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Participant Handbook

Sector
Green Jobs

Sub-Sector
Renewable Energy

Occupation
Installation, Operation & Maintenance

Reference ID: **SGJ/Q0101, Version 1.0**
NSQF Level 4

Solar PV Installer (Suryamitra)

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If we have to move India towards development then Skill Development should be our mission.

Shri Narendra Modi
Prime Minister of India

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QUALIFICATION PACK – NATIONAL OCCUPATIONAL STANDARDS

is hereby issued by the

SKILL COUNCIL FOR GREEN JOBS

for

SKILLING CONTENT : PARTICIPANT HANDBOOK

Complying to National Occupational Standards of
Job Role/ Qualification Pack: '**Solar PV Installer (Suryamitra)**' QP No. '**SGJ/ Q 0101 NSQF Level 4**'

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About this book

Government of India is aiming towards a capacity of about 100,000 MW to come from Solar Energy by the year 2022. This includes a capacity of 40,000 MW to come up on the rooftops of various buildings and houses spread throughout the country. The Ministry of New and Renewable Energy sources is looking for training about 50,000 Suryamitra in next 3 years Considering the huge technically trained manpower requirement to meet this ambitious goal, Skill Council for Green Jobs is targeting a special skilling course on Solar PV Installer with the name called Suryamitra. The Solar PV Installer (Suryamitra) would be specialised for mechanical, civil and electrical installations of rooftop Solar Photovoltaic systems as well as maintaining them.

This Participant book is designed to enable theoretical and practical training on Rooftop Solar PV Installation, Operation and Maintenance as per Solar PV Installer (Suryamitra) Qualification Pack, SGJ/Q0101 and is available for free download at **www.greenskillcouncil.in/NOS.**

This book is designed considering the minimum education qualification of Suryamitra to be ITI/Diploma. However, as part this book, efforts have been made to revise their knowledge of electrical and civil concepts required for this job. The contents of this book are in simple language, without going into too much theoretical details and calculations. It is envisaged that this training manual will provide the participants with the knowledge and skills required for installing and maintaining a rooftop Solar Photovoltaic System, complying with all applicable codes, standards, and safety requirements; and enable them to actively participate in the growing solar rooftop market.

The Skill Council for Green Jobs is thankful to the valuable contributions made by:

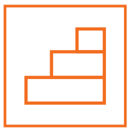
- National Institute of Solar Energy
- USAID PACE-D program
- Clean Energy Access Network
- ADS Global Knowledge Academy
- Smart Brains

On behalf of Skill Council for Green Jobs, the book has been coordinated, compiled and co-authored by Mr. Tanmay Bishnoi, Head – Standards & Research and Ms Geetika Chauhan, Technical Associate.

Units and symbols used in the book have been listed below.

Symbols Used


Key Learning Outcomes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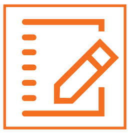
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1. Introduction to Solar PV Installer - Suryamitra

Unit 1.1 – Training Code of Conduct, Job Role and Career Opportunities

SGJ/N0101

Key Learning Outcomes

At the end of this module, you will be able to:

1. Demonstrate general discipline in the class room and during the training program
2. Explain the role of Solar PV Installer and job opportunities
3. Explain the advantages of doing this course
4. Acquire basic skills of communication

UNIT 1.1: Introduction to the Program

Unit Objectives

At the end of this unit, you will be able to:

1. Demonstrate general discipline in the class room and during the training program
2. Explain the role of Solar PV Installer and job opportunities
3. Explain the advantages of doing this course
4. Acquire basic skills of communication

1.1.1 The Solar PV Installer Classroom – Discipline and Code of Conduct

This course has been designed to introduce you to the concepts of solar photovoltaic power plants from an installation technician's perspective. The delivery of this training is divided into both practical and theoretical components. In order to derive the maximum benefit of undergoing this training program, you are encouraged to adopt a code of conduct during lectures, workshops and industry visits. Imbibing values of discipline, integrity and core professional skills will help you obtain a satisfactory outcome at the end of the program. Moreover it will help you integrate better with your future employers and co-workers.

In the Classroom:

- Be punctual and regular in attending lectures. It will help maintain your pace with the entire class.
- Minimize distractions by keeping mobile phones and music devices turned off during training delivery. Participating in the classroom can be very interesting, and it reflects you commitment to the program.
- Interact with your trainer to find out more about the course and clarify concepts
- Engage in discussions with your batch mates to become a team player and actively participate in group activities to clear concepts and fill knowledge gaps
- Take this opportunity to freely ask your trainer any kind of questions related to the course. Clear understanding of practical and theoretical concepts is very critical to carry out the installation of solar PV plants.
- You must complete assignments and submissions on time with honesty and integrity. This will help you truly assess yourself and develop confidence to independently handle projects.

During practical training:

- Keeping in mind your personal safety, always wear Personal Protective Equipment (PPE) while handling electrical and mechanical tools, devices and equipment. This will protect you from electric shocks, physical damage to yourself and your team members. PPE and safety guidelines are extensively covered in later chapters of the book.

1.1.2 Personal Attributes

As a solar installer, you are required to concentrate on the job at hand and complete it without any accidents, so diligence and hardworking are desired attributes for performing this role. You should be able to demonstrate strong work ethics, an ability to communicate courteously with co-workers, and effectively carry out or follow the instructions of your supervisor.

1.1.3 Role of Solar PV Installer

Brief Job Description

Solar PV Installer checks, adapts, implements, configures, installs, inspects, tests, and commissions different components of photovoltaic systems, that meet the performance and reliability needs of customers by incorporating quality craftsmanship and complying with all applicable codes, standards, and safety requirements.

The Solar PV Installer (Suryamitra) has the following tasks to be carried out for a successful installation of a Rooftop Solar PV Power Plant. The first two modules on 'Basics of Solar Energy and Electrical Energy' and 'Basics of Solar Photovoltaic systems) will cover fundamental concepts.

The module on **'Site Survey for Installation of Solar PV System'** is about Solar Photovoltaic Technology and Plant Components. The aim is to understand the customer's requirement for solar PV system. This task covers the following:

- Assess the site condition
- Understand the work requirement
- Engage with customers to understand their requirement
- Visit and evaluate the site for installation
- Identify load to be connected to Solar PV System
- Assess the photovoltaic system required
- Assess the cost of system installation
- Ensure quality, standards and regulatory requirement are adhered

The module on **'Procure Solar PV system components'** is about confirming and adapting system design. This task covers the following:

- Prepare Bill of Material
- Procure the components
- Verify the components On-site

The module on '**Install Civil and Mechanical parts of Solar PV system'** is about installation of civil and mechanical components of the Solar Photovoltaic systems (for rooftop installations). This task covers the following:

Get Equipment Foundation constructed

- Install Mounting System
- Install Photovoltaic modules.
- Install Battery Bank Stand and Inverter Stand.

The module on **'Install electrical components of Solar PV system'** is about installation of electrical components of the Photovoltaic system. This task covers the following:

- Prepare for Solar Installation.
- Install Electrical Components.
- Install Conduits and cables.
- Get the Grounding Systems installed
- Install Battery bank (as required)

The module on **'Test and Commission Solar PV System'** is about Testing and Commissioning of electrical components of Photovoltaic System. This task covers the following:

- Test the System.
- Commission the System.

The module on **'Maintain solar photovoltaic system'** is about maintenance of solar photovoltaic system for effective functioning to achieve the specified energy output. It also includes troubleshooting of the system. This task covers the following:

- Clean the solar panels periodically
- Inspect the system periodically
- Troubleshoot to identify faults in the system
- Report and document completion of work
- Follow quality and safety procedures

The module on **'Maintain Personal Health & Safety at project site'** is about maintaining Work Safety for the technicians, customers, and site safety at the location of Solar Photovoltaic Power Plants. This task covers the following:

- Establish and follow safe work procedure
- Use and maintain personal protective equipment.
- Identify and mitigate safety hazards.
- Demonstrate safe and proper use of required tools and equipment.
- Identify work safety procedures and instructions for working at height.

The module on **'Customer Orientation for Solar PV System'** is about orientation of customer towards Solar PV System and handling over the completion documents. This task covers the following:

- Handover System Completion Documentation.
- Demonstrate Working Procedure of Solar PV system

1.1.4 Market Demand

The demand of skilled manpower in the Solar Photovoltaics Industry in India and worldwide is a subject under study which has been undertaken by various organizations. As of the time that this Participant Handbook was prepared, several reports have emerged that establish the imperative as well futuristic demand of Solar Photovoltaic Installers in the solar energy market.

As per the 'Human Resource Development Strategies for Indian Renewable Energy Sector', by Ministry of New and Renewable Energy and Confederation of Indian Industry, October 2010, 23 lakh persons were employed in the renewable energy sector globally in 2008. There is a huge job opportunity for solar installers since not many skilled installers are available in the market.

As per this report, the future projections for employment in Solar PV Off-Grid Sub-sector are as follows:

Table 1.1: Future projections for employment in Solar PV Off-Grid Sub-sector

Year	Estimated Employment		
	Direct	**Indirect**	**Total**
2010	24,000	48,000	72,000
2017	47,000	93,000	1,40,000
2022	75,000	1,50,000	2,25,000

As per the report on 'Filling The Skill Gap in India's Clean Energy Market: Solar Energy Focus', by Natural Resources Defense Council (NRDC) and the Council on Energy, Environment and Water (CEEW), February, 2016, India would need a large number of skilled manpower to meet the 100 GW target of Solar Installations by 2022. The availability of appropriately skilled manpower has been identified as one of the most prominent challenges in hiring required personnel.

Table 1.2: Scale of skilled workers needed to achieve Solar targets

Function	Key Skills	Trained Manpower to achieve 40 GW of Rooftop Solar by 2022	Trained Manpower to achieve 60 GW of Utility Scale Solar by 2022
Business development	Tracking the market, Drafting Bids, land selection, project finance	15,200	2,400
Design and Pre-Construction	Plant Design engineering	18,400	10,200
Construction and Commissioning	Site engineering	1,54,000	28,200
	Electricals training and PV installation	3,38,400	2,86,200
Operations and maintenance	Performance data monitoring and troubleshooting	1,40,400	1,23,000

1.1.5 Career Progression

Apart from existing reports and analysis carried out, Skill Council for Green Jobs, through collaboration industry interactions, has conducted an Occupational Mapping and Skill Gap Analysis to identify the employment patterns in the Solar Industry. As part of this exercise, an Occupational Map has been prepared to show the career progression for the installers.

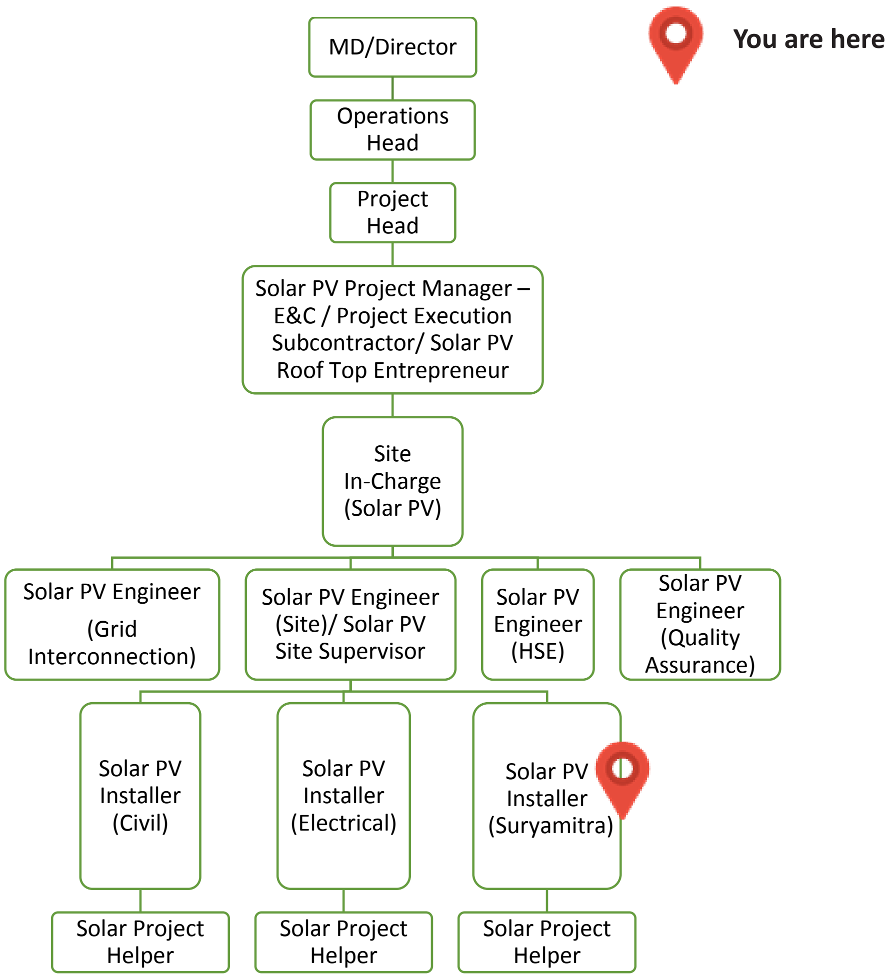

Fig 1.1.1 Career progression of a Solar PV Installer (Suryamitra)

Exercise

1. Briefly introduce yourself to your classmates telling them your name, age, address, educational background and any previous experience. Write down the purpose and expectations that you may have from this course and read it out to the class. You may like to frame this introduction in complete sentences.

