Installation, Operation & Maintenance of Solar PV Microgrid Systems

A Handbook for Technicians

GSES INDIA global sustainable energy solutions

CLEAN Clean Energy Access Network — Energy off the Grid and of the People

First Edition

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About this Handbook:

This Technicians Handbook for Installation, Operation & Maintenance of Solar PV Microgrid Systems has been compiled with the help of different training materials and resources available in GSES library, reference of relevant IEC, NEC and ANZ standards, and GSES India's in-house expertise and experience.

This handbook is designed to give the skills and knowledge required for installation, operation & maintenance of solar PV microgrid systems. The handbook contains OH& safety aspects of PV systems, basic working principles of solar PV systems, overview and configurations of solar microgrid systems, matrix of system sizing for different load and site specific solar radiation, system Design overview and Safety aspects, complete installation and commissioning procedure of solar microgrid system and operation and maintenance of microgrid system. The handbook also briefly covers commercial and management aspects managing microgrid business.

The main desired outcome of this manual is to integrating skills required to specify appropriate electrical and mechanical components as per international best practices on installation, operation and maintenance of standalone and microgrid PV systems.

We hope that this handbook for technicians will provide solar PV technicians with specialized knowledge of solar photovoltaic standalone and microgrid system that will enhance their existing skills and enable them to take part more actively in the growing solar photovoltaic market.

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CHAPTER 1

1 Working safely with solar PV system

Safety is a full-time job and everyone working with PV systems is responsible for it. To work safely with a PV system one must have:

- Good work habits;
- A clean and orderly work area;
- Proper equipment and training in its use;
- An awareness of potential hazards and how to avoid them;
- Periodic review of safety procedures; and
- Instruction in cardio-pulmonary resuscitation (CPR) and basic first aid.

Prior to any installation or maintenance work of PV system it is necessary to:

- Identify all the possible risks;
- Determine the work practices that will be undertaken to remove the risk, or to minimise the risk if it cannot be removed altogether; and
- Communicate to other colleagues working in that site about these risks and how they will be removed or minimised.

1.1 Potential Risks from solar PV systems

1.1.1 PV Modules

PV modules generate electricity as long as light falls on them. Attempting to cover them, using a blanket or cardboard for example, is not a safe practice. Light could still reach the PV module, or the cover may come off.

In many PV systems, the PV array is in excess of 120V DC. This voltage level is dangerous and any installation or maintenance work must be undertaken with extreme care.

PV modules generally have aluminium frames and are mounted on metal array frames, which are often located on metal roofs. All these metal objects can become very hot during the day and touching these could causes burns on the skin; wear gloves and suitable clothing.

1.1.2 Battery Hazards

Standalone PV systems contain batteries. A large percentage of the batteries are the lead-acid type and the sulphuric acid which is hazardous. Chemical burns will occur if the acid makes contact with an unprotected part of the body - eyes are particularly vulnerable. Anytime you are working around lead-acid batteries you should wear non-absorbent gloves, protective eyewear, and apron.

Even though the total voltage of battery banks in photovoltaic systems may be low, there can be lethal levels of electrical power present.

Never smoke or have open flames or sparks around batteries. As the batteries charge, explosive hydrogen gas is produced. Always make sure battery banks are adequately vented and that a No Smoking sign is posted in a highly visible place.

When measuring the short-circuit current of either the modules or the entire array, be careful not to short circuit the battery bank. An explosion can result. To prevent this, open the battery disconnect switch between the short circuit and the batteries.

Never allow tools to fall onto the terminals or connections. Never allow the construction or use of shelves above the batteries, as objects can fall off the shelves onto the batteries. Battery banks must always be adequately vented.

If the battery bank does not have a disconnect switch, be very careful when removing a wire from right at the batteries. If the batteries are charging, and the hydrogen gas being given off has not been properly vented, it can be ignited by the spark, resulting in an explosion. Make sure the battery enclosure is properly vented.

Batteries are generally heavy. Proper care must be taken when handling and carrying the batteries. Appropriate lifting device should be used while installing the batteries and to shift the batteries from one place to another.

1.1.3 Inverters

Inverters are generally heavy. Care should be taken when carrying an inverter and installing an inverter, particularly if it is to be mounted in a high location. The output of the inverter is 230V or 415V AC, which is potentially a deadly voltage.

1.1.4 Insects, snakes, and other vermin

Spiders, wasps, and other insects often move in and inhabit junction boxes in PV systems. Some wasp build nest in the array framing. Rattlesnake uses the shades provide by the array and fire ants are commonly found under arrays or near battery storage boxes. Always be prepared for the unexpected when you open the junction box. Look carefully before you crawl under the array. It may sound funny, but fire ants or black widow spiders (let alone rattlesnake) can cause painful injury.

1.2 Safety Equipment

Following is a list of recommended safety equipment that you should have available. Check these items against a site safety plan and check to make sure all equipment is in working order before beginning a job.

1.2.1 Personal Safety Resources

- A work partner (never work alone!)
- An understanding of safety practices, equipment, and emergency procedures
- Safety checklists
- Safety helmets & eye protection
- Battery safety accessories
- Appropriate safety harnesses, if working on elevated sites
- Proper measuring equipment: electrical and dimensional
- Tape and use wire nuts or cable connectors on end of cables

1.2.2 Site Safety Resources

- First-aid kit
- Fire extinguisher
- Appropriate ladders
- Appropriate lifting equipment
- Safety goggles, apron, gloves
- Use suitable labels on all equipment’s, wiring, etc.
- Remove all jewelry that might come in contact with electrical components
- Do not wear loose clothing or have loose hair

CHAPTER 2

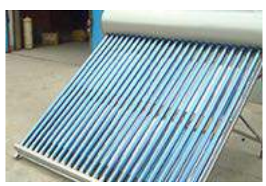
2 Overview of solar microgrid system

2.1 What is solar energy?

Solar power is energy from the sun and is a form of renewable energy. It will never be exhausted and can be used again and again at free of cost. A simple example of the Sun's power can be seen by using a magnifying glass to focus the Sun's rays on a piece of paper which burns it easily.

There are many different ways of harnessing solar energy. The most commonly available technologies are:

Solar Photovoltaic (PV) Systems



Solar Hot Water Systems

Concentrated Solar Power (CSP)

Passive Solar Design

Solar Photovoltaic (PV) Systems:
Solar PV systems directly convert sunlight into electricity. There are two types of solar PV systems exists. Standalone or off-grid PV systems and grid connected or on-grid PV systems. Standalone systems are generally smaller in size and distributed.




Examples of Standalone PV systems: solar water pumping system, street lighting, rural micro grid and solar home system

Grid connected PV systems can be small distributed systems installed in building rooftops or ground and connected at 230V or 440V grid. Large utility scale PV projects are generally connected to grid substation at a voltage level of 11KV or higher.

Examples of grid connected PV systems: Rooftop distributed systems and MW scale project

Solar Hot Water Systems:

Solar hot water is one of the most common applications to use solar energy. Solar energy is used to heat water through a "flat plate solar collector" or "evacuated tube collector". Solar collectors should not be confused with solar modules which produce electricity.

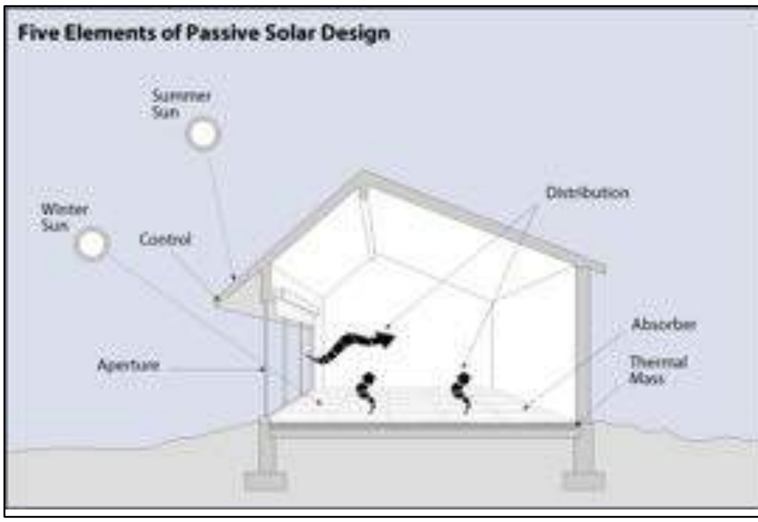
Concentrated Solar Power (CSP)

CSP is a centralized form of solar thermal power that uses sunlight to make steam and then uses this steam to supply heat or drive a turbine to make electricity. CSP uses large mirrors to concentrate the Sun's rays towards a central point which is normally transparent tube carrying water. This concentrated energy is used to boil water and create steam, which can be directly used for heating/ cooking, or to drive a steam turbine and create electricity. In order that the concentrators work effectively throughout the day, tracking systems are used to track the concentrators.

Parabolic Dish | Parabolic Trough | Power Tower

Passive Solar Design

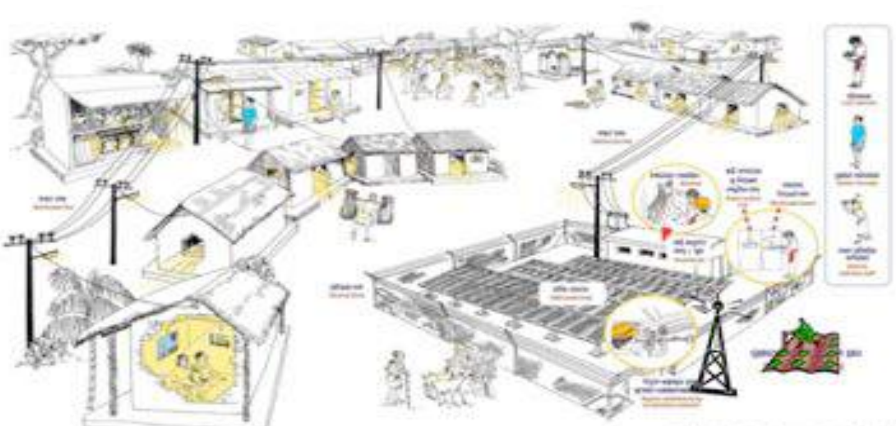
Passive solar design refers to designing a building in order to utilize the sun's energy as intelligently as possible. Techniques will vary significantly throughout the world; however the central idea is to keep the sun's rays out of the house in the summer and to trap the sun's rays inside the house during winter



- Lower energy needs
- Cool in summer
- Warm in winter
- Orientation
- Window sizes
- Insulation
- Site specific

2.2 What is a Solar Microgrid System?

A solar microgrid is a small-scale solar powered grid that can operate independently to supply energy for limited number of consumers in a village or a hamlet. A solar microgrid generally consist of a solar PV array, a battery bank, charge controller or control system, inverter (in case of AC supply), cables for power distribution and safety devices.



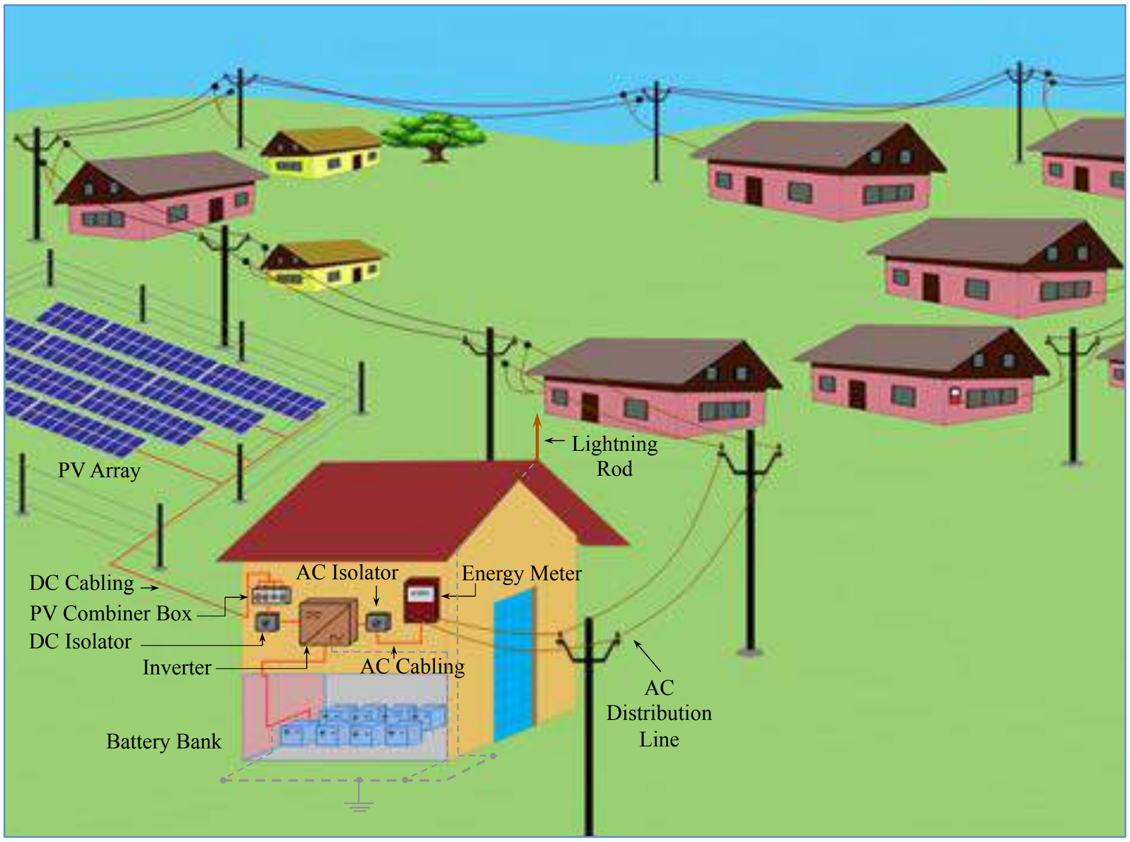
Picture Courtesy: Bush Light

Size of a microgrid system depends on the number of consumers and corresponding energy demands. Capacity of a microgrid system can be as small as 100W to supply basic lighting load for few adjacent households or even more than 100kW to supply residential and commercial load in a village.

The IEC62257 Part 9-1:2008: Micropower systems technical specifications covers low-voltage AC, three-phase or single-phase, with rated capacity of the power plant at the electrical output less than, or equal to, 100kVA.

The voltage levels covered under this IEC technical specification are:

(i) Low Voltage (LV) AC systems at voltage level of 120-240V single phase /208-415V three phase at 50Hz or 60Hz
(ii) Extra low voltage IELV) DC systems less than 120V DC



A conceptual schematic of solar microgrid system

2.3 Components of a solar microgrid system

PV Module – variations on size/wattages

PV modules are the device that captures the Sun's energy and converts it into electricity. There are a wide variety of modules available today which differ in the type of silicon used, the manufacturing process, and the product quality. The vast majorities of commercially available PV modules are made from silicon and differentiate into the three main varieties; mono-crystalline, polycrystalline and thin-film solar cells. The different types of PV module vary significantly by cost, efficiency and appearance. The choice is highly dependent on the application, however the most important thing is to ensure that they are compliant to the relevant codes and standards as will be discussed.

Rated Capacity at STC (Wp)	I_{sc}	I_{mp}	V_{oc}	V_{mp}	Length (mm)	Width (mm)	Weight (kg)
50Wp	3.04	2.8	21.77	17.89	608	666	4.6
100Wp	6.11	5.57	21.84	17.99	1152	666	8
200Wp	8.1	7.48	32.65	26.74	1486	982	15.5
250Wp	8.71	8.18	37.55	30.58	1639	982	17.45
300Wp	8.74	8.05	45.1	37.28	1956	992	27


PV Modules


Storage Battery


Inverter & Electronics

Charge Controller


Solar Array Mounting System


Cables & Connectors

Battery storage – type and classifications

In a standalone PV system, battery storage is required if electrical loads are required to operate at night time, or during extended periods of cloudy or overcast weather when the PV array by itself cannot supply enough power. The primary functions of a storage battery in a PV system are:

(i) Energy Storage Capacity and Autonomy

(ii) Voltage and Current Stabilization

(iii) Supply Surge Currents

The number of days the battery storage capacity is available to operate the electrical loads directly from the battery, without any energy input from the PV array is called days of "autonomy" in a standalone PV system. For common, less critical PV applications, autonomy periods are typically designed for between two and six days. For critical applications involving essential loads or public safety autonomy periods may be greater than ten days.

In general, electrical storage batteries are broadly classified as Primary and Secondary Batteries. Primary batteries are not used in PV systems because they cannot be recharged. A secondary battery can store and deliver electrical energy, and can also be recharged by passing a current through it in an opposite direction to the discharge current.

		
Flooded Electrolyte LA battery	VRLA battery	Lithium Ion battery

The batteries that are commercially available and viable for use in photovoltaic system include:

- Flooded Lead Acid Batteries
- Valve Regulated Lead Acid (VRLA) Batteries
- Nickel Cadmium (NiCd)
- Nickel metal Hydride (NiMH)
- Lithium Ion (Li-ion)

There are several types of lead-acid batteries manufactured. The following sections describe the types of lead-acid batteries commonly used in PV systems.

Flooded Lead-Acid Batteries
Flooded lead-acid batteries are the most common lead-acid batteries. They contain vents which allow the resulting hydrogen gas from electrolysis escape. As a result, the electrolyte level will fall over a period of time, and must be monitored and topped up with water, preferably demineralised water.

The hydrogen gas produced is highly flammable. Care must be taken to ensure that there is adequate ventilation above and around flooded batteries.

Valve Regulated Lead-Acid (VRLA)

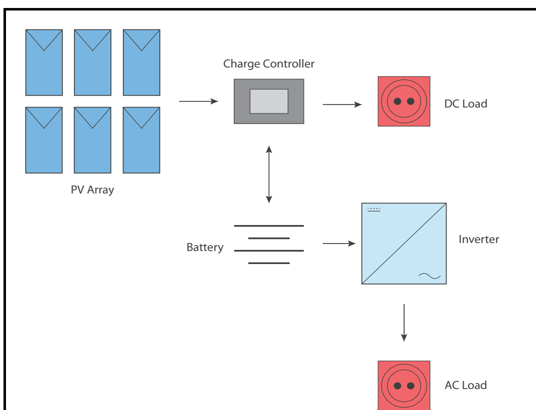
Valve regulated lead acid (VRLA) batteries are also known as captive electrolyte batteries and as the name implies, the electrolyte is immobilized in some manner and the battery is sealed under normal operating conditions. Under excessive overcharge, the normally sealed vents open under gas pressure through a pressure regulating mechanism. Electrolyte cannot be replenished in these battery designs; therefore they are intolerant of excessive overcharge. VRLA batteries are available in two different technologies: **Absorbed Glass Mat (AGM)** and **Gelled Electrolyte**.

Lithium Ion Batteries

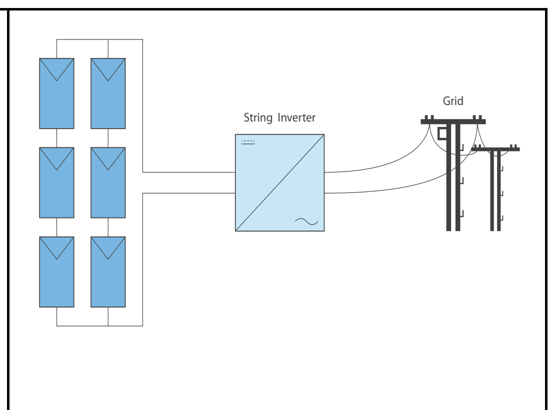
Lithium ion batteries are an emerging technology and have a number of advantages over other batteries, especially lead acid batteries. They are generally smaller and lighter for the same capacity, are faster at charging, and are less susceptible to degradation due to charging and discharging. However, lithium ion batteries have a very high up-front cost and they can be sensitive to extreme temperature and voltages.

Inverters & other electronic equipment

The photovoltaic array and battery produce DC current and voltage. The purpose of an inverter is to convert the DC electricity into a form suitable for AC electrical appliances and/or exportable to the AC grid. The typical low voltage (LV) supply into a domestic dwelling or small commercial building will be either 230V AC single phase or 415V AC three phase. Higher voltages may be supplied to larger commercial buildings which will then have transformers for stepping down to 230V or 415V.



Standalone PV System with inverter



Grid Connect PV System with inverter

Stand-alone inverters, or off-grid inverters, are very different from grid-connected inverters. Stand-alone inverters do not include the same MPPT function as grid-connected inverters because in stand-alone systems, the PV array is not usually connected to the inverter but is wired through a system controller to the batteries as shown in Figure above.

The inverter in a stand-alone power system takes its power from the batteries to supply the AC circuit(s). The system controller (voltage regulator) itself can be a MPPT. The advantage of the MPPT controller is to optimise the battery charging. This function has no impact on whether the inverter itself will supply power to any AC circuits. Stand-alone inverters are typically voltage-specific, i.e. they are manufactured to operate from a specific nominal battery voltage e.g. 12V, 24V, 48V or 120V DC.

In a grid-connected PV system, the PV array is directly connected to the grid-connected inverter. The grid-connected inverter is the device which delivers the solar power to the AC power grid. The PV array is configured so that it operates within specific range of DC voltages to suit the grid-connected inverter's specifications. The inverter will convert the solar DC power to an AC sine wave that matches the AC supply in voltage and frequency to which it is connected.
Grid-connected inverters cannot independently produce a grid equivalent AC sine wave: the inverter must see and reference the grid to be able to operate. If the AC grid is not present, the inverter will simply not function.

Charge controller
Battery charge regulation and control of the energy produced by the PV array is a critical function in PV systems. The most important functions of battery charge regulators and system controls are listed below.

(i) Prevent Battery Overcharge
(ii) Prevent Battery Over discharge
(iii) Provide Load Control Functions
(iv) Provide Status Information to System Users/Operators
(v) Interface and Control Backup
(vi) Energy Sources
(vii) Divert PV Energy to an Auxiliary Load
(viii) Serve as a Wiring Centre

Balance of Systems Equipment

In addition to the PV modules, battery, inverter and charge controller there are other components required in a solar PV microgrid system; these components are referred to as Balance of Systems (BoS) equipment.

BoS equipment includes:

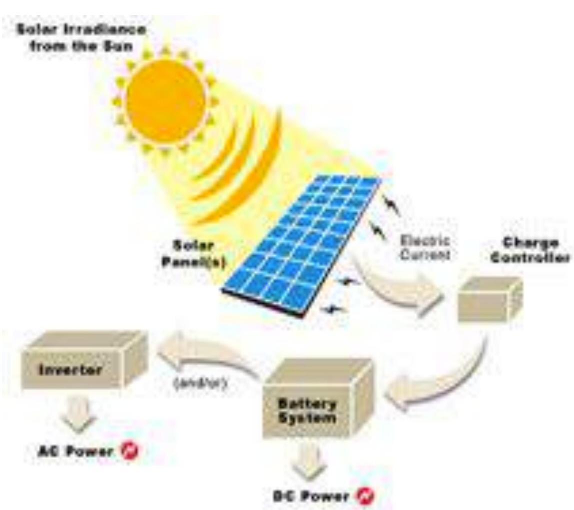
- **Solar Array Mounting System:** The equipment used to safely secure the PV modules to the mounting surface or ground.
- **Cabling**: Both DC and AC cabling is required to connect components.
- **Array Junction Box:** This may or may not be required depending on the PV array; it is used to combine the different array strings.
- **Protection and Disconnect Switches:** These components ensure the safety of the system.
- **Lightning Protection:** May or may not be required (depending on criteria in IEC62305-2/IEC 62305-3) to protect the system from lighting strikes.
- **Metering:** Measures the quantity of electricity generated by solar or quantity of electricity consumed by a customer.
- **System Monitoring:** Shows the system owner exactly how much electricity their system is producing and can be helpful in detecting a problem within the system.
- **Signage:** PV systems installed requires various signs to ensure safety.

CHAPTER 3

3 How solar system works?

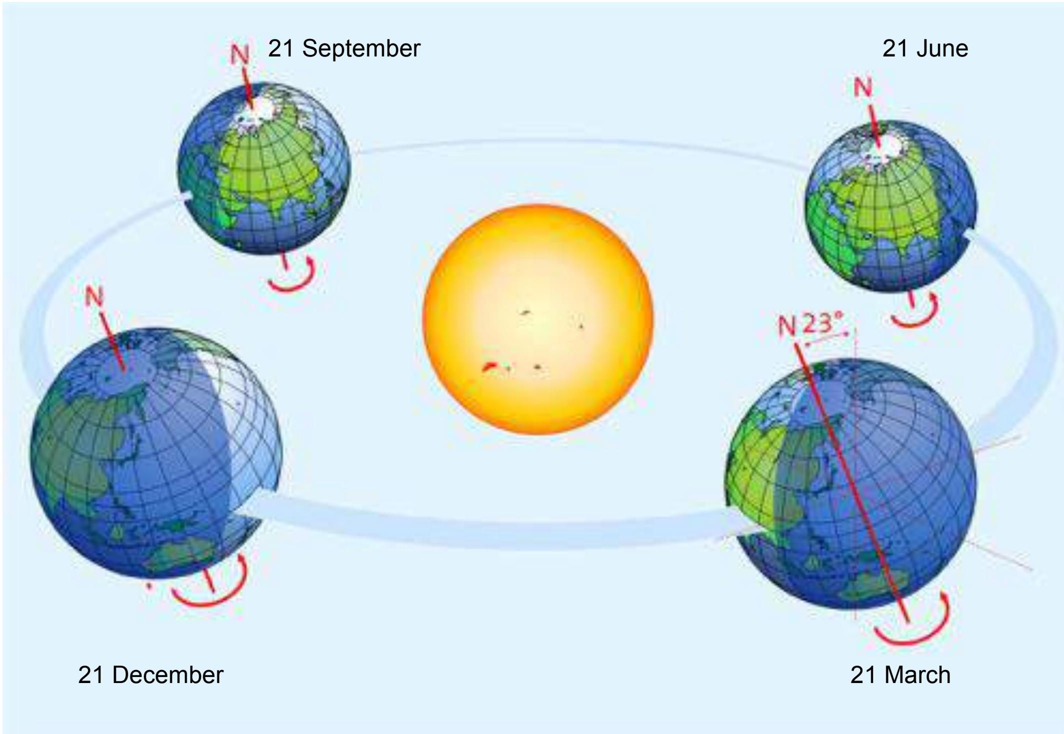
A PV module's performance is directly related to the amount of sunlight it receives. If a PV module is shaded, even partially, its performance will be very poor. PV modules should never be installed in a location, where they will be shaded all the time as they will produce little to no power and prolonged shading can damage the module. On overcast days as well as on sunny days, PV modules will not perform because the clouds reduce the amount of sunlight hitting the modules.

The solar panel converts sunlight into direct current ("DC") electricity. This DC electricity is used to charge a battery through a charge controller. The inverter converts that "DC" power from the solar panel or battery into alternating current or "AC" power. AC power output from inverter can be used to operate light, fan, TV, computer etc. It is also possible to operate DC loads like DC lights, DC pump, computer, mobile charger, etc. directly from the solar panel or battery.



3.1 Movement of Sun across the sky

On 21st June the Sun reaches highest position in the northern hemisphere sky and on the 21st December the Sun position is lowest in the sky. In the summer season the days are long and the Sun is high in the sky. The days during summer are longer than the days during the winter season.



Seasonal variation of solar radiation due to earth's movement

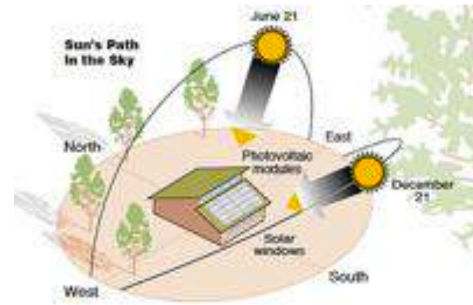
3.2 Geometric Effect

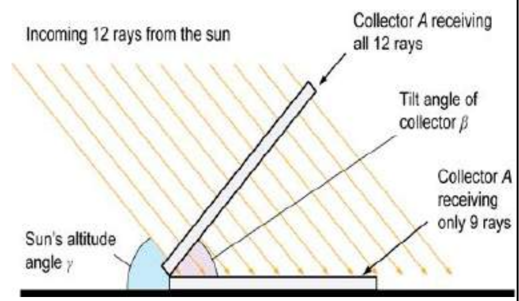
The direction that a solar panel faces is referred to as its orientation. The orientation of the solar array is very important as it affects the amount of sunlight hitting the array and hence the amount of power the array will produce. The orientation generally includes the direction the solar module is facing (i.e. due south) and the tilt angle which is the angle between the base of the solar panel and the horizontal. The amount of sunlight hitting the array also varies with the time of day because of the sun's movement across the sky.

Picture shows a flat plate collector having an area, A, of 1 m^2 tilted at an angle, β, from the horizontal and is perpendicular to the incoming radiation. At some time during the day, there are 12 "rays" of the sun's beam coming from an altitude angle, denoted γ (gamma), that strike the collector at this position.

Solar radiation available at a particular location keeps changing during the day and also during the year. Amount of solar radiation received by a solar array is not same during all the time of the day and it is also not the same in different months of a year.

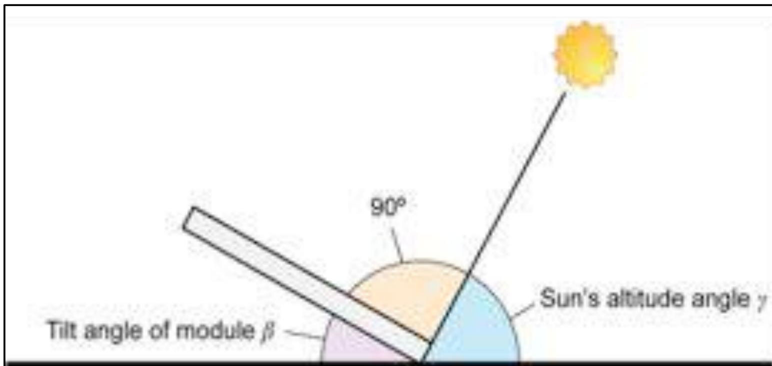
Solar modules should be installed so that as much radiation is collected as possible. Ideally, the solar modules should be tilted at an angle to the horizontal (β°) as shown, facing true south (if installed in the northern hemisphere) such that there is 90 degrees between the sun (at solar noon) and the solar module.





3.3 Tilt Angles

Solar modules should be installed so that as much radiation as possible is collected. Ideally the solar modules should be tilted at an angle to the horizontal (β°) as shown, facing true south (if installed in the northern hemisphere such that there is 90 degrees between the sun (at solar noon) and the solar module. To have a module face directly towards the sun at all times would require a solar tracking frame to be installed. This can be expensive, so it is not common practice for most PV applications.



The ideal tilt angle for a solar module, the orange segment shows 90° between the direct sunrays and the module's tilt angle

To have a module face directly towards the sun at all times would require a solar tracking frame to be installed. This can be expensive, so it is not common practice for most PV applications.

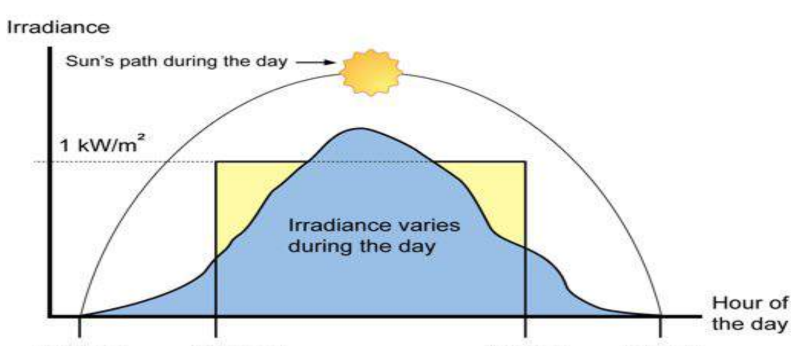
Modules mounted on a fixed structure should be tilted up from the horizontal. The correct tilt angle varies with the times of year the system is used, and the latitude of the site.

