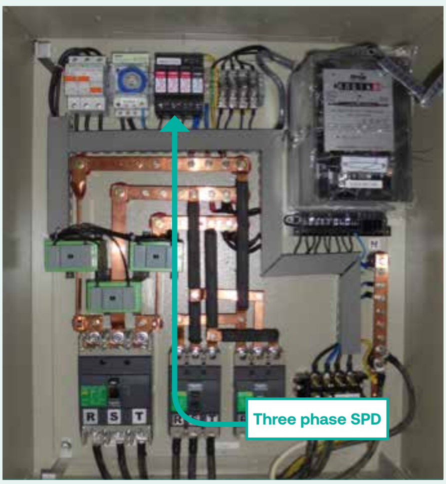
- Re-install the grounding electrode from concrete to the soil and install inside a grounding box
- Connect the down conductor to the grounding electrode through equipotential bonding bar. Lightning equipotential bonding and main equipotential bonding bar should be connected with conductor not less than 16 mm2 for copper.
- Check in regular basis the connection between down conductor and equipotential bonding bar as well as between the bar and grounding electrode.

SURGE PROTECTION DEVICE

Surge protection device (SPD) is used to protect against indirect lightning strikes or nearby strike to the grounded structure as well as inter and intra cloud lightning that generates electromagnetic field to induce transient current into the cable loop. SPD works by diverting the surge current to the ground during transient voltage. In this phase, the semiconductor switch in the SPD changes its state to low impedance and safely short the connection to the ground. Therefore, it is necessary to have the SPD grounded. Surge protection should be ideally be installed at the cable entrance to protect the power electronic components such as charge controller, grid inverter, or battery inverter from damaging transients.

What is the purpose of surge protection device?

- Reduce the risk of flashover in the system by providing equipotential bonding to the main grounding system.
- Mitigate the surge in the system due to direct or indirect strike. Direct lightning strike on the distribution grid, lightning conductors, or nearby the PV mini-grid installation can affect the installation within radius of 10 km. While the Induction in the conductive elements of the PV installation such as in the power cables due to indirect strike can be felt within 1 km distance.
- Protect electrical and sensitive electronic equipment as well as PV modules. The sensitive semiconductor of the PV cell should be protected from static discharges and voltage surge.



Three phase surge protection device is installed in the panel to protect the installation against overvoltage

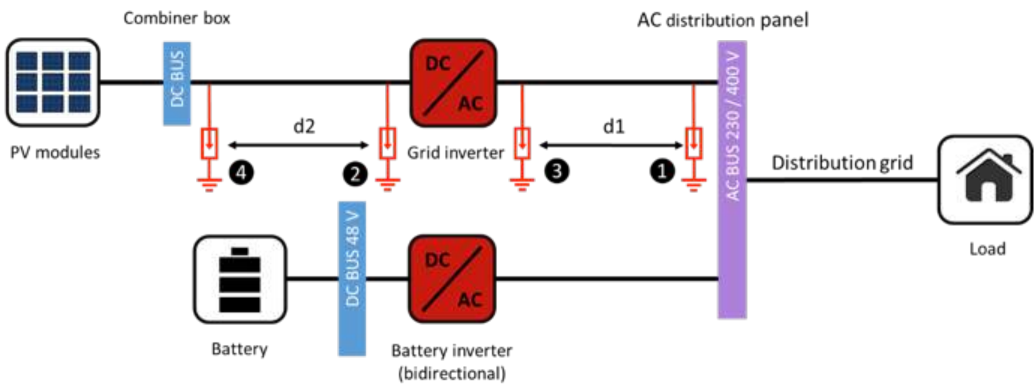
The installation is not equipped with SPD. Electronics devices are at risk of being affected by lightning surge or induced voltage

Never leave the electrical installation unprotected. Induced voltage or transients caused by lightning strike may enter the installation and damage the main power electronic devices or cable insulation and terminals to be damaged.

What to consider when installing SPD?

- Always use DC rated SPD at the DC system, and AC for the AC system as the switch works differently in extinguished arc.
- The required SPD should be based on the distance between the installation and separation distance between external lightning protection and PV modules frame.
- SPD should not only be installed to protect the power line, but also the communication line if the cables are coming from outside the power house (i.e. from grid inverter). Additional SPD might be required to be installed at the communication line.
- Install the surge protection device closed to the incoming cable.
- SPD in combiner boxes to protect the inverters and PV arrays against surge voltage. The selection should be in accordance to IEC 61643-12.
- SPD should always show green lifetime indicator. Replace the device when the indicator shows that the device is already in its end of lifetime, which is typically in red colour.