2. Basics of Solar Energy and Electrical Energy

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Key Learning Outcomes

At the end of this module, you will be able to:

1. Explain the basic concept of solar energy
2. Explain the basic electrical terms like current, voltage, resistance and explain the relationship between using Ohm's Law
3. Differentiate between series and parallel connections between a combination of resistors
4. Identify the typical measuring instruments used to measure variables in an electrical circuit
5. Explain the terms power and energy, along with the relationship between them
6. Differentiate between Alternating Current (AC) and Direct Current (DC)

UNIT 2.1: An Introduction: Energy from the Sun

Unit Objectives

At the end of this unit, you will be able to:

1. Know about energy from the sun
2. Know about what is solar photovoltaic
3. Know about other sources of renewable energy

2.1.1 The Sun

The sun is like a sphere which contains hot gases. Due to nuclear fusion reactions happening at the core, the internal temperature of sun reaches over 20 million degree Kelvin. Because of nuclear reaction hydrogen is converted into helium (noble gas). Heat energy is transferred from inner layer to outer layer by the process of convection and then radiated into the space. The inner core of sun is not directly visible due to layer of hydrogen atom. The temperature of outer surface (called as photosphere) is about 6400 Kelvin.

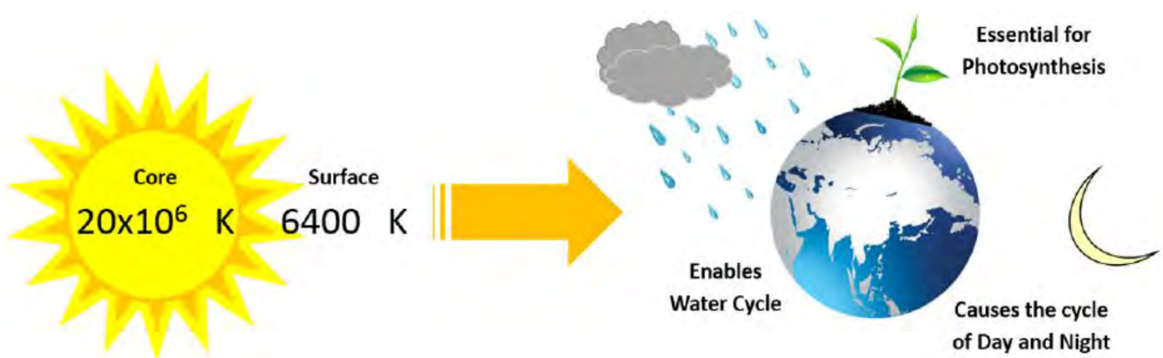

Fig 2.1.1 Utilization of the energy from the sun

The Earth has access to this energy 365 days a year for almost 8 hours per day (on an average). Let us try to understand how nature uses this tremendous power:

- The entire ecosystem on earth exists because of the sun's energy, which is also called 'Solar Energy'.
- This is absorbed by plants and trees which is then used by animals, birds and humans in the form of food.
- The sun plays an important role in maintaining the kind of climate Earth has. It enables the water cycle. That is why we have access to water for our daily uses from rivers, lakes and the seas.

Temperature is measured in Kelvin (K) and Centigrade (^{0}C). The sun's temperature on its outer surface is around 6400 Kelvin or 6127 ^{0}C (Temp K = 273 + Temp ^{0}C).

2.1.2 What form of Energy do we Get from the Sun?

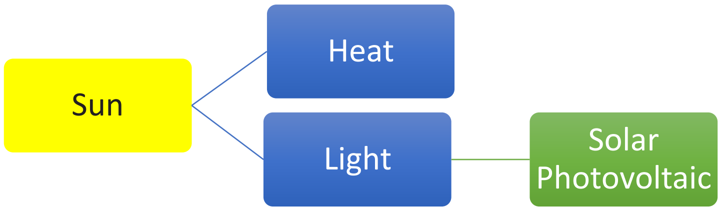

Fig 2.1.2 Components of the energy from the sun

The rays of the sun mainly has two components: Heat and Light.

The Light component of the Sun's power can be used to produce electricity.

The technology available to convert solar energy into electrical energy is called 'Solar Photovoltaics'.

2.1.3 What is Solar Photovoltaic?

The Solar PV Panel is manufactured from Silicon. The process can be seen in the figure depicted below.

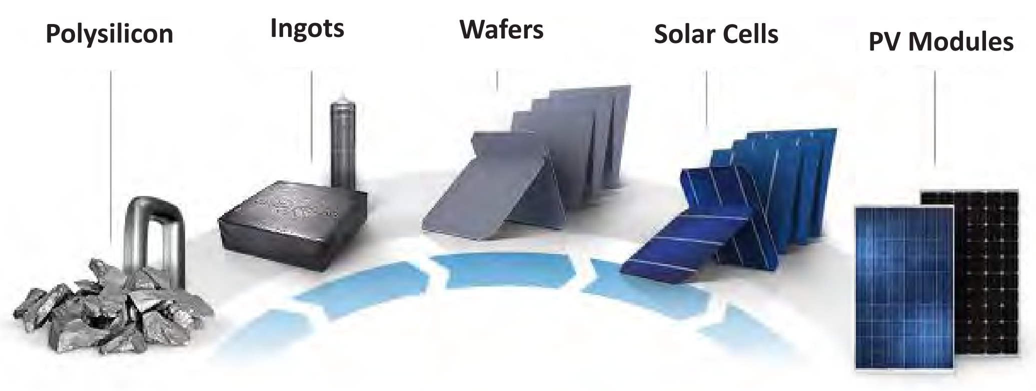

Fig 2.1.3 Manufacturing of a solar PV panel from Silicon

Solar photovoltaic (PV) technology: It refers to the direct conversion of sunlight energy into electrical energy.

Solar pv cell: It is defined as the semiconductor device that directly converts sunlight energy into DC (direct current) electricity.

Solar PV module: It is defined as the series connected assembly of solar PV cells to generate dc electricity.

Solar PV array: It is defined as the connected (series/ parallel or both) assembly of solar PV modules to generate DC electricity.

2.1.4 Other Sources of Renewable Energy

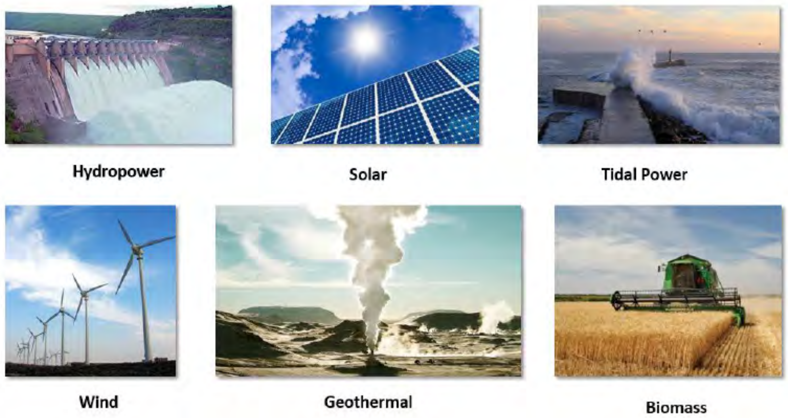

Fig 2.1.4 Various sources of renewable energy

Main advantages of Renewable Energy are:

1. It is an inexhaustible source of energy, which means, it will always be available naturally in the environment.
2. It reduces negative impact on the environment since it doesn't pollute the surroundings like conventional energy sources (coal, petroleum, etc.) do.
3. It is an additional source of electricity to the overall resources of the country.
4. Renewable energy sources can be harnessed in areas which don't have access to national grid or poor access to national grid electricity.

Notes

UNIT 2.2: Ohm's Law: Electric Current, Voltage and Resistance

Unit Objectives

At the end of this unit, you will be able to:

1. Define the basic terms used in electrical power systems
2. Apply Ohm's Law to perform simple calculations

2.2.1 Current

How do we express electric current? Electric current is expressed by the amount of charge flowing through a particular area in unit time. In other words, it is the rate of flow of electric charges.

How does an electrical appliance use current? A switch makes a conducting link between the cell and the appliance (say, an LED lamp). A continuous and closed path of an electric current is called an electric circuit. Now, if the circuit is broken anywhere (or the switch of the LED lamp is turned off), the current stops flowing and the LED does not glow.

The electric current is expressed by a unit called ampere (A). An instrument called ammeter measures electric current in a circuit. It is always connected in series in a circuit through which the current is to be measured.

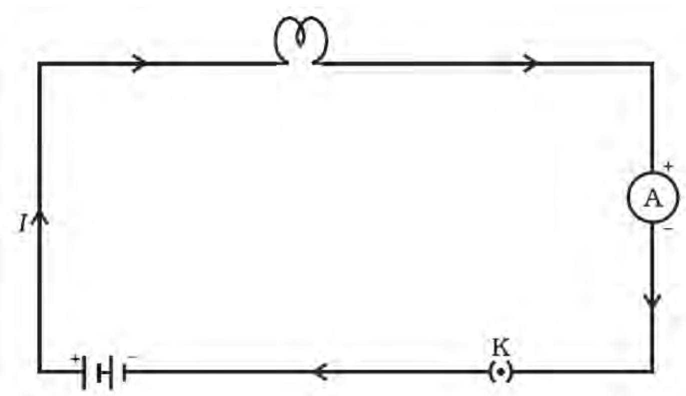

Fig 2.2.1 Schematic diagram of an electric circuit comprising – cell, LED bulb, ammeter and plug key

Note that the electric current flows in the circuit from the positive terminal of the cell to the negative terminal of the cell through the bulb and ammeter.

2.2.2 Direct Current (DC) and Alternating Current (AC)

AC is characterized by 'frequency'. In India, 50 Hertz (cycles per second) is the Alternating Current (AC) frequency. In some countries like USA and Canada, 60 Hertz (cycles per second) is the Alternating Current (AC) frequency.

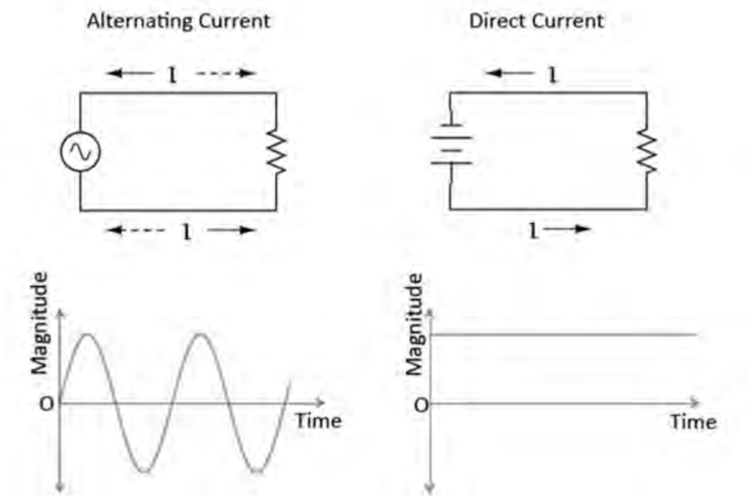

Fig 2.2.2 Alternating Current and Direct Current - Circuit and Waveforms

2.2.3 Voltage – Electric Potential and Potential Difference

What makes the electric charge flow?

For flow of charges in a conducting metallic wire, the electrons move only if there is a difference of electric pressure – called the potential difference – along the conductor. This difference of potential may be produced by a battery, consisting of one or more electric cells. Potential is also called Voltage.

We define the electric potential difference between two points in an electric circuit carrying some current as the work done to move a unit charge from one point to the other. The SI unit of electric potential difference is volt (V).

The potential difference is measured by means of an instrument called the voltmeter. The voltmeter is always connected in parallel across the points between which the potential difference is to be measured.

2.2.4 Single Phase and Three Phase Voltage

As explained above, the current in a circuit flows due to the potential difference or voltage across two points. If the voltage source gives rise to DC flow, it is called DC voltage.

A voltage source which gives rise to flow of AC form of current in a circuit is called AC voltage. In the late 19th Century, AC became popular because it became a more cost effective alternative to DC.

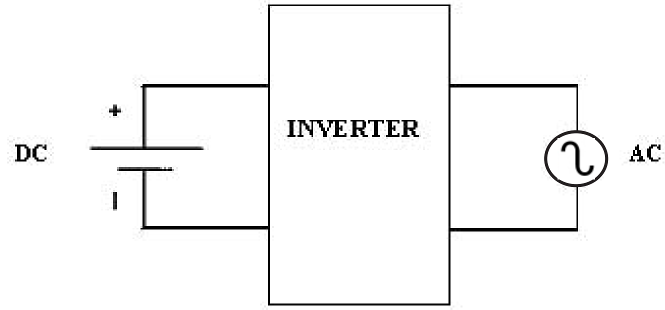

Fig 2.2.3 An inverter converts DC to AC

Electromechanical Energy Conversion is used to convert electricity from DC form to AC form. That is how voltage sourced from solar energy is converted to AC form, so that it can be fed into the electrical grid. A device which converts DC current to AC form is called an 'inverter'.

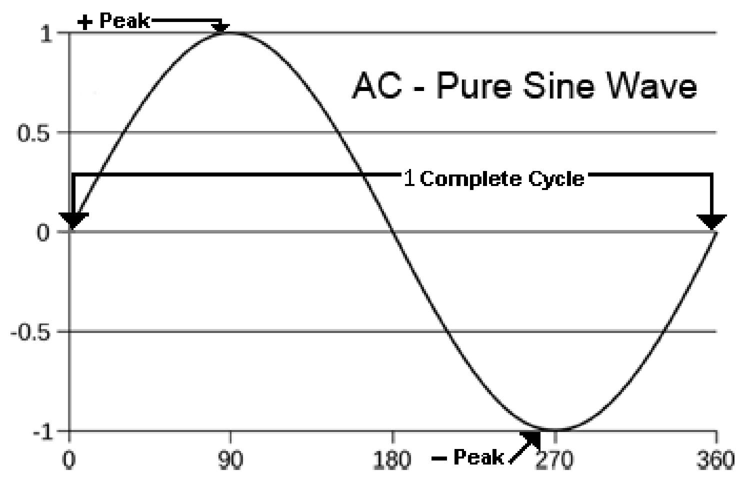

Fig 2.2.4 AC waveform – Single Phase Supply

Single Phase supply refers to a two wire Alternating Current (AC) power circuit. Typically there is one live wire and one neutral wire. In India, 230V is the standard single phase voltage with one 230V live wire and one neutral wire. Power flows between the live wire (through the load) and the neutral wire.