The tilt should be within 10 degrees of the listed angle. For example, a system used throughout the year at a latitude of 25° can have a tilt angle of 15° to 35° without a noticeable decrease in annual performance.

3.4 Peak Sun Hour

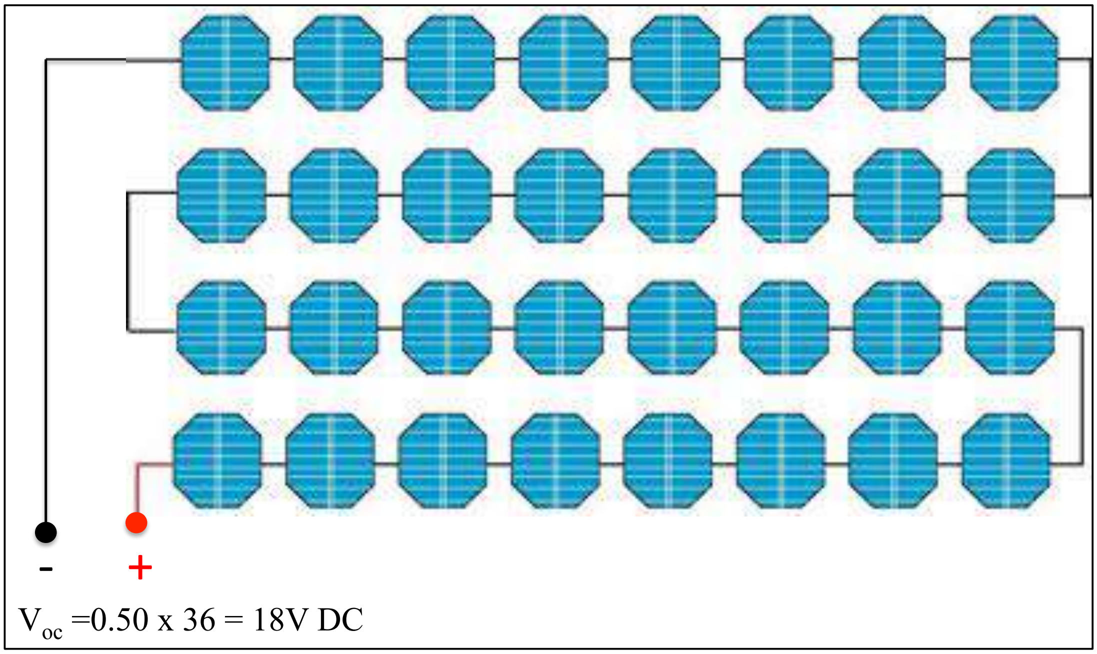
In solar PV system design practice, the average daily solar insolation in units of $kWh/m^2/day$ is referred to as "peak sun hours". Since the peak solar radiation is $1kW/m^2$, the number of peak sun hours is numerically identical to the average daily solar insolation. For example, a location that receives $5kWh/m^2$ per day can be said to have received 5hours of sun per day at $1kW/m^2$. This helps to calculate energy generation from a PV power plant as PV modules are rated at an input rating of $1kW/m^2$.

- Solar energy available in a given location is expressed as kWh/m2/day. This is commonly referred as Peak Sun Hours (PSH).
- For example, if solar radiation for a particular location is 5kWh/m2/day then PSH for that location will be 5 hours.
- Now, if you install 1kW solar panel on that location, it will produce 1kW **x** 5h = 5kWh energy per day without considering any losses.



3.5 Operations of a PV Module

A typical silicon solar cell produce only about 0.5 volt. A solar module is basic building block of any solar system where multiple cells are connected in series. Usually 36 solar cells are connected together to give a voltage of about 17V, which is enough to charge 12V battery. Similarly, a 72 cells module produces about 34V, which can be used to charge a 24V battery.



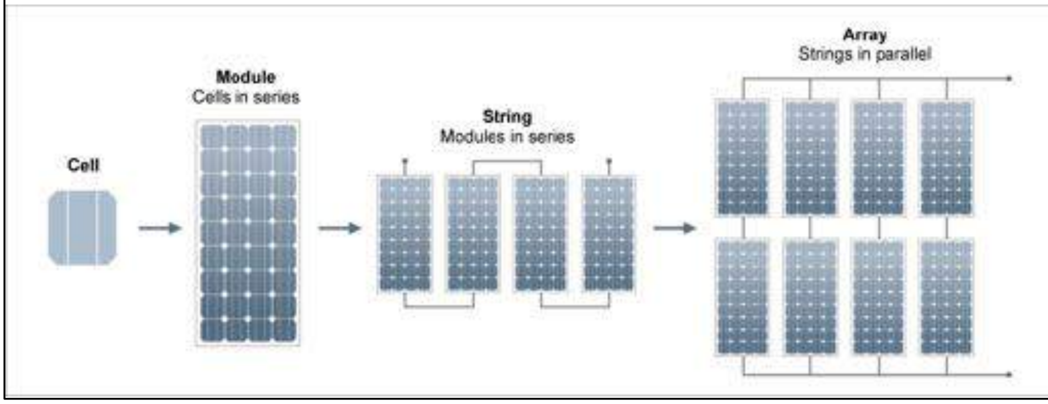
Cells are connected in series to make a PV module

In many applications the power available from one module is inadequate for the load. Individual modules can be connected in series, parallel, or both to increase either output voltage or current. This also increases the output power. When a number of modules are connected in series, it is called a PV string. Voltage of a string is addition of voltages of individual module. If 10 modules of 34V are connected to make one string, voltage of the string will be 340V.

When modules or PV strings are connected in parallel, the current increases. For example, three modules which produce 34V and 5A, connected in parallel, will produce 34V and 15A. If three PV strings of 340V are connected in parallel, will produce 340V and 15A.

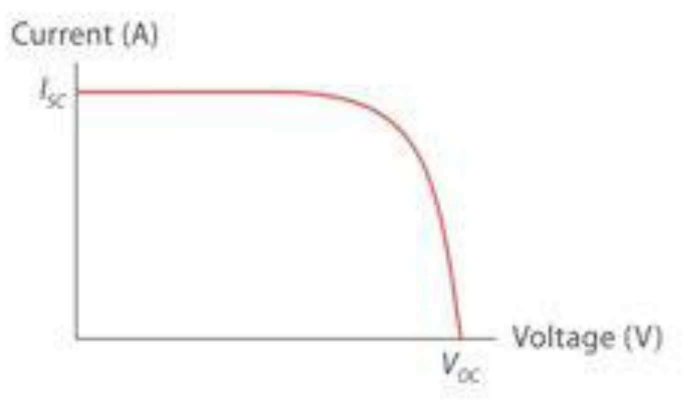
The collective of multiple strings connected in parallel for greater power is called PV Array.

- A typical silicon solar cell produce only about 0.5 volt.
- 36 solar cells are connected in series to make a 17V module.
- A PV string is made with multiple modules connected in series.
- Multiple strings are connected in parallel to make a Solar Array.



3.5.1 PV Module I-V Characteristics

I-V curve represents a 'snap-shot' of all the potential combinations of current and voltage possible from a module under specified environmental conditions. Every solar cell has a characteristic I-V curve, where I_{SC} and V_{OC} are quoted to help characterize a cell.



Current-voltage characteristics of a solar cell

Short Circuit Current (I_{sc}):
A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current (I_{sc}). When the module is shorted, the voltage in the circuit is zero.

Open Circuit Voltage (V_{oc}):
The maximum voltage in a PV module is produced when there is a break in the circuit. This is called the open circuit voltage (V_{oc}). Under this condition the resistance is infinitely high and there is no current, since the circuit is incomplete.

Maximum Power (P_{max}):
The power available from a photovoltaic module at any point along the curve is expressed in watts (W). Watts are calculated by multiplying the voltage times the current (W = VA). At the short circuit current point, the power output is zero, since the voltage is zero. At the open circuit voltage point, the power output is also zero, since the current is zero. There is a point on the "knee" of the curve where the maximum power output is located. Maximum power (P_{max}) is the product of current at maximum power times the voltage at maximum power.

$$P_{max} = I_{mp} \, x \, V_{mp}$$

Current at Maximum Power (I_{mp}):
The current that results in maximum power under given conditions of light and temperature, used as the "rated" current of a device. This value occurs at the "knee" of the I-V curve.

Voltage at Maximum Power (V_{mp}):
The voltage that results in maximum power under given conditions of light and temperature, used as the "rated" current of a device and to determine how many cells or modules are needed to match a load voltage requirement. This value occurs at the "knee" of the I-V curve.

3.5.2 Module Energy Output

For a specific load, PV module output depends on the following factors:

- Irradiance or light intensity
- Temperature

Solar irradiance directly affects the module energy output. If light falling on a solar module increases twice, it will produce twice as much current. The open circuit voltage does not change dramatically with irradiance; however it increases slightly with higher irradiance. This is why modules should be completely unshaded during operation. A shadow across a module can almost stop electricity production.

Module temperature affects the output voltage inversely. Higher module temperatures will reduce the voltage by 0.04V/°C to 0.1V/°C, for every one degree centigrade rise in temperature.

This is why the modules should be installed in such way that there is enough air circulation in the back of each module, so that its temperature does not rise and reducing its output. An air space of 4 – 6 inches is usually required to provide proper ventilation.

Standard Test Conditions (STC):
The specifications in manufacturers' data sheets are all determined using standard test conditions (STC) which are considered as below:

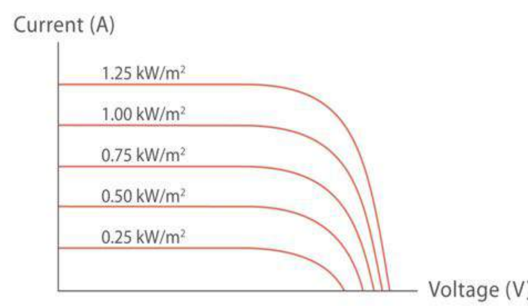
- Cell Temperature 25°C
- Irradiance of 1000 W/m^2
- Air Mass of 1.5

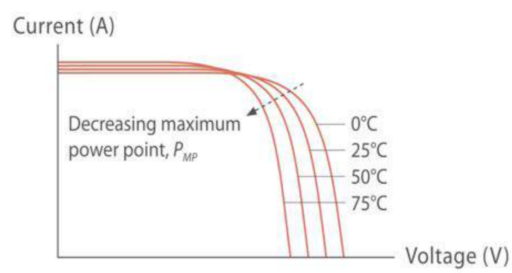
For a specific load, PV module output depends on two major factors:

- Irradiance or light intensity
- Temperature

The higher the solar radiation it receives, the higher is the current a module will produce. The voltage will remain the same.

As the temperature of a solar cell increases, the open circuit voltage V_{oc} decreases but the short circuit current I_{sc} increases marginally.





Example:
On a clear sunny day a 1kWp PV array received 6 Peak Sun Hours. Expected output can be determined as follows:

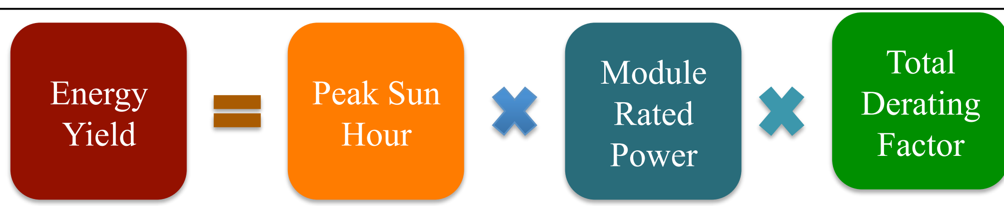
Peak Power Output x Peak Sun Hours = Expected Output
1kW x 6PSH = 6kWh

The calculation above shows the maximum theoretical energy output, which will never be produced in a real PV system. The actual output would be a lot lower than calculated because of inefficiencies of and losses in the PV system (known as derating factors). Losses in a solar PV system arise from weather factors, site constraints and voltage drop.

A summary of typical losses is provided in the following table. Estimated loss for a solar microgrid system depends on system design, component selection and site operating temperature and normally total loss is around 30%.

Cause of loss	*Estimated Loss (%)	De-rating Factor
Temperature	10%	0.90
Dirt	3%	0.97
Manufacturer's Tolerance	3%	0.97
Shading	2%	0.95
Orientation	0%	1.00
Tilt Angle	1%	0.99
Voltage Drop	2%	0.98
Inverter	5%	0.95
Loss due to irradiance level	3%	0.97
Distribution & transmission	2%	0.98
Total de-rating factor (multiplying all de-rating factors)		0.70

** Typical losses in PV systems. Actual loss will be as per site conditions*



Example:

On a clear and a sunny day, a 1kWp PV array received 6 Peak Sun Hours. Expected output can be determined as follows:

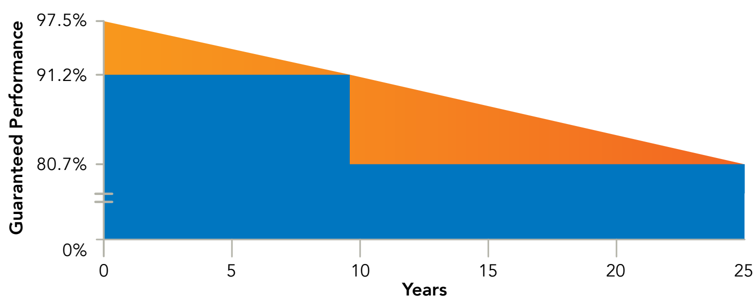
Expected Output = Peak Sun Hours **x** Peak Power Output **x** Total derating factor

= 1kWp **x** 6 **x** 70%

= 4.2kWh

Performance degradation over life cycle:

The performance of a PV module will decrease over time. The degradation rate is typically higher in the first year upon initial exposure to light and then stabilizes. Factors affecting the degree of degradation include the quality of materials used in manufacture, the manufacturing process, the quality of assembly and packaging of the cells into the module, as well as maintenance levels employed at the site. Generally degradation of a good quality module is considered to be about 20% during the module life of 25 years @ 0.7% to 1% per year.



Example of PV module degradation

Example:

On a clear and a sunny day, a 1kWp PV array received 6 Peak Sun Hours (hours). Total loss (de-rating factor) in the system is estimated as 0.70 (70%)

Expected output can be determined as follows:

Expected Output = Peak Sun Hours x Peak Power Output x Total derating factor

= 1kWp x 6 hour/day x 0.70
= 4.2kWh per day (1st year)

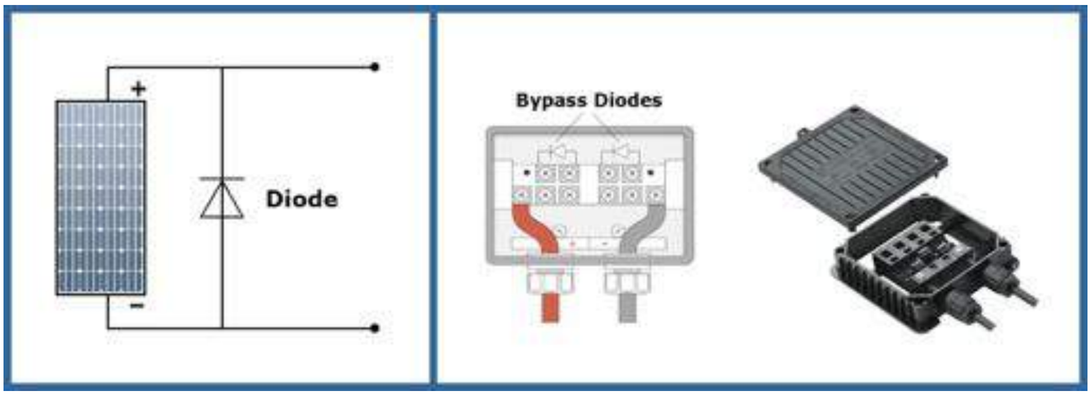
Now considering degradation of module as per the indicative profile above (example only, actual degradation of module will be based on module quality and climatic conditions)

Energy generation:

= 3.83kWh per day (on 10th year)
= 3.39kWh per day (on 25th year)

3.5.3 Bypass Diodes

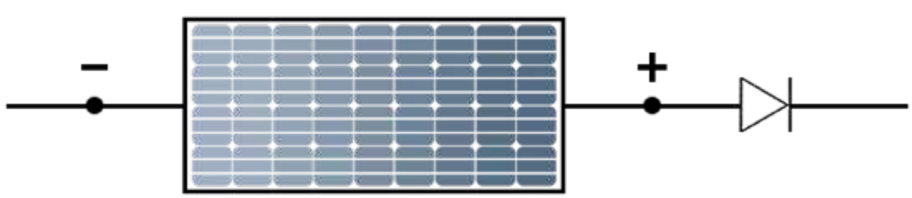
When a cell in photovoltaic module is damaged or a part of module is shaded, the shaded cells will not be able to produce as much current as the unshaded cells. Since all the cells are connected in series, the same amount of current will flow through the damaged or shaded cell that will now act as a resistance and become hot and energy generated in the module will be lost. This is known as 'hotspot' phenomenon. This can be avoided by using a bypass diode in the module in parallel to the output terminal as shown in the diagram below.



3.5.4 Blocking Diodes

During daylight, an array has more voltage potential than the battery, so current flows from the array into the battery. But at night, the module potential drops to zero, and the battery could discharge all night backwards through the module. This would not be harmful to the module, but would result in loss of precious energy from the battery bank. Diodes placed in the circuit between the module and the battery can block any night time leakage flow.

To protect the loss of energy flowing from the battery through the module during night, blocking diodes are used in series.



CHAPTER 4

4 Configurations of solar PV microgrid system

Solar PV microgrid systems are custom designed for their particular situation. The following factors are generally taken into account while determining the system configuration for solar microgrid system.

- Target consumer and type of electrical appliances to be operated
- Load size and daily energy demand
- Time of operation
- Correlation with load on a daily, weekly and seasonal scale
- Installed cost and maintenance costs
- User specific preferences
- Local regulations/ constraints/ benefits
- Photovoltaic only or hybrid generation

The system configuration should be chosen so as to satisfy the design criteria, to make it most cost-effective, efficient, reliable system operation and long life. Economic evaluation of different options, if required, may be carried out on the basis of life cycle costing.

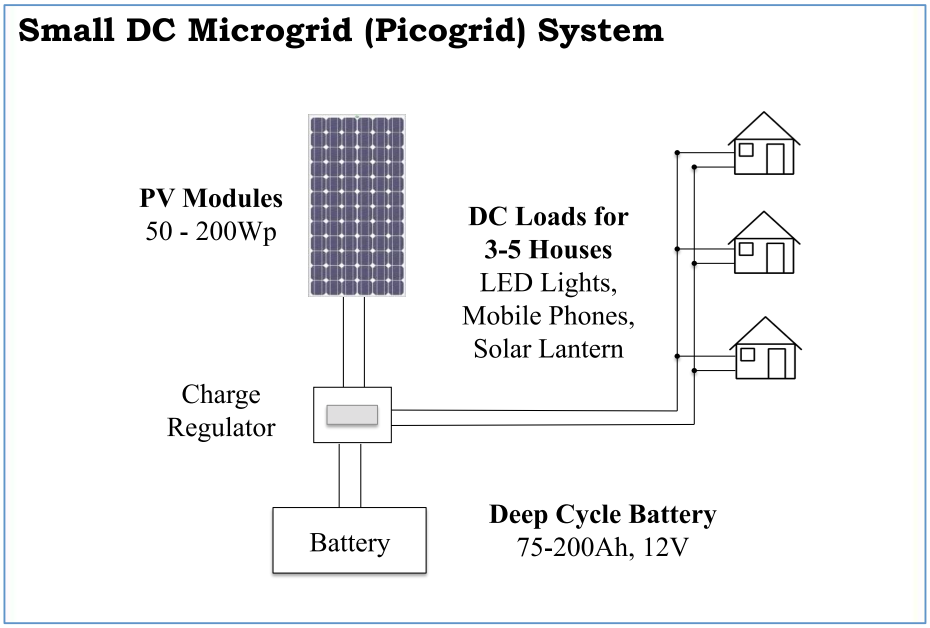
For reference purpose, we can group solar micropower or microgrid system types into five broad categories:

- Small DC microgrid (Pico-grid) system
- Large DC microgrid system
- AC Power microgrid system
- AC – DC combined microgrid system
- PV-Generator hybrid microgrid system

In the following pages typical system configurations are described.

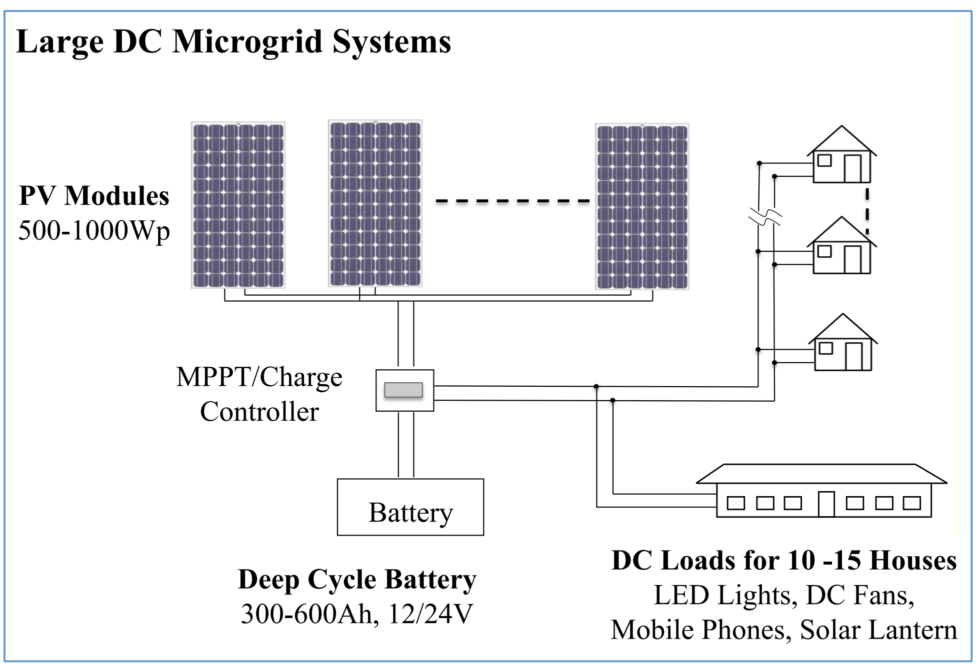
4.1 Small DC microgrid system

This configuration is similar to a solar home system shared by 3-5 houses to meet basic electricity demand for 2-3 LED lighting per house, mobile charging and charging of solar lanterns, etc. Typical battery capacity could be 75-200Ah, 12V and array capacity shall be 50-200Wp based on availability of solar radiation on the site. Generally, a typical charge regulator is used to protect the battery from deep discharge and overcharge.



4.2 Large DC microgrid system

This type of system can be designed by adding more modules and batteries. A large single charge controller or multiple charge controllers would be needed to handle the increased current from the array. If number of loads is more, a DC circuit breaker distribution box could be used. Typical array size of these types of systems may be 500 watts to few kilowatts with nominal system voltage 12, 24 or 48V based on size of the system. Similarly battery bank capacity may be of 300Ah to 600Ah.

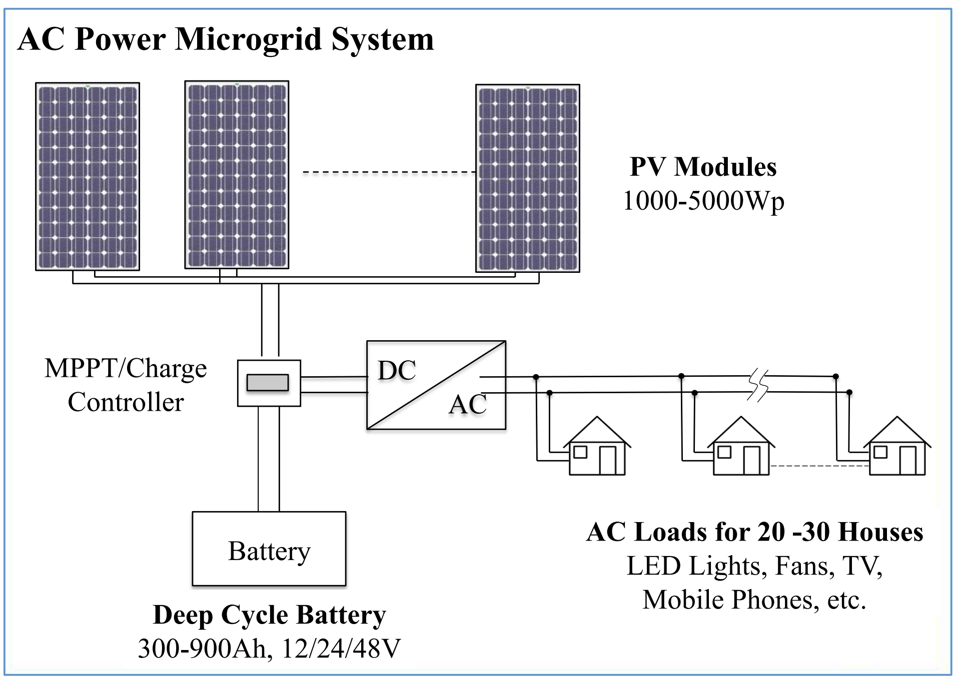


4.3 AC Power microgrid system

AC appliances can be powered by adding a DC-to-AC inverter. In general, system size more than 1000 watts can be designed for standalone AC operation. Depending on the capacity of the system and type of inverter, various types of AC appliances could be operated by this type of system.

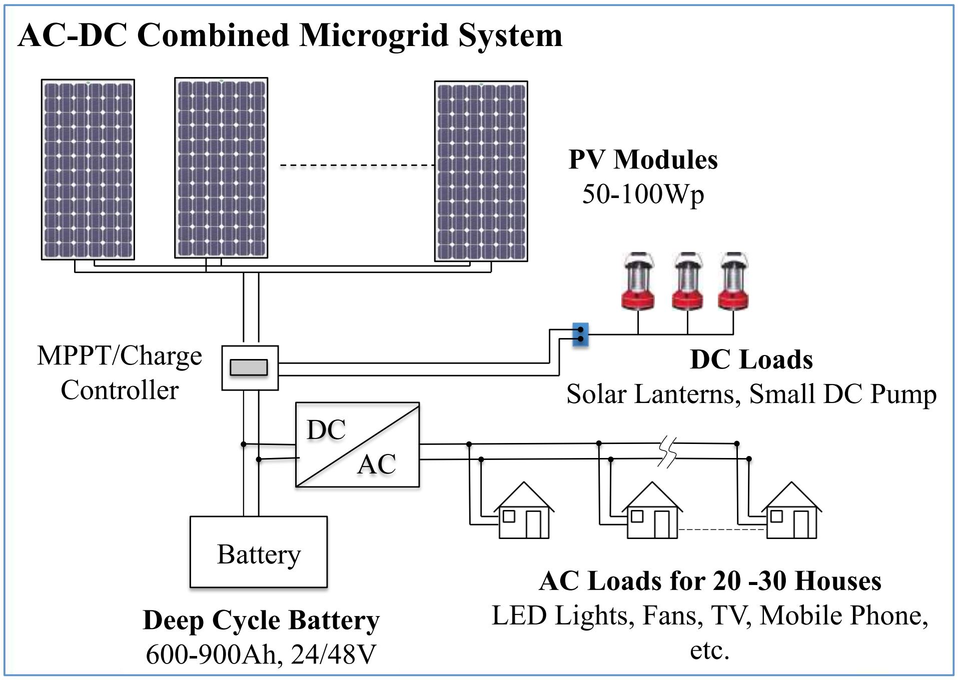
Using an AC standalone system is convenient as most of the electrical and electronic appliances available in the market run on AC. However, care has to be taken, particularly in small system for overloading of the system and inverter, as the users may not be aware of limitation of the system and they may tend to think as conventional AC system and end up discharging the complete battery capacity using the loads continuously or damage the inverter connecting loads of larger than the inverter capacity.

When low quality or inverters with square wave or modified square wave form are used, some electrical or electronic equipment may not function or even get damaged.



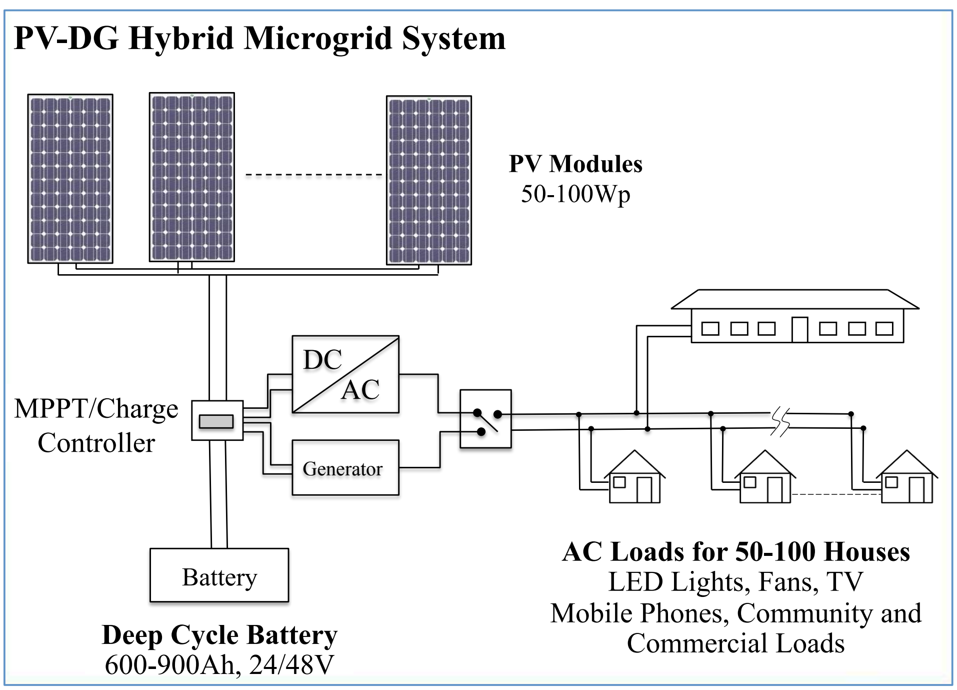
4.4 AC – DC combined microgrid system

Design and operational features of this configuration is similar to the AC power system as mentioned in the previous section. The only additional feature in this configuration is facility to use DC appliances directly from the regulator without going through the inverter. If the user has some DC loads and these are efficient, it is recommended that DC loads be used directly from the DC bus bar. This might reduce the size of the inverter and also increase overall efficiency of the system, as there is no conversion loss for DC loads.



4.5 PV-Generator hybrid microgrid system

Solar microgrid system can be integrated to other renewable energy generator such as wind turbines or micro hydro generator. A common choice is a diesel, kerosene or petrol fuel based generator. By combining a generator, the reliability of solar microgrid system can be assured with availability power during any season or weather condition during the year.



Generator AC power output can be directly connected to AC loads. A transfer switch is needed to prevent generator power from feeding backwards in the inverter. The transfer switch can be electronically operated or a manual change over switch. The generator can also be used to recharge the batteries.