Where and which type of surge protection device to install?



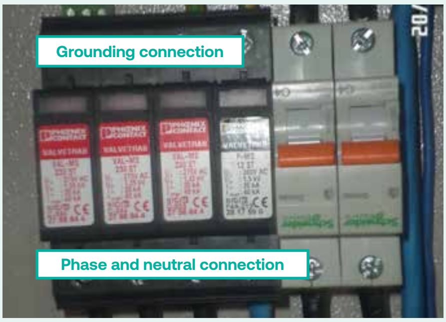
- Install type 1 AC SPD close to the outgoing cable in the AC distribution panel if the distance between inverter and AC distribution panel is not greater than 10 meters (d1 < 10m)
- Install type 2 DC SPD close to the grid inverter (or solar charge controller for DC coupling) if the distance between combiner box and power electronic components is less than 10 meters (d2 < 10 m). Install type 1 DC SPD if the distance between combiner box and power electronic components is greater than 10 meters (d2 > 10 m)
- Install additional type 2 AC SPD close to the inverter, if the distance between grid inverter and AC distribution panel is greater than 10 meters (d1 > 10 m).
- Install additional type 2 SPD close to the combiner box if the distance between combiner box and power electronic components is greater than 10 meters (d2 > 10)

Surge protection devices should be selected properly according to the possible discharge current, voltage protection level, system voltage. Ensure that the maximum continuous operating voltage of the DC SPD is greater than 1.2 times of open circuit voltage of the connected PV array.

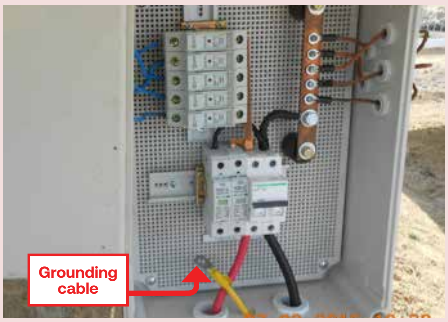
The surge capability of the power line surge protector is not high enough to handle the lightning surge.

Type 2 AC SPD is not sufficient to protect the electrical equipment against lightning surge.

Minimum of type 1 AC SPD should be installed in the AC distribution panel if external lightning protection is installed regardless the separation distance.



Phase, neutral, and grounding cables are properly connected to the surge protection device.



Ungrounded surge protection device. It will omit its function to divert the surge to the ground.

Never left an SPD ungrounded. SPD should be grounded with low resistive path to safely divert the surge current.

How to improve such installation?

- Connect the grounding cable to the SPD. Minimum of 6 mm^2 copper conductor should be used for type 2 SPD and 16 mm^2 copper conductor for type 1 SPD.
- Short circuit protection device such as MCB or fuse should be installed before the surge protection device to avoid interruption in the installation caused by short circuit in the SPD.

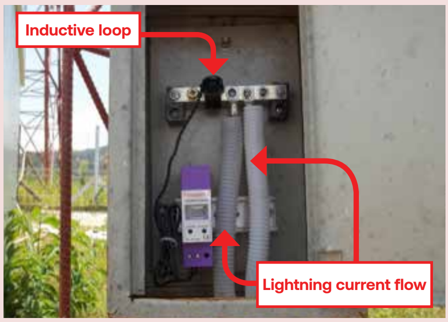
LIGHTNING COUNTER

Lightning counter is installed to measure the lightning flash density in the PV mini-grid site. The data can be used as basis to take additional preventive action to avoid any damage caused by direct or indirect lightning such as replacement of air termination system or surge protection devices.

Battery powered lightning counter is in operation and protected from harsh environment inside the box.

Lightning counter is not protected from direct sun and water exposure.

Inductive sensor from the impulse counter is instlled on the down conductor



Impulse counter is installed at wrong location. The inductive loop should be installed on the down conductor.

AC-powered impulse counter is used. Absence of grid voltage may cause interruption in the monitoring.

Impulse counter is not connected to the grid and no inductive loop is installed.