Three Phase power refers to three wire Alternating Current (AC) power circuits. Typically there are three (Phase 1, Phase 2, Phase 3) power wires (120 degrees out of phase with one another) and one neutral wire.

Let us consider a 3 Phase 4 Wire 415Y/240V power circuit

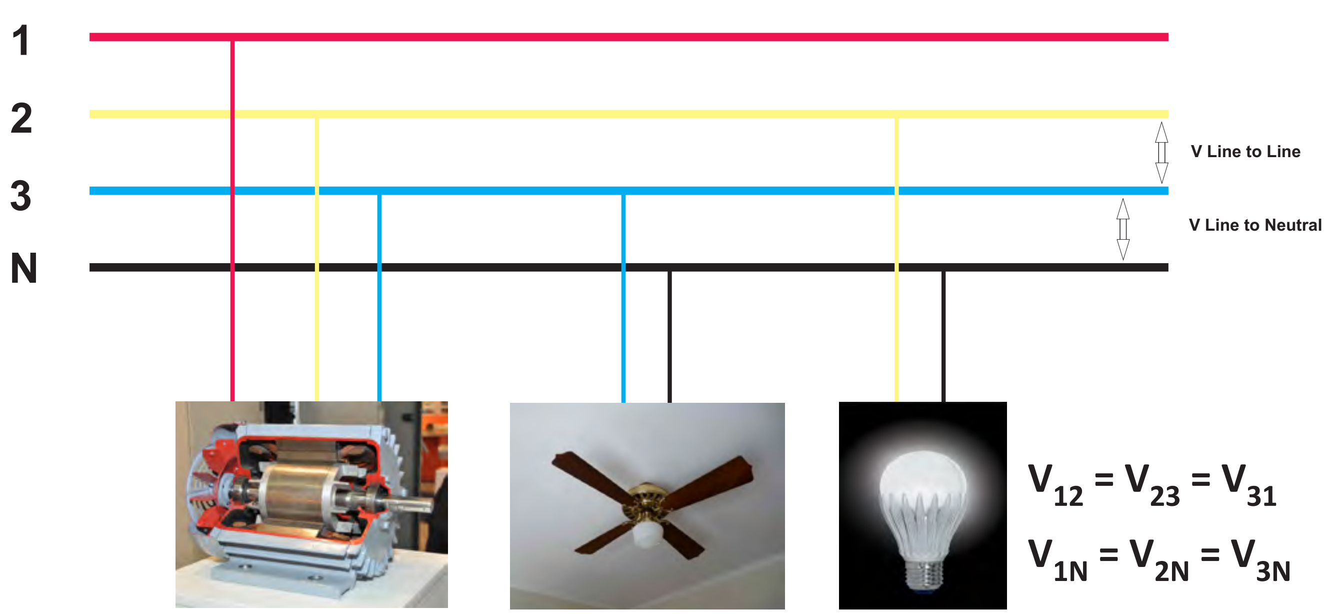

Fig 2.2.5 Connection of load to a three phase supply (Three phase, four wire system)

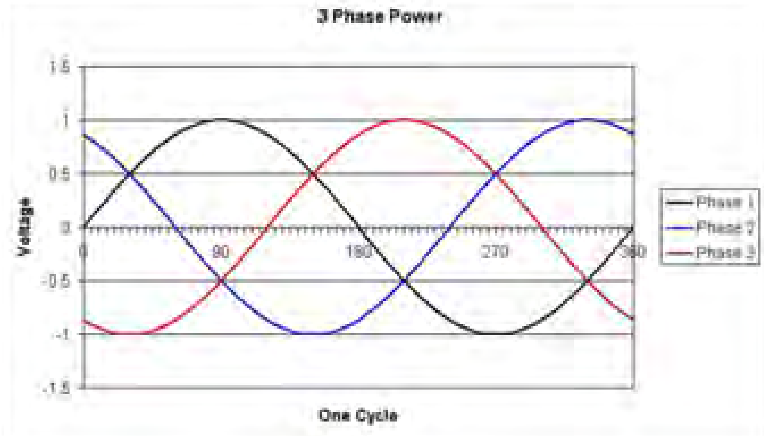

Fig 2.2.6 AC Waveform – Three Phase Supply

Tips

1. Countries across the world maintain a uniform frequency which is either 50 Hz or 60 Hz. In India, the frequency of AC is 50 Hz.
2. Typical values of Supply Voltage at the final Load points:

Single Phase Supply	**230 Volts**
Three Phase Supply	**240/415 Volts**

3. In case of three phase supply, the total load connected should be equally distributed between the three phases for a balanced power system. Overloading of one phase may cause under-voltage in the other phases and damage the functioning of connected equipment.
4. Using a 3 Phase power arrangement saves on electrical construction costs by reducing the current requirements, the required wire size, and the size of associated electrical devices. It also reduces energy costs because the lower current reduces the amount of electrical energy lost to resistance (converted to heat).
5. As a matter of fact, the electricity voltage supply we get at homes is AC Supply. All appliances like LED lamps, Fans, Air Conditioners, Heaters and all electrical points draw current (or energy) from AC Voltage supply.

2.2.5 Ohm's Law

The relationship between voltage and current can be simply explained by Ohm's Law.

Activity:

1. Set up a circuit as shown in figure, consisting of a nichrome wire XY of length, say 0.5 m, an ammeter, a voltmeter and four cells of 1.5 V each. (Nichrome is an alloy of nickel, chromium, manganese, and iron metals.)

Table 2.1 Observation Table to calculate V-I Ratio

S.No.	Number of cells used in the circuit	Current through the Nichrome wire, I (ampere)	Potential difference across the nichrome wire, V (volt)	V/I (Voltage/Ampere)

2. First use only one cell as the source in the circuit. Note the reading in the ammeter I, for the current and reading of the voltmeter V for the potential difference across the nichrome wire XY in the circuit. Tabulate them in the Table given.
3. Next connect two cells in the circuit and note the respective readings of the ammeter and voltmeter for the values of current through the nichrome wire and potential difference across the nichrome wire.
4. Repeat the above steps using three cells and then four cells in the circuit separately.
5. Calculate the ratio of V to I for each pair of potential difference V and current I.
6. Plot a graph between V and I, and observe the nature of the graph.

It is found that approximately the same value for V/I is obtained in each case. Thus the V–I graph is a straight line that passes through the origin of the graph, as shown in figure above. Thus, V/I is a constant ratio.

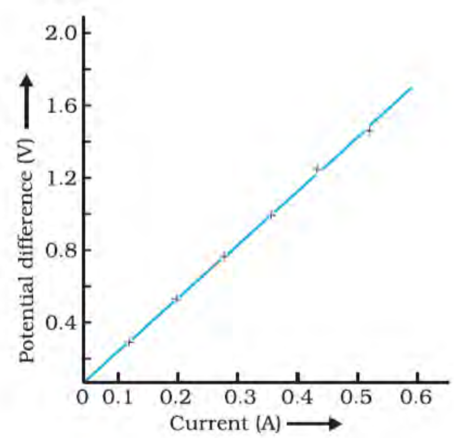

Fig 2.2.7 Graph for a nichrome wire

The potential difference, V, across the ends of a given metallic wire in an electric circuit is directly proportional to the current flowing through it, provided its temperature remains the same. This is called Ohm's law.

$$V \alpha I$$

$$V = R.I$$

R is a constant for the given metallic wire at a given temperature and is called its resistance. Ohm's triangle can be used to calculate voltage, current or resistance in a circuit for standard conditions.

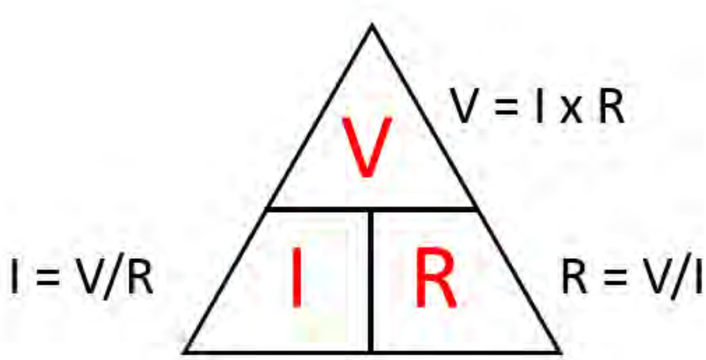

Fig 2.2.8 Ohm's triangle

2.2.6 Resistance

Resistance is the property of a conductor to resist the flow of charges through it. Its SI unit is ohm, represented by the Greek letter 'Ω'.

According to Ohm's Law, R=V/I and conversely, I=V/R

It can be observed that the current through a resistor is inversely proportional to its resistance. If the resistance is doubled the current gets halved. In many practical cases it is necessary to increase or decrease the current in an electric circuit. A component used to regulate current without changing the voltage source is called variable resistance. In an electric circuit, a device called rheostat is often used to change the resistance in the circuit.

Certain components offer an easy path for the flow of electric current while the others resist the flow.

The motion of electrons in an electric circuit constitutes an electric current. The electrons, however, are not completely free to move within a conductor. They are restrained by the attraction of the atoms among which they move. Thus, motion of electrons through a conductor is retarded by its resistance.

- A component of a given size that offers a low resistance is a good conductor.
- A conductor having some appreciable resistance is called a resistor.
- A component of identical size that offers a higher resistance is a poor conductor. An insulator of the same size offers even higher resistance.

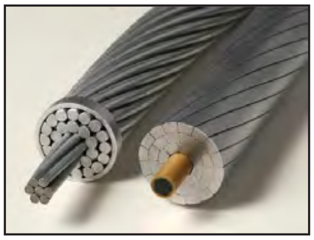

Fig 2.2.10 Good conductor - copper wire

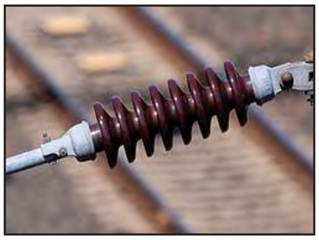

Fig 2.2.11 Insulator – ceramic

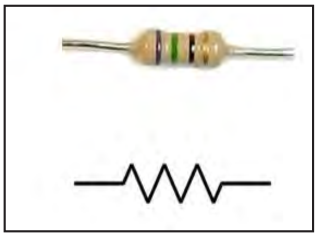

Fig 2.2.12 Resistor (with symbol)

Notes

UNIT 2.3: Connection in Series and Parallel

Unit Objectives

At the end of this unit, you will be able to:

1. Differentiate between series and parallel connection
2. Calculate total load connected to a simple circuit

2.3.1 Combination of Resistors

In various electrical gadgets, we often use resistors in various combinations. We now therefore intend to see how Ohm's law can be applied to combinations of resistors. There are two methods of joining the resistors together – Series and Parallel.

Table 2.2 Voltage across and current flowing through a system of resistors

For 'n' Lamps connected across a Source	Series	Parallel
Voltage	Divided as per Resistance of Individual Loads	Same across all Loads
Current	Same flowing through all Loads	Divided as per Resistance of Individual Loads

2.3.2 Series

In a series combination of resistors the current is the same in every part of the circuit or the same current through each resistor.

Secondly, the total potential difference across a combination of resistors in series is equal to the sum of potential difference across the individual resistors.

The individual voltages can be calculated as follows:

- Calculate Total/Effective resistance

  $R_t=R_1+R_2+R_3+....+R_n$

- Calculate Current flowing through circuit

  $It=Vs/Rt$

  Also, $I_t=I_1=I_2=I_3=....=I_n$

- Calculate Voltage through each element/LED lamp:

  $V_n=I_n \times R_n$

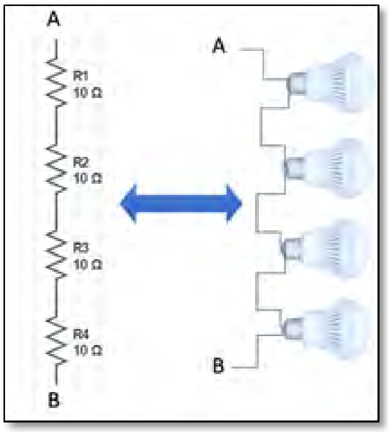

Fig. 2.3.1 Series connected LED lamps

Table 2.3 Voltage and Current for elements connected in series

Voltage is added in a series branch	$V_t=V_1+V_2+V_3+....+V_n$
Current remains same across the series branch	$I_t=I_2=I_3=I_4=....+I_n$

2.3.3 Parallel

Now, let us consider the arrangement of three resistors joined in parallel with a combination of cells (or a battery).

It is observed that the total current I, is equal to the sum of the separate currents through each branch of the combination.