4.6 Connecting microgrid system to grid

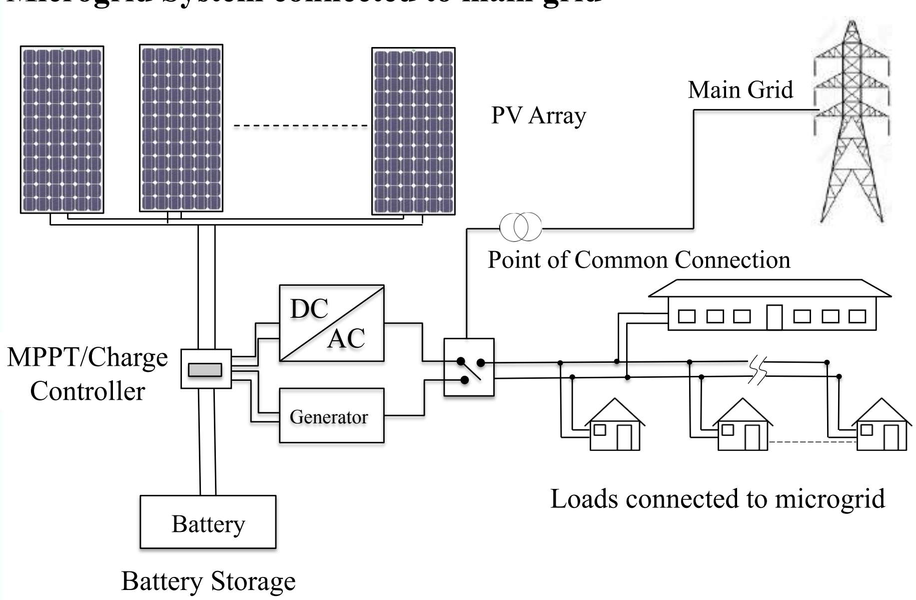
In general, solar microgrid is standalone and installed in such areas where there is no grid. As and when the main grid is extended to these areas, microgrid systems may become obsolete or have less importance due to its limited power generation capacity in comparison to the main grid. The best way to avoid such situation is to make the microgrid systems compatible to interface the main grid. A solar microgrid system can be connected to the main grid through different methods. However, such integration must be as per requirement of local grid code and provision from IEEE1547 need to be followed. Connecting microgrid system to the main grid may provide multiple benefits as below:

(i) Solar microgrids are typically designed with extra capacity to take care of energy demand during the months when solar radiation is low. If microgrid system is connected to the main grid, surplus power can be injected into the grid, which will increase capacity utilization factor of the plant.

(ii) The consumers connected to microgrid system will have more flexibility in use of electrical appliances when microgrid is connected to the main grid.

(iii) Due to availability of grid, battery capacity may be reduced or even removed if grid is reliable.

Microgrid System connected to main grid



CHAPTER 5

5 System Design Overview and Safety Aspects

5.1 Basic Design Principles for Solar Microgrid Systems

Appropriate system design and component sizing is fundamental requirement for reliable operation, better performance, safety and longevity of solar PV based micro grid system. Therefore correct approach towards designing a standalone microgrid PV system is critical.

5.1.1 Design Criteria:

A solar microgrid system is designed based on the following criteria:

- Average daily load demand;
- Maximum and surge power demand;
- System voltage and service (distribution) voltage
- System cost and availability of fund;
- Power quality (for example, waveform quality or continuity of supply);
- Only solar or combination of other backup source (such as diesel/ wind hybrid);
- Use of efficient electrical appliances
- Availability of spare parts and maintenance service;
- Type of control system

Major system parameters for designing solar microgrid systems are:

- Energy supply strategy and how to manage supply of electricity with respect to demand;
- Whether distribution is for DC loads or AC loads
- Maximum and surge demand;
- System voltage;
- Days of autonomy;
- In case of a hybrid system size and optimized run time of generator
- Size or capacity of solar array;
- Size or capacity of battery bank;
- Ratings of major components.

5.1.2 System Voltage:

Distribution system voltage

AC distribution system voltage of a microgrid system is designed for single-phase 230V or three phase 415V at 50Htz frequency.

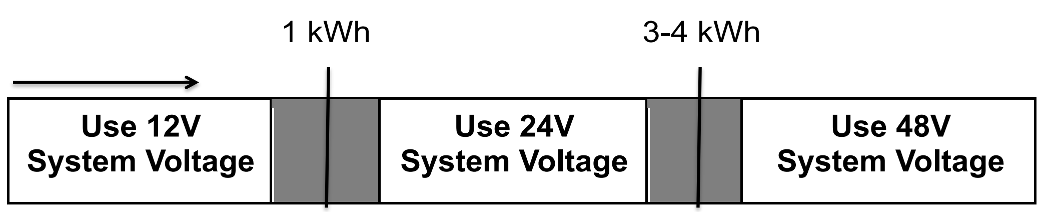
For small DC systems, electricity may be distributed at extra low voltage (ELV) such as 12V, 24V, 48V etc. but it should be lower than 120V DC for safety reason. Actual voltage of DC systems is decided based on size of the system, distance from battery room to load point and availability of DC electrical appliances and control systems.

Solar system (Battery) voltage

Voltage of solar system (battery voltage) may be different from the voltage power distribution system. Voltage level at solar system depends on the system size, battery and solar array capacity and skill level of operating staff at the site. IEC-62257-6 suggests that if the local level skill is relatively low, the system voltage should be of Extra Low Voltage i.e. lower than 120V DC.

Systems of higher capacity (500Wp and above) may use MPPT or AC bus configuration where solar array voltage likely to be higher than 120V DC. Technicians working with voltage level higher than 120V must have appropriate training to work with such system.

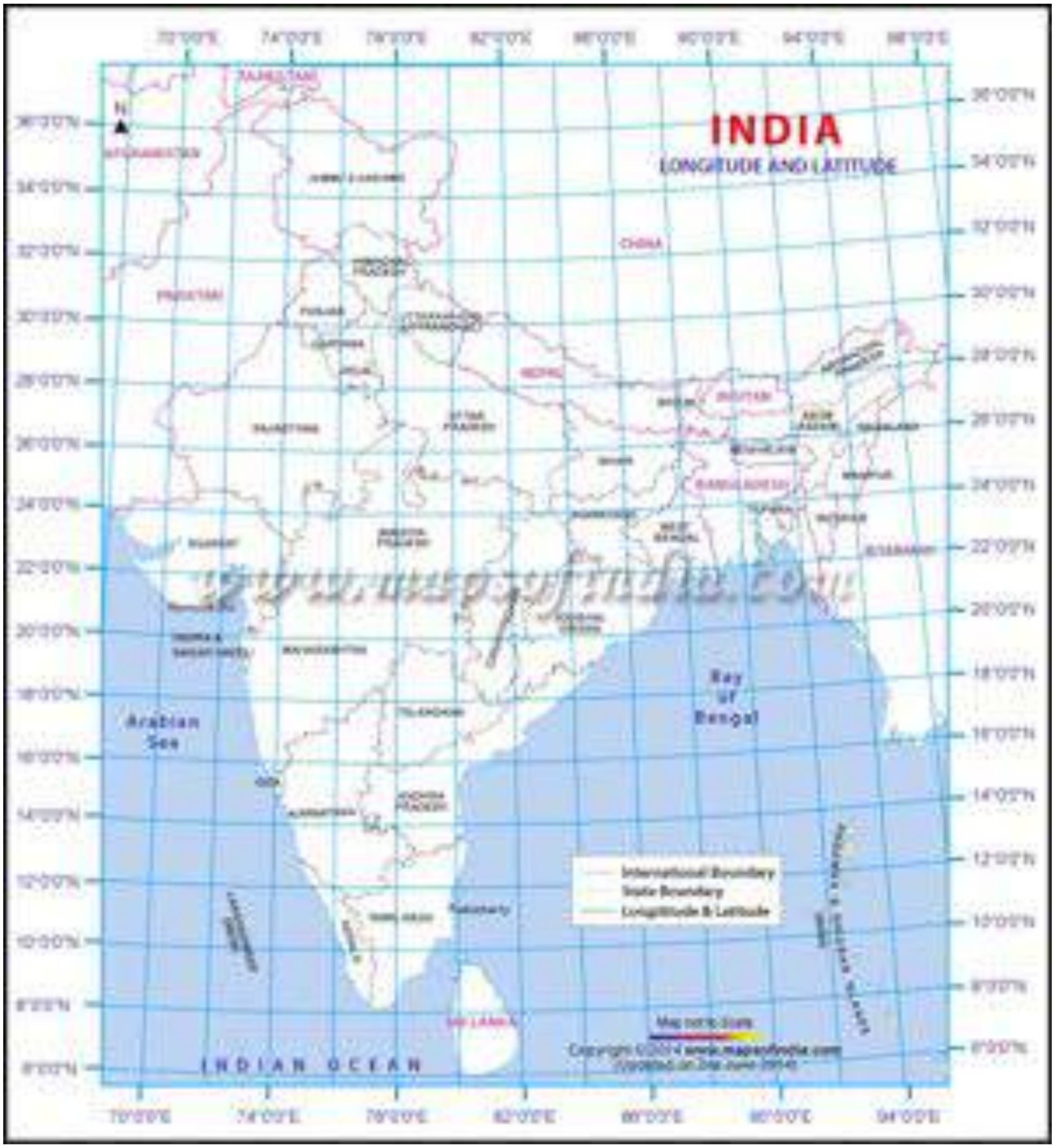
For small microgrid system, solar system voltages are generally 12, 24 or 48 V based on requirement. In larger systems, 120V or 240V DC could be used.



5.1.3 Module tilt angle

For standalone PV system, optimum tilt angle of solar array (panel) is decided based on the latitude of the location. Since India is a large country laying on the latitude of 8°N to 36°N, optimum tilt will be different for different states/ locations. The table below provides rules of thumb to determine optimum tilt angle for any location. It may be noted that slight variation in the tilt angle does not effect on the system.

Latitude	Recommended Tilt Angle		
	No Seasonal Load Variation	Winter	Summer
5° to 25°	Lat to Lat $+5^{\circ}$	Lat $+5^{\circ}$ to Lat $+15^{\circ}$	Lat $- 5^{\circ}$ to Lat$+5^{\circ}$
25° to 45°	Lat $+5^{\circ}$ to Lat $+10^{\circ}$	Lat $+10^{\circ}$ to Lat $+20^{\circ}$	Lat to Lat $+10^{\circ}$



India map with latitude and longitude

A minimum tilt angle of 10° is recommended under any circumstances, to ensure adequate self-cleaning of solar array

Example:

Recommended Tilt angle for different states of India and neighbouring countries

States/location	Latitude	Fixed array	Array with seasonal tilt	
		Recommended Fixed Tilt	Recommended tilt in winter	Recommended tilt in Summer
Jammu &Kashmir, Punjab, Himachal and Uttarakhand	30°N to 36°N	**35 - 40**	**40 - 50**	**30 - 40**
Rajasthan, Haryana, UP, Assam, Arunachal, Nagaland, Nepal & Bhutan	26°N to 30°N	**30 - 35**	**35 - 45**	**25 - 35**
Gujarat, MP, Bihar, Jharkhand, Meghalaya, Mizoram, West Bengal, Manipur, Bangladesh	22°N to 26°N	**25 - 30**	**30 - 35**	**20 - 25**
Maharashtra, Telangana Chhattisgarh, Odisha	18°N to 22°N	**20 - 25**	**25 - 30**	**15 - 20**
North Karnataka, Goa, South Telangana, Andhra Pradesh	14°N to 18°N	**15 - 20**	**20 - 25**	**10 - 15**
South Karnataka, Kerala, Tamilnadu, Pondicherry	10°N to 14°N	**10 -15**	**15 - 20**	**10 - 15**
South Kerala, South Tamilnadu, Sri Lanka	6°N to 12°N	**10 - 15**	**10 - 15**	**10 - 15**

5.1.4 Module orientation

For best output from solar array, the modules must be oriented as close as possible toward the equator. In the Northern Hemisphere, this direction is true south. An array with fixed orientation should be set up to face within ± 20° of true south unless system or site requirements dictate otherwise.

5.2 Determining solar array and battery capacity

Solar array size and capacity of battery storage is determined by the following parameters:

(i) Daily energy demand (connected load and operating time)
(ii) Solar radiation received in the site and
(iii) Days of battery storage autonomy meaning for how many days system will work if there is a cloudy weather.

5.2.1 Capacity of solar array

PV array should be sized to allow full recharge of the batteries from maximum depth of discharge in an acceptable time frame, e.g. 14 days, as well as the capacity to provide an equalizing charge. For microgrid systems without generator backup, solar radiation available in the worst month of the year may be considered for sizing the array capacity. The worst month may be determined by finding the month in which the ratio of renewable generator output to load energy is smallest. The array size should as such that solar energy fraction should be atleast 75%, for satisfactory performance of the plant.

5.2.2 Battery capacity and hours of backup

Batteries should be capable of meeting both the power and energy requirements of the system. For microgrid system without generator backup, minimum autonomy should be kept as 3 days for regular loads. For critical loads autonomy should be more than 3 days based on weather conditions of the particular area. In a hybrid system with generator backup, autonomy of 1-2 days may be considered.

5.2.3 Example of solar array and battery capacity sizing for typical microgrid systems

Configuration 1	Indicative Capacity of Array & Battery	Annual average solar radiation (kWh/m²/day)			
		3.50	4.50	5.50	6.50
No. of households: 3 Connected load: 50Watt Average daily energy demand: 260Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: 2 LED lights/ house, mobile charging and lantern charging in all houses	Battery Voltage (V)	12	12	12	12
	Battery Capacity (Ah)	100	100	100	100
	PV Array capacity (Wp)	100	75	60	50

Configuration 2	Indicative Capacity of Array & Battery	Annual average solar radiation (kWh/m²/day)			
		3.50	4.50	5.50	6.50
No. of households: 5 Connected load: 85Watt Average daily energy demand: 450Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: 2 LED lights/ house, mobile charging and lantern charging in all houses	Battery Voltage (V)	12	12	12	12
	Battery Capacity (Ah)	150	150	150	150
	PV Array capacity (Wp)	175	140	120	100

Configuration 3	Indicative Capacity of Array & Battery	Annual average solar radiation (kWh/m²/day)			
		3.50	4.50	5.50	6.50
No. of households: 10 Connected load: 170Watt Average daily energy demand: 900Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: 2 LED lights/ house, mobile charging and lantern charging in all houses	Battery Voltage (V)	12	12	12	12
	Battery Capacity (Ah)	360	360	360	360
	PV Array capacity (Wp)	400	300	250	200

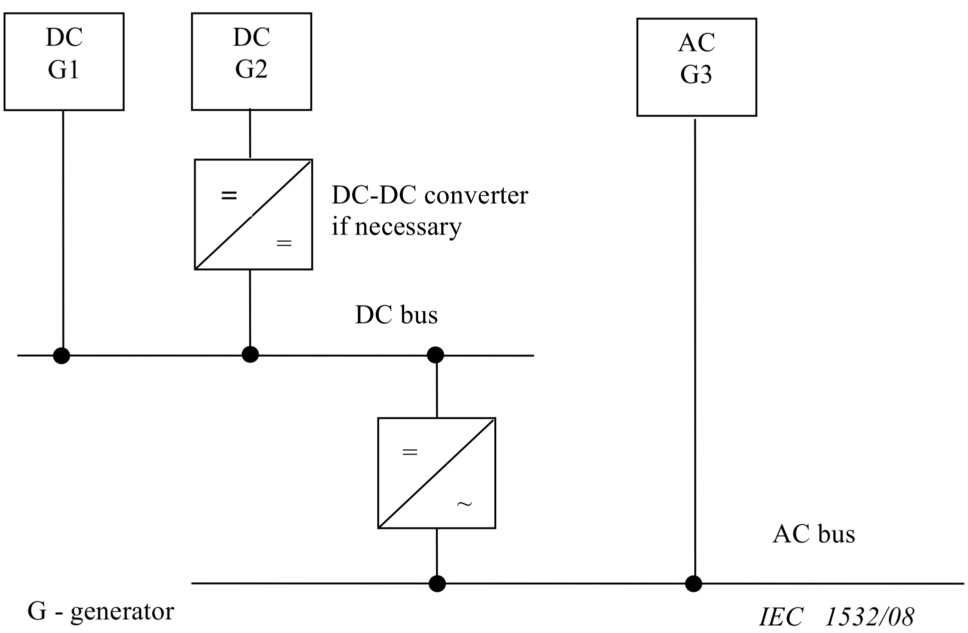
Configuration 4	Indicative Capacity of Array & Battery	Annual average solar radiation (kWh/m²/day)			
		3.50	4.50	5.50	6.50
No. of households: 10 Connected load: 600Watt Average daily energy demand: 3000Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: LED lights, DC fans, mobile & lantern charging, computer and LCD/LED TV	Battery Voltage (V)	24	24	24	24
	Battery Capacity (Ah)	600	600	600	600
	PV Array capacity (Wp)	1300	1000	800	700

Configuration 5	Indicative Capacity of Array & Battery	Annual average solar radiation (kWh/m²/day)			
		3.50	4.50	5.50	6.50
No. of households: 20 Connected load: 1200Watt Average daily energy demand: 6000Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: LED lights, DC fans, mobile & lantern charging, computer and LCD/LED TV	Battery Voltage (V)	48	48	48	48
	Battery Capacity (Ah)	600	600	600	600
	PV Array capacity (Wp)	2600	2000	1650	1400

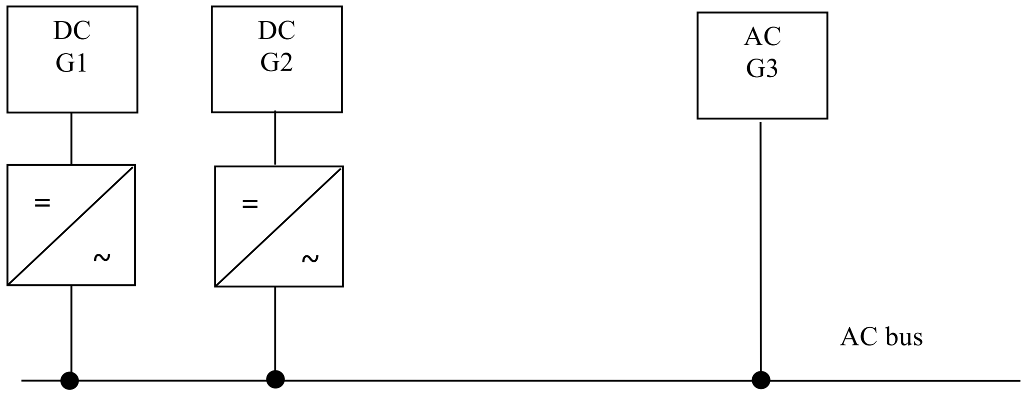
Configuration 6	Indicative Capacity of Array & Battery	Annual average solar radiation ($kWh/m^2/day$)			
		3.50	**4.50**	**5.50**	**6.50**
No. of households: 30 Connected load: 1800Watt Average daily energy demand: 9000Wh/day Days of Autonomy: 3 Over supply co-efficient: 1 Typical loads: LED lights, DC fans, mobile & lantern charging, computer and LCD/LED TV, commercial loads	Battery Voltage (V)	48	48	48	48
	Battery Capacity (Ah)	900	900	900	900
	PV Array capacity (Wp)	3900	3000	2500	2100

5.3 DC Bus and AC Bus

In a hybrid microgrid system, more than one generating devices are used, the system can be configured in a DC bus or AC Bus system. The following figures illustrate hybrid system interconnection in DC Bus and AC Bus system.



Interconnection configuration with DC bus and AC bus



IEC 1533/08

Interconnection configuration with AC bus only

5.4 System Protection and Safety Aspects

5.4.1 Cables & Wiring

Improper wiring of the components can sabotage all the precise calculations in the PV system design. Poor choice of wire size can restrict battery charging and eventually cause system failure.

Proper wiring and design of safe, user-friendly photovoltaic systems are the most overlooked aspect of PV system designs. Adherence to the relevant electrical codes and standards and safe practices will result in reduced hazards associated with electrical installations. Careful design of the wiring subsystem will result in efficient and reliable PV systems that are safely and easily serviced.

Important considerations on cables

- Cable should be selected as per IEC 62548: Design requirements for Photovoltaic (PV) arrays
- Array cables be suitable for DC application,
- String cables shall be UV-resistant,
- Be water resistant,
- Reinforced or double-insulated cables should be used when laid in metallic tray or conduit,
- Cable shall have ability to carry current safely without overheating in specified conditions that cable will be laid/ installed,
- Total voltage drop in all DC cables will be less than 3%
- Total voltage drop in all AC cables will be less than 2%
- Cables are to be laid/ installed in such a way that all connections and wiring should be protected from inadvertent contact and mechanical damage.

5.4.2 PV Array Maximum Voltage

All system protection devices (and cables) must have a voltage rating of at least the 'PV Array Maximum Voltage' of the system. IEC 62548 defines the 'PV Array Maximum Voltage' as the voltage of the array at the lowest expected temperature at the installation site. Since voltage increases as temperature decreases, therefore, array voltage will be its' highest when array is at its coldest temperature. IEC 62548 states two ways in which the PV Array Maximum Voltage can be calculated:

(i) Using the temperature coefficient given by the manufacturer.
(ii) Using the voltage correction factors in given Table 2 in IEC 62548.

Using temperature coefficients:

The PV Array Maximum Voltage can be calculated using the following formula:

$$PV\ Array\ maximum\ Voltage = \mathbf{N}\ \mathbf{x}\ \left\{V_{oc} - \left(\Upsilon_{V_{oc}}\ x\ (T_{min} - T_{STC})\right)\right\}$$

Where:
N = Number of modules in series
V_{oc} = Open circuit voltage of the module at STC, in Volts
$\Upsilon_{V_{oc}}$ = Open circuit voltage coefficient in V/°C (absolute value)
T_{min} = Lowest expected cell temperature in °C
T_{STC} = Stand Test Conditions (STC) temperature, which is 25°C

Using correction factor:

The correction factor needs to be multiplied by the array open circuit voltage.

That is:

$$PV\ Array\ maximum\ Voltage = \mathbf{V_{CF}}\ \mathbf{x}\ (N\ x\ V_{oc})$$

Where,

V_{CF} = The voltage correction factor from Table 2 in IEC 62548
N = Number of modules in series
V_{oc} = Open circuit voltage of the module at STC, in Volts

Voltage Correction Factors Crystalline Silicon PV Modules

Lowest expected operating temperature (°C)	Correction factor
24 to 20	1.02
19 to 15	1.04
14 to 10	1.06
9 to 5	1.08
4 to 0	1.1

−1 to −5	1.12
−6 to −10	1.14
−11 to −15	1.16
−16 to −20	1.18
−21 to −25	1.2
−26 to −30	1.21
−31 to −35	1.23
−36 to −40	1.25

5.4.3 Overcurrent Protection

Whenever there are voltage sources such as batteries, photovoltaic systems, or generators, there is the potential for dangerously large currents. A battery bank in a short circuit condition can discharge hundreds or thousands of amps causing damage to equipment and even physical harm or death. Care must be taken to protect equipment from such high current conditions.

Array Fault Current Protection

When multiple strings are connected in parallel and there is a risk of feeding high current from combined strings to a fault string due to short circuit or shading condition. Whether fault current protection is required is determined with the help of the following formula.

If:

$$\boldsymbol{I_{sc} = (Number\ of\ Strings - 1) \geq Module\ Reverse\ Current\ Rating}$$

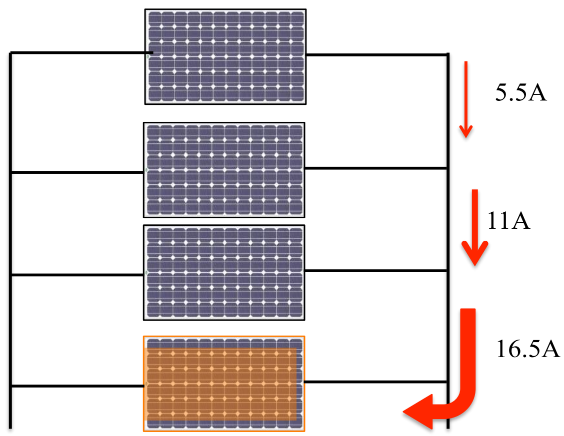
Then, fault current protection is required.

For most modules, reverse current rating is between 10A and 20A. If the current generated by the other strings is greater than current rating of the module then there is a risk of damage to that string and over current protection is required.

Example:

Module: I_{SC}: 5.5A
Number of strings: 4
Module Reverse Current /Maximum series fuse rating: 15A

In the above configuration, if one string is faulty or shaded it will produce 0A as it is in short circuit. Currents from other strings without fault current protection will freely flow through it instead of through the inverter, as it is the path of least resistance. Combined current of three strings will be 5.5A x 3 = 16.5A which is higher than the module reverse current rating. Therefore, fault current protection must be provided in the array.



Faulty module/ string

Maximum fault current is 16.5A which is larger than the module reverse current (15A).

Therefore, fault current protection (Fuse) must be installed in each string

Sizing Fault Current Protection Devices:
Unless specified by the module manufacturer the rated trip current (I_{trip}) of over current protection for the PV string is determined by the following formula from IEC 62548: Design requirements for Photovoltaic (PV) arrays:

$$\mathbf{1.5\ x\ I_{sc-mod\ trip} \leq I_{trip} \leq 2.4\ x\ I_{sc\ mod}}$$

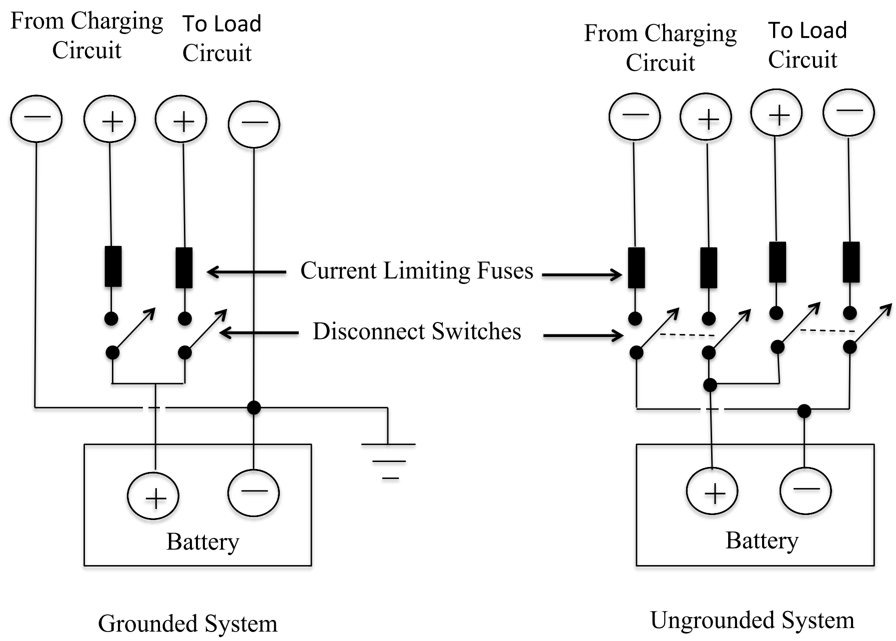
Where,
$I_{sc\ mod}$= Short circuit current of the module
I_{trip} = Rated trip current of the fault current protection device

Battery Overcurrent Protection

The output conductors of the battery bank shall be protected against overcurrent, by high rupturing capacity (HRC) fuses or DC rated circuit breakers, as follows:

(i) Where the battery bank is electrically floating (i.e. neither side of the battery is earthed), protection shall be provided in both positive and negative battery leads.
(ii) Where one side of the battery bank is earthed, protection shall be provided in the unearthed battery lead.

Battery Overcurrent and Disconnect Requirement



5.4.4 Disconnection Devices

Safety disconnects or switches are placed into power systems to allow equipment to be safely installed and maintained. Typically there are four locations where disconnect devices are needed in photovoltaic systems. They are:

(i) Between the array and the charge regulator;
(ii) Between the regulator and the battery;
(iii) Between the battery and any DC loads or load centre; and
(iv) Between the battery and the inverter.

In many cases the disconnection means can be combined with the over-current protection in the form of a DC circuit breaker. If this is done, care needs to be taken to ensure that the circuit breaker chosen is fit for purpose; for example polarised DC circuit breakers cannot be used in many situations.

As per EC 62548: Photovoltaic Arrays –Design Requirement, the location of fault current protection related to battery systems is generally between the battery and charge controller. The protection should be mounted as close as practicable to the battery terminals while offering no possibility for spark ignition of any hydrogen emitted from the batteries during charging.

Main Battery Protection:

The main battery protection is generally sized to cope with the requirements of a connected inverter. The required rating for battery current (I_b) is then calculated as follows:

$$I_b = \frac{Inverter\ Power\ Rating\ (W)}{Inverter\ efficiency\ x\ Nominal\ Battery\ Voltage}$$

Where, an inverter is not used, the main battery protection is sized for the DC maximum demand. In this case, separate DC mains protection is not required.

The protection size is never to exceed the current carrying capacity of the battery cabling or inverter cabling.

5.4.5 Protection against effects of lightning

For small microgrid systems, lightning risk is, often low, and protection is usually not needed. The exceptions are installations on high ground and in lightning-prone areas, wind generator towers or masts, and aerial wiring where any part is exposed to a lightning risk.

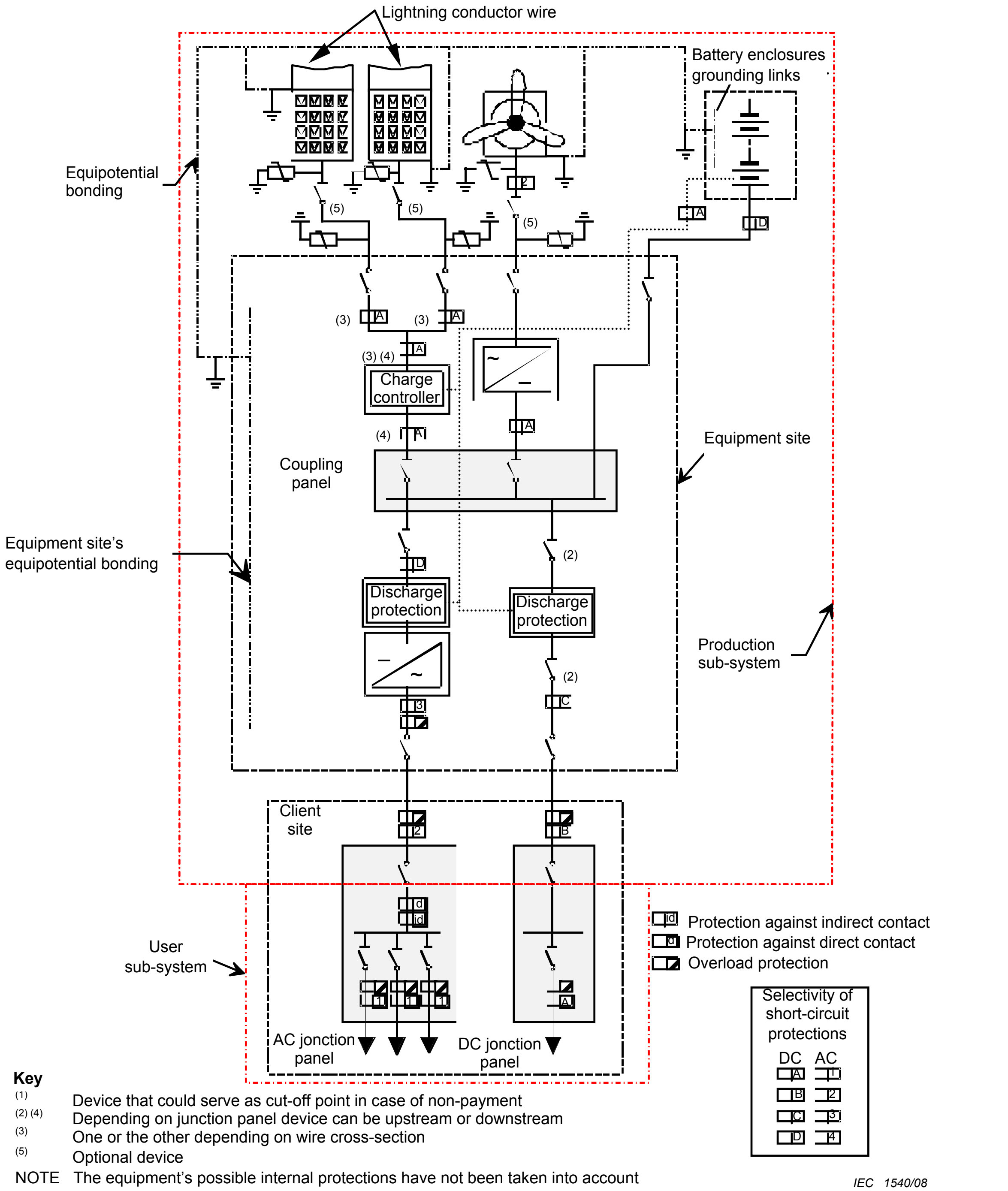
In order to asses the necessity of providing protection to micropower plants against effects of lightning methodologies are provided in Annex B of IEC62257-9-1. As the cost of installing surge protection devices could be high, this assessment shall be made carefully.

If the risk assessed is quoted as being higher than 14 (Clause B.3) of IEC62257-9-1 or if the number of thunderstorm days per year is higher than 25 days per year (Clause B.2), special provision shall be made in order to protect the micropower plant from the effect of lightning.

Whether the lightening arrestors are installed or not, an equipotential bonding shall be made using a copper conductor (or conductor of other material e.g. aluminium and stainless steel, which has the resistivity equivalent to 16mm^2 copper) with a sectional area of at least 16mm^2 installed between the solar array and the “control room”. This conductor shall be installed direct in the earth, in the same earth pit as the power cable as close as possible to it. One of the ends shall be connected to the earthing electrode of the PV array and the other shall be connected to a special terminal provided for this purpose in the control room. This creates an equipotential bonding system as shown in the figure.

If the distance between the PV array and the control room (inverter room) is greater than 15m, surge arresters shall be installed as shown in the figure. Surge protective devices shall be installed between each live conductor (AC or DC) and between each live conductor and the earth at the two ends of the bonding conductor. If the distance between the PV array and the control room is less than 15m, no additional special measure is required.

Example of the selectivity of protection against overcurrent, lightning and overvoltage



CHAPTER 6

6 Installation & commissioning

6.1 Site survey & planning

The installer shall gather all design documents and engineering drawings of the system including site layout, system schematic, single line diagrams, drawings for structure and foundations, distribution systems, module and battery interconnection drawings, control system drawing, etc. The installer shall also have information (data sheet) on the major components such as modules, controls, inverter, and batteries and must be familiar with the instruction manual for installation of such equipments.

The first step of installation is to visit the site and finalize the layout of the equipments. If site layout is already given, this should be verified at site identifying actual locations for installation of equipments and verify the distances and dimensions.

6.1.1 Occupational Health & Safety Assessment:

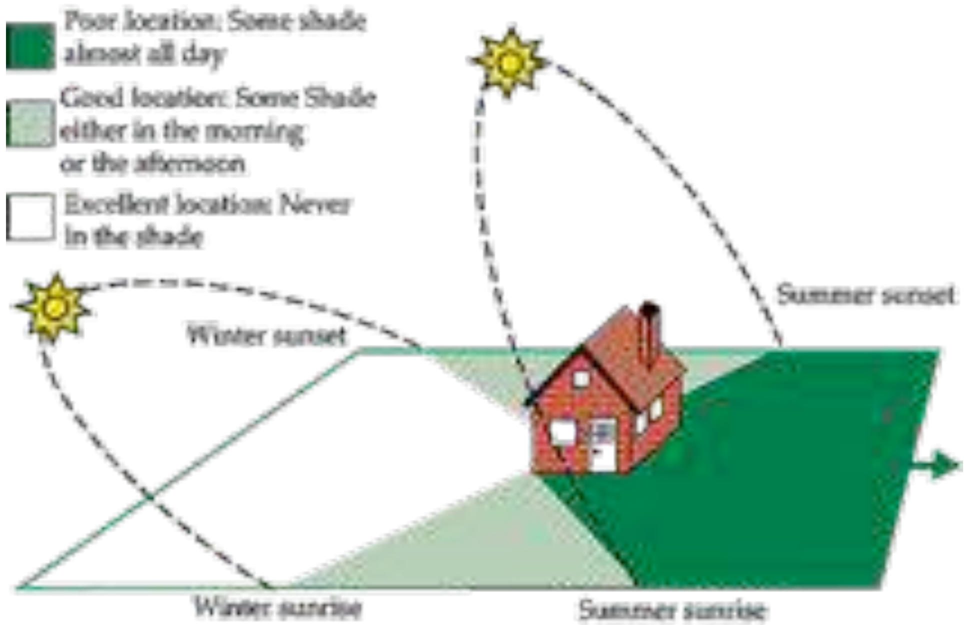
Prior to starting any on-site work it is recommended that the installer undertake an on-site risk assessment. This requires:

- The identification of all possible risks;
- Determination of the work practices that will be undertaken to remove the risk, or to minimise the risk if it cannot be removed altogether; and
- Communicating with all the staff working on-site about these risks and how they will be removed or minimised.

Typical risks with respect to the installation of PV systems are discussed in the Chapter 1.

6.1.2 Solar Array Location

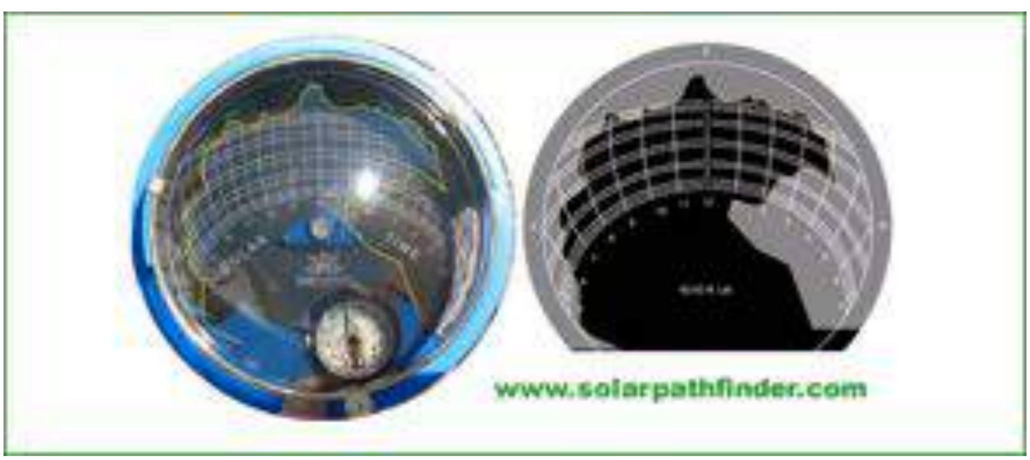
For a solar photovoltaic system, it is crucial that the solar array is installed at a location that is free from any shading throughout the day. Finding a shadow free location for placement of array is usually not an issue for remote sites, where ample space and options for locating may be available. Shadow during winter season is much longer that the shadow during summer season due to change in earth's altitude. There may be shadow from nearby trees and houses or even shadow from mountains, which is not very far from the site. Sometime shadow in the early morning and late afternoon cannot be avoided due to very low altitude of sun. In such situation arrays must be placed in such a way that there is no shading between the hours of best insolation, usually from 8 a.m. to 4 p.m., on the day with the longest shadows, December 21 in the Northern Hemisphere.



Placement of solar arrays considering summer and winter sun position

Using Solar Pathfinder

The most accurate and convenient way to place the array away from any tall object that can possibly cause shadow is to use the solar pathfinder. When you use a solar pathfinder there is no need to measure distance or height of any objects that can create shadow at any point of time during the year. Just placing the solar pathfinder in the potential array location, you will understand if there is any shadow. If there is any shadow image seen in the pathfinder, move away from that point to the direction where the shadow can be avoided. Solar pathfinder should be located at the four corners of the array to ensure that the complete array is shadow free.

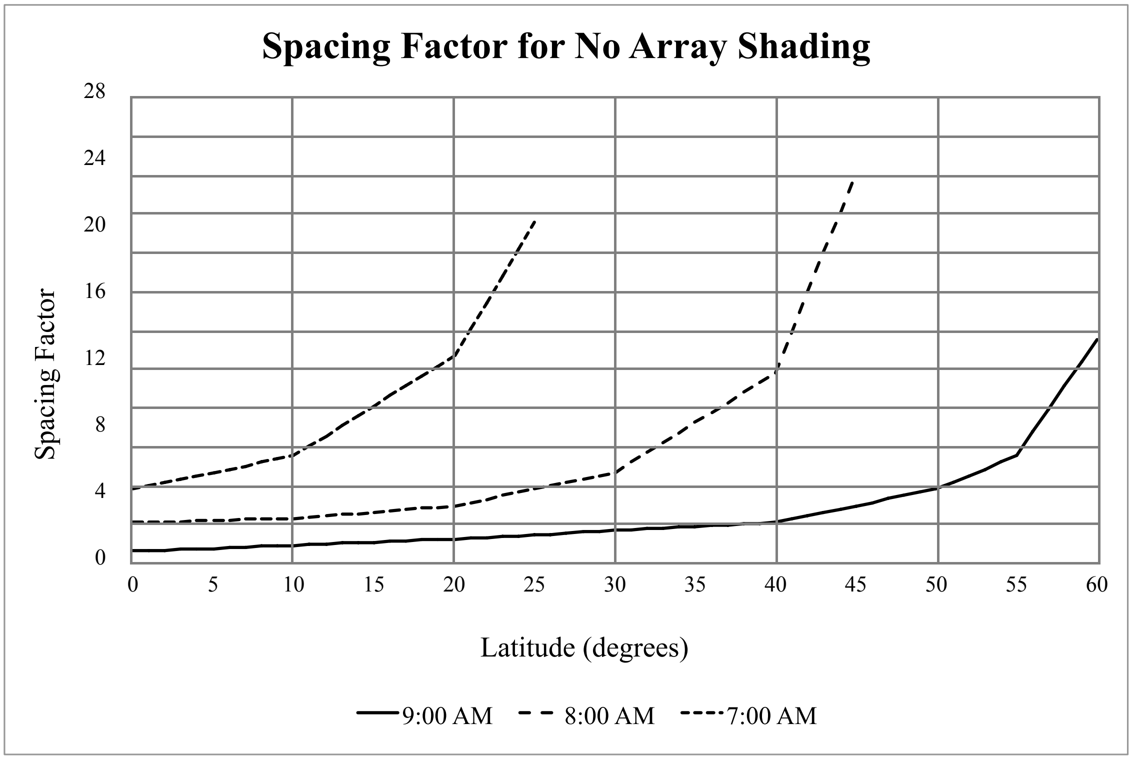


Shadow analysis using a Sunpath finder and sunpath diagram

If you do not have access to a solar pathfinder, use the following calculations to ensure that the array will be located away from potential shading. However, these methods require some measurement, calculation and good assumptions to decide whether the array will be shadow free for all days of the year.

Using Spacing Factor Graph

One easy approach is to use the "spacing factor graph" given in the figure below. This graph will help in deciding where to place an array for no winter shading. Read up from the latitude of the site to the curve for the hour when no shadows are to reach the array (again usually 8 a.m. to 9 a.m.). Then read across to find the Spacing Factor. Multiply this factor times the height of the object to calculate the distance the array must be placed away from the object.



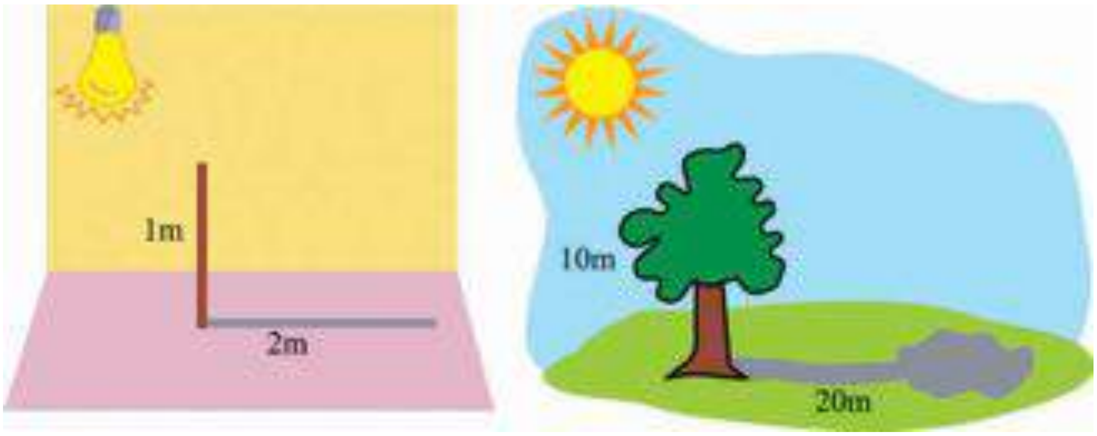
Graph to determine array Spacing Factor

The proper distance depends on the latitude, the time, and the height of the nearest tall object. With the help of the graph now calculate the minimum distance from object to the array using the following formula.

$$Distance\ from\ object\ to\ array = Object\ Height\ x\ Spacing\ Factor$$

Applying Rule of Thumb

The general rule of thumb is locate the array at a distance away from the object that is atleast twice the height of the object. This will ensure that the object will not cast a shadow for 4 hours either side of solar noon.



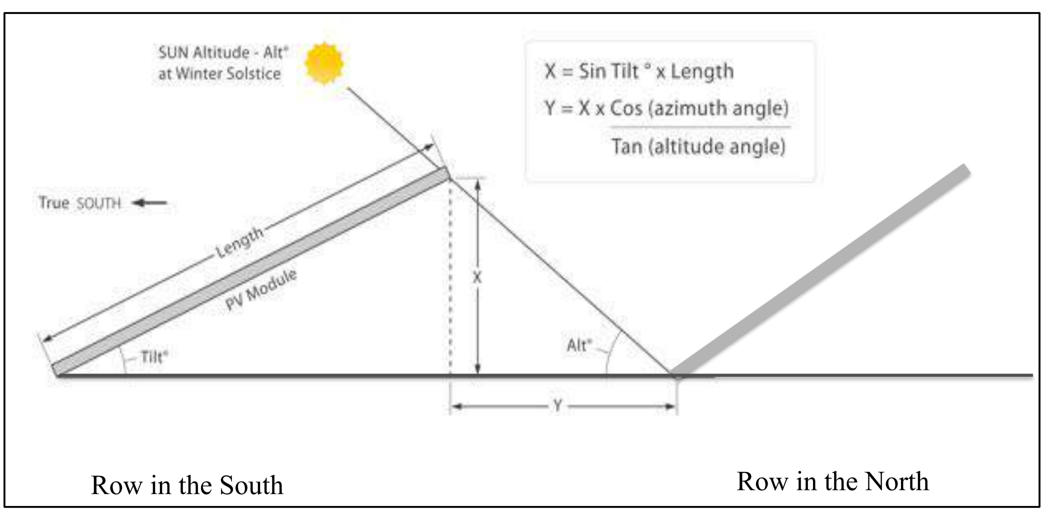
Placing of array away from objects

Space Between Two Rows

When PV modules are installed in multiple rows, consideration must be given so that one row of modules does not cast a shadow on the row behind. Calculations need to be done to find the minimum distance between PV Array rows to avoid winter mid-day shading.

This can be calculated using basic trigonometry as shown in the figure below.

$$\textbf{Row spacing } (Y) = (X) \; x \; \frac{\textbf{Cos } (\textbf{azimuth angle})}{\textbf{Tan } (\textbf{altitude angle})}$$



Calculating the minimum distance between rows

Example:
The PV array is located in New Delhi: Latitude 28.5°N. The row spacing should avoid shading at solar noon on December 21.

Azimuth = 173°
Altitude = 38° at solar noon on December 21

$$Y = X\ x\ \frac{Cos\ (173^o)}{Tan\ (38^o)} = X\ x\ \frac{0.99}{0.78} = X\ x\ 1.27$$

If height of the row is 1m, distance between two rows shall be 1m x 1.27 = 1.27m

6.1.3 Other Equipment Location

The next step of site survey is to determine the location of the control equipment, inverter, battery bank, earth pits and cable route.

- Controls and inverter should be placed in such a way that access is controlled
- Switches are to be located in a place which is easily accessible

Example of location for inverter, control and switching devices

- Batteries should be installed in a separate room closed to the inverter /control room and access to the room should be controlled.
- Batteries to be located in cool and dry and well ventilated place

Location of battery bank in a separate well ventilated room

Power distribution lines connecting the load centres

6.2 Tools for Installation

Some tools for installing and maintaining photovoltaic power systems are listed below.

Sl. No.	Tools and equipments for Installation
1	First aid kit
2	System service logbook
3	Datasheet & O&M manual
4	This manual
5	Paper/Pencil
6	Multimeter, digital voltmeter, with at least 10A current capability, spare batteries
7	Clampon DC ammeter
8	Wrenches: Specific sizes, for all mounting bolts; Adjustable, for unexpected on-site problems; Vise-Grips for variable and heavy duty
9	Compass and Sun Pathfinder
10	Screw Drivers: flat Blade, in sizes for all mounting hardware; Phillips, in sizes for all mounting hardware; Small jewelry size, for adjusting controls
11	Linesman pliers, nose pliers
12	Nut drivers 1/4in and 5/16in
13	Measuring tape (25m)
14	Tilt Angle indicator, or plumb line and protractor
15	Hydrometer
16	Safety goggles
17	Rubber gloves
18	Electrical Tape
19	Wire Crimping, Stripping and Cutting Tool (s)
20	Miscellaneous for connections: Split bolts, wire nuts, lugs, solder-less connectors
21	A hand drill or DC operated electric drill
22	DC soldering iron
23	Hacksaw
24	Utility knife
25	Hammer
26	Ladder

6.3 Installation Processes

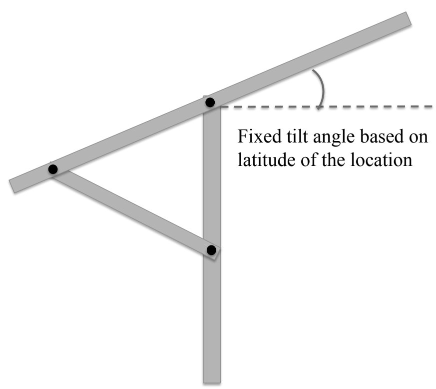
6.3.1 Installation of Mounting Structure

Generally, PV arrays for solar microgrid system are installed in the ground as there is ample of space available in rural area and finding a appropriate roof for installation of PV arrays may not be easy.

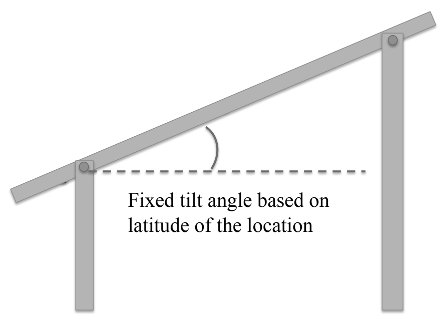
The ground mounting system has the following advantages:

(1) It is easier to have seasonal or daily tracking provision in a ground mounted structure
(2) Easy cleaning and maintenance access of PC array
(3) Better air flow keep the modules cool hence will have better performance
(4) Easy maintenance of structure, cable tray, electrical connectors and cable etc.
(5) Easy to expand PV array capacity if required

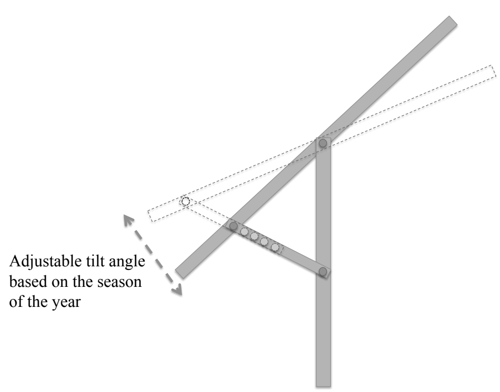
Array mounting structure could be different types depending upon site, system capacity maintenance plan, type of soil, wind velocity, waterlogging possibility etc. Conceptual drawing of few commonly used array structures are presented below:



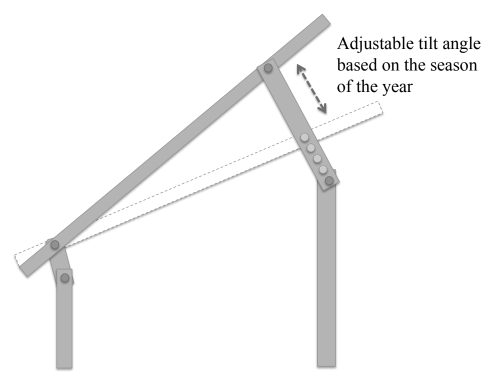
Single pole structure with fixed tilt angle



Double pole structure with fixed tilt angle



Single pole structure with adjustable tilt angle



Double pole structure with adjustable tilt angle

Foundation and Structural Alignment

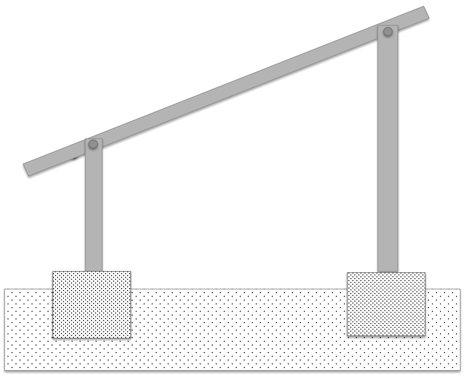
The most critical element of foundation and structure installation is alignment. The points where the mounting structure is to meet the foundation must be level, and any mounting bolts must be spaced correctly. It is critical that careful measurements be made both for spacing and for flatness. The orientation of the foundation must face true south.

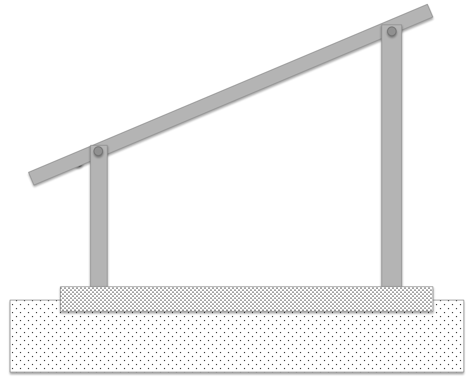
Determining and marking the north-south direction with the help of a compass

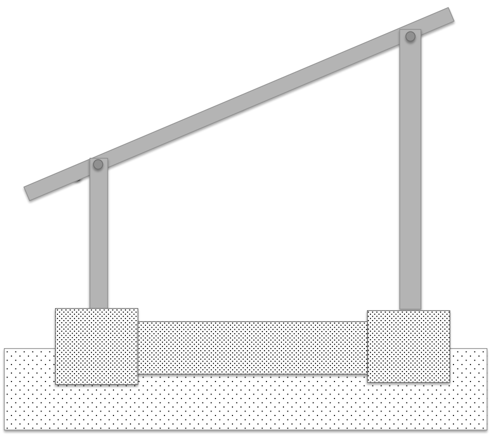
Aligning the locations for foundation for mounting structure

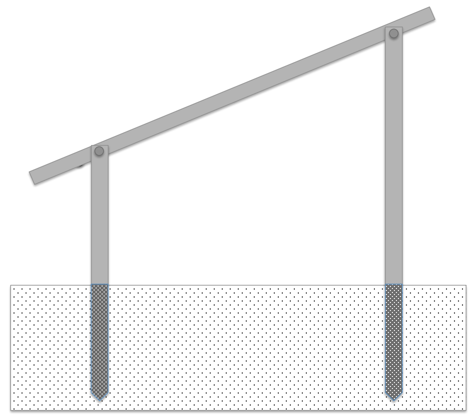
6.3.2 Type of foundations for mounting structure

Foundation for array mounting structure may be different for different sites, type and load bearing capacity of soil, wind velocity, waterlogging possibility and type of mounting structure. Conceptual drawing of foundation type generally used to hold PV array structure are presented below:


Block type foundation


Slab type foundation


Beam type foundation


Pile foundation

Example of block type foundation

Example of array installed on a RCC roof of the control room

Example of slab foundation

Example of beam type foundation

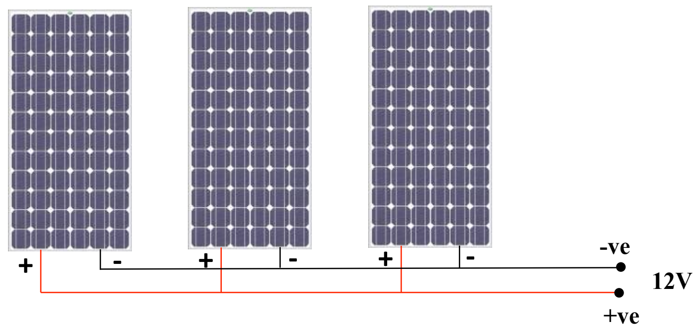
Example of pile foundation

6.3.3 Array Installation and Wiring

Once the mounting structure is in place, modules are place on to it and fixed properly. Modules pre-wired with MC4 connector before fixing to the structure. Modules are connected together in series and parallel as per design. It is necessary to draw the module interconnection diagrams before connecting them in series or parallel. This can be done in two steps, first for clarity as a theoretical schematic, and then actual details as they would be installed. Examples of module interconnection for 12V, 24V and 48V array configuration are presented below.

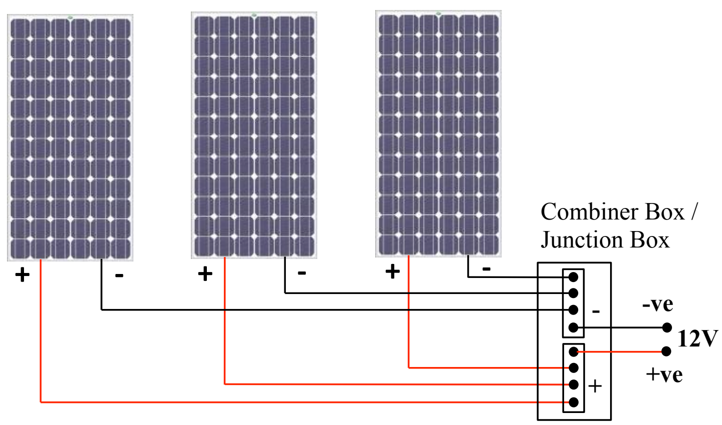
12 Volt Array Wiring

The schematic arrangement of a 12V array involves placing the modules side by side, with all the positive terminals connected in parallel. The current from each module adds to give the total array current, while voltage of the entire array is the same as the voltage of one module. The schematic below shows three numbers of 12V modules connected in parallel.

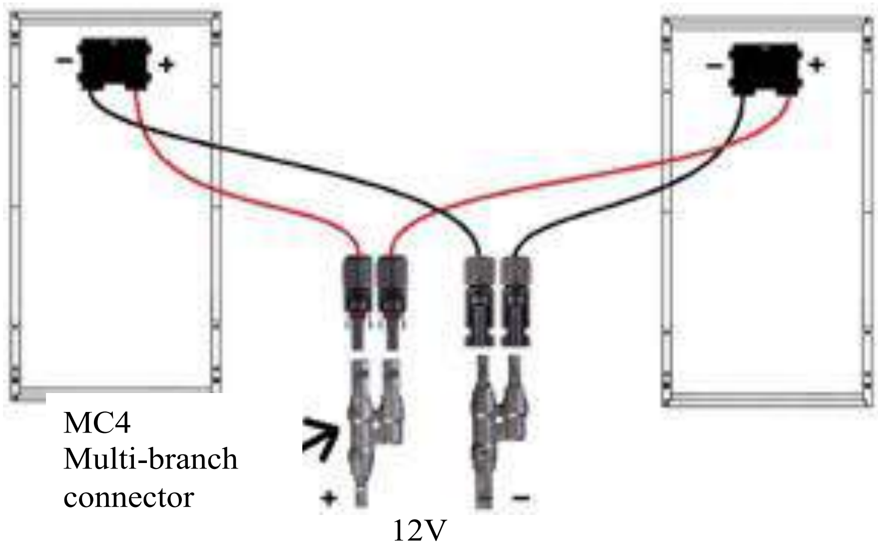


12V Array Schematic with three modules in parallel

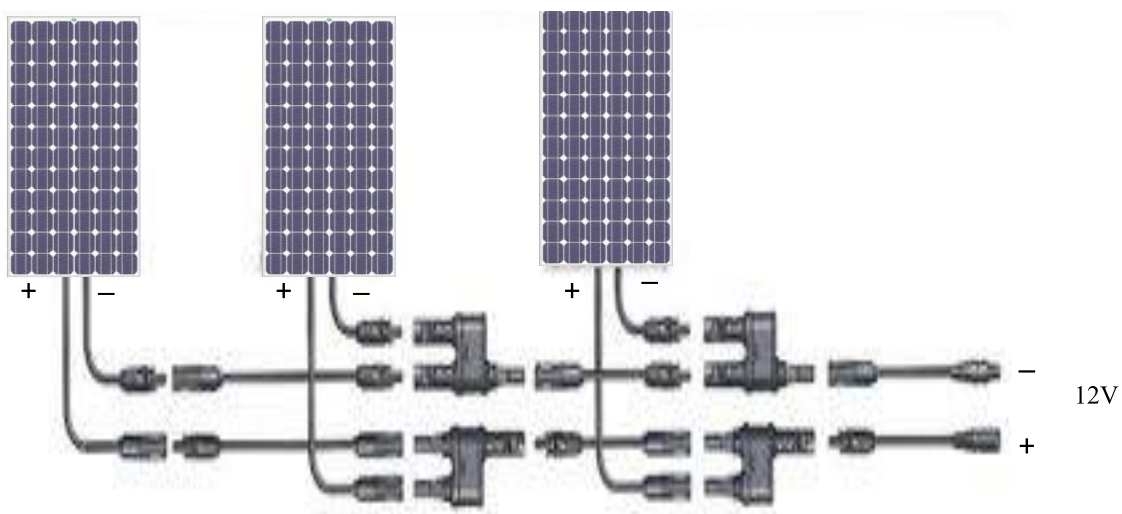
The installed wiring of 12V array modules would have all the positive connected together in parallel, and all the negative connected together in a bus bar of a junction box or with the help of a MC4 multi-branch connector as shown in the figures below.



Two 12V modules are connected in parallel in a junction box



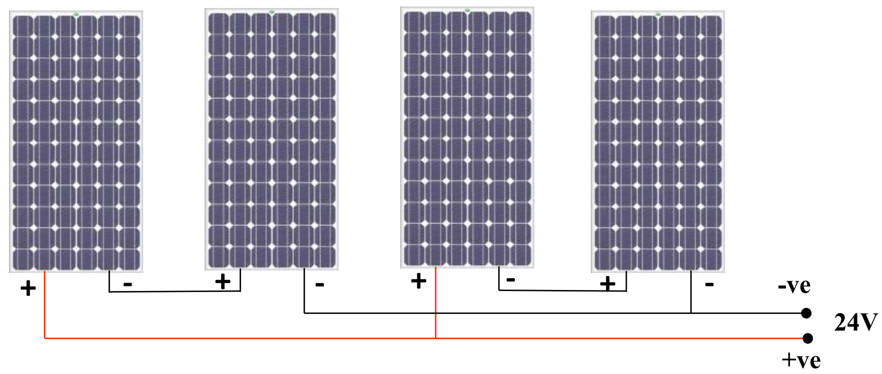
Two 12V modules are connected in parallel with the help of MC4 connectors



Three 12V modules are connected in parallel with the help of MC4 connectors

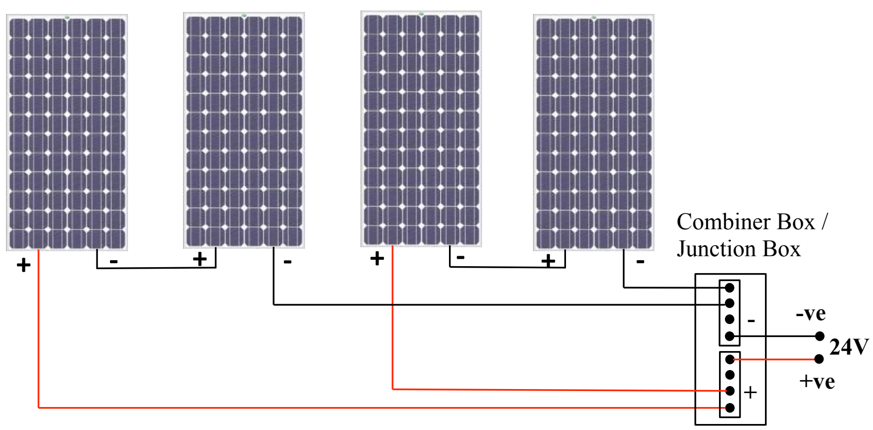
24 Volt Array Wiring

For a 24V array, two modules are connected in series (string). Any number of such series strings can then be connected in parallel to give the required current. A schematic view of a 24V array is shown below. In this example, two 12V modules are connected in series string to produce 24V and two such strings are connected in parallel to get required current.