The individual current through elements can be calculated as follows:

- Calculate Total/Effective resistance

  $1/R_t=1/R_1+1/R_2+1/R_3+.....+1/R_n$
- Voltage remains the same as Source Vs (across terminals A-B),

  $V_s=V_1=V_2=V_3=V_n$
- Calculate current through individual element as follows:

  $I_n=V_s/R_n$

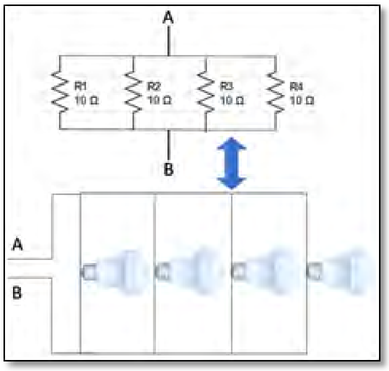

Fig. 2.3.2 Parallel connected LED lamps

Table 2.4 Voltage and Current for elements connected in parallel

Current is added in a parallel branch	$V_t=V_1=V_2=V_3=....=V_n$
Voltage remains same across the parallel branch	$I_t=I_1+I_2+I_3+....+I_n$

Tips

1. We have seen that in a series circuit the current is constant throughout the electric circuit. Thus it is obviously impracticable to connect an electric bulb and an electric heater in series, because they need currents of widely different values to operate properly.
2. Another major disadvantage of a series circuit is that when one component fails the circuit is broken and none of the components works.
3. On the other hand, a parallel circuit divides the current through the electrical gadgets. The total resistance in a parallel circuit is decreased. This is helpful particularly when each gadget has different resistance and requires different current to operate properly.
4. All household circuits and appliances are connected in Parallel. Hence, they all operate at the same voltage. The total current requirement of a house is addition of individual current required for each appliance.

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UNIT 2.4: Measuring Instruments

Unit Objectives

At the end of this unit, you will be able to:

1. Measure and record voltage and current using Voltmeter and Ammeter, respectively
2. Measure various electrical circuit parameters using Multi-meter and Clamp-on meter

2.4.1 Voltmeter

- The measurement of voltage in an electrical circuit can be done using a Voltmeter. It can measure the potential between any two nodes in a circuit.
- It is connected in parallel across the circuit elements where Voltage has to be measured. It is designed to have very high resistance (which means lesser current is drawn) leading to lesser energy loss due to measuring device.
- There are some voltmeters which measure only DC voltage and there are certain types which measure both AC and DC voltages.
- Range of the voltmeter is the limits between which the voltage can be measured. Typical laboratory DC voltmeters are available in the range of 0-5 V, 0-10V, 0-20V, etc.

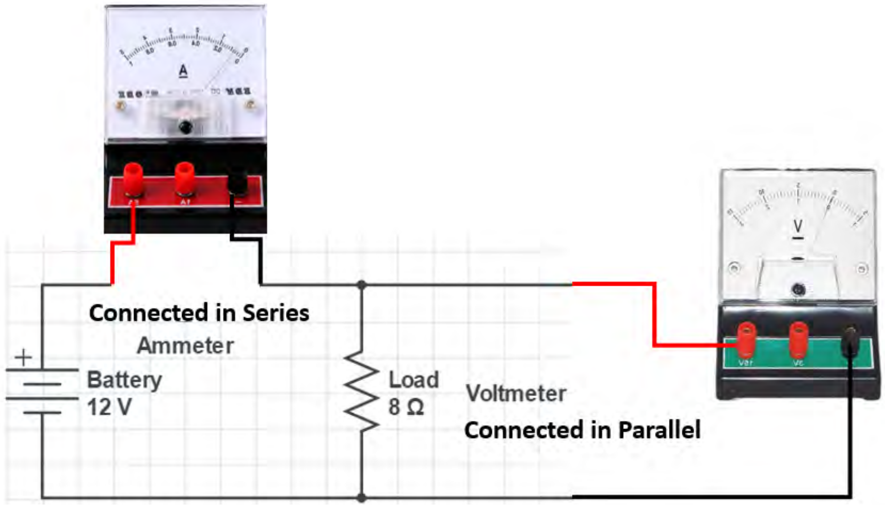

Fig. 2.4.1 Voltmeter is connected across the load (i.e., parallel) whereas ammeter is connected in series with the load

2.4.2 Ammeter

- The measurement of current in any branch of the circuit can be done using an Ammeter. The typical current range is from 0-1 A to 0-5 A for laboratory measurements.
- It is connected in series with the branch circuit, as illustrated above, because current in all elements remains the same. Thus, the ammeter has a very low resistance itself (almost like a short circuit path). This creates nearly zero voltage drop, causing negligible interference in the circuit.

2.4.3 Digital Multimeter

A digital Multimeter is a measuring instrument which can measure several parameters of an electrical circuit. The standard measurements it performs is that of:

1. Voltage (volts)
2. Current (A, mA, µA)
3. Resistance (Ω or ohms)

The other additional measurements which can be performed include temperature, frequency, capacitance, continuity, etc.

The parts of the multimeter include:

Display screen - It has illuminated display screen for better visualization. It has five digits display screen, one represent sign value and the other four are for number representation.

Selection knob - A single multimeter performs many tasks like reading voltage, resistance, and current. The selection knob allows the user to select the different task.

Port - There are two ports on the front of the unit. One is the mAVΩ port which allows the measurement of all the three units: current up to 200 mA, voltage, and resistance. The red probe is plugged into this port. The other is COM port which means common and it is normally connected to negative of a circuit and black probe is plugged into it. There is one special port of 10A which is used to measures large current in the circuit.

Fig. 2.4.2 Multimeter

2.4.4 Clamp Meter

A clamp meter is an electrical tester that combines a basic digital multimeter with a current sensor. Clamps measure current. Probes measure voltage. Having a hinged “clamp” jaw integrated into an electrical meter allows users to simply clamp around wire, cables and other conductors at any point in the electrical system and measure its current, without disconnecting it.

What do clamp meters measure?

Any of these: AC current, AC and DC voltage, resistance, continuity, and, with some models, DC current, capacitance, temperature, frequency and more.

Typically, they measure to the nearest tenth of a unit (rather than the milli-units you find in a full-function multimeter), making them perfect for electrical work.

Advantages:

- Safer to measure electrical parameters because no direct interaction with the bare electrical wire is required

Fig. 2.4.3 Clamp meter

Notes

UNIT 2.5: Power and Energy

Unit Objectives

At the end of this unit, you will be able to:

1. Explain the terms Power and Energy
2. Perform basic calculations for power and energy

2.5.1 Electrical Power

In electricity, besides voltage and current, the next important term is power.

When electricity flows in an electrical circuit, it results into some work done. For example when electricity flows in a fan, the blade of fan rotates, or when electricity flows in a TV, the TV operates.

Power (P), is a measure of the speed or rate at which work is done. More power means that the electrical work is done faster and lesser power means that the electrical work is done at a lower speed.

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Electrical Power = Voltage X Current; or

Power (watt) = Voltage (Volt) X Current (Ampere)

This may be expressed as,

$P(W)=V_I=(IR).I=I^2 R$

Power is measure in Watts.

2.5.2 Electrical Energy

Energy is another important terminology related to the use of electricity. There is very clear difference between energy and power. As the electrical power represents the rate or speed of work done then "electrical energy" represents the total work done. Energy consumed by an electrical appliance depends on two factors:

- Power (P) of an appliance (Given in watts i.e. W)
- Duration of usage (given in hours i.e. h)

Electrical Energy = Power X Duration of usage.

Or

Energy (E) = Power (watt) X Time (hours)

Or E(Wh) = P(W) X T(h)

Since the electrical energy is the product of power and time, the unit of electrical energy is the product of unit of power and time i.e. watt X hour i.e. Watt-hour

- 1KWh = 1000 Wh
- Energy = Power X Time
- Power = Energy / Time

Table 2.5 Units of measurement for electrical circuit parameters

S.N.	Electrical Term	Symbol of Electrical Term	Unit of measurement	Symbol of unit	Alternative unit
1	Voltage	V	Volt	V	mV
2	Current	I	Ampere	A	mA
3	Power	P	Watt	W	kW, MW
4	Energy	E	Watt-hour	Wh	kWh

Notes

UNIT 2.6: Earthing and Lightning Protection

Unit Objectives

At the end of this unit, you will be able to:

1. Identify the purpose of earthing and lightning protection

2.6.1 Introduction

Lighting protection systems are particularly aimed at providing personal protection when there are direct lightning strikes. If the PV system is in an exposed location, then a suitable lightning conductor must be used. Lightning can induce voltage surges in the PV modules, module cables and the DC main cable. The following points usually apply for overvoltage protection for PV systems:

- PV systems, In general, do not increase the risk of buildings being struck by lightning.
- If a lightning protection system exists, the PV generator must be connected to this.
- Suitable surge arrestors on the DC side in the panel junction box is recommended.
- Overvoltage protection on the AC side is also recommended.
- External lightning protection includes all measures and devices for intercepting and providing a exit path for lightning. Such a system consist of and interception unit the lightning wire and earthing system.
- The internal lightning protection encompasses all considerations and equipment like electronic devices and switching gear. All potentially conductive systems like AC's, heating appliances, etc. must be connected with earth/ ground system.

2.6.2 Protection Methods

AC and DC side protection

- In order to reduce surges in the module cables, each string's positive and negative cables should be routed as close to each other as possible. Here it should be maintained that the ca le laying is short-circuit proof.
- Shielded individual cables are recommended in a system exposes to the risk of lightning. The cross section of the shield should be as per minimum standards.
- It is often a safe solution to arranage the shielded DC main cable along the building's side and to lead it towards the earth/ground. It is also possible to adopt metallic protective pipe system.
- Surge arrestors are used to protect PV system and downstream electronic devices.
- The Surge Protection Devices are usually a combination of Metal Oxide Varistors (MOV) and/or Gas Discharge Tubes (GDT) acting like a diode (or Zener diode) shunting the current created by the high voltage away from protected sensitive areas when triggered. Both MOVs and GDTs have a limited lifetime, and can handle a finite number of transients.

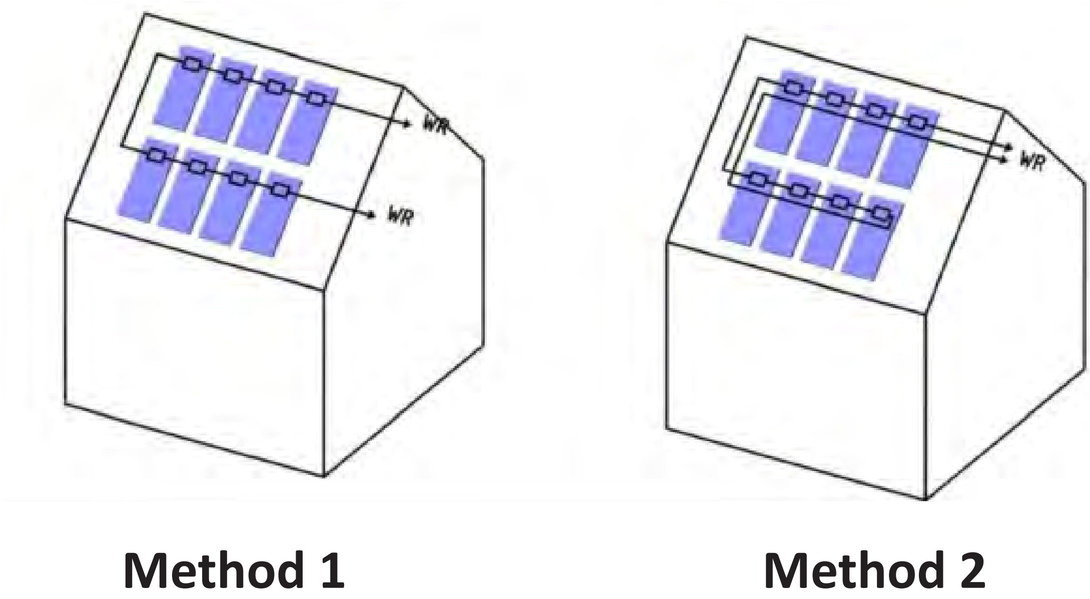

Fig. 2.6.1 The module cables should be placed close together (Method 2)

When using string protectors such as fuses, DC breakers or string diodes together (This comes integrated into the panel's junction box) with SPDs, the SPD must be installed between the junction box and the inverter.

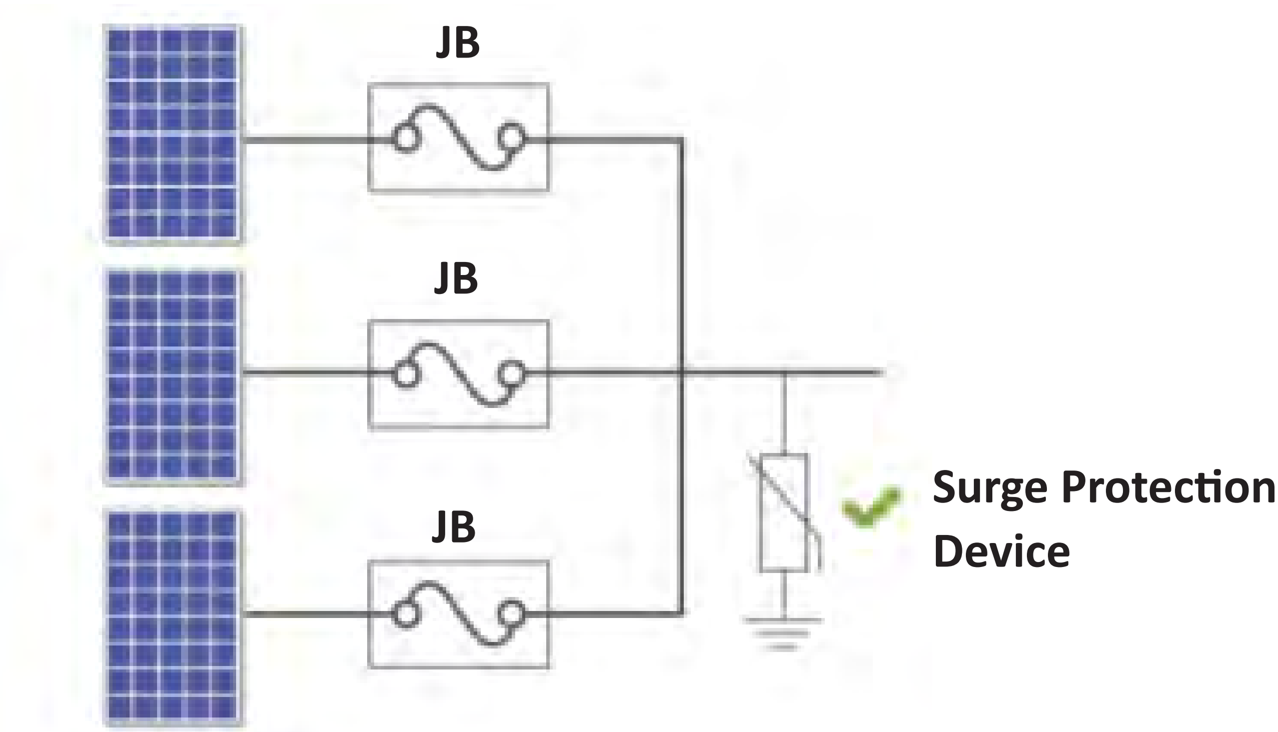

Fig. 2.6.2 Surge protection device (SPD) is connected between the junction box and inverter

On the AC Side, Inverters can be connected to the same SPD if they are sharing the same grid connection. The type of surge arrestors for the AC side are different. Surge protection should be according to the wiring specifications.

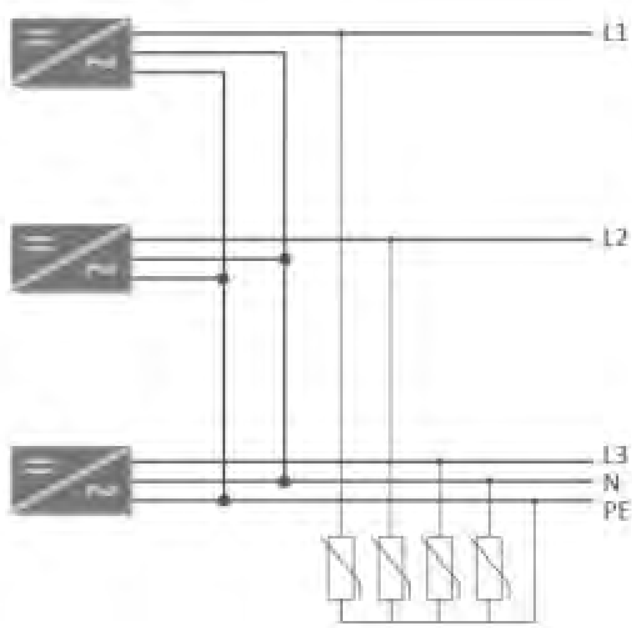

Fig. 2.6.3 Surge protection device (SPD) is connected between the junction box and inverter

2.6.3 Earthing/Grounding

An effective overvolatge protection involves a complete potential equalisation and thorough earthing/grounding. The grounding conductor must be led to the earth along the shortest path possible. Loop formations must be avoided. The earthing conductors must be laid straight to ensure an optimum path. The mounting system of the PV panels must be equipotentially bonded. The material used for eathing/grounding conductors can include copper (16 mm^2), Aluminium (25 mm^2), Steel (50 mm^2) and/or the natural components of the building (existing metal frames, railings and other metal facades).

For practical purposes, the importance of Earthing is not just to create a reference point but to provide safety. It includes the protection of

1. Personnel (Engineer, Technicians and also consumers) from
   - Electrocution
   - Fire
2. Equipment and Facility from
   - Failure
   - Fire
3. Protect electrical circuit from
   - Cable failures

For effective protection of systems, the response time must be fast in order to eliminate or at least minimize possible damage.

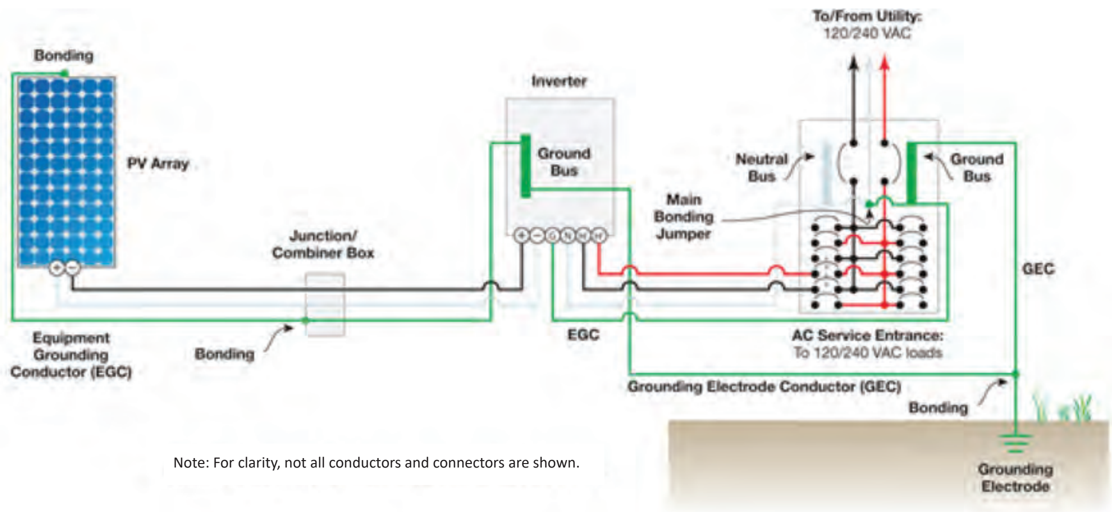

Fig. 2.6.4 Earthing/Grounding of a Solar PV System

Tips

Usually, in most cases, accidents and system failures occur because of two failures or events that co-exist. For example, poor earthing alone is not a problem, until a short circuit occurs. That is when an accident happens.

Improper grounding can cause more harm than no grounding. Misunderstood grounding often leads to the installation of improper grounding systems that are ineffective, or even worse, dangerous.

Exercise

1. Name and briefly describe the stages of manufacturing a Solar PV Module.
2. Why is solar energy advantageous over other sources of energy?
3. How will you explain the relationship between Voltage and Current? Find out how this relationship is different for metals and semi-conductors. Also use a V-I graph for discussion.
4. How does the voltage across and current flowing through 2 LED bulbs change if it is connected in (i) Series; and (ii) Parallel.
5. **Activity**

Draw a Single Line Diagram for a household circuit. Assume that the following loads are to be connected:

(i) 3 fans;

(ii) 5 LED Lamps;

(iii) 1 Refrigerator; and

(iv) 3 Electrical points.

6. What are the safety considerations while working with electrical components and power systems? Name any 'Safety Standard' which is nationally or internationally recognized as a safety benchmark by the industry.
7. Differentiate between a Digital Multimeter and a Clamp-on meter.
8. What form of current is produced from harnessing Solar Photovoltaic Energy? Can this current be utilized directly? Explain with reasons.

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3. Basics of Solar Photovoltaic (PV) Systems

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Key Learning Outcomes

At the end of this module, you will be able to:

1. Identify the terminology and technical parameters associated with solar photovoltaic systems
2. Explain sun path diagram and solar radiation
3. Identify the different components of a solar PV system, their working and importance
4. Identify the different types of solar photovoltaic systems
5. Explain the performance parameters of a solar PV panel

UNIT 3.1: Terms and Definitions

Unit Objectives

At the end of this unit, you will be able to:

1. Explain the terms / definitions associated with solar photovoltaic systems
2. Identify units of measurement associated with technical terms used for solar photovoltaic systems

3.1.1 Terminology and Definitions Explained

1. **Irradiance (w/m2):** Irradiance (or power density) is defined as the solar energy received by earth's surface per unit area.
2. **Insolation or Irradiation (wh/m2):** Insolation or irradiation (or energy density) is defined as the amount of solar energy received by earth's surface over a given duration of time.
3. **Solar constant:** The solar constant is the amount of energy that normally falls on a unit area (1 m2) of the earth's atmosphere per second when the earth is at its mean distance from the sun. The value of the Solar constant is 1367 W/m2.
4. **Direct normal irradiance (w/m2):** It is defined as the solar radiation which reaches to earth's surface without being absorbed or scattered.
5. **Beam radiation (w/m2):** It is defined as the Cosine component of the Direct Normal Irradiance.

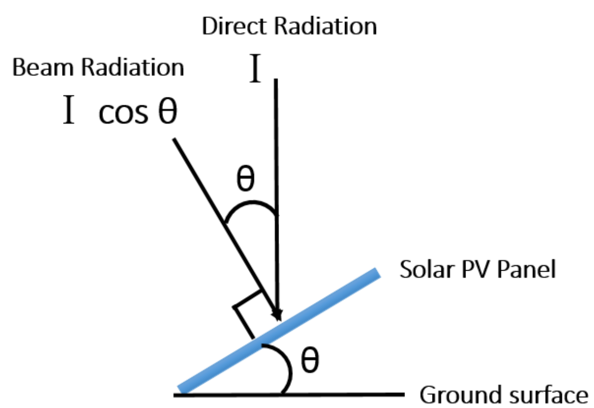

Fig. 3.1.1 cosine component of direct radiation is called 'Beam Radiation'

6. **Diffused horizontal irradiance (w/m2):** It is defined as the sum of all scattered radiations.
7. **Albedo radiation (w/m2):** It is defined as the radiation (part of diffused and direct radiation) that gets reflected by earth and other objects on the earth.
8. **Global horizontal irradiance (w/m2):** It is defined as the sum of the diffused radiation, direct radiation and albedo radiation.

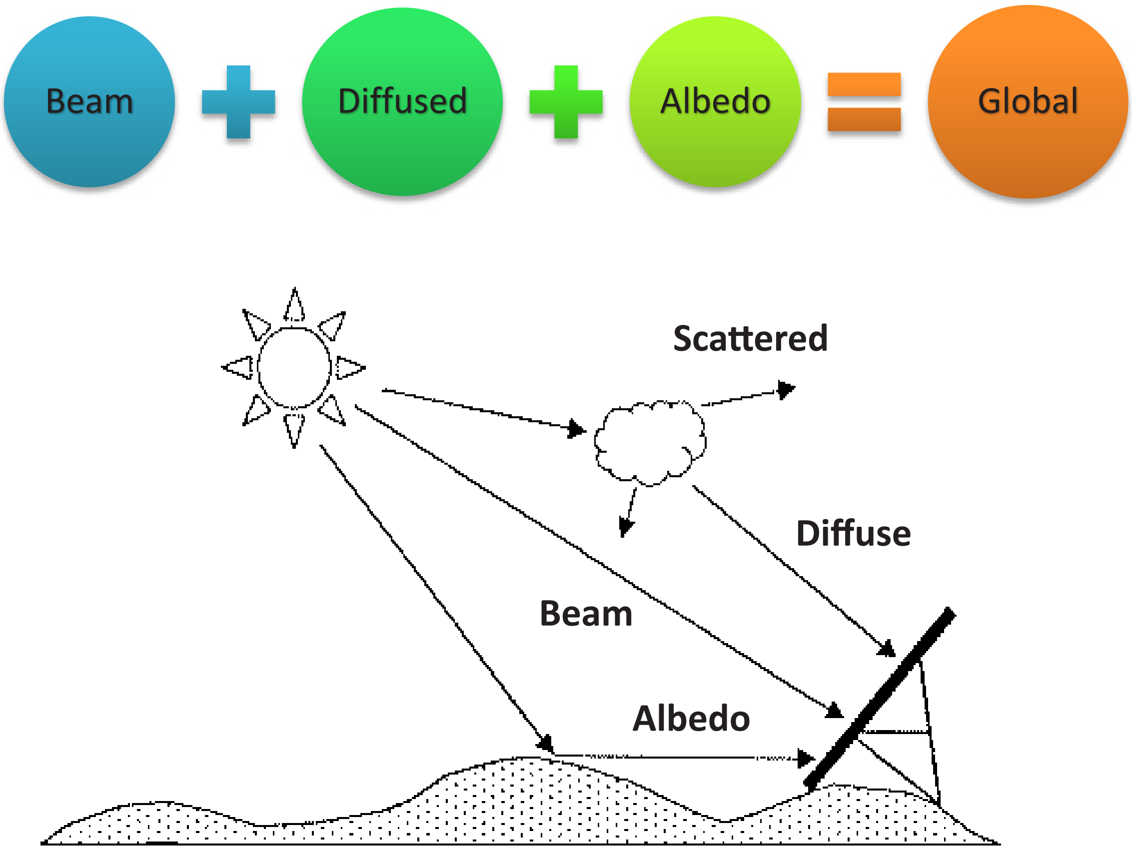

Fig. 3.1.2 Global horizontal radiance is the sum total of all radiation (beam, diffuse and albedo) falling on the solar pv panel

9. **Irradiance at tilted surface (w/m2):** It is defined as the radiation falling on any tilted surface.
10. **Air mass:** The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass measures reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.

    In simple terms, it is defined as the distance travelled by solar radiation in earth's atmosphere.

$$AM = 1/ \cos \theta$$

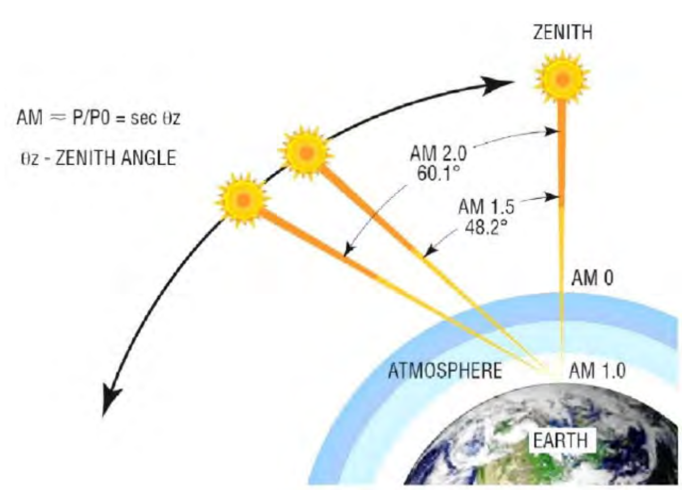

Fig. 3.1.3 Air Mass

11. **Latitude angle (or angle of latitude):** It is defined as the angle drawn between the lines joining the centre of earth to the site with its projection on the equatorial plane. For India, it is considered to be positive. It is denoted by '**φ**'.
12. **Solar hour angle:** It is defined as the angular measurement of time. Conventionally, it is taken positive in morning and negative in the afternoon. It is denoted by 'ω'.
13. **Declination angle:** It is defined as the angle drawn between the lines joining the centre of earth to the centre of sun having its projection on the equatorial plane of the earth. It is denoted by 'δ'.