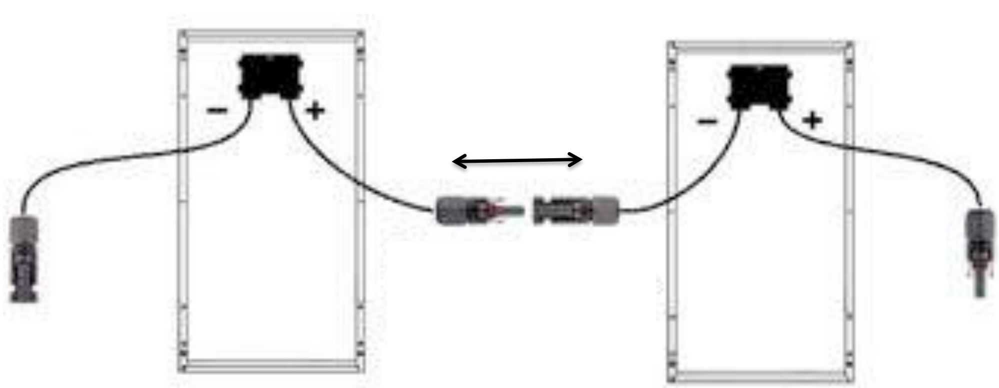


24 Volt Array Wiring Schematic

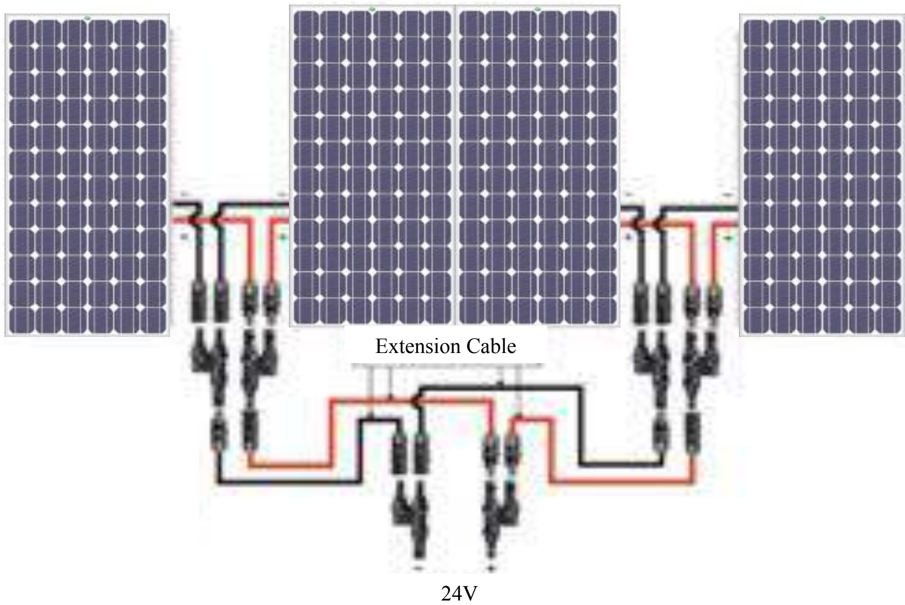
In actual field installation two 24V strings will be connected parallel in a common bus bar of a combiner box/ junction box or with the help of a MC4 multi-branch connector as shown in the figure below.



Two modules in series string and two strings in parallel connected through a junction box



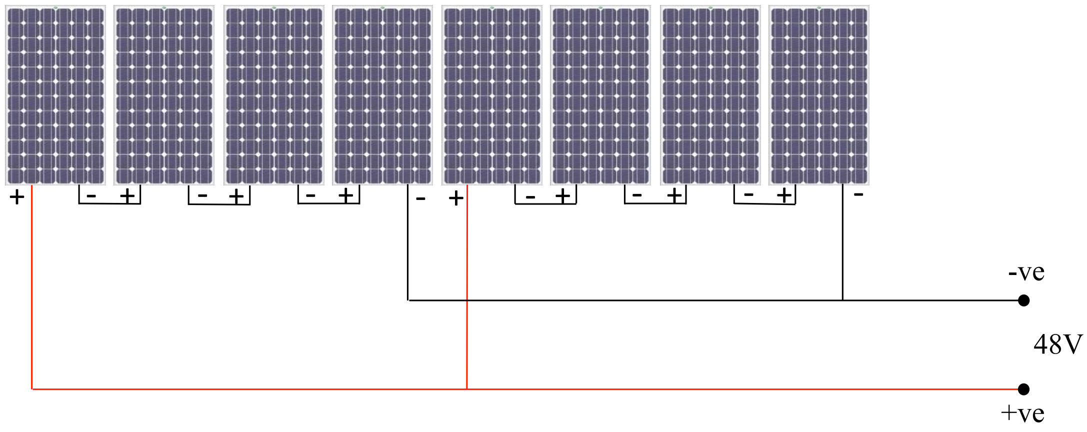
Two modules are connected in series with the help of MC4 connectors



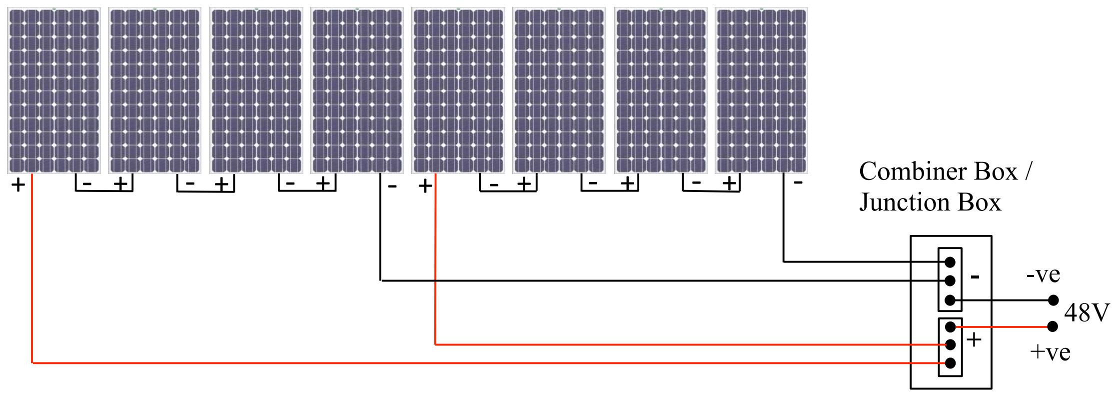
Two modules are connected in series and two strings are connected in parallel with the help of MC4 connectors

48 Volt Array Wiring

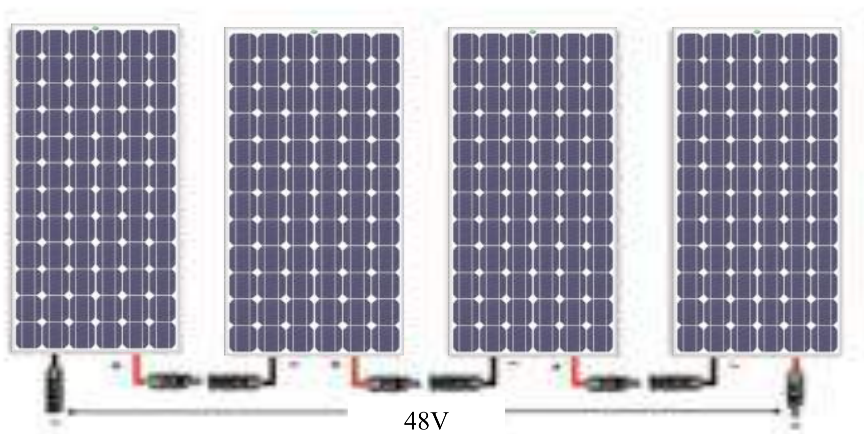
In the case of 48V system, we need four modules connected in series. Strings of four modules can be combined in parallel to give final array current. Example in the figure below shows two strings of 48V are connected in parallel.



48 Volt Array Schematic with 4 modules connected in series and two strings connected in parallel



Four modules are connected in series string and two strings are connected in parallel through a junction box



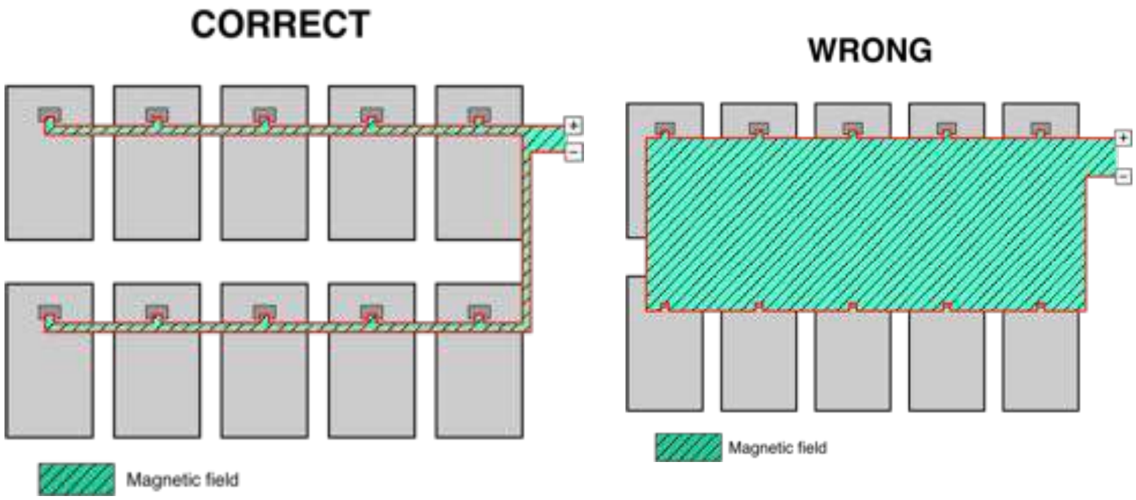
Four modules connected in series string with the help of MC4 connectors

> *It is recommended that modules in series should be connected first to produce the required voltage, and then connecting similar series string in parallel to produce the required current. In that case, if a series string is removed from the circuit, the rest of the strings still operate at the normal system voltage, and the array continues to charge the batteries or operate the load.*

Tools and connectors required for PV module wiring

Correct Wiring Loops

The PV array wiring should be installed in a way to minimise any conductive loops as shown in the figure below.



Example of correct wiring loop for a PV array

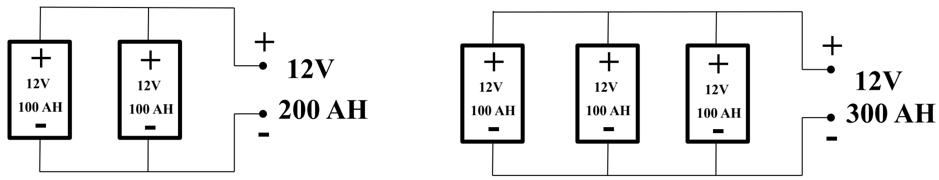
6.3.4 Battery Installation

It is essential to check the following before installation of batteries:

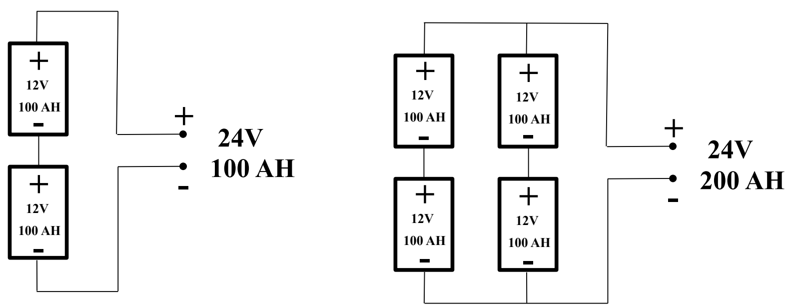
- Review battery safety procedures
- Do not mount the batteries directly on a concrete floor. Mount onto wooden or other non-conducting rails.
- Make sure the batteries are fully charged, and that the electrolyte level is at manufacturer's recommended level.
- Check all cell voltages and write down on a status sheet for later comparison.
- Handle batteries with extreme care, and use tools carefully. The greatest danger will occur if wires are hastily connected, or if tools are dropped onto the bare battery terminals.
- All connections should be “walked through” a few times, perhaps with another installer present to confirm, before actual wiring is done.
- Make sure to place a sign at the batteries warning unauthorized personnel about the dangers.

Battery Wiring:

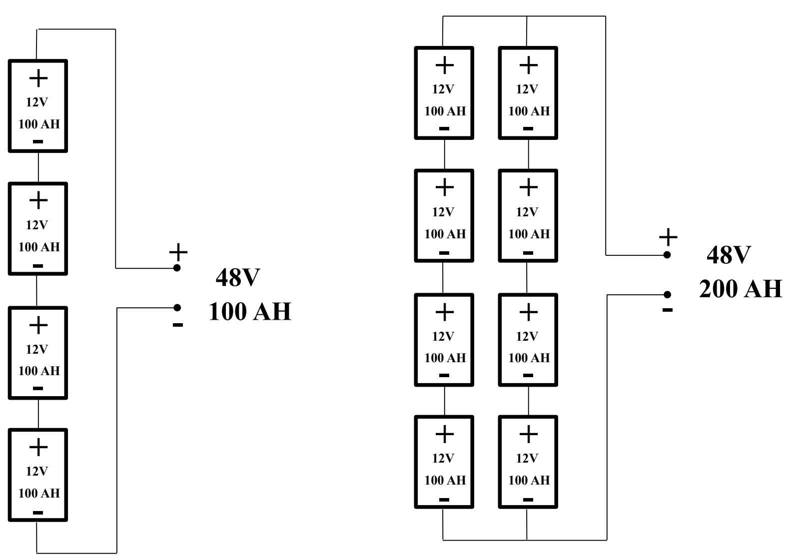
Similar to solar modules, batteries are connected in series and parallel to achieve required voltage and capacity. To operate at a higher voltage, batteries are connected in series. Examples of wiring of battery bank at different voltage configurations and capacity are shown below.



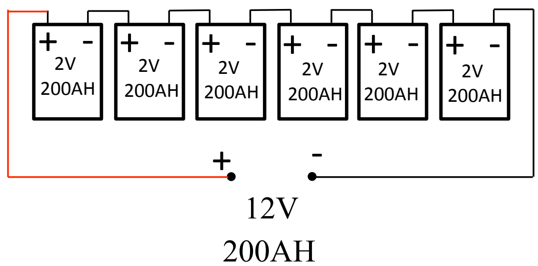
Two 12V, 100AH batteries are connected in parallel to get 12V, 200AH and three 12V batteries are connected in parallel to get 12V, 300AH



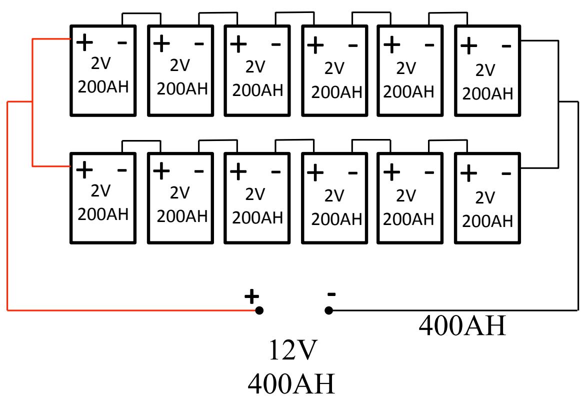
Two 12V, 100AH batteries are connected in series to get 24V, 100AH and two 24V strings are connected to get 24V, 200AH



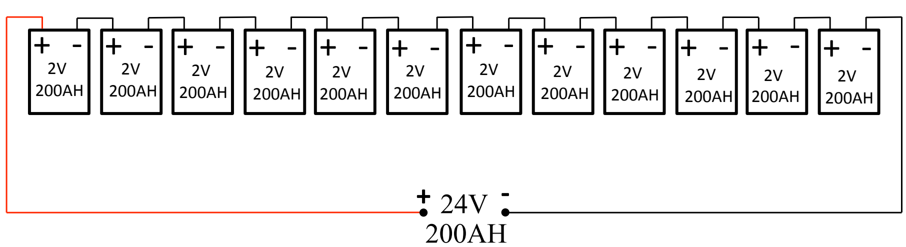
Four 12V, 100AH batteries are connected in series to get 48V, 100AH and two 48V strings are connected to get 48V, 200AH



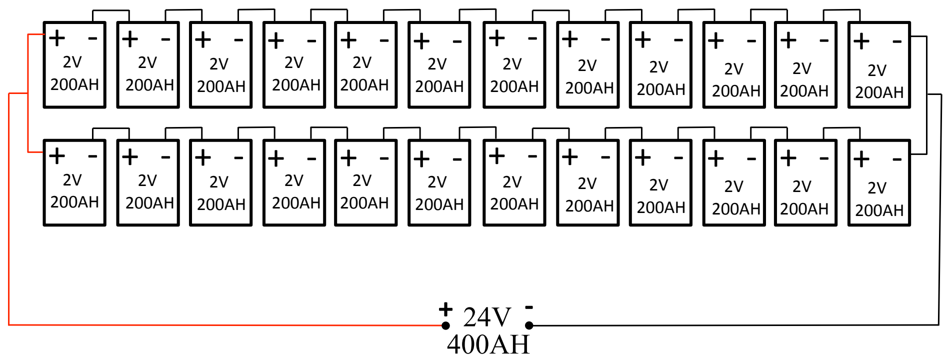
Six 2V, 200AH batteries are connected in series to get 12V, 200AH



Six 2V, 200AH batteries are connected in series and two 12V strings are connected to get 12V, 400AH



Twelve 2V, 200AH batteries are connected in series to get 24V, 200AH



Twelve 2V, 200AH batteries are connected in series and two 24V strings are connected to get 24V, 400AH

Twenty-four 2V batteries are connected in series and to get 48V battery bank

Important to note:

- Not more than four parallel connections should be made in a battery bank
- Tap off the battery at opposite corners when batteries are connected in combination of series and parallel

6.3.5 Control Centre Pre-Wiring

- Understand and follow the schematic diagram of the system wiring
- Assemble all controls, disconnect switches, alarms and meters and load centres as pre-planned.
- Make sure there is the required safe space between any boxes and walls or pipes or other equipment.

- Check that all connections are secure and clean, that all wiring is colour coded or marked for correct polarity and that all wire lugs are fastened tight to their wires.
- Before connecting the inverter, make sure the polarity is correct. Most inverters can be damaged if connected with the wrong polarity.
- Label all main switches so that an uninformed person with the operation guide can safely and easily disconnect the system in an emergency.

Example of control centre wiring

6.4 Power distribution system

Three basic configurations could be applied for distribution of power in solar microgrid systems. Applicability and techno-economic feasibility of these configurations depend on system capacity, configuration, equipment type and distribution of loads.

(i) DC distribution system;
(ii) AC single phase distribution system;
(iii) AC three phase distribution system;

Recommended conductor size for different configurations is presented in the next pages.

Table 6.1: Maximum cable route length of copper cable with different cross-section area for 12V DC power distribution system considering 2% voltage drop.

Maximum cable route distance (m) with different cross section area of cable with 2% voltage drop							
Current (A)	**1.5mm^2**	**2.5mm^2**	**4mm^2**	**6mm^2**	**10mm^2**	**16mm^2**	**25mm^2**
1	10	16	26	39	66	105	164
2	5	8	13	20	33	52	82
3	3	5	9	13	22	35	55
4	2	4	7	10	16	26	41
5	2	3	5	8	13	21	33
6	2	3	4	7	11	17	27
7	1	2	4	6	9	15	23
8	1	2	3	5	8	13	20
9	1	2	3	4	7	12	18
10	1	2	3	4	7	10	16

Table 6.2: Maximum cable route length of copper cable with different cross-section area for 24V DC power distribution system considering 2% voltage drop.

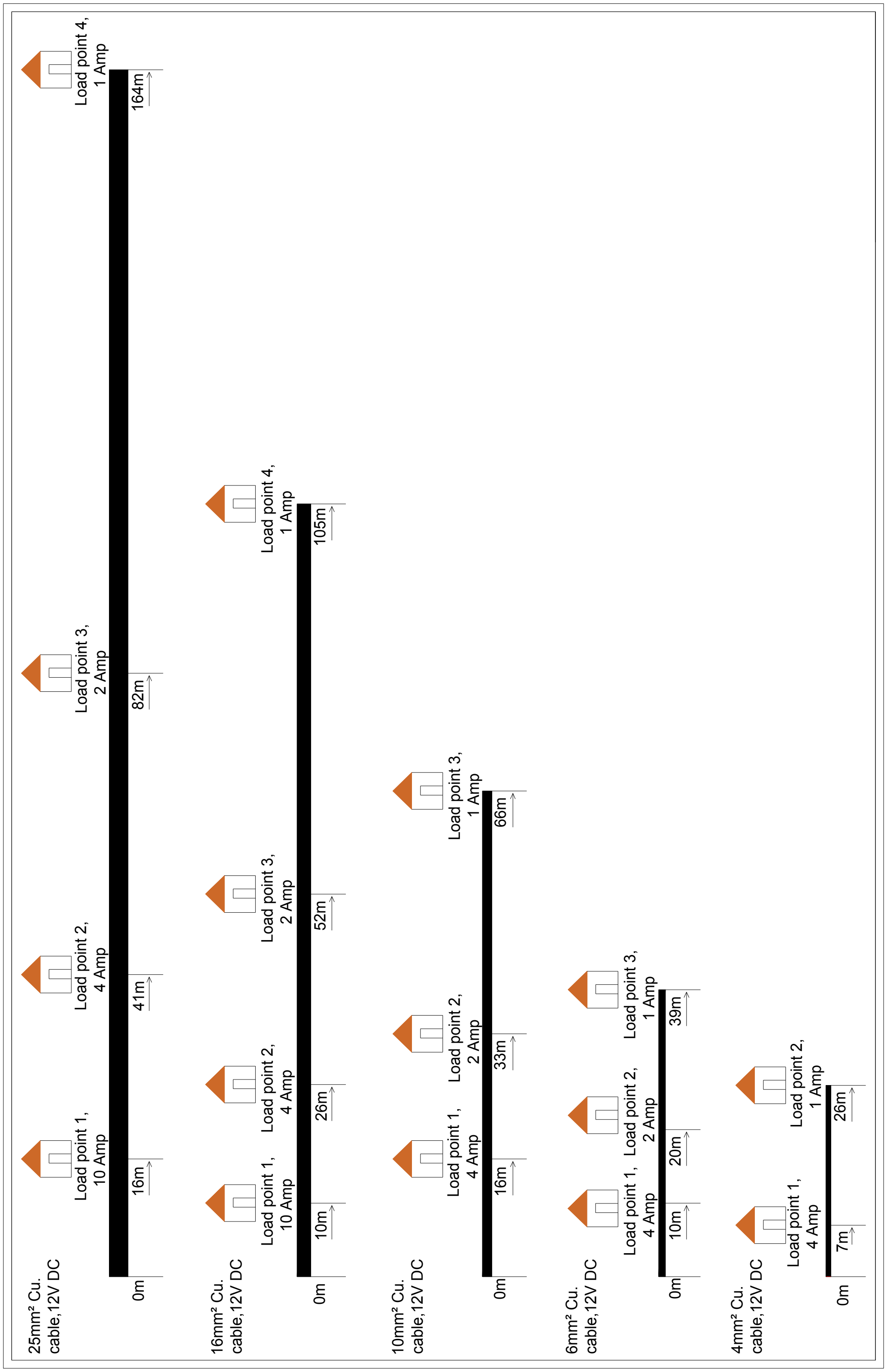
Cable route distance (m) with different cross section area of cable with 2% voltage drop							
Current (A)	**1.5mm^2**	**2.5mm^2**	**4mm^2**	**6mm^2**	**10mm^2**	**16mm^2**	**25mm^2**
1	20	33	52	79	131	210	328
2	10	16	26	39	66	105	164
3	7	11	17	26	44	70	109
4	5	8	13	20	33	52	82
5	4	7	10	16	26	42	66
6	3	5	9	13	22	35	55
7	3	5	7	11	19	30	47
8	2	4	7	10	16	26	41
9	2	4	6	9	15	23	36
10	2	3	5	8	13	21	33

Table 6.3: Maximum cable route length of copper cable with different cross-section area for 48V DC power distribution system considering 2% voltage drop.

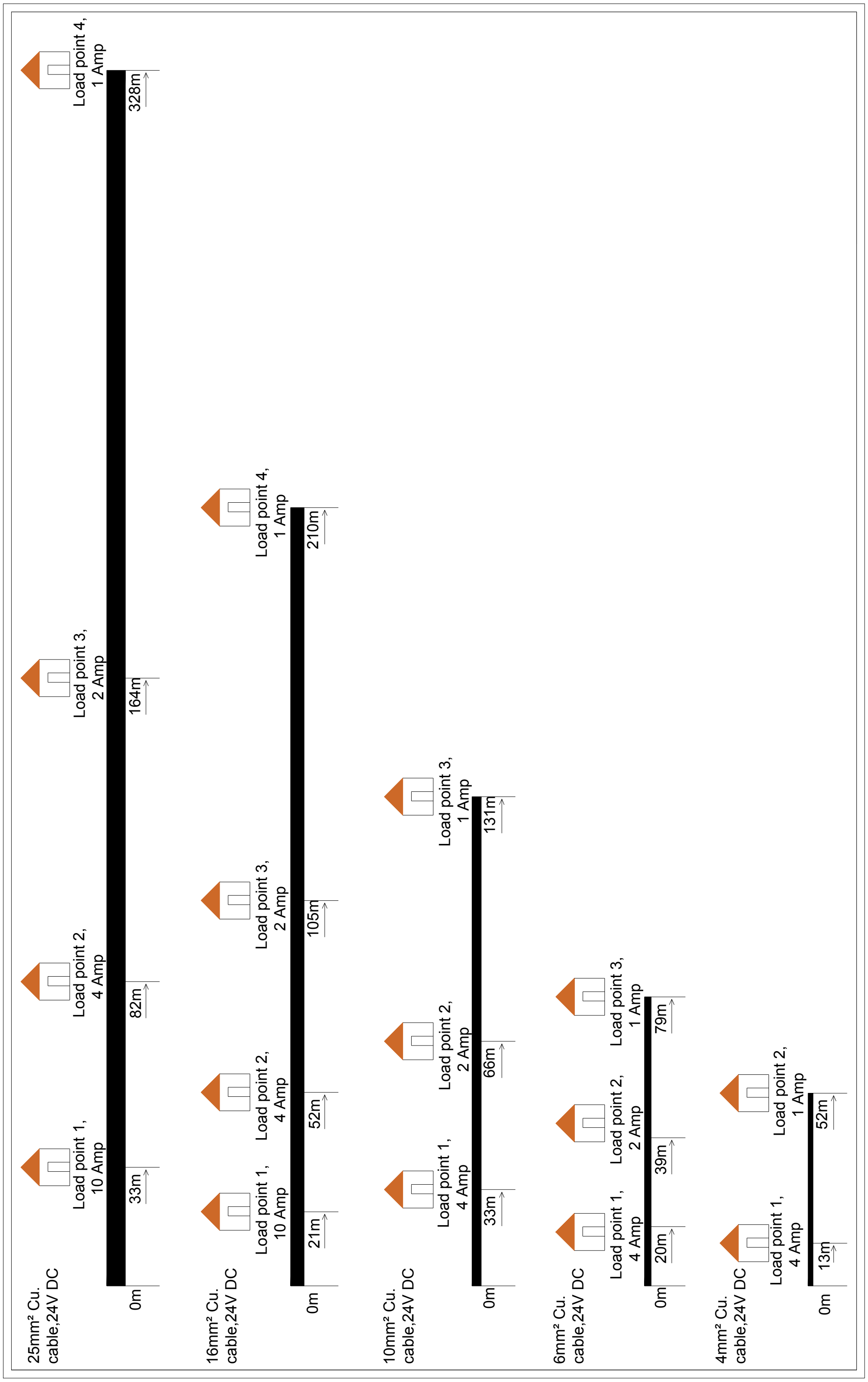
Cable route distance (m) with different cross section area of cable with 2% voltage drop							
Current (A)	**1.5mm^2**	**2.5mm^2**	**4mm^2**	**6mm^2**	**10mm^2**	**16mm^2**	**25mm^2**
1	39	66	105	157	262	420	656
2	20	33	52	79	131	210	328
3	13	22	35	52	87	140	219
4	10	16	26	39	66	105	164
5	8	13	21	31	52	84	131
6	7	11	17	26	44	70	109
7	6	9	15	22	37	60	94
8	5	8	13	20	33	52	82
9	4	7	12	17	29	47	73
10	4	7	10	16	26	42	66

Table 6.4: Maximum cable route length of aluminums cable with different cross-section area for 230V AC power distribution system considering 2% voltage drop.

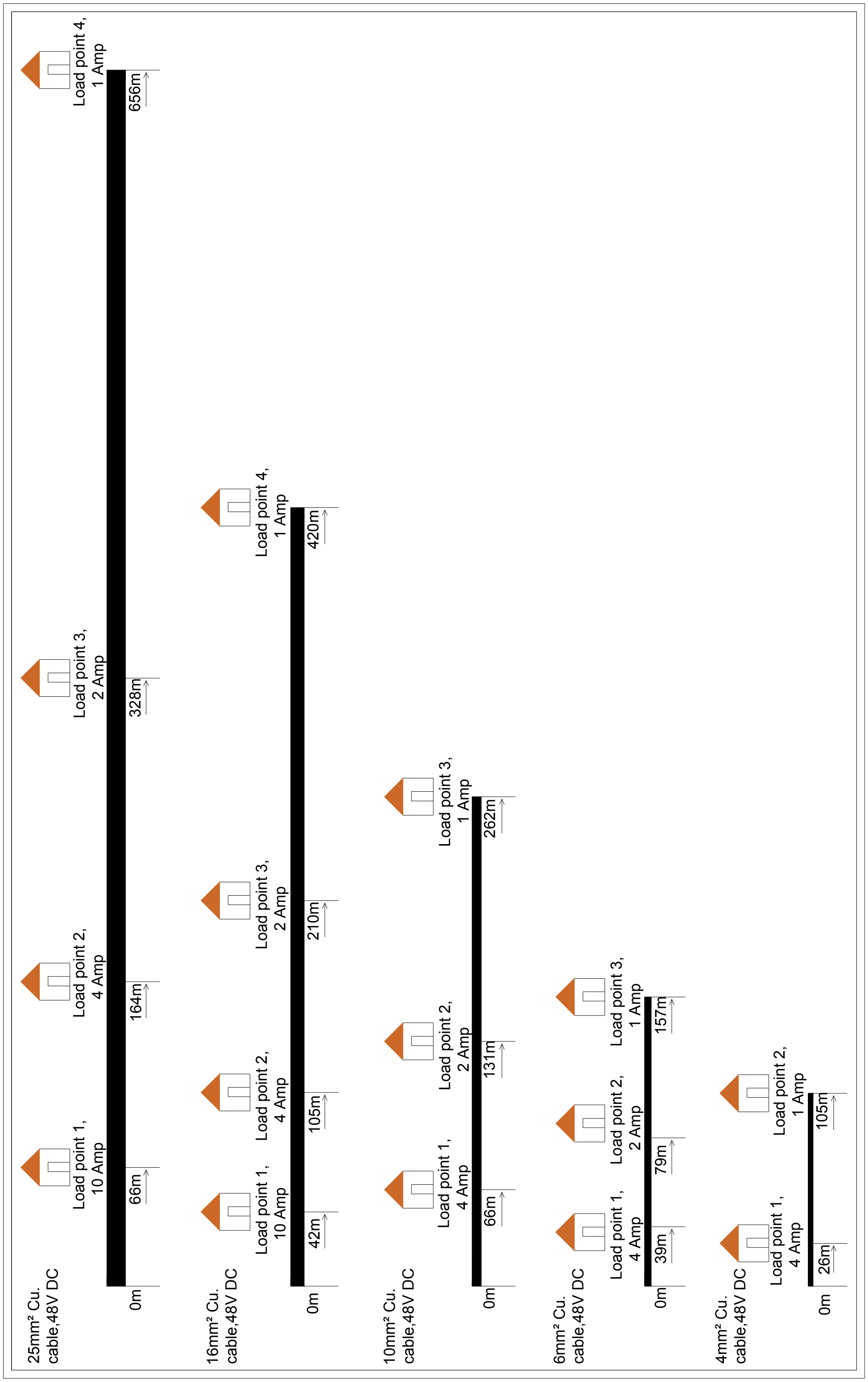
Cable route distance (m) with different cross section area of cable with 2% voltage drop						
Current (A)	**1.5mm^2**	**2.5mm^2**	**4mm^2**	**6mm^2**	**10mm^2**	**16mm^2**
1.0	1.5	117	195	313	469	782
2.0	1.5	59	98	156	235	391
3.0	1.5	39	65	104	156	261
4	1.5	29	49	78	117	195
5.0	1.5	23	39	63	94	156
6.0	1.5	20	33	52	78	130
7.0	1.5	17	28	45	67	112
8	1.5	15	24	39	59	98
9.0	1.5	13	22	35	52	87
10.0	1.5	12	20	31	47	78



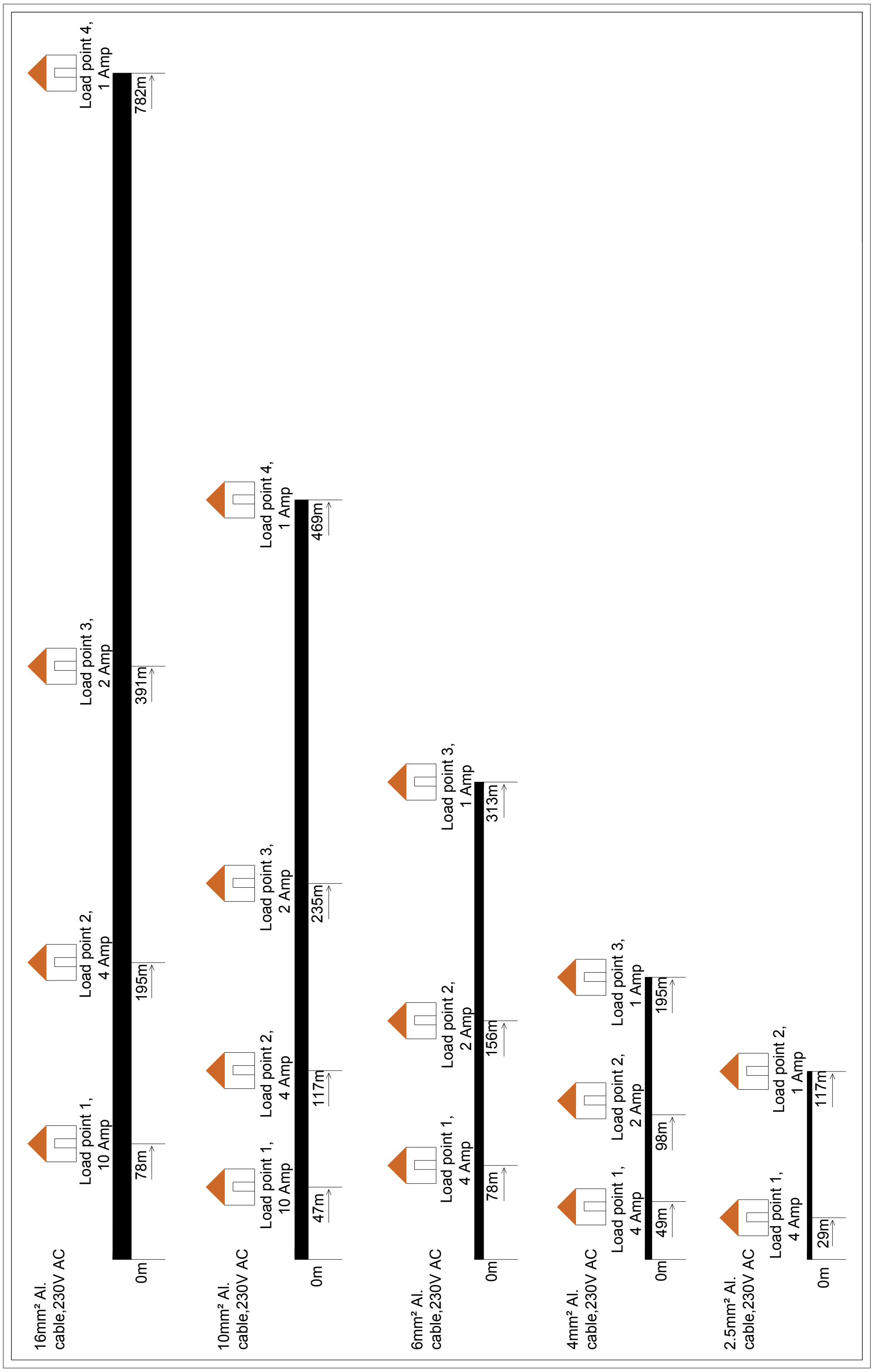
Example of 12V DC distribution system for reference



Example of 24V DC distribution system for reference



Example of 48V DC distribution system for reference



Example of 230V AC distribution system for reference

6.5 System Commissioning

All equipments and items must be tested for its correct operation before commissioning a system. Testing should be started with the array connection followed by battery connections and wiring to check continuity, voltage and polarity. Testing of individual equipment must be done as per the manufacturer's recommendations. Test results should be recorded and kept as a part of documentation.

The following tests are to be carried out before start up the system:

- Measure output voltage of each string and check if there is deviation;
- Measure battery voltage;
- Measure output voltage and frequency of inverter;
- Test all functions of inverter controller;
- Measure voltages at all major points in the system to check if there is excess voltage drop;
- Measure the resistance of the earth system;
- Start up the system

6.6 Marking and signage

According to IEC 62257 the following marking and signs are to be placed with micropower system.

(i) Emergency de-energisation procedure to isolate the system
(ii) Isolation of the battery bank
(iii) Isolation of the PV power inputs
(iv) Isolation of the generator set (if any)
(v) Sign at the battery room should include *"WARNING: SPARK HAZARD. Follow shutdown procedure before connecting or disconnecting any equipment."*

Example of signage to be used near battery bank

6.7 Documentation

The following information should be included in the documentation of a solar microgrid system.

(i) List of equipment installed with rated power, models, manufacturers and quantity
(ii) Wiring Diagrams (Single line diagram with equipment information)
(iii) Data sheets (Module, batteries, charge controller and inverter)
(iv) Operating instructions (systems and components)
(v) A checklist of what to do in case of a system failure
(vi) Emergency shutdown and isolation procedures.
(vii) Maintenance procedure and timetable
(viii) Test results and commission data
(ix) Battery record logbook
(x) Generator set record logbook

6.8 Applicable Standards

The following standards are relevant to design, installation and safety of standalone and hybrid solar microgrid systems:

- IEC 62548: Design requirements for Photovoltaic (PV) arrays
- IEC 62257: Standards for small renewable energy and hybrid systems for rural electrification
- IEC 60364: PV power supply systems
- IEC 62305: Lightning Protection
- IS 3403: Code of practice for earthing
- IS 2309: Code of practice for Protection of buildings and allied Structures against lightning.
- IS 732/IEC 60364: Wiring Rules
- IS 875: Minimum design loads on structures - Part 2: Wind Loads.

CHAPTER 7

7 Operation and Maintenance

7.1 Tools required for operation and maintenance

Solar microgrid systems are generally installed in remote locations. Therefore, it is important that all essential tools, spares and consumables are kept in the site ready for use. A list of such tools and materials are listed below. Some systems may require special tools not listed here. In such cases, tools required as per site condition or special tools recommended by the equipment manufacturer should be used.

Person responsible for O&M of solar microgrid systems must familiar and equipped with these tools & equipment. Also, they must be kept in a secured location and maintained properly. Measuring instrument must be checked regularly for its functionality and accuracy.

Table 7.a: List of tools and materials required for O&M of solar microgrid systems

Tools	Needed for			
	Inspection	Troubleshooting	Maintenance	Repair
First aid kit	X	X	X	X
System service logbook	X	X	X	X
Datasheet & O&M manual	X	X	X	X
This manual	X	X	X	X
Paper/Pencil	X	X	X	X
Multimeter	X	X	X	X
Clampon ammeter	X	X	X	X
Hydrometer	X	X	X	X
Screwdrivers	X	X	X	X
Nut drivers 1/4in and 5/16in	X	X	X	X
Measuring tape (25m)	X	X	X	X
Angle measuring device	X	X	X	X
Compass	X	X	X	X
Flashlight	X	X	X	X
Sun Pathfinder	X	X	X	X
Safety goggles		X	X	X
Rubber gloves		X	X	X
Combination square		X	X	X
Wire strippers			X	X
Crimping tool			X	X
Needle nose pliers			X	X
Linesman pliers			X	X

Tools	Needed for			
	Inspection	Troubleshooting	Maintenance	Repair
Diagonal cutters			X	X
DC soldering iron			X	X
Hacksaw			X	X
Battery terminal cleaner			X	X
Battery terminal puller			X	X
Clamp spreader			X	X
Utility knife			X	X
Hammer			X	X
Cell water filler			X	X
Cleaning brush			X	X
Small container			X	X
Caulking gun			X	X

Recommended materials and supplies list for repair or maintenance

- Distilled water
- Baking soda
- Wire nuts
- Crimp connectors
- Ring, spade, and lug terminals
- Load, inverter, and charge controller fuses
- Rosin core electrical solder
- Conduit connectors
- Cable ties
- Rags or paper towels
- Dish soap or pulling grease
- Red and black electrical tape
- Assorted screws and nails
- Cable, wire and/or conduit, as needed
- Silicone sealant

		
Multimeter	Clampon ammeter	Hydrometer
		
Screwdrivers	Nut drivers	Crimping tool set
		
Measuring tape	Angle gauge	Laser distance/ angle meter
		
Compass	Sun Pathfinder	Combination square
		
Battery Safety accessories	Battery water filler	Battery Maintenance kit

Tools and accessories for O&M and troubleshooting of microgrid system

7.2 Preventive Maintenance

A sample maintenance schedule is presented below to indicate typical frequencies of maintenance actions.

Weekly Maintenance:

- Clean PV array from dust, birds drop. Use clean water and avoid hard water.

- Observe battery state of charge (SOC) using hydrometer. In case of VRLA battery use voltmeter to measure voltage to check corresponding SOC.

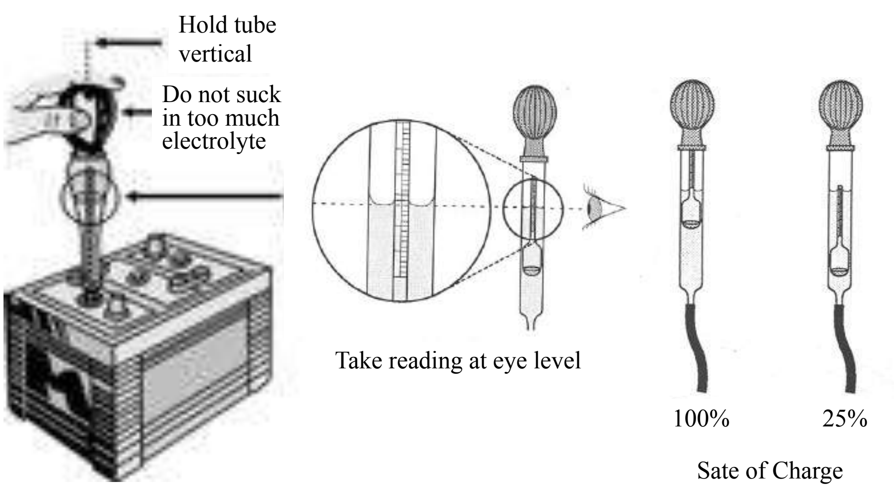


Table 7.b: Typical Battery Voltages as Function of State of Charge

SOC	Specific Gravity	Battery Voltage	
		12 volt	24 volt
100%	1.265	12.68	25.35
90%	1.250	12.60	25.20
80%	1.235	12.52	25.05
70%	1.225	12.44	24.88
60%	1.210	12.36	24.72
50%	1.190	12.28	24.56
40%	1.175	12.20	24.40
30%	1.160	12.10	24.20
20%	1.145	12.00	24.00
10%	1.130	11.85	23.70
0 %	1.120	11.70	23.40

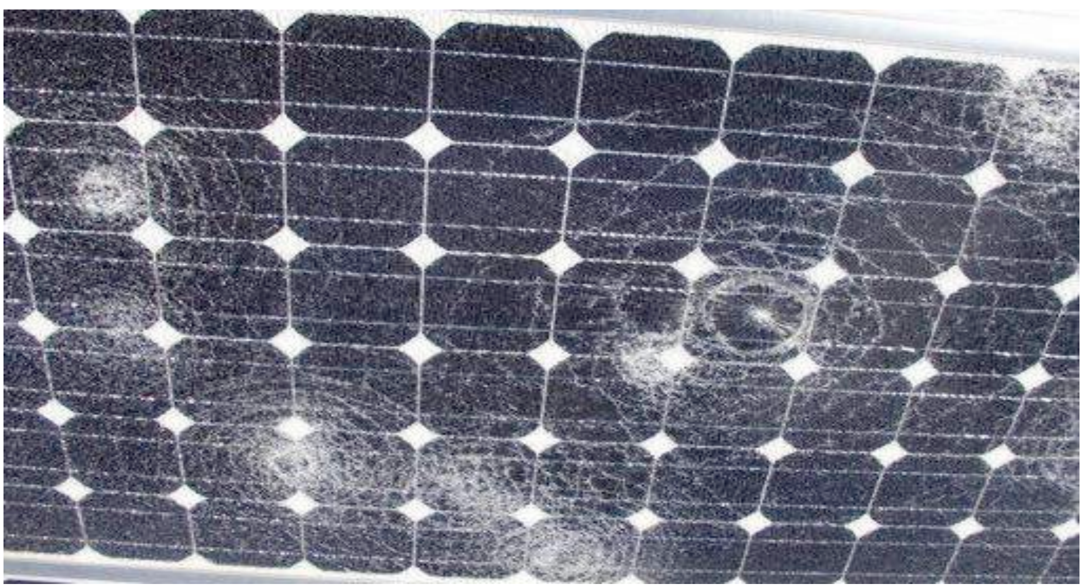
Monthly Maintenance:

- If flooded lead acid batteries are use check electrolyte level and top up if required. Wipe electrolyte residue from the top of the battery.

- Inspect all terminals for corrosion and loosened cable connections. Clean and tighten as necessary. After cleaning, add anti-oxidant to exposed wire and terminals.


- Check if new loads have been added and system is overloaded

- Inspect array for broken modules. If any, replace it with appropriate module



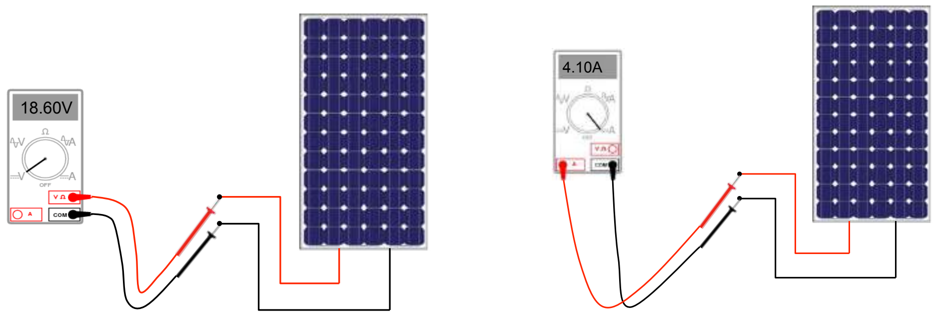
Annual Maintenance:

- Check array wiring for physical damage and wind chafing


- Check array mounting hardware for tightness

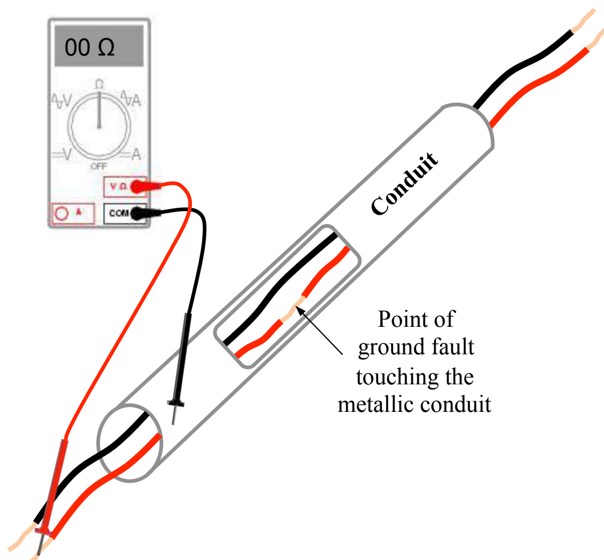

- Inspect inverter - remove dust or dirt, inspect system wiring for poor connections. Look for signs of excessive heating, inspect controller for proper operation

- Verify output from the array (I_{sc} and V_{oc} and if possible I_{mp} and V_{mp})



7.3 Inspection and maintenance of Earthing and Lightening Protection

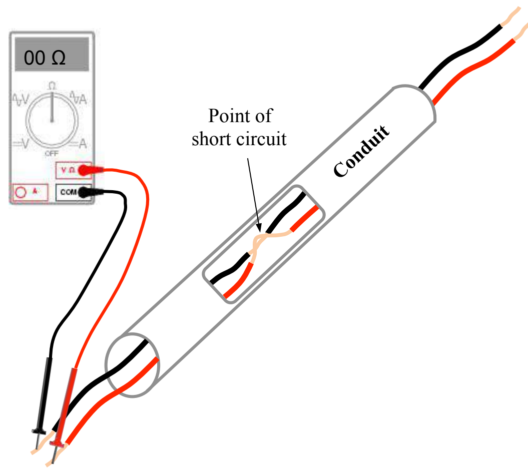
- Use an ohmmeter to check the continuity of the entire grounding system.
- Make sure that all module frames, metal conduit and connectors, junction boxes, and electrical components chassis are earth grounded.



Finding a ground fault

7.4 Inspection and maintenance of System Wiring

- Visually check all conduit and wire insulation for damage.
- Check for loose, broken, corroded, or burnt wiring connections.
- Check if all equipments are connected with proper wire and conduit
- Make sure all wiring is secured, by gently but firmly pulling on all connections.
- Check all terminals and wires for loose, broken, corroded, or burnt connections or components.



Finding a short circuit

7.5 Inspection and maintenance of Batteries

Checking state of charge

A hydrometer describes the state of charge by determining the specific gravity of the electrolyte. Usually, the specific gravity of electrolyte is between 1.120 and 1.265. At 1.120, the battery is fully discharged. At 1.265, it is fully charged.

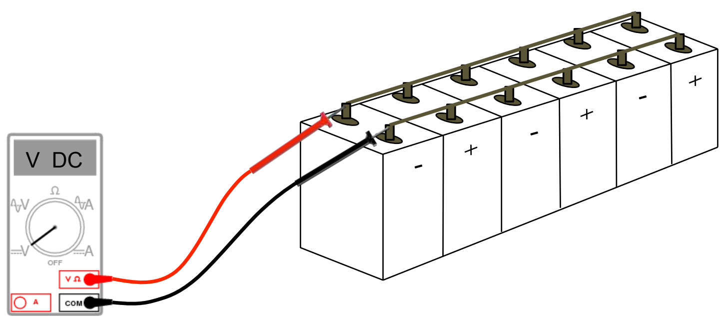
Table 7.c: Battery specific gravity and corresponding state of charge

Electrolyte Temperature (°C)	Specific Gravity Reading and State of Charge				
	SG Reading at 100% SOC	SG Reading at 75% SOC	SG Reading at 50% SOC	SG Reading at 25% SOC	SG Reading at 0% SOC
48.9	1.249	1.209	1.174	1.139	1.104
43.3	1.253	1.213	1.178	1.143	1.106
37.8	1.257	1.217	1.182	1.147	1.112
32.2	1.261	1.221	1.186	1.151	1.116
26.7	1.265	1.225	1.190	1.155	1.120
21.1	1.269	1.229	1.194	1.159	1.124
15.6	1.273	1.233	1.198	1.163	1.128
10.0	1.277	1.237	1.202	1.167	1.132
4.4	1.281	1.241	1.206	1.171	1.136
-1.1	1.285	1.245	1.210	1.175	1.140
-6.7	1.289	1.249	1.214	1.179	1.144
-12.2	1.293	1.253	1.218	1.183	1.148
-17.8	1.297	1.257	1.222	1.187	1.152

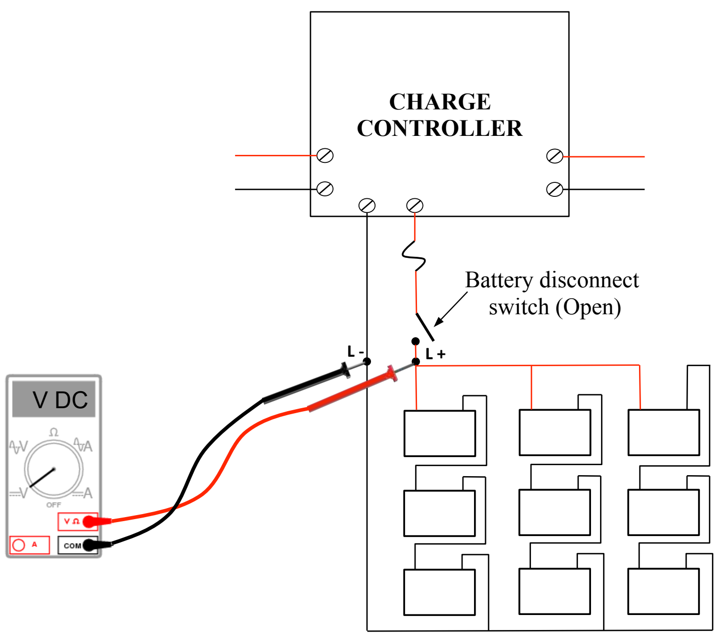
Battery load test:

For this test, an accurate DC voltmeter is required.

- Operate the system loads from the batteries for five minutes. This will remove any minor "surface charge" the battery plates may have. Turn off the loads and disconnect the batteries from the rest of the system.
- Measure the voltage across the terminals of every battery, as shown in Figure below. If external cell connectors are used, measure the voltage across each cell, as shown in Figure. Do not attempt to measure individual cell voltages unless the connectors are external.



Measuring the Open Circuit Voltage of Cells with External Connections



Measuring the Batteries' Open Circuit Voltage

Table 7.d: Battery open circuit voltages and corresponding states of charge

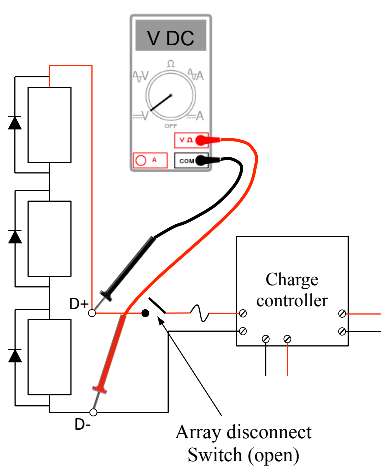
Open Circuit Voltages			**State of Charge**
2 Volt Battery	**6 Volt Battery**	**12 Volt Battery**	
2.12 or more	6.36 or more	12.72 or more	100%
2.10 to 2.12	6.30 to 6.36	12.60 to 12.72	75-100%
2.08 to 2.10	6.24 to 6.30	12.48 to 12.60	50-75%
2.03 to 2.08	6.90 to 6.24	12.12 to 12.48	25-50%
1.95 to 2.03	5.85 to 6.90	11.70 to 12.12	0-25%
1.95 or less	5.85 or less	11.70 or less	0%

7.6 Inspection and maintenance of Solar Arrays

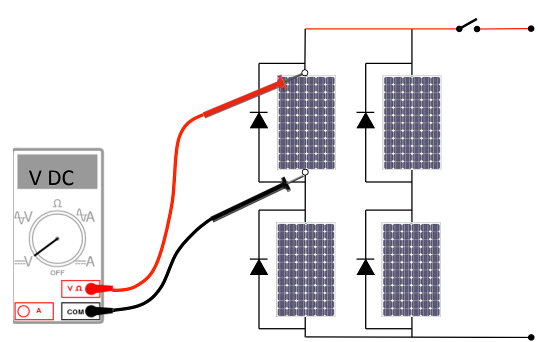
- Use a DC clamp-on ammeter to determine the array output current during a sunny weather.
- Conduit and connections must all be tight and undamaged. Look for loose, broken, corroded, vandalized, and otherwise damaged components. Check close to the ground for animal damage.

Measuring open circuit voltage

- Measure the open circuit voltage of the array as shown in the figure below. Compare the measured amount of open circuit voltage from the array against the manufacturer's specifications.



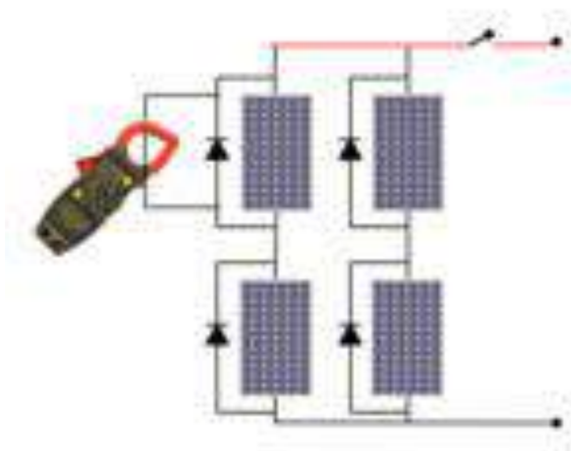
Measuring the open circuit voltage of array



Measuring the open circuit voltage of module

Short circuit current:

- If your DC meter has leads, connect them to the positive and negative terminals of each module and set the meter to the 10A range.



Measuring module short circuit current

7.7 Inspection and maintenance of Inverters

- Check the operation of the inverter at the time of the inspection.
- Measure and record the current draw of the inverter in both idling and operating states.
- Check all inverter wiring for loose, broken, corroded, or burnt connections or wires. Look for potential accidental short circuits or ground faults.

7.8 Hybrid system maintenance

A typical maintenance schedule of diesel engine based generators is given below.

Table 7.e: Example maintenance frequencies- hybrid vs. prime

Maintenance Task	Interval	PV-DG hybrid (500 hours)	Only diesel (8760 hours)
Oil change	250	2 per year	35 per year
Decoke	1,500	1 every 3 years	6 per year
Overhaul	6,000	1 every 12 year	3 every 2 year

7.9 Maintenance of distribution system

Appropriate design and use of good quality components in a microgrid power distribution system is extremely important for overall performance and revenue generation. Undersized distribution cable may cause voltage drop and energy loss in the distribution and low quality components will cause frequent breakdown in power distribution. Both will contribute towards low system performance, revenue loss and poor services to the users.

A periodic verifications and maintenance of distribution system is also essential. The distribution lines, power connections, switchboard and all its equipment may get physically damaged and also continue to degrade whether they operate or not.

The following verification has to be made by a qualified person during installation:

(1) The distribution cables and its components are not exposed to extreme optimum environmental and operating conditions.
(2) There distribution cables, poles, guy wires and isolators and are not subject to any excessive stress and physical damage.
(3) Outdoor joints, connectors, fuses and switches are placed in IP65 rated boxes.
(4) If insulated cables are used, ensure that cables are UV stabilizes and certified to use in outdoor.
(5) Ensure that provision for expansion and contraction is considered for distribution cables due to change in temperature.
(6) Ensure that a galvanized steel wire is used to supports the entire route of distribution line.
(7) Ensure that all safety requirement and regulations are followed based on the voltage level of the distribution system

Preventive maintenance

The table below indicates monthly and annual maintenance operations for microgrid distribution system:

Interval	Maintenance operations
Monthly	Check if there any physical damage to cables, poles or guy wires
1 year	Visual inspection and functional testing, replacement of faulty components, accessories

7.10 Troubleshooting & Repair

The following guidelines are presented for troubleshooting of generic solar microgrid system. A more detailed and project specific guidelines should be created for a specific system with input from the system designer and component manufacturers. Use the troubleshooting tables given below to understand the symptoms, probable cause, results and remedial actions.