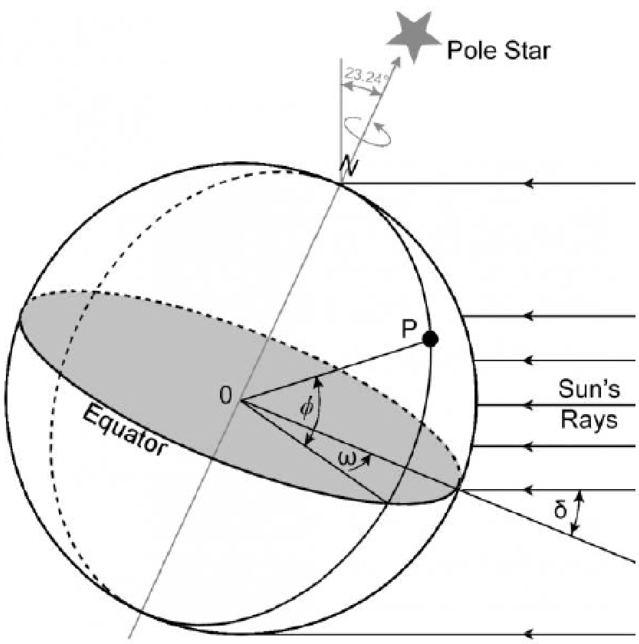

Fig. 3.1.4 Declination angle

14. **Equinox:** Literally "equal night", a day when the number of hours of daylight equals the number of hours of night. The vernal equinox, usually March 21, signals the onset of spring, while the autumnal equinox, usually September 21, signals the onset of autumn.
15. **Solstice:** A day when the sun is at the highest point in the sky (summer solstice, 21 June) or at the lowest point in the sky (winter solstice, 22 December).
16. **Azimuth angle:** It is defined as the angle between the sun's rays and true South. A positive solar azimuth angle indicates a position East of South, and a negative azimuth angle indicates West of South.

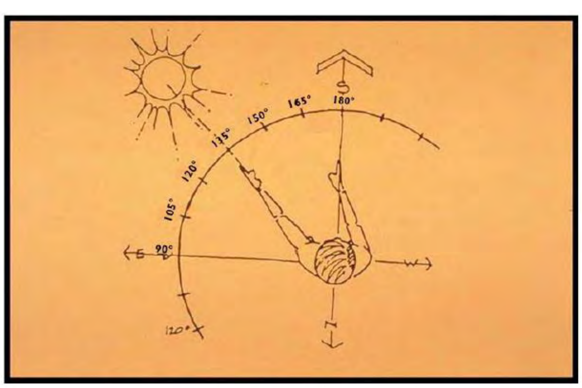

Fig. 3.1.5 Sun azimuth

17. **Zenith angle:** It is defined as the angle drawn between the sun and the vertical.

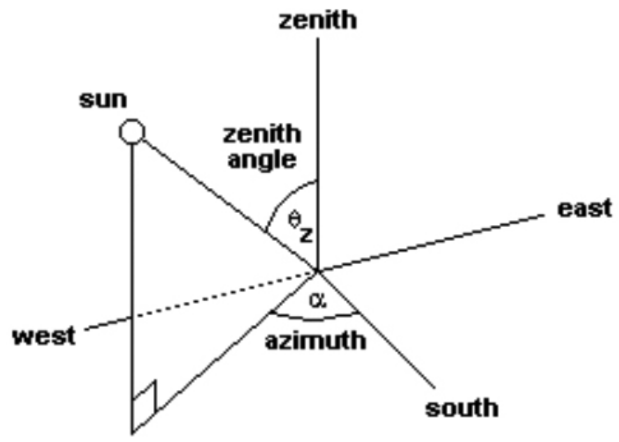

Fig. 3.1.6 Zenith angle and azimuth angle

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UNIT 3.2: Solar Radiation and Sun Path Diagram

Unit Objectives

At the end of this unit, you will be able to:

1. Explain the sun path diagram for a specific location and time
2. Estimate the angle of inclination for the solar panels

3.2.1 Sun Path Diagram

The path followed by the sun across the sky from sunrise to sunset can be drawn for any situation. It depends on:

1. The location of observation on earth; and
2. The time of the year

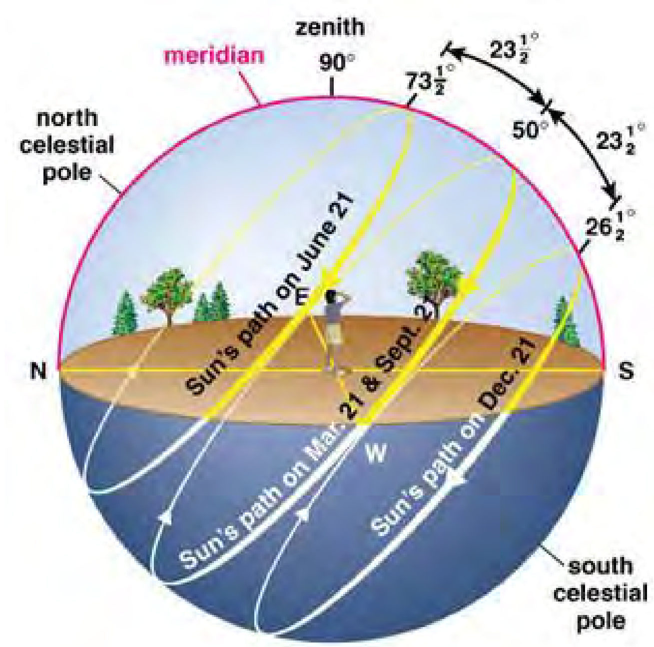

Fig. 3.2.1 Sun's path (east - west) during the year for a specific site in the northern hemisphere

3.2.2 Use of Sun Path Diagram

Sunpath diagram is used to locate the position of sun at any time and day throughout year. To locate sun in sky generally two parameters are required:

1. Azimuth angle
2. Sun height

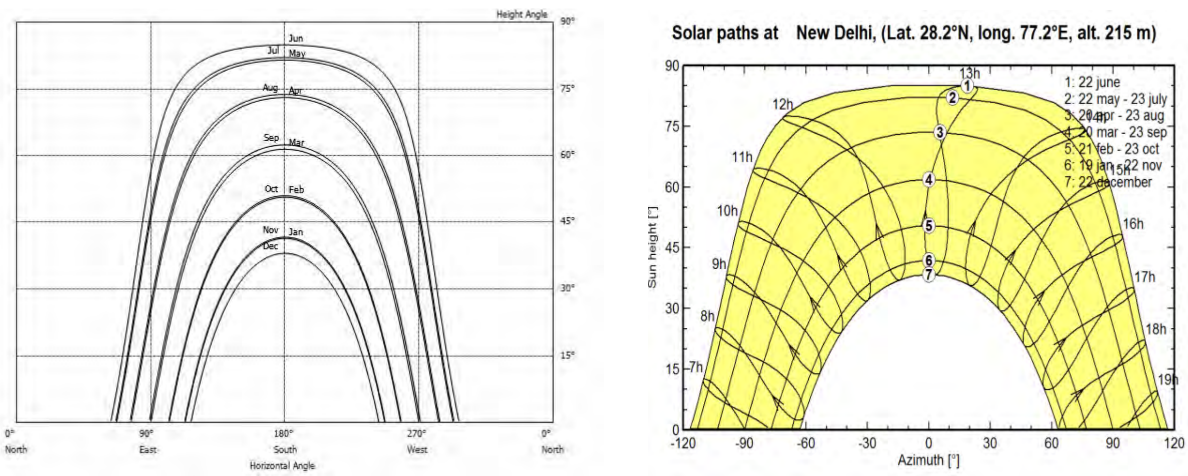

Fig. 3.2.2 Sun Path

In the sunpath diagram shown above, azimuth angle is on horizontal axis and sun height is on vertical axis. Seven lines (numbered from 1 to 7 in above figure) generally called as date line represent twelve month of a year. Top line represents summer solstice while bottom line represents winter solstice. All the lines (concentric circles) crossing these seven lines represent hour of the day (from 7 AM to 7 PM). These lines are called hour lines.

Figure shown below, shows sun location for particular day and time (23 Oct, 2 PM). For this location sun height is 45 and sun azimuth is 30 degree.

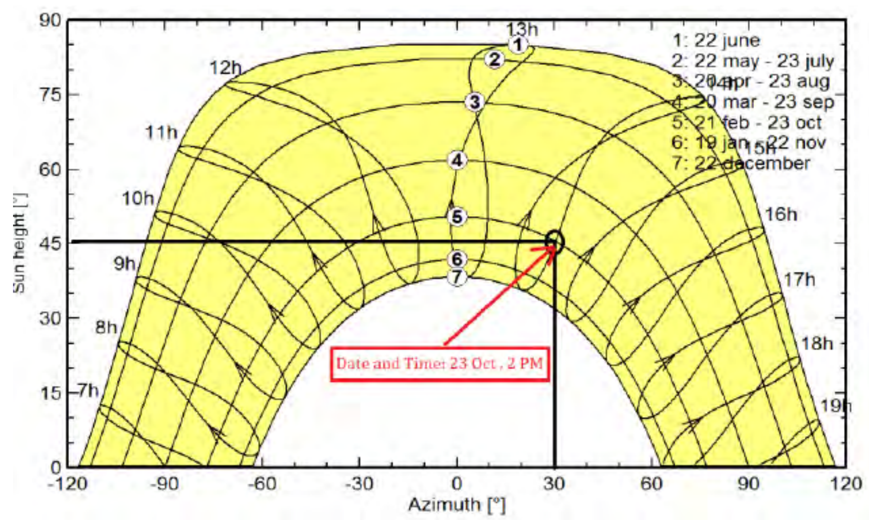

Fig. 3.2.3 Solar paths at new delhi, (Lat. 28.2^0 N, long. 77.2^0 E, alt. 215m)

3.2.3 Tilt Angle and Cosine Effect

When the sun is lower in the sky, its energy is spread over a larger area, and is therefore weaker per surface area. This is called the “cosine effect”. More specifically, assuming no atmosphere, in any place on a horizontal surface the direction of the sun at its zenith forms an Solar irradiance is maximal when the sun is directly overhead angle with the vertical. The irradiance received on that surface is equal to the irradiance on a surface perpendicular to the direction of the sun, multiplied by the cosine of this angle. Conventionally, the tilt angle for maximum average annual energy generation = Latitude of the Location

However, the optimal tilt angle of the module for that location is a design parameter and is calculated using softwares like PVSOL, PVsyst, etc.

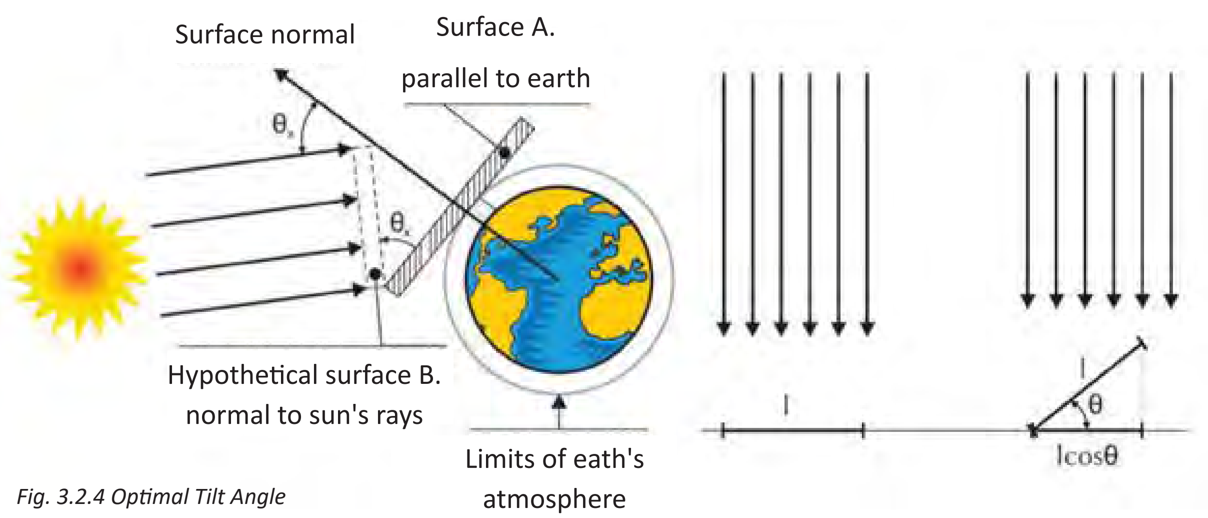

Fig. 3.2.4 Optimal Tilt Angle

To illustrate, India lies between the Latitude: 8o0’0” N to 36o0’0” N

For example, as Delhi’s latitude is 28.6o N , the tilt angle of the solar panel will be:

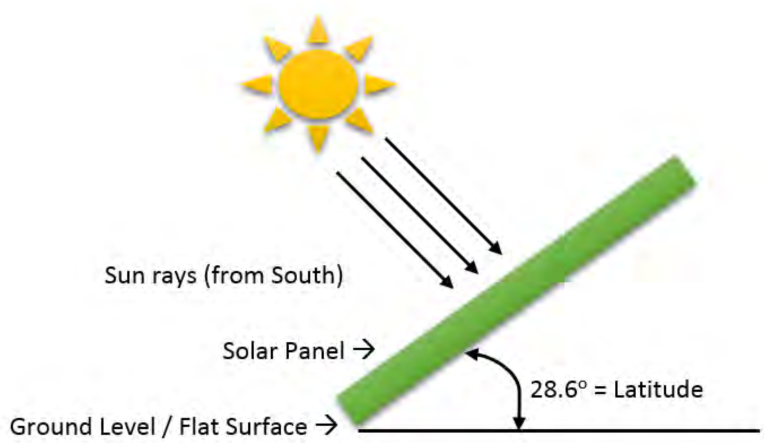

Fig. 3.2.5 Example of tilt angle of a solar PV panel for a location in Delhi

Notes

UNIT 3.3: Components of a Solar PV System

Unit Objectives

At the end of this unit, you will be able to:

1. List the different components of a solar PV system
2. Explain the importance and operation of various components

3.3.1 Solar PV Module

In the market, different modules are used depending on cost and technical considerations. These are predominantly identified according to their cell type:

1. Monocrystalline
2. Ponocrystalline
3. Thin-film (Amorphous, microcrystalline, CdTe or CIS modules)

Modules are characterised by the performance of the solar cell technology used. The specifications of a panel are provided by the manifacturer on a name plate given behind the panel.