Table 7-1: Reference for troubleshooting tables
Table 7-2: Wiring, switches, and fuses
Table 7-3: Loads
Table 7-4: Batteries with low voltage
Table 7-5: Batteries that will not accept a charge
Table 7-6: Batteries with high voltage
Table 7-7: Charge controllers
Table 7-8: Inverters
Table 7-9: Solar arrays

Table 7.1: Reference for troubleshooting tables

Symptom	Refer to the Table
Battery voltage is low	Table 7-2: Wiring, switches, and fuses Table 7-3: Loads Table 7-4: Batteries with low voltage Table 7-5: Batteries that will not accept a charge Table 7-7: Charge controllers
Batteries will not accept a charge	Table 7-2: troubleshooting wiring, switches, and fuses Table 7-3: troubleshooting loads Table 7-7: Charge controllers
Battery voltage is high	Table 7-6: Batteries with high voltage Table 7-7: Charge controllers
Load does not operate at all	Table 7-2: Wiring, switches, and fuses Table 7-3: Loads Table 7-8: Inverters
Load operates poorly	Table 7-1: Reference for troubleshooting tables Table 7-2: Wiring, switches, and fuses Table 7-3: Loads Table 7-5: Batteries that will not accept a charge Table 7-7: Charge controllers Table 7-8: Inverters
Array voltage is zero	Table 7-2: Wiring, switches, and fuses Table 7-7: Charge controllers Table 7-9: Solar arrays
Array voltage is low	Table 7-2: Wiring, switches, and fuses Table 7-9: Solar arrays

Table 7-2: Wiring, switches, and fuses

Symptom	Cause	Result	Action
Load does not operate at all	Switches in the system are turned off or are in the wrong position	PV array electricity cannot be supplied to loads or batteries	Put all switches in correct position
	System circuit breakers or fuses are blown		Determine why fuses or circuit breakers blew or tripped & Reset circuit breaker or replace fuse
Load operates poorly or not at all	There is a high voltage drop in the system	Inadequate voltage to charge batteries or operate loads	Check for undersized or too long wiring.
	Oversized loads a ground fault, or a defective diode		Increase wire size, reduce load size, find and correct ground faults or defective didoes
	Wiring or connections are loose, broken burned or corroded		Repair or replace damaged wiring or Connections.
	Wiring or connections are short-circuited or have a ground fault		Repair short circuits or ground faults

Table 7-3: Loads

Symptom	Cause	Result	Action
Load does not operate at all	Load is too large for the system or Inadequate sun	Shortened battery life, possible damage to loads	Reduce load size or Increase array or battery Size
	The load is turned off Inadvertently breakers tripped	Load does not operate	Repair or replace load Reset switches
	The load is in poor condition. Check for short circuits in load, a broken load, or an open circuit in the load	Shortened battery life, possible further damage to loads	Repair or replace load Check load manufacturer for service information
Load operates poorly or not at all	There is Inadequate voltage at load.	Inadequate voltage to charge batteries or operate loads	Increase wire size reduce load size, find and correct ground faults
	Wiring or connections are loose, broken burned or corroded		Repair or replace damaged wiring
	Small "phantom" load keeps inverter idling, draining battery		Turn off phantom load or replace it with one not requiring PV power
	Wiring polarity is reversed	Loads operate backwards or not at all	Correct wiring polarity

Table 7-4: Batteries with low voltage

Symptom	Cause	Result	Action
No apparent battery defect	Load too large, on too long or Inadequate sun	Battery is always at a low state of charge	Reduce load size or Increase system size
	Batteries too cold	A higher voltage is required to reach full charge	Insulate battery enclosure
Low electrolyte level	Overcharging	Loss of battery capacity	Add distilled water
Voltage below charging resumption setting	Faulty charge controller	Excessive discharge depth	Adjust settings or repair or replace charge controller
Voltage below low voltage disconnect setting	Faulty charge controller	Excessive discharge depth.	Adjust settings or repair or replace charge controller
Voltage loss overnight even when no loads are on	Faulty blocking diode	Reverse current flow at night discharging batteries	Replace diode
Voltage Increasing very slowly even when no loads are on	Controller not in full charge, stuck in float charge	Inadequate current flow to charge fully charge	Repair or replace batteries controller
Voltage not increasing even when no loads are on and system is charging	Otherwise faulty charge controller	Inadequate current flow to charge fully charge	Repair or replace batteries controller
	Loose corroded or broken wiring	No power from array going into batteries	Close switch, reset circuit breaker, or replace fuse
	Switch, circuit breaker, or fuse open, tripped or blown	Less power from array going into batteries	Repair or replace damaged wiring
	Shaded modules broken cell or disoriented modules	Array output reduced	Remove source of shading, replace module or correct module orientation
	Wiring too long or undersized	Voltage reduced	Increase wire size
Voltage just above charge resumption setting but controller not charging batteries	Faulty or misplaced temperature probe or poor connection at "battery sense" terminals on charge controller	Charge controller thinks batteries are cooler than their actual temperature	Repair, replace or reposition probe Reset controller dial or replace controller

Table 7-5: Batteries that will not accept a charge

Symptom	Cause	Result	Action
No apparent battery defect	Load too large, on too long or Inadequate sun	Battery is always at a low state of charge	Reduce load size or Increase system size
High water loss	Overcharging	Heat damage to plates and separators	Replace battery, repair or replace charge controller
Electrolyte leakage shorts	Broken, leaking container	Sulphation, lead sulfate	Replace battery
Muddy electrolyte material, shorts between plates	Age	Shedding of plate	Replace battery
Discolored or odorous electrolyte	Contaminated electrolyte	Battery failure	Replace battery
No symptoms other than not accepting a charge	Undercharging, usually without adding water	Sulphation, possibly lead sulfate shorts between plates	Replace battery
	Left uncharged too long	Sulphation, or plates hard when scratched	Replace battery
	Cracked partition between cells	Discharge between adjacent Replace battery cells	Replace battery
	Hammering cable connections on to terminal posts	Shorts between terminal post strap and plates, electrolyte leak	Replace battery
	Misaligned plates and separators	Treeing shorts between bottoms of plates	Replace battery
	Plate material carried to top of plates	Mossing shorts between tops of plates	Replace battery
	Shorts between plates and straps	Grid top broken and moved upward to strap. Lead rundown from strap to plate	Replace battery
	Overcharging	Disintegration of positive plates	Replace battery
	Specific gravity and temperature too high for too long	Soft negative plates	Replace battery
	Too many shallow charging cycles	Cracked negative plates	Replace battery

Table 7-6: Batteries with high voltage

Symptom	Cause	Result	Action
Voltage over charge termination setting and/or high water loss	Faulty or nonexistent charge controller	Shortened battery life, possible damage to loads	Replace with charge controller with lower charge termination setting
	Battery storage too small for array	Shortened battery life, possible damage to loads and batteries	Install more batteries
	Misadjusted charge controller	Shortened battery life, possible damage to loads and batteries	Adjust charge controller
	Mismatched battery and voltage regulator	Shortened battery life, possible damage to loads and batteries	Replace charge controller, or change setting on adjustable units
	Batteries are cold and charge controller has temperature compensation	Shortened battery life, possible damage to loads	Insulate batteries, or move to warm environment
High water loss	Batteries are too hot	Voltage at which gassing starts is lower than normal	Insulate battery enclosure, and /or provide ventilation
	Infrequent maintenance	Low water levels, battery damage	Shorten maintenance interval
Voltage only slightly above charge termination setting	Faulty or misplaced temperature probe or poor connection at "battery sense" terminals on charge controller	Charge controller thinks batteries are warmer than their actual temperature	Repair, replace, or reposition probe

Table 7-7: Charge controllers

Symptom	Cause	Result	Action
Battery voltage below charge resumption setting	Faulty charge resumption function in charge controller	Excessive battery discharge.	Repair, readjust or replace charge controller
Battery voltage just below charge resumption setting, but controller not charging batteries	Faulty or misplaced temperature probe or poor connection at "battery sense" terminals on charge controller	Charge controller thinks batteries are cooler than their actual temperature	Repair, reposition or replace probe
Battery voltage below low voltage disconnect setting	Faulty low voltage cut-off in charge controller	Excessive battery discharge	Repair or replace charge controller
Battery voltage are low overnight even when no loads are ON	Faulty blocking diode, no diode or faulty charge controller	Reverse current flow at night, discharging battery	Replace or add diode, or repair or replace series relay charge controller
	Old or faulty batteries	Batteries self discharging	Replace batteries
Battery voltage not increasing even when no loads are on and system is charging	Otherwise faulty charge controller	No power from array going into batteries	Repair, replace charge controller
Battery voltage over charge termination setting and/or high water loss	Faulty or non existing charge controller	Shorten battery life, possible damage to loads and batteries	Repair or replace charge controller and possibly batteries
	Misadjusted charge controller	Shorten battery life, possible damage to loads and batteries	Repair or replace charge controller and possibly batteries
	Mismatched battery and voltage regulator	Shorten battery life, possible damage to loads and batteries	Change charge controller or change setting on adjustable units
	Controller always in full charge, never in float charge	Shorten battery life, possible damage to loads	Repair or replace charge controller and possibly batteries
Battery voltage just above charge termination setting, but controller still charging batteries	Faulty or misplaced temperature probe or poor connection at "battery sense" terminals on charge controller	Charge controller thinks batteries are cooler than their actual temperature	Repair, replace or reposition temperature probe or change charge controller
Buzzing relays	Too few batteries in series	Voltage is low	Reconfigure or add batteries
	Loose or corroded battery connections	High voltage drop	Repair or replace cables
	Low batter voltage	See table 7-4 for more information	Repair or replace batteries
Erratic controller operation and/or loads being	Timer not synchronized with actual time of day	Controller turn on and off at wrong times	Either wait until automatic reset nest day or disconnect array wait

disconnected improperly			10seconds and reconnect array
	Electrical "noise" from the inverter	Rapid on and off cycling	Connect inverter directly to batteries, put filters on load
	Low battery voltage	System shutdown	Repair, replace battery
Erratic controller operation and/or improper load disconnection	Faulty or misplaced temperature probe or poor connection at "battery sense" terminals on charge controller.	Charge controller thinks batteries are cooler than their actual temperature	Repair, reposition or replace temperature probe or charge controller
	High surge from load	Battery voltage drops during surge	Use large wire to load or add batteries in parallel
	Otherwise faulty charge controller, possibly from lightning damage	Loads disconnected improperly, other erratic operation	Repair or replace charge controller and check system grounding
	Adjustable low voltage disconnect set incorrectly	Loads disconnected improperly	Reset low voltage setting
	Load switch in wrong position on controller	Loads never disconnected	Reset switch to correct position
	Charge controller has low voltage disconnect feature	Loads never disconnected	If necessary replace charge controller with one with a low voltage disconnect feature
Fuse to array blows	Array short circuited with batteries still connected	Too much current through charge controller	Disconnect batteries when testing array's short circuit current
	Current output of array too high for charge controller	Too much current through charge controller	Replace charge controller with one with a higher rating
Fuse to load blows	Short circuit in load	Unlimited current	Repair short circuit or replace load
	Current draw of load too high for charge controller	Too much current through charge controller	Reduce load size or Increase charge controller size
	Surge current draw of load too high for charge controller	Too much current through charge controller	Reduce load size or Increase charge controller size
"Charging" at night	Normal operation for some charge controller upto two hours after dark	No appreciable energy loss	Check the system later that night
	Timer not synchronized with actual time of day	Controller turn on and off at wrong times	Either wait until automatic reset next day or disconnect array, wait 10 seconds and reconnect

Table 7-8: Inverters

Symptom	Cause	Result	Action
No output from the inverter	Switch, fuse or circuit breaker open, blown or tripped or wiring broken or corroded	No power can move through inverter	Close switch, replace or reset fuse or circuit breaker or repair wiring or connections
	Low voltage disconnect on inverter or charge controller open	No power available to inverter	Allow batteries to recharge
	Time delay on inverter start-up from idle	Few seconds delay after starting load	Wait a few seconds after starting loads
	High battery voltage disconnect on inverter open	Inverter does not start	Connect load to batteries and operate it long enough to bring down battery voltage. Adjust high voltage disconnect on charge controllers
Motors running hot	Square wave inverter used	Harmonics of wave form rejected as heat	Change to DC motors or use inverters with quasi-sine or sinusoidal waveform
Loads operating improperly	Excessive current draw by load	Voltage from inverter too low for load	Reduce size or loads or replace inverter with one of large capacity
	Square wave inverter used	Load operate improperly	Change to DC motors or use inverters with quasi-sine or sinusoidal waveform
	Defective inverter	Load do not operate	Replace inverter
Motors operating at wrong speeds	Inverter not equipped with frequency control	AC frequency varies with battery voltage	Replace inverter with one equipped with frequency control
Inverter circuit breaker trips	Load operating or surge current too high	Excessive current draw by load	Reduce size of loads or replace inverter with one of larger capacity
Inverter DC circuit breaker trips	Inverter capacitors not charged up on initial start up	Excessive current draw by inverter	Install momentary contact switch and 15ohm, 50 watt resistor in parallel with the circuit breaker, use it for a few seconds to charge capacitors on first start up

Table 7-9: Solar arrays

Symptom	Cause	Result	Action
No current from array	Switches, fuses or circuit breaker open, blown or tipped or wiring broken or corroded	No current can flow from array	Close switches, replace fuses, reset circuit breakers, repair or replace damaged wiring
Array voltage low	Some modules shaded	Drop in output current	Repair source of shading
	Some array interconnections broken or corroded	Drop in output current	Repair interconnections
	Defective bypass or blocking diode	Drop in output current	Repair defective diodes
	Some modules damage or defective	Drop in output current	Replace affected modules
	Full sun not available	Drop in output current	Wait for sunny weather
	Modules are dirty	Drop in output current	Wash modules
	Array tilt or orientation incorrect	Drop in output current	Correct tilt and/or orientation
No voltage from array	Switches, fuses or circuit breaker open, blown or tipped or wiring broken or corroded	No power can move from array	Close switches, replace fuses, reset circuit breakers, repair or replace damaged wiring
Array voltage low	Some modules in series with others disconnected or bypass diode defective	Drop in array voltage	Repair, replace modules, connections or diodes
	Wiring from array to balance of system undersized or too long	Drop in array voltage	Reduced undersized wiring

CHAPTER 8

8 Operation & maintenance of microgrid system (commercial)

8.1 Day-to-day operations

A microgrid facility runs smoothly on the freely available sunshine. Power thus generated is distributed over a small distance from the battery bank to households. The number of hours for which the power is supplied may vary between 5-8 hours per day. Each household gets lighting via the highly energy efficient light emitting diodes. These are expected to last for up to 50,000 hours. LED lighting brings down the power consumption by as much as 90%. Each household gets between 2-4 such lamps besides a charging point for the mobile phone. This is the way a typical village based micro grid operates on a daily basis. Rural electrification committee may help in running a micro grid alongside the entrepreneur and franchise company.

Microgrid presents a wholesome opportunity to take up the following few types of business activities. All of these however, may not be exactly fit to locate closest to the microgrid facility.

- Small businesses like grocery shops
- Weaving and crafting
- Mobile money transfer outlets
- Water pumping for micro irrigation
- Poultry firms
- Automatic teller machines (ATM)
- Mobile communication towers
- Petrol Pumps
- Computer kiosk
- Rice huller and thresher
- Flour and spice milling machines

8.2 Maintaining service manual

A service manual is kept at the micro grid facility. It list the steps needed to keep the facility in a good condition. There are different types of service manuals such as a) instructional manual, b) repair manual and c) record manual. It is very important to maintain a service manual which may include information under the following few heads mainly:

- Type of system installed
- Key components of the system
- Brief function of each such component
- Technical details i.e. specifications of these components
- Operating principle of the system
- Reference values of key parameters
- Do's and Don'ts

8.3 Billing and revenue collection

Micro-grids use different revenue models. These models take into account the daily electricity consumption. Users choose one such model out of many. There is a choice of buying the electricity in advance. It is much like the pre-payment facility for the mobile phones. Electricity that is used by each user is kept track of. On the basis of which, billing amount is worked out. Electricity fees is thus collected from the users on a regular basis. At present, multiple models and tools such as the pre-payment and digital meters are being made use of. This brings down the cost of transaction and increases payment rates and revenues. In totality the billing together with revenue collection forms a very important part of a solar micro grid in India.

Table: Record of Revenue Collection from the beneficiaries of Solar Micro Grid at-----------

A: Fixed Type Load

Sl. No.	Customer ID	Daily Load under use	Monthly payment fixed	Monthly Amount Paid
1				
2				
3				
4				

B: Non-fixed type Load

Sl. No.	Customer ID	Daily Energy Consumption	No. of units consumed	Total monthly amount due
1				
2				
3				
4				

8.4 Settlement of billing issues

Microgrid business is basically a service business. It requires a robust operation and maintenance along with a payment collection setup. The microgrids are mainly the plants running often in remote areas. There are virtually little or no facilities in the villages. The poorest of the poor are expected to spend between Rs.100 - Rs.200 per month. It can be termed as a low spending on electricity. Thus the customer profile is very demanding.

Bill settlement

Do's

- Carry out a background check of the customers-even though it may sound a weird idea.
- Verify if, the load being used is being utilized in full or partially.
- If, partially, seek to reduce it so as to keep the bill amount low.

Don'ts

- Try not to cut off the power supply to the customer with genuine difficulty to pay the bill.
- Try not to publicize the name of such a non-paying household amongst the other beneficiaries.
- Try not to show some special favour to a community headman via the micro grid in any manner.

8.5 Maintaining complaint book from client

A customer is key element of a micro grid system. After all, he is the one to use it on a daily basis. The entrepreneur of a micro grid is expected to keep a complaint book. It encourages the users to note down any issues, problems or even doubts about the daily use of a micro grid facility. A well maintained micro grid facility is a good enough record. Entry. Every complaint booked by a client is generally looked into for an early solution.

Sl. No.	Date of Complaint Registration	Name of the Complainant	Type of Complaint made	Estimated Time for Repairs etc.	Name of the Technician/ Engineer entrusted with the complaint	Date/ Time of Attending the fault	Type of fault actually detected	Brief details about the fault repairs	Functional status of the connected load at household level
1									
2									

8.6 Communicating to the users regarding variation of solar energy availability and dependence of performance of system accordingly

- The amount of sunlight varies across the day.
- The amount of solar radiation received is the highest at noon time.
- Solar module is the power producing part of a micro grid system.
- Solar module surface should always be kept clean.
- Solar module should not be shaded in any way.
- Solar module should not have any kind of shadow on it.
- Dust, dirt, shading, shadowing all reduce the amount of power that is finally available from a solar module.

CHAPTER 9

9 Challenges & risks of solar microgrid projects

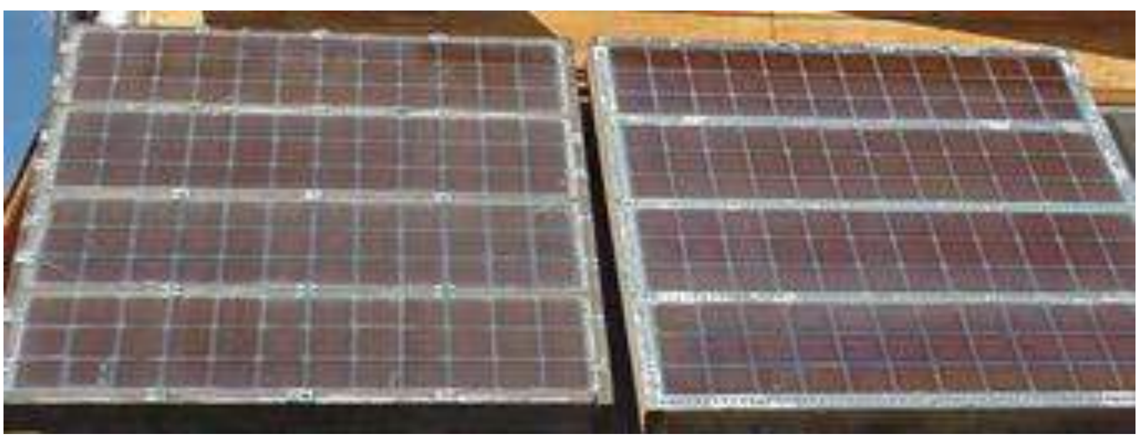
A solar microgrid is not entirely a new idea in the making. In fact, facility of this kind was put years before in the Sundarbans islands of the eastern state of West Bengal. However, there are several issues which need to be resolved sooner than later. A brief treatment of the identified issues is presented below for a serious consideration by the stakeholders.

9.1 Issues related standards and compliances

A micro grid usually comprises of a distributed energy resource (i.e. solar in this case) together with advanced control system, load management, energy storage and importantly, network communication. There is design cum performance available in respect of these components, which are to be complied with so as to ensure real gain from the microgrid.

Issues due to non-adherence of standards:

- Amount of power available from a solar module may reduce
- Solar module may not last long
- System may not work in a reliable manner
- System may not be safe to use in full



Poor quality solar modules degrades fast

Following is a brief run-through of the applicable standards for the power producing part i.e. the solar modules and balance of system components:

Solar Module

The solar modules must confirm to the latest edition of any of the following IEC/equivalent BIS standard for PV module design qualification and type approval.

a) Crystalline Silicon terrestrial Modules IEC 61215
b) Thin film terrestrial Modules IEC 61646
c) Concentrator Modules & Assemblies IEC 62108

BoS Item/ Component	Applicable IEC/ Equivalent BIS Standards	
	Standard Description	Standard Number
Inverters	Efficient measurement environmental testing	IEC 61683 IEC 60068 2
Charge Controller	Design qualifications environmental testing	IEC 62093 IEC 60068
Storage Batteries	General requirements and methods of test tubular lead-acid	IEC 61427 IS 1651/IS 13369
Cables	General test and measuring methods PVC insulated cables for working voltages up to and including 1100 V	1EC 60189 IS 694/IS 1554 IS/IEC 69947
Switches/Circuit Breakers/Connectors	General requirements Connectors-safety	IS/IEC 60947 EN 50521
Junction Boxes/Enclosures	General requirements	IP 65 (for outdoor) IP 21 (for indoors)
SPV System design	PV Standalone system Design verification	IEC 62124
Installation practices	Electrical installation of building requirement for SPV power supply system	IEC 60364-7-712

9.2 Quality of component and workmanship

Majority of micro grid developers happen to be the private entrepreneurs. Quality component selection, well-designed component assembly and reliable component engineering are very important factors to ensure good quality of a solar micro grid facility. Suitable quality workmanship also ensures smooth operation of the micro grid over its expected lifetime

- Solar microgrid is usually positioned in a remote area. Thus, it all the more important to design and develop fully reliable working system.
- Quality components if, not used may lead to their frequent replacement.
- Frequent replacement may make the system operation and maintenance cost higher.

- Poor workmanship does not result in a well performing system.

Poor quality structure and foundation

9.3 System protection and safety

A micro grid is made of a low voltage distribution system with a distributed energy source. Such a source could well be solar PV in the present case. It is very important to protect a micro grid in both the grid connected and the island mode of operation against different types of defects. The safety design concept is equally important in a micro grid protection and their fault analysis. The safety model offers suitable level of confidence in protection system. Further the intelligent control and monitoring unit need to meet the safety requirements on the basis of a safety design criteria.

For a micro grid safety design, six type of parameters are to be considered. These include:

- *Sensitivity*
  It simply means there should be some nominal threshold value. Further the control/protection system is able to identify any abnormal condition.
- *Selectivity*
  It means that when any fault is detected in a system based on voltage, current and power direction fault zone is determined. Simply put, smallest part containing the fault should be disconnected.

- *Speed*
  It simply means to act in the least possible time in any abnormal condition. The purpose is to avoid any damage to equipment and maintain stability.
- *Security*
  It simply means that security level should be high. The protection/control system should run only when there is a need to operate.
- *Redundancy*
  The redundant systems are planned and simply mean backup protection. Simple idea is to ensure the desired level of safety.
- *Reliability*
  The distributed generation systems i.e. a Micro grid is becoming a more dynamic structure. So reliability should be high while dealing with control and protection system analysis.

Improper design and installation can cause fire in a PV system

Do's

- Use a good quality load limiting device to stop misuse
- Use a pre-payment card which can not be changed in any manner
- Maintain voltage level for equipment safety
- Use a cluster based household feature so as to identify a wrong doer easily
- Make the users aware about not fiddling with the Micro grid system more so in the absence of a technician.
- Do keep the system installed area safe and secure i.e. via fencing etc.
- Do keep the safety and protective features related spares available at the system area.

Don'ts

- Do not allow any one to tamper with the distribution line
- Do not think of laying the wires/cables underground
- Do not use the lighting device i.e. LED's of miniscule power capacity
- Do not allow any user to repair any broken link etc. when the technician may not be present in the plant area

9.4 Issues related to appropriate use

Majority of standalone PV systems are generally put up in the rural areas. These are designed to meet a bare minimum load of an individual household. The load thus powered could be lights, fan, TV or lately a cell phone charger. Few households at times may like to run a tape recorder for example. This cannot be called as an appropriate or suitable use of a micro grid facility. In a few cases, few may try to connect directly some non-designated load to a battery for example. This can lead to some damage to the battery. On a micro grid community level, wire/cable may be snapped just for a small tiff off with an entrepreneur. Well, novel technological solutions have been found to problems like these. The simple idea is to keep the system running smoothly.

- Installations of a solar microgrid say for example for a household sample of between 20-30 households takes just a day or two. So, it is very important to do this appropriately.
- A micro grid facility can be scaled up much faster than any other power option. Thus, it is desired practice to test each and every component suitably.
- It is far better for a user to get connected to a micro grid rather than go for a solar lantern use. The lantern means having a high initial cost for the user. Thus it is more appropriate not to buy a lantern.
- Only such loads as have been initially recommended should be put to use.
- Any occasional demand for more power should be requested for in appropriate terms/situations.

Explain how microgrid system can be affected by inappropriate use of appliances due to limited source of energy and battery storage and provide some bullet points what should not be done in terms of using loads.

9.5 Issues related to battery storage capacity and limitation

Rural areas generally need lighting after the sunset. This leads to the use of batteries in a micro grid facility. Batteries store solar power during the daytime. Several issues exist with the use of battery storage. These mainly include the following few:

- Lead-acid battery has been the most widely used battery in rural areas. Be it for a standalone system like an indoor or outdoor lighting system.
- Lead-acid battery does not last longer. However, the flooded lead-acid type cost less than lithium-ion batteries.
- Batteries need to be topped up with distilled water and thus not so easy to maintain.
- 2V cells are suitable for a higher capacity micro grid. However, these are quite heavy to move and place in a typical rural surrounding.

Battery is still thought of as a weak link in a solar system. Today, a wide range of batteries are available in varying designs, capacities, charging/discharge efficiencies, daily hours of use, etc.

- Battery unit should be of a standard make only. Do not try to use a non-standard make battery.
- Battery is prone to explosion if, made with any sub-standard material.
  Battery should be housed properly in a well-ventilated environment.

9.6 Issues related to revenue collection

Any user of a micro grid facility is expected to pay the monthly bill. He also has the choice of buying an electricity card in advance. This is more commonly known as a pre-payment card. However, every user may not be willing to do so. They may like to pay the electricity bill on a monthly basis but refuse to do so later on. Thus it leads to a serious issue in a regular collection of revenue. The revenue collection could also get affected if; the system fails to work properly?

- Selection of the user community should be done with sufficient care.
- Individual user attention is important to understand the load choice, any additional load demand, capacity to pay on a regular basis etc.
- Identification of any such user from a chosen cluster as may be different from the rest in terms of a) affordability, b) availability of appliances, c) habitation etc. The intention is to determine the possibility of system misuse in any possible manner
- Any customer failing to make the monthly payment must be encouraged to keep on paying even on extended timelines.
- Customers need to be made aware about the revenue stream and the critical need to collect the revenue as per a laid out time cycle.

9.7 Issues related to handling customers

A micro grid can be run in several ways. It offers the facility of buying electricity in advance. A pre-payment card does this trick much like the working of a mobile phone. However, non-customers can steal the electricity. Flat monthly rates can also be fixed. Some customers may not pay at the end of a normal billing cycle. A ready solution is to make use of load limiting devices etc.

- Make an on-the-spot assessment of demand fulfilment of power at an individual level
- Make the user understand about grid power not landing up any time soon
- Make the user know about the disadvantages of using energy choices such as candles, kerosene oil lanterns etc. in quite clear terms.
- Try to understand difficulties if, any being faced by the non-paying customer?
- Make all out efforts at removing the conveyed difficulty.

9.8 Issues related to variation of energy supply due to variable weather conditions

The amount of energy got from a solar micro grid can vary on a day-to-day basis. Several reasons could lead to one change or the other in the amount of energy generated.

There are two main types of uncertainties which have some effect on the power system operation. One of these is the outage of generation unit and b) departure from the forecasts. The first one could possibly lead to a supply shortage in a system. Any deviation from the forecasts due to uncertain loads and integration of renewable energy sources may add additional operational uncertainty. Wind and solar generation usually depend on wind speed and solar generation. These are more important in micro grids owing to the high penetration levels of such resources.

Variable weather conditions

Solar energy generation at a location does not depend only on solar irradiation. Several factors affect the amount of energy generation on a daily/weekly/monthly /yearly basis.

These may be listed below as:

- Altitude of the place
- Ambient temperature
- Wind velocity
- General weather conditions
- Soil conditions

A technician is the force behind keeping a micro grid facility in a good working condition. He does not have any control over the sunshine availability as such. However, he can keep the solar modules clean so as not to lose any power due to dust/dirt.

CHAPTER 10

10 Managing microgrid business

10.1 What does an entrepreneur need to set up a microgrid business?

A micro grid is generally set up in a rural area. Rural area offers its own opportunities and challenges. Thus it is not an easy task for an entrepreneur. Anyway he needs to take up the following type of activities:

- Finding a suitable location
- Collection of baseline data
- Site selection
- Preparation of detailed project report
- Installation of system
- System upkeep (i.e. operation and maintenance)
- Collection of revenue

10.2 Economics of a microgrid system

Many factors have one effect or the other on economics of a microgrid. The life cycle costs, tariffs and bills depend on the following few parameters:

- Load
- Capital cost of the system
- Running cost
- Financing (which also includes in how much time the capital cost can be got back)
- Tax related benefits
- Tariff structure

Economic feasibility is about the willingness to pay. Willingness for the essential services generally ranges from Rs.100 to Rs.200 per month. While as for higher service (i.e. more electricity use), it ranges between Rs.300 – Rs.500 per month.

Case specific example on setting up a Microgrid

A micro grid is basically a standalone unit. It usually meets the bare minimum power requirements for household sizes ranging between 25-60 households. Key components of a micro grid are the solar modules, battery besides a control cum monitoring device. Take a case specific example of a micro grid design requirements for a household size of 35. Two modules of 120Wp each together with two storage batteries would suffice. The estimated system cost comes to around Rs.35000. The households can get power access for about 7 hours daily. The load appliances in this case are 2 LED lamps with a connection for charging of mobile phone. As per the available information, operational costs for a microgrid like this do not count much. Yes maintenance is needed on an occasional basis. It generally takes anywhere between 3-5 years for a micro grid developer to recover his cost. These micro grids in a way do not face much competition in a typical rural environment. This is so as the user community does not have any other choice (s) in terms of energy use.

10.3 Developing of a Business Plan

A business plan is a very important part of a Micro grid activity. There are several models available today to set up a micro grid as under:

- *Purchase of the product*: A consumer makes a down payment for the small amount of electricity. Electricity thus received is to be commonly used for lighting and charging a mobile phone. The facility is linked with a smart meter.
- *Regular payment:* The consumer makes a cash payment to a designated payment point. It could well be a local shop or entrepreneur.
- *Credit Recharge*- The payment point sends entrepreneur the customer identification and recharge information. In turn, consumer receives the recharge code
- *System unlock*: The consumer uses the recharge code to unlock the system and gets energy credits. The consumer can use the facility for as long as the energy credits allow.
- *System lock*: The meter simply locks the system after the consumers energy credits have run out

10.4 Understanding government policy and plan

A micro grid came into being several years back. Many policies have been put into place to support rural area electrification by the government. Special attention was given to decentralized models such as the Micro grids. The concerned govt. departments are providing subsidies and grants etc. Simple purpose is to make the micro grids useful within the rural areas. The government is keen to provide all Indians with reliable 24×7 power. There are still 300-400 million Indians without any electricity benefit at all. The govt. is planning to extend the grid to electrified households as far as possible. It is also trying to develop the micro grids on a large scale. However, it is important to keep in view the following few factors:

- Speed of development
- Cost of reliable power (kWh)
- Climate effect of each choice

The Govt. of India has put in place various schemes and programmes for rural electrification from time to time. Table below lists such initiatives along with the implementation agency

Initiative	Implementation Agency
Electricity Act 2003	Ministry of Power
Remote Village Electrification Programme	Ministry of New and Renewable Energy
Rajiv Gandhi Grammen Vaidyutic Yojanan	Ministry of Power
Village Energy Security Programme (VESP)	Ministry of New and Renewable Energy
Jawaharlal Nehru National Solar Mission	Ministry of New and Renewable Energy

10.5 Building relationship with the suppliers

Today there are many suppliers of energy solutions in the country. It is important for an entrepreneur to develop good business relationship with the suppliers. An entrepreneur gets and assembles different components and installs the complete facility. The suppliers on their part are trying to offer the quality component use. So, relationship between a micro grid developer and supplier is growing by the day.

- Frame carefully the technical specifications for the intended range of equipment with the supplier
- Carry out a basic check on the market standing of a supplier
- Match the rated values of the components/sub-components with the actual requirements.
- Discuss the comparative availability of the best available micro grid specifics with other suppliers.
- Put together the needed micro grid system configuration for extensive pre-testing before actual installation.

10.6 Where and how does an entrepreneur raise the finance?

A simple challenge for the entrepreneur is to have some funds. The micro grid is still evolving. The banks are not quite willing to lend money to an entrepreneur. Present day trend is to raise the finance via a mixture of grants and equity. The micro grid business is a low revenue one. It makes sense to have more micro grids to put up. In a few cases, entrepreneurs have got access to bilateral and multi-lateral funding sources. It has also helped them to work closely with some more experienced organisations too.