Tips

1. Hot spots

   Under certain conditions a shaded solar cell can become so heated that the cell material is damaged and a 'hot spot' develops. This occurs due to relatively high reversed current which can flow through a shaded solar cell. This reduces the power output of the cell. Frequent occurence can lead to the module failure.

2. Bypass/blocking diodes

   To prevent a hot spot from developing, the current can be diverted past a cell using a bypass diode. Such a diode can be connected anti-parallel across 18-20 solar cells. Besides hot spot prevention bypass diode also help reduce power losses that result from shading.

3.3.2 PV Junction Box

A string of modules is connected together in the array junction box. This junction box also contains DC main cable, compensation cable, supply termimals, isolation points, string fuses and string diodes. Often surge arrestor are also included in PV junction boxes to divert surge voltage to the ground.

3.3.3 Inverter

A solar inverter connects a PV array to the AC grid and AC loads. Its basic funstion is to convert solar DC electricity generated by the PV module into AC electricity as per the required frequency and voltage level of the building's electrical system.

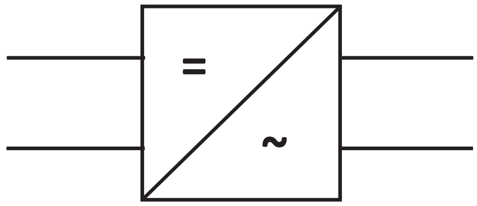

Fig. 3.3.1 A symbol for inverter

In the inverter an MPP tracker (Maximum Power Point Tracker) ensures that the inverter is adjusted to the maximum power point. An electronic circuit connected to the inverter ensures that the voltage and current vary as per optimum condition requirement. This MPP tracker ensures that the maximum possible power is derive from the solar PV system. This tracker is essentially and electronic DC converter. Inverters perform the follwing functions:

1. Convergion of DC to AC
2. Adjustment of operating point to maximum power point through tracker
3. Recording of operating data and signaling
4. Establishment of DC and AC protective measure
5. Grid monitoring/management

The convergion efficiency of an inverter describe the losses arising out of DC to AC convergion. It is mainly due to power switching devices.

$$\text{Efficiency } (\eta) = \frac{P_{ac} \text{ Output power}}{P_{dc} \text{ Input real power}}$$

3.3.4 Cabling and Wiring

Module and String cable

The cabling and wiring of a solar PV system should meet the requirement of the specific application. The electrical connecting cables between individual modules and the junction box are called module cables or string cables. Single wire cables with double insulations offer a reliable solution.

Connection System

Connection of module cables and other DC cables must be carried out with extreme care. Usually screw terminals are made using fine - stranded wires, cable lugs, nuts and bolts, plug connectors, etc. MC4 connectors are commonly used in the market.

DC main cable

The DC main cable connects the PV combiner box to the inverter. If the PV junction box is located outdoors, the PVC sheathed cables must be laid in the protective pipe since they are not UV resistant.

AC connection cable

The AC connection cable links the inverter to the grid through appropriate protection equipment. In case of three phase inverters, the connection to the low voltage grid needs to be made as per specified codes and regulation.

3.3.5 Batteries

Energy storage is required in most stand-alone systems, as energy generation and consumption do not generally coincide. The power generated during the day is very often not required until the evening and there has to be temporarily stored. We scrutinize the batteries not only in terms of energy density but also longevity, load characteristics, maintenance requirements, self-discharge and operational costs. Since NiCd remains a standard against which other batteries are compared, we evaluate alternative chemistries against this classic battery type.

Nickel Cadmium (NiCd) — mature and well understood but relatively low in energy density. The NiCd is used where long life, high discharge rate and economical price are important. Main applications are two-way radios, biomedical equipment, professional video cameras and power tools. The NiCd contains toxic metals and is environmentally unfriendly.

Nickel-Metal Hydride (NiMH) — has a higher energy density compared to the NiCd at the expense of reduced cycle life. NiMH contains no toxic metals. Applications include mobile phones and laptop computers.

Lead Acid — most economical for larger power applications where weight is of little concern. The lead acid battery is the preferred choice for hospital equipment, wheelchairs, emergency lighting and UPS systems.

Lithium Ion (Li ion) — fastest growing battery system. Li ion is used where high-energy density and lightweight is of prime importance. The technology is fragile and a protection circuit is required to assure safety. Applications include notebook computers and cellular phones.

Lithium Ion Polymer (Li ion polymer) — offers the attributes of the Li-ion in ultra-slim geometry and simplified packaging. Main applications are mobile phones.

The most common types of battery found in standalone systems are Lead ci batteries. These are the most cost effective and can handle large and small charging currents.

3.3.6 Charge Controllers

The main function of charge controller is to regulate the flow of electricity from the photovoltaic panels to the batteries. In PV systems with batteries, the batteries must be protected from overcharging and be maintained at fully charged state. The PV Charge Controller uses the Micro-Processor and PWM (Pulse Width Modulation) to give optimal and safe charging .

Following essential requirements are expected from charge controllers connected to a PV system:

1. Overcharging protection
2. Deep discharge protection
3. Preventing unintentional discharge
4. Optimal charging of batteries
5. Reverse polarity protection
6. Battery indicator
7. Short circuit protection

Notes

UNIT 3.4: Types of Solar Photovoltaic Systems

Unit Objectives

At the end of this unit, you will be able to:

1. Identify and differentiate between the types of solar photovoltaic systems

3.4.1 Types of Solar PV Systems

The types of Solar PV Systems can be broadly categorized as follows:

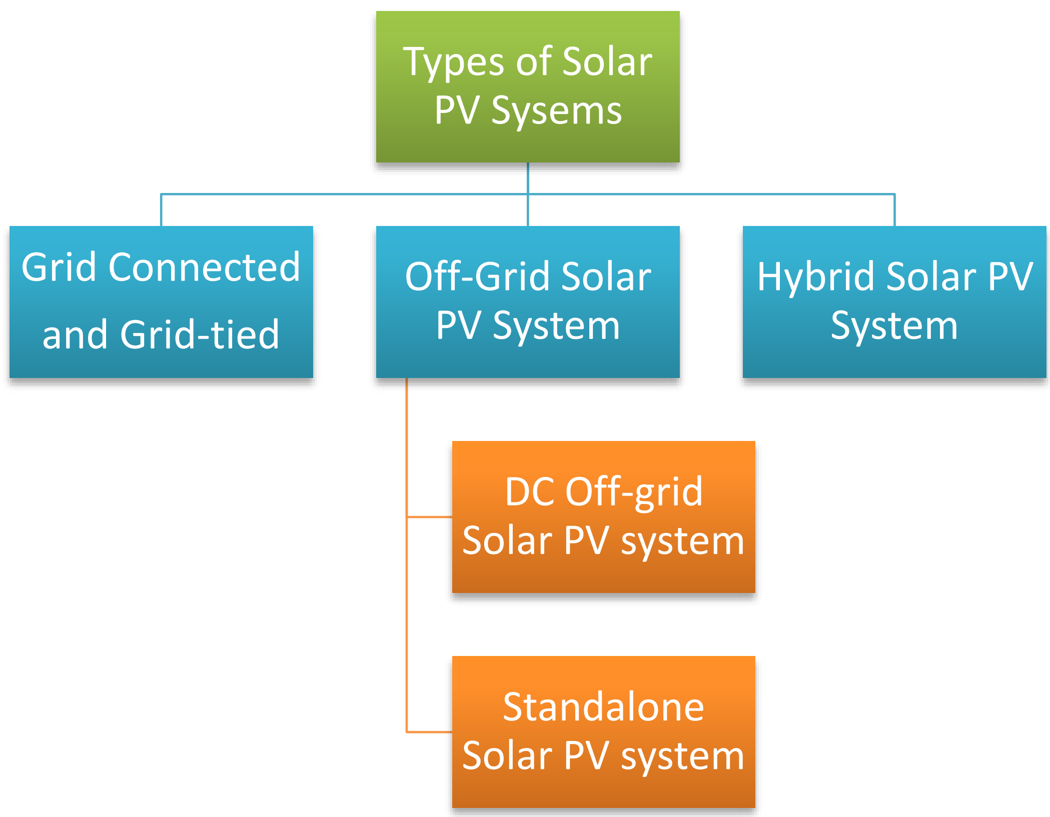

Fig. 3.4.1 Types of solar photovoltaic rooftop systems

Grid-tied PV System

- Works only with grid supply
- Capable of feeding unutilised solar energy to the grid
- Cannot be used for charging batteries directly from solar energy
- Cheaper than an AC off-grid system and saves on electricity bill
- But does not provide backup

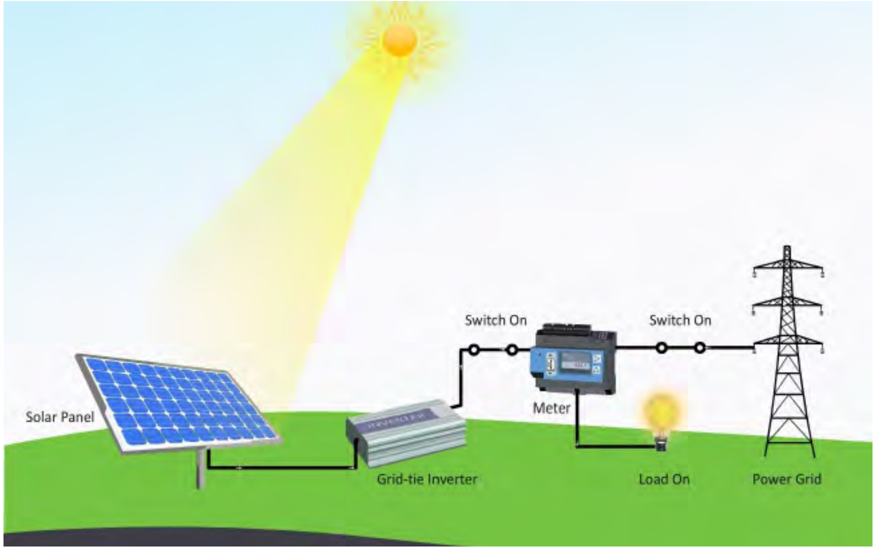

Fig. 3.4.2 Grid-tied system

DC Off-grid Solar PV System

- DC Systems are designed for loads on different voltage ranges e.g. 12V, 24V, 48V.
- DC Power from solar panels is stepped down by the charge controller to provide regulated DC output to the Load
- There is no Standard Voltage in DC based systems
- Stepping UP/Down of Voltages in DC Power is difficult
- Transmission Losses in DC are high
- DC Power can be easily stored in batteries
- Suitable for off grid Solar PV Systems as power is to be stored for usage at night
- For operating during the day, a DC load, like fan, etc. can also be connected to a Solar Panel directly without a battery
- Hence, Off Grid Solar PV System can be with battery bank or without battery bank depending on the requirement and need of the customer.