10.7 Day-to-day operations of a business

- Make a daily note of the key activities related with micro grid operation through the day and night.
- Display prominently the list of customers associated with the micro grid facility.
- Raise awareness about the gains available from the system in the surrounding areas.
- Analyze the system operation data to generate daily/weekly/monthly performance reports. This is needed to know the strengths and weaknesses alike under the actual field operating conditions.

10.8 Marketing and sales skill

- A grass root worker is best suited to take up the role of a marketing and sales person
- Familiarize the worker with the manner in which the system actually works
- Identify the weak learning skills from an extensive field check of the worker
- Do not necessarily seek the services of those who can neither understand nor communicate easily with the user community.
- Do not try to convince the users about using more loads than they feel is necessary

10.9 Handling questions from clients and consumers

- Listen to the questions minutely
- Try to note down the same in a register that may be specifically kept for the purpose
- Use the interactive sessions to understand the adequacy/inadequacy of the system related gains perceived by the client
- Do not discourage the consumer from putting up even the very basic questions
- Do not try to put up the solution without a verification check that may well be needed for the purpose

10.10 Business expansion plan

A microgrid is best suited to a rural environment. However, it is also the one where the affordability amongst the potential user community is a big issue. There is an increasing migration of the rural youth into the city areas. It also leads to availability of more appliances within a household at times. Importantly, the business expansion plan may derive its main strength by some income generating activities for the community. Following few type of activities may make some business sense:

- Flour grinding
- Oil extraction
- Yarn spinning
- Cash crop irrigation
- Any such activity that can be based on local resource availability whether from the field or an adjoining forest for that matter.

CHAPTER 11

11 Use of mobile application for troubleshooting & repair

Troubleshooting Master Sheet

Symptom	Refer to
Load operates poorly or not at all	TR-1
Battery voltage constantly remain low	TR-2
Batteries do not accept charge	TR-2
Battery voltage constantly remain high	TR-2
Buzzing relay	TR-3
Erratic controller operation	TR-3
Fuse blown	TR-3
Showing charging at night	TR-3
No output from inverter	TR-4
Problem with inductive loads	TR-4
Tripping of inverter/ switch	TR-4
No current from array	TR-5
No voltage from array	TR-5
Low voltage from array	TR-5

A mobile application has been developed in android platform to address troubleshooting and repair procedure as discussed in the chapter 7.

Technicians will require a smart phone to operate this application.

The first screen of the application is the "Troubleshooting master sheet" where technician will select the reference table based on the symptoms given in the left side of the screen.

There are five troubleshooting & repair tables referred as TR-1, TR-2, TR-3, TR-4 and TR-5. Corresponding area of troubleshooting and repair has been indicated in the table below.

Respective tables will guide the technicians to check and understand the cause of problem and take necessary remedial action to make the system functional.

The application is available at google play store and one can download at free of cost. Search at google play store using key word "solar troubleshooting app" or click in the link below:

https://play.google.com/store/apps/details?id=com.netsoftsolution.tatasky&hl=en

CHAPTER 12

12 Reference video clips

The following selected videos clips are referred as useful audio-visual learning tool in the context of this manual. These videos clips are sourced from www.youtube.com.

12.1 Use of multimeter

This video clip demonstrates how to use an analog and a digital multimeter.

12.2 Tools and procedures for MC4 connection

This video clip demonstrates step-by-step procedure and tools required for making an MC4 and/or equivalent connector.

12.3 Module interconnection

This video clip demonstrates how to connect two modules in series and parallel with the help of MC4 connectors

12.4 Batteries interconnection

This video clip shows how to make battery series and parallel connections

12.5 Battery maintenance

This video clip demonstrates step-by-step procedure and tools required for maintaining flooded electrolyte deep cycle batteries.

12.6 Installation of earth pit

This video shows how to install an earth pit

12.7 AC arc vs. DC arc

This video shows the difference between AC arc and DC arc and why DC current arc can potentially cause fire if not installed properly.

12.8 AC circuit breaker vs. DC circuit breaker

This video shows difference between AC and DC circuit breakers and why AC circuit breaker does not qualify to be used in DC applications.

12.9 Sun pathfinder

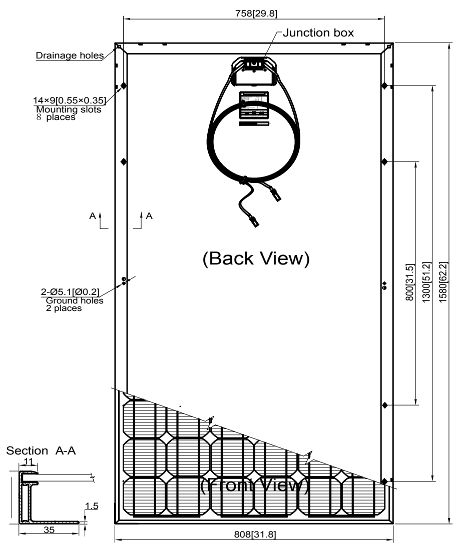
This video demonstrates the use of a sun pathfinder for site analysis and how to find a shadow free location for installation of solar array.

CHAPTER 13

13 Reference datasheet and tables

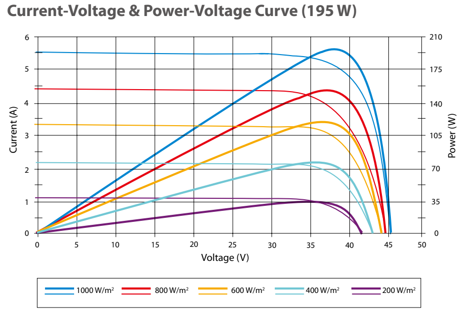
The datasheets and tables presented below are for reference purpose only. For actual practice in the field technicians are to use datasheet of actual equipment and tables need to be customised according to the system type and configuration.

13.1 Typical datasheet for PV module



Note: mm [inch]

Current-Voltage & Power-Voltage Curve (195 W)



Electrical Characteristics

STC	PLUTO200-Ade	PLUTO195-Ade
Optimum Operating Voltage (Vmp)	37.9 V	37.6 V
Optimum Operating Current (Imp)	5.28 A	5.19 A
Open - Circuit Voltage (Voc)	45.7 V	45.4 V
Short - Circuit Current (Isc)	5.62 A	5.52 A
Maximum Power at STC (Pmax)	200 W	195 W
Module Efficiency	15.7%	15.3%
Operating Temperature	-40°C to +85°C	-40°C to +85°C
Maximum System Voltage	1000 V DC	1000 V DC
Maximum Series Fuse Rating	15 A	15 A
Power Tolerance	0 / +5 W	0 / +5 W

STC: Irradiance 1000 W/m², module temperature 25°C, AM=1.5

NOCT	PLUTO200-Ade	PLUTO195-Ade
Maximum Power (W)	148 W	144 W
Maximum Power Voltage (V)	34.8 V	34.3 V
Maximum Power Current (A)	4.26 A	4.20 A
Open Circuit Voltage (Voc)	41.1 V	40.9 V
Short Circuit Current (Isc)	4.60 A	4.50 A
Efficiency Reduction (from 1000 W/m² to 200 W/m²)	<4%	<4%

NOCT: Irradiance 800 W/m², ambient temperature 20 °C, wind speed 1 m/s

Mechanical Characteristics

Solar Cell	Monocrystalline 125 × 125 mm (5 inches)
No. of Cells	72 (6 × 12)
Dimensions	1580 × 808 × 35 mm (62.2 × 31.8 × 1.4 inches)
Weight	15.5 kgs (34.1 lbs.)
Front Glass	3.2 mm (0.13 inches) tempered glass
Frame	Anodized aluminium alloy
Junction Box	IP67 rated
Output Cables	H+S Radox Solar Cable 4.0 mm² (0.006 inches²), symmetrical lengths (-) 1000 mm (39.4 inches) and (+) 1000 mm (39.4 inches), Radox Solar connectors

Temperature Characteristics

Nominal Operating Cell Temperature **(NOCT)**	45±2°C
Temperature Coefficient of Pmax	-0.38 %/°C
Temperature Coefficient of Voc	-0.29 %/°C
Temperature Coefficient of Isc	0.046 %/°C

13.2 Typical datasheet for standalone inverter

Technical data	Sunny Island 6.0H	Sunny Island 8.0H
AC output (loads / stand-alone grid)		
Rated grid voltage / AC voltage range	230 V / 202 V ... 253 V	230 V / 202 V ... 253 V
Rated frequency / frequency range (adjustable)	50 Hz / 45 Hz ... 65 Hz	50 Hz / 45 Hz ... 65 Hz
Rated power (for Unom / fnom / 25 °C / cos φ = 1)	4600 W	6 000 W
AC power at 25 °C for 30 min / 5 min / 3 sec	6 000 W / 6 800 W / 11 000 W	8 000 W / 9 100 W / 11 000 W
AC power at 45 °C	3 700 W	5 430 W
Rated current / maximum output current (peak)	20 A / 120 A	26 A / 120 A
THD output voltage / power factor with rated power	< 4 % / -1 ... +1	< 4 % / -1 ... +1
AC input (PV array, grid or MC box)		
Rated input voltage / AC input voltage range	230 V / 172.5 V ... 264.5 V	230 V / 172.5 V ... 264.5 V
Rated input frequency / allowable input frequency range	50 Hz / 40 Hz ... 70 Hz	50 Hz / 40 Hz ... 70 Hz
Maximum AC input current	50 A	50 A
Maximum AC input power	11 500 W	11 500 W
Battery DC input		
Rated input voltage / DC voltage range	48 V / 41 V ... 63 V	48 V / 41 V ... 63 V
Maximum battery charging current	110 A	140 A
Rated DC charging current / DC discharging current	90 A / 103 A	115 A / 136 A
Battery type / battery capacity (range)	FLA, VRLA / 100 Ah ... 10 000 Ah	FLA, VRLA / 100 Ah ... 10 000 Ah
Charge control	IUoU charge procedure with automatic full charge and equalization charge.	IUoU charge procedure with automatic full charge and equalization charge
Efficiency / self-consumption		
Maximum efficiency	96 %	96 %
Self-consumption without load / standby	< 26 W / < 4 W	< 26 W / < 4 W
Protective devices (equipment)		
AC short-circuit / AC overload	● / ●	● / ●
DC reverse polarity protection / DC fuse	– / –	– / –
Overtemperature / battery deep discharge	● / ●	● / ●
Overvoltage category as per IEC 60664-1	III	III
General data		
Dimensions (width x height x depth)	467 mm x 612 mm x 242 mm	467 mm x 612 mm x 242 mm
Priority	63 kg	63 kg
Operating temperature range	-25 °C ... +60 °C	-25 °C ... +60 °C
Protection class according to IEC 62103	I	I
Climatic category according to IEC 60721	3K6	3K6
Degree of protection according to IEC 60529	IP54	IP54
Features / function		
Operation and display / multifunction relay	External via SRC-20 / 2	External via SRC-20 / 2
Three-phase systems / parallel connection	● / ●	● / ●
Integrated bypass / multicluster operation	– / ●	– / ●
State of charge calculation / full charge / equalization charge	● / ● / ●	● / ● / ●
Integrated soft start / generator support	● / ●	● / ●
Battery temperature sensor / data cables	● / ●	● / ●
Certificates and approvals	www.SMA-Solar.com	www.SMA-Solar.com
Warranty: 5 years	●	●
Accessory		
Battery cable / battery fuse	○ / ○	○ / ○
Interface SI-COMSMA (RS485) / SI-SYSCAN (Multicluster)	○ / ○	○ / ○
Extended generator start "GenMan"	○	○
Load-shedding contactor / battery current measurement	○ / ○	○ / ○
Type designation	SI6.0H-11	SI8.0H-11

13.3 System installation and commissioning checklist

13.3.1 System identification

Microgrid site name:
Address:
Contact person's name:
Contact person's phone number:

System commissioning date:
Battery commissioning date:

Array Peak power: kWp
Installed battery capacity (C_{10}):
Nominal system voltage:

Installer or assembler:
Installer phone number:

13.4.2 PV array installation checklist

PV Array		**Reference value**	**Measured value**	**Conform to reference Y/N**
Modules	Unit peak power			
	Technology			
	Quantity			
	Manufacturer			
	Power tolerance			
	Efficiency			
	Sealing of junction boxes			
	Bypass diodes			
Assembly	Orientation			
	Inclined/horizontal			
Structures	Type of structure			
	Structure material			
	Mechanical strength			
	Bolts and nuts material			
	Resistance to corrosion			
	Theft prevention device			
	Quality of fittings			
	Quality of anchors			
	Earthing			

13.4.3 Cables and connections checklist

Cabling		Reference value	Measured value	Conform to reference Y/N
Interconnections of modules	Cable type			
	Cross-section area (mm^2)			
	Length (m)			
	Protection of junction			
	Junction attachment			
Modules-to-junction boxes connections	Cable type			
	Cross-section			
	Length			
	Quantity			
	Protection of junctions			
	Attachment of junctions			
Junction boxes	Quantity of boxes			
	Number of strings per box			
	AR diode specifications			
	Control of diodes			
	Sealing efficiency of cable junction and penetrations			
	Torque value for terminal strips			
	Protection of contacts (grease)			
	Box attachment quality			

13.4.4 Acceptance test of PV array

Cabling		**Reference value**		**Measured value**		**Conform to reference Y/N**
Cabling Control through Disconnected string	Voc and Isc per string	Voc	Isc	Voc	Isc	
	String 1					
	String 2					
	String 3					
	String 4					
	String 5					
	String 6					
	String 7					
	String 8					
	String 9					
	String 10					
	Total generator current					
PV field/control Junction	Cable type					
	Cross-section area					
	Length					
	Number of junctions					
	Protection of junctions					
	Lighting arrestors					
	Attachment of junctions					
	Voltage drop at I max					
Cabling control by input regulator on load	Control input	V	I			
	Input 1					
	Input 2					
	Input 3					
	Input 4					
	Total generator					
Control/ Battery Junctions	Cable type					
	Cross-section					
	Length					
	Number of junctions					
	Protection of junctions					
	Attachment of junctions					
	Voltage drop at I max					

13.4.5 Acceptance of batteries

Battery Bank		Reference value		Measured value		Conform to reference Y/N
Commissioning date:						
Type	Type of battery					
	Manufacturer					
Specifications status	Rated voltage					
	Rated voltage per cell					
	Capacity per cell (C_{10})					
	Number of cells					
	Status of cleanliness					
	Connections status					
	Electrolyte level					
	Legibility of levels Existing deposits in vats					
Inspection of Battery	Voltage and density cell	V_{cell}	D_{cell}			
	Cell 1					
	Cell 2					
	Cell 3					
	Cell 4					
	Cell 5					
	Cell 6					
	Cell ----					
	Total battery (voltage)					
	Ambient temperature					
Accessories	Battery maintenance tools					
	Battery safety accessories					
Battery room	Location and access					
	Hazard sign					
	Ventilation					
	Thermal insulation					
	Acid retention tank					
	Room padlocking					

13.4.6 Acceptance of measuring and control equipments

Measuring and control equipments		Reference value	Measured value	Conform to reference Y/N
Location of installation	Visibility and legibility			
	Ventilation			
	Control room lighting			
Type	Manufacturer			
	Reference			
	Rated voltage			
	Serial number			
	General schematics present			
	Terminal strip marking			
Charge setting	Maximum allowable current			
	Threshold of forced charge			
	High threshold			
	Load reconnection threshold			
	High alarm threshold			
Discharge limitation	Maximum allowable current			
	Limiting threshold			
	Reconnection threshold			
	Low alarm threshold			
Displays	Array current measurement			
	Load current measurement			
	Battery voltage measurement			
	Energy generation measurement			
	Energy consumption measurement			
Data acquisition	Manufacturer			
	Reference			
	Rated voltage			
	Serial number			

13.4.7 Acceptance of Inverter

Inverter		Reference value	Measured value	Conform to reference Y/N
Commissioning date:				
Inverter (DC-AC converter)	Manufacturer			
	Reference			
	Serial number			
	Rated AC power or current			
	Peak AC power or current			
	Rated voltage input			
	Input voltage range			
	Rated output frequency			
	Output frequency range			
	Output signal type (wave)			
	Consumption at zero load			
	Overcurrent protection			
	Technical documentation			
AC/DC converter/ rectifier	Rated output voltage			
	Rated output current			
	Output voltage range			
	Consumption at zero load			
	Adaptability to battery capacity			
	Technical documentation			

13.4.8 Acceptance of LV distribution

LV distribution boards	Reference value	Measured value	Conform to reference Y/N
Location and access			
Visibility			
Maximum current			
Earthed polarity			
Earthed neutral			
Solar field outage			
Battery outage			
Control power supply outage			
Supply general circuit-breaker			
Protection of solar array			
Battery protection type			
Type of protection for load			
Overload protection			
Protection against direct contact			
Protection against indirect contacts			
Plant schematics present			
Cross-section cabling internal			
Inside cabling marking			
Terminal strip marking			
Spare fuse present			
LV cabinet IP protection (IEC 60529)			
Board earthing			

13.4.9 Acceptance of ELV distribution

ELV distribution boards	Reference value	Measured value	Conform to reference Y/N
Location and access			
Visibility			
Maximum current			
Earthed polarity			
Solar field outage			
Battery outage			
Control power supply outage			
General supply cut out			
Solar field protection type			
Battery protection type			
Utilities protection type			
Overload protection			
Protection against direct contact			
Plant schematics present			
Cabling inside cross-section			
Inside cabling marking			
Terminal strip marking			
Spare fuse present			
ELV cabinet IP protection (IEC 60529)			
Board earthing			

13.5 System inspection and troubleshooting worksheet

PHOTOVOLTAIC SYSTEM FIELD EVALUATION WORKSHEET (Page 1)

PRELIMINARY INFORMATION

Date:_______________ Inspector Name:__________________
Name of the Owner: ____
System Location: ____
System Description: ____
Reference: ____

PHOTOVOLTAIC MODEULES AND ARRAY

Manufacturer:_________________________ Model #:______________
Array Configuration: __________series X __________parallel
Total No. of Modules: ____________ (#)
Array Mount Type: _______________________________(ground/roof, rack, tracking)
Array Tilt Angle: __________(degree) Array Azimuth: __________(degree)
Seasonal or daily adjustable Tilt or Tracking (describe): __________________________

Module/ Array Specification @STC (1000W/m², 25°C)

	Module	Array
Open Circuit Voltage (V_{oc})	_________(V)	_________(V)
Short Circuit Current (I_{sc})	_________(A)	_________(A)
Maximum Power Voltage (V_{mp})	_________(V)	_________(V)
Maximum Power Current (I_{mp})	_________(A)	_________(A)
Maximum Power (P_{mp})	_________(W)	_________(W)

BATTERY SUB-SYSTEM

Manufacturer:_________________________ Model #:______________
Battery Chemistry Type: ___________________ (antimony, calcium, VRLA)
Battery Bank Configuration: __________series X __________parallel
Total No. of Batteries __________ (#)

Battery Specification @ 25°C

	Cell/Battery	Bank
Capacity at Rate ____________ C/#)	_________(Ah)	_________(Ah)
Nominal Voltage	_________(V)	_________(V)
Open Circuit Voltage at 100% SOC	_________(V)	_________(V)
Open Circuit Voltage at 50% SOC	_________(V)	_________(V)
Specific Gravity at 100% SOC	_________(#)	_________(#)
Specific Gravity at 50% SOC	_________(#)	_________(#)
Cycle Life at 20% DOD	________(cycles)	
Cycle Life at 50% DOD	________(cycles)	
Cycle Life at 80% DOD	________(cycles)	

PHOTOVOLTAIC SYSTEM FIELD EVALUATION WORKSHEET (Page 2)

ELECTRICAL LOADS

Devices	DC/AC	Amps/Watts	Hours/Day	Ah/Day
1. ____________________	____	____	____	____
2.____________________	____	____	____	____
3. ____________________	____	____	____	____
4.____________________	____	____	____	____
5. ____________________	____	____	____	____
6.____________________	____	____	____	____
7. ____________________	____	____	____	____
8.____________________	____	____	____	____
9. ____________________	____	____	____	____
10.____________________	____	____	____	____
11. ___________________	____	____	____	____
12. ___________________	____	____	____	____

Seasonal Variation in Load ? ____

Total Electrical Load

DC Loads: Peak Amps _________(A) Average Daily ________(Ah)

AC Loads: Peak Watts _________(W) Average Daily ________(Wh) _______(Ah)

Total Average Daily Loads DC & _______(Ah)

CHARGE CONTROLLER/ VOLTAGE REGULATOR

Manufacturer:_________________________ Model #:______________

Regulator Type: ___________________ (series, shunt, PWM, constant voltage)

Controller Specifications:

Nominal Voltage _________(V)

Maximum Rated Currents: PV Array ______(A) Load_______(V)

Array Regulator Set Points: VR__________(V) VRH________(V)

Array Regulation Switching Element: _______(SS/EM) ______(pos/neg)

Load Disconnect Set Points: LVD_________(V) LVDH_______(V)

Load Disconnect Switching Element: _______(SS/EM) ______(pos/neg)

Temperature Compensation: ________(mV/°C/cell) Type______(probe/board)

Other Controller Functions/ Characteristics (meters, indicators, alarms, etc)

____

PHOTOVOLTAIC SYSTEM FIELD EVALUATION WORKSHEET (Page 3)

INVERTER/ POWER CONDITIONER

Manufacturer:__________________________ Model #:______________
Waveform: ____________________ (sine, quasi -sine, square)
Output Voltage Regulation: __________ (%)
Harmonic Distortion __________ (%)
Minimum Input/Operating Volta __________ (V)
LVD function on Inverter DC In __________ (yes) _________No __________ (V)

Inverter Specifications:
Nominal DC Input Voltage: _________(V)
Nomilan AC Output Voltage: _________(V) Frequency______(Hz)
Maximum Continuous Output Power: _________(W)
Standby Power Requirement: _________(W) ______(pos/neg)
Charge Capacity: _________(W) _______(minutes)
_________(W) _______(minutes)
Nominal Efficiency (resistive load): _________(%) at 25% Load
_________(%) at 50% Load
_________(%) at 75% Load
_________(%) at 100% Load
Other Inverter Features: (Battery Charger, disconnect, reverse polarity, overcurrent protection etc)
____
____

OTHER SYSTEM SPECIFICATIONS AND INFORMATION

Mounting Structure:
Mounting Structure Materials: ____________________ (MS, Aluminium, SS etc)
Mounting Structure Coating: ____________________ (Galvenised, painted, annealed etc)
Fasteners/Nut/Bolts/Clamps ____________________ (MS, SS etc)
Type of foundation/ fixing: ____ (describe)

Conductors and Wirings:

	Type (Cu/Al, Insul, cor	Size (sqmm)	Length (m)
PV Array interconnection			
PV Array J-Box to PCU/Control	__________________	_______(sqmm)	_______(m)
PCU/Controller to DC Loads:	__________________	_______(sqmm)	_______(m)
PCU/Controller to Battery:	__________________	_______(sqmm)	_______(m)
Battery to Inverter:	__________________	_______(sqmm)	_______(m)
Inverter to AC Loads:	__________________	_______(sqmm)	_______(m)

Overcurrent Protection and Disconnect Devices (List Types, location and ratings):
____
____

Grounding (System Grounding, equipment grounding, earth electrode):
____
____

Surge Protection Devices (List Types, locations and ratings):
____

Blocking and Bypass Diodes (List Types, locations and Ratings):
____
____

Other Information:
____
____

13.6 DC voltage drop tables

Voltage Drop Table - 12 Volt Nominal

Maximum one-way distance for 2% voltage drop in 12 volt systems

Wire Size (mm^2) [distance in meters]

Amps	2.5	4	6	10	16	25	35	50	70	95	120	150
1	15	24	35	63	99	154	217	311	441	583	745	930
2	7	12	18	31	50	77	108	155	221	291	373	465
3	5	8	12	21	33	51	72	104	147	194	248	310
4	4	6	9	16	25	38	54	78	110	146	186	233
5	3	5	7	13	20	31	43	62	88	117	149	186
6	2	4	6	10	17	26	36	52	74	97	124	155
7	2	3	5	9	14	22	31	44	63	83	106	133
8	2	3	4	8	12	19	27	39	55	73	93	116
9	2	3	4	7	11	17	24	35	49	65	83	103
10	1	2	4	6	10	15	22	31	44	58	75	93
15	1	2	2	4	7	10	14	21	29	39	50	62
20	1	1	2	3	5	8	11	16	22	29	37	47
25	1	1	1	3	4	6	9	12	18	23	30	37
30	0	1	1	2	3	5	7	10	15	19	25	31
35	0	1	1	2	3	4	6	9	13	17	21	27
40	0	1	1	2	2	4	5	8	11	15	19	23
45	0	1	1	1	2	3	5	7	10	13	17	21
50	0	0	1	1	2	3	4	6	9	12	15	19
60	0	0	1	1	2	3	4	5	7	10	12	16
70	0	0	1	1	1	2	3	4	6	8	11	13
80	0	0	0	1	1	2	3	4	6	7	9	12
90	0	0	0	1	1	2	2	3	5	6	8	10
100	0	0	0	1	1	2	2	3	4	6	7	9

Voltage Drop Table - 24 Volt Nominal

Maximum one-way distance for 2% voltage drop in 24 volt systems

Wire Size (mm^2) [distance in meters]

	2.5	4	6	10	16	25	35	50	70	95	120	150
Amps												
1	29	47	71	126	198	308	433	622	882	1165	1491	1860
2	15	24	35	63	99	154	217	311	441	583	745	930
3	10	16	24	42	66	103	144	207	294	388	497	620
4	7	12	18	31	50	77	108	155	221	291	373	465
5	6	9	14	25	40	62	87	124	176	233	298	372
6	5	8	12	21	33	51	72	104	147	194	248	310
7	4	7	10	18	28	44	62	89	126	166	213	266
8	4	6	9	16	25	38	54	78	110	146	186	233
9	3	5	8	14	22	34	48	69	98	129	166	207
10	3	5	7	13	20	31	43	62	88	117	149	186
15	2	3	5	8	13	21	29	41	59	78	99	124
20	1	2	4	6	10	15	22	31	44	58	75	93
25	1	2	3	5	8	12	17	25	35	47	60	74
30	1	2	2	4	7	10	14	21	29	39	50	62
35	-	1	2	4	6	9	12	18	25	33	43	53
40	-	1	2	3	5	8	11	16	22	29	37	47
45	-	-	2	3	4	7	10	14	20	26	33	41
50	-	-	1	3	4	6	9	12	18	23	30	37
60	-	-	1	2	3	5	7	10	15	19	25	31
70	-	-	1	2	3	4	6	9	13	17	21	27
80	-	-	1	2	2	4	5	8	11	15	19	23
90	-	-	1	1	2	3	5	7	10	13	17	21
100	-	-	1	1	2	3	4	6	9	12	15	19

Voltage Drop Table - 36 Volt Nominal

Maximum one-way distance for 2% voltage drop in 36 volt systems

Wire Size (mm^2) [distances in meters]

Amps	2.5	4	6	10	16	25	35	50	70	95	120	150
1	44	71	106	188	298	462	650	933	1324	1748	2236	2791
2	22	35	53	94	149	231	325	466	662	874	1118	1395
3	15	24	35	63	99	154	217	311	441	583	745	930
4	11	18	27	47	74	115	162	233	331	437	559	698
5	9	14	21	38	60	92	130	187	265	350	447	558
6	7	12	18	31	50	77	108	155	221	291	373	465
7	6	10	15	27	43	66	93	133	189	250	319	399
8	5	9	13	24	37	58	81	117	165	218	280	349
9	5	8	12	21	33	51	72	104	147	194	248	310
10	4	7	11	19	30	46	65	93	132	175	224	279
15	3	5	7	13	20	31	43	62	88	117	149	186
20	2	4	5	9	15	23	32	47	66	87	112	140
25	2	3	4	8	12	18	26	37	53	70	89	112
30	1	2	4	6	10	15	22	31	44	58	75	93
35	1	2	3	5	9	13	19	27	38	50	64	80
40	1	2	3	5	7	12	16	23	33	44	56	70
45	1	2	2	4	7	10	14	21	29	39	50	62
50	1	1	2	4	6	9	13	19	26	35	45	56
60	1	1	2	3	5	8	11	16	22	29	37	47
70	1	1	2	3	4	7	9	13	19	25	32	40
80	1	1	1	2	4	6	8	12	17	22	28	35
90	0	1	1	2	3	5	7	10	15	19	25	31
100	0	1	1	2	3	5	6	9	13	17	22	28

Voltage Drop Table - 48 Volt Nominal

Maximum one-way distance for 2% voltage drop in 48 volt systems

Wire Size (mm^2) [distances in meters]

	2.5	4	6	10	16	25	35	50	70	95	120	150
Amps												
1	58	94	142	251	397	615	866	1244	1765	2330	2981	3721
2	29	47	71	126	198	308	433	622	882	1165	1491	1860
3	19	31	47	84	132	205	289	415	588	777	994	1240
4	15	24	35	63	99	154	217	311	441	583	745	930
5	12	19	28	50	79	123	173	249	353	466	596	744
6	19	16	24	42	66	103	144	207	294	388	497	620
7	8	13	20	36	57	88	124	178	252	333	426	532
8	7	12	18	31	50	77	108	155	221	291	373	465
9	6	10	16	28	44	68	96	138	196	259	331	413
10	6	9	14	25	40	62	87	124	176	233	298	372
15	4	6	9	17	26	41	58	83	118	155	199	248
20	3	5	7	13	20	31	43	62	88	117	149	186
25	2	4	6	10	16	25	35	50	71	93	119	149
30	2	3	5	8	13	21	29	41	59	78	99	124
35	2	3	4	7	11	18	25	36	50	67	85	106
40	1	2	4	6	10	15	22	31	44	58	75	93
45	1	2	3	6	9	14	19	28	39	52	66	83
50	1	2	3	5	8	12	17	25	35	47	60	74
60	1	2	2	4	7	10	14	21	29	39	50	62
70	1	1	2	4	6	9	12	18	25	33	43	53
80	1	1	2	3	5	8	11	16	22	29	37	47
90	1	1	2	3	4	7	10	14	20	26	33	41
100	1	1	1	3	4	6	9	12	18	23	30	37

Voltage Drop Table - 120 Volt Nominal

Maximum one-way distance for 2% voltage drop in 120 volt systems

Wire Size (mm^2) [distances in meters]

	2.5	4	6	10	16	25	35	50	70	95	120	150
Amps												
1	146	236	354	628	992	1538	2166	3109	4412	5825	7453	9302
2	73	118	177	314	496	769	1083	1554	2206	2913	3727	4651
3	49	79	118	209	331	513	722	1036	1471	1942	2484	3101
4	37	59	88	157	248	385	542	777	1103	1456	1863	2326
5	29	47	71	126	198	308	433	622	882	1165	1491	1860
6	24	39	59	105	165	256	361	518	735	971	1242	1550
7	21	34	51	90	142	220	309	444	630	832	1065	1329
8	18	29	44	79	124	192	271	389	551	728	932	1163
9	16	26	39	70	110	171	241	345	490	647	828	1034
10	15	24	35	63	99	154	217	311	441	583	745	930
15	10	16	24	42	66	103	144	207	294	388	497	620
20	7	12	18	31	50	77	108	155	221	291	373	465
25	6	9	14	25	40	62	87	124	176	233	298	372
30	5	8	12	21	33	51	72	104	147	194	248	310
35	4	7	10	18	28	44	62	89	126	166	213	266
40	4	6	9	16	25	38	54	78	110	146	186	233
45	3	5	8	14	22	34	48	69	98	129	166	207
50	3	5	7	13	20	31	43	62	88	117	149	186
60	2	4	6	10	17	26	36	52	74	97	124	155
70	2	3	5	9	14	22	31	44	63	83	106	133
80	2	3	4	8	12	19	27	39	55	73	93	116
90	2	3	4	7	11	17	24	35	49	65	83	103
100	1	2	4	6	10	15	22	31	44	58	75	93

Clean Energy Access Network (CLEAN)

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