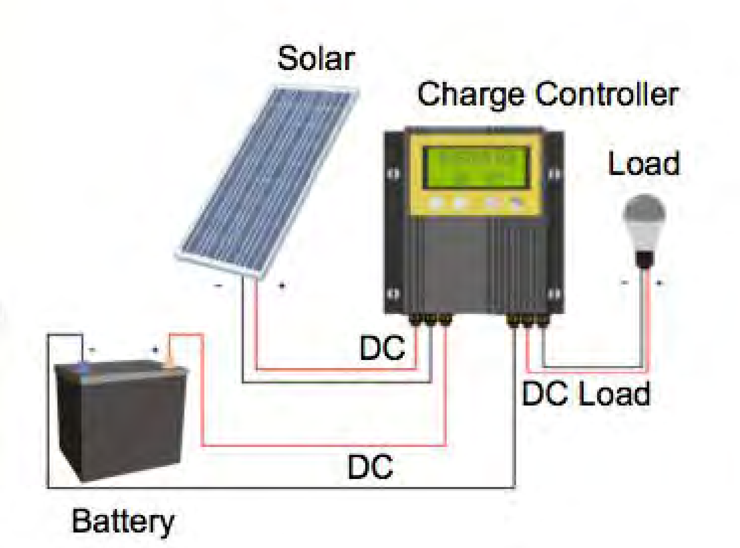

Fig. 3.4.3 DC Off-Grid Solar PV system with battery bank

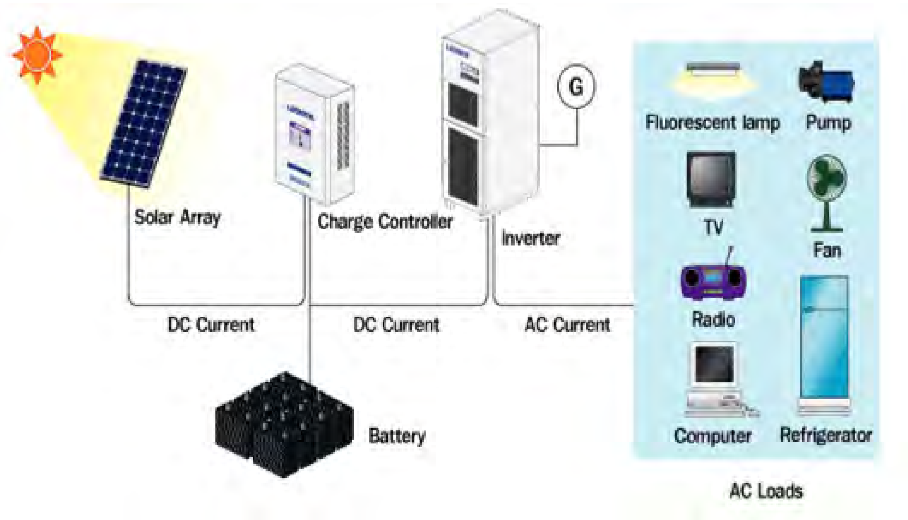

Fig. 3.4.4 Stand-alone Solar PV System

Hybrid Solar PV System

There is another category of Solar PV system which can be grid connected as well as have a battery bank. This type of system is called a Hybrid Solar PV System.

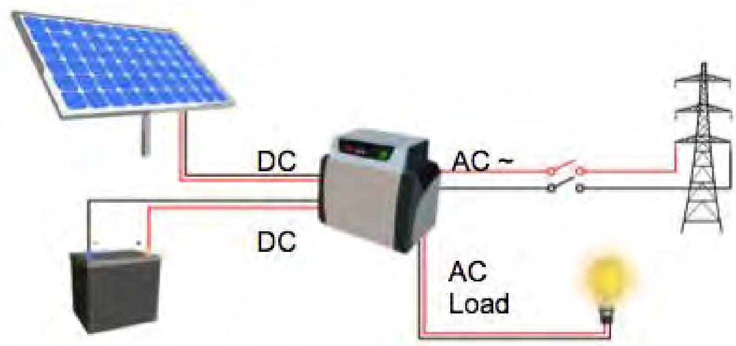

Fig. 3.4.5 Hybrid Solar PV System

Tips

Solar PV system is selected depending on the load requirements of the client, central/state policy regulations and budget

Exercise

1. Identify different components of a Solar PV system
2. Draw the schematic diagram for different types of Solar PV systems

UNIT 3.5: Technical Parameters and Performance of a Solar PV Panel

Unit Objectives

At the end of this unit, you will be able to:

1. List the technical parameters characterizing a solar PV module
2. Connect Solar PV modules in Series
3. Calculate the Voltage and Current of Modules connected in series
4. Identify and differentiate between the types of Solar PV Systems

3.5.1 Technical Parameters and Performance of Solar PV Panel

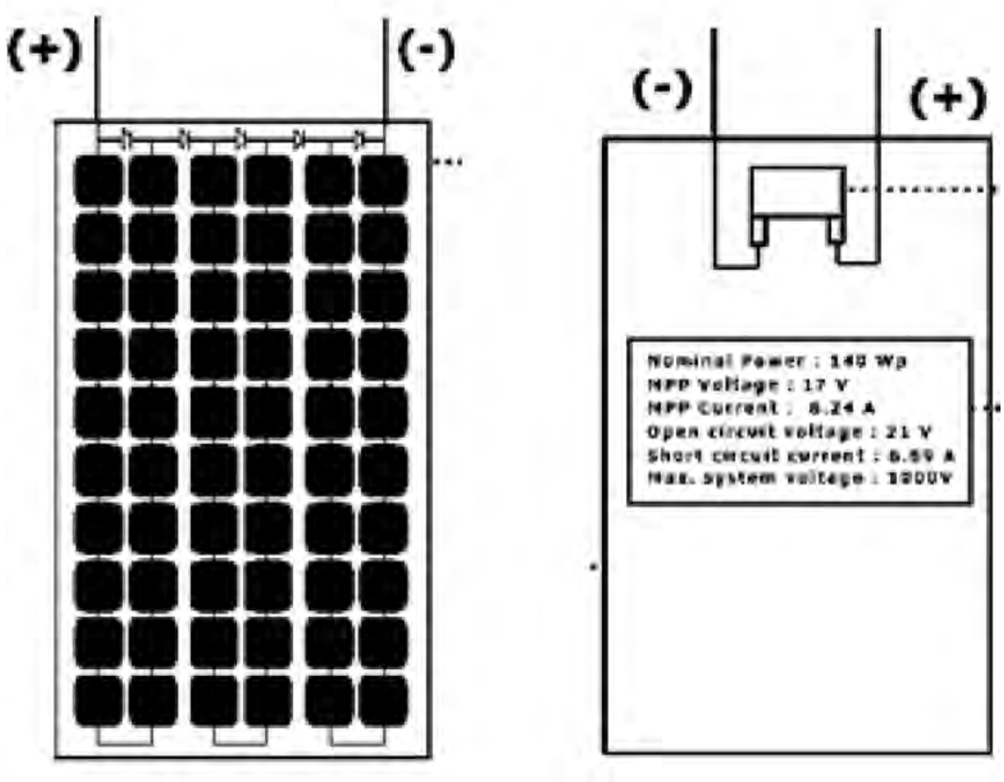

Fig. 3.5.1 Front Side and Back side of a PV Module – The Junction Box consisting of Positive and Negative Terminals is placed behind the module

A Solar PV Module is characterised by the following parameters:

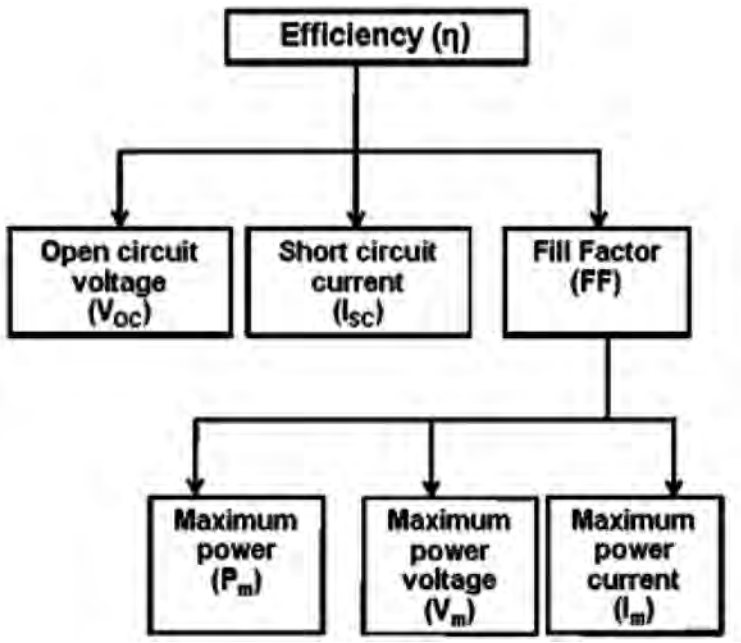

Fig. 3.5.2 Solar PV Module characteristisation

Table 3.1: Sample values of major Technical Specifications of a solar PV panel

Parameter	Value
Max Power P_{max} (W)	100 W
Power Tolerance (+/-)	0.05%
Max Power Voltage V_{mp} (V)	18 V
Max Power Current I_{mp} (A)	5.56 A
Open Circuit Voltage V_{oc} (V)	22.3 V
Short Circuit Current I_{sc} (A)	6.1 A
Max. System Voltage V_{dc}	1000/600

Short Circuit Current I_{sc}

The short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited). It is represented by ISC. It is dependent upon the generation and collection of light-generated carriers. The short-circuit current is the largest current which may be drawn from the solar cell.

Open Circuit Voltage

The open-circuit voltage, VOC, is the maximum voltage available from a solar cell, and this occurs at zero current. The open-circuit voltage corresponds to the amount of forward bias on the solar cell due to the bias of the solar cell junction with the light-generated current.

Maximum Power P_{max}

This refers to the maximum PV output of the solar PV module. **Max Power Voltage V_{mp}** and **Max Power Current I_{mp}** are the corresponding voltage and current values that result in maximum power output.

Fill Factor

The Fill Factor or FF is defined as the ratio of the maximum power from the solar cell to the product of Voc and Isc. As FF is a measure of the "squareness" of the IV curve, a solar cell with a higher voltage has a larger possible FF since the "rounded" portion of the IV curve takes up less area. Fill Factor measures the quality of a solar cell. Commercial value of FF is usually above 0.7 and can go up to 0.82.

I-V Curve

An I-V curve basically represents all of a solar panel's possible operating points (voltage/current combinations) at a given cell temperature and light intensity. Increases in cell temperature increase a solar panel's current slightly, but significantly decrease voltage output. At a given intensity, a solar panel's output current and operating voltage are determined by the characteristics of the load.

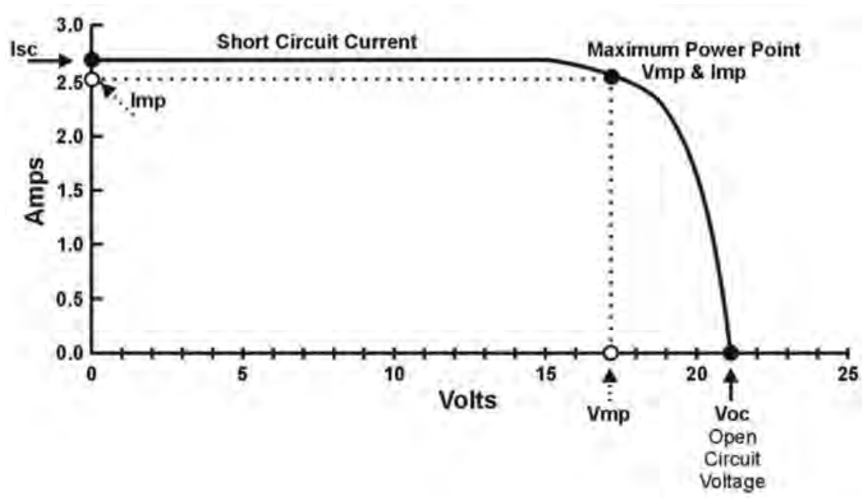

Fig. 3.5.2 Characteristics of a PV Cell with Operating Point (V_{mp}, I_{mp})

Efficiency

Usually Solar PV system efficiency of commercially available modules falls in the range of around 15-18%. It is the part of energy received from the sun which is actually converted to useable electricity. The efficiency of solar cells, along with latitude and climatic conditions, is used to determine the annual energy output of the system.

Standard Testing Conditions (STC)

The electric output performance of solar PV modules is generally measured under standard test conditions (STC), ensuring a relatively independent comparison and output evaluation of different solar PV modules. These correspond to the irradiance and spectrum of sunlight incident on a clear day upon a sun facing surface. These conditions are listed as follows:

a. Irradiance on cell surface : 1000 W/m^2

b. Air temperature : 25 °C

c. Air Mass (AM) : 1.5

Nominal Operating Cell Temperature (NOCT)

A PV module will be typically rated at STC i.e. 25 °C, 1000 W/m^2 and AM 1.5. However, when operating in the field, they operate at higher temperatures and at somewhat lower insolation conditions. In order to determine the power output of the solar cell, it is important to determine the expected operating temperature of the PV module. The Nominal

Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions as listed below:

a. Irradiance on cell surface : 800 W/m^2

b. Air Temperature : 20°C

c. Wind Velocity : 1 m/s

d. Mounting : open back side

3.5.2 Series Connection of PV Modules – Effect on Voltage and Current

As we have learnt as part of Fundamental Electrical Concepts, voltage for individual loads is added together when connected in series. The current remains the same.

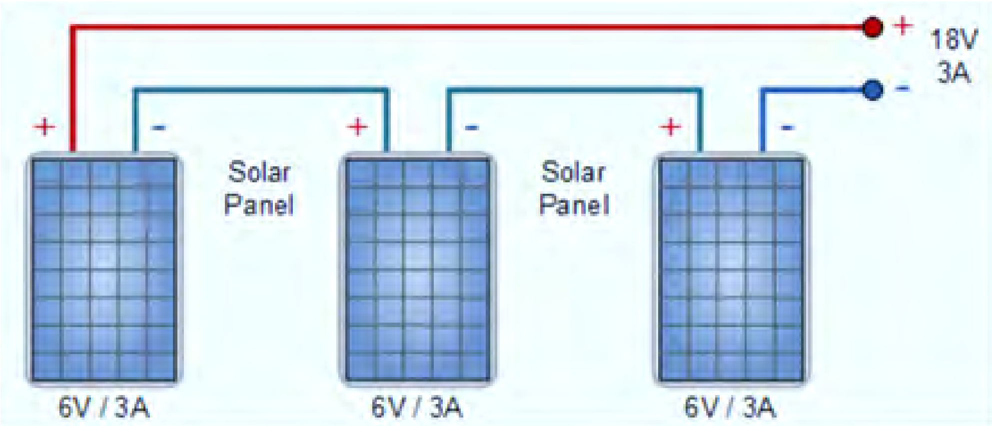

Fig. 3.5.3 need to do

When connecting panels in series, it must be ensured that the short circuit current of the panels matches the load requirement. This is important, since the largest current which may be drawn from the system, and thus the entire series connected array, is limited to a maximum value corresponding to the panel with highest short circuit current value.

For instance, observe the output Voltage and Current of the array in the following figure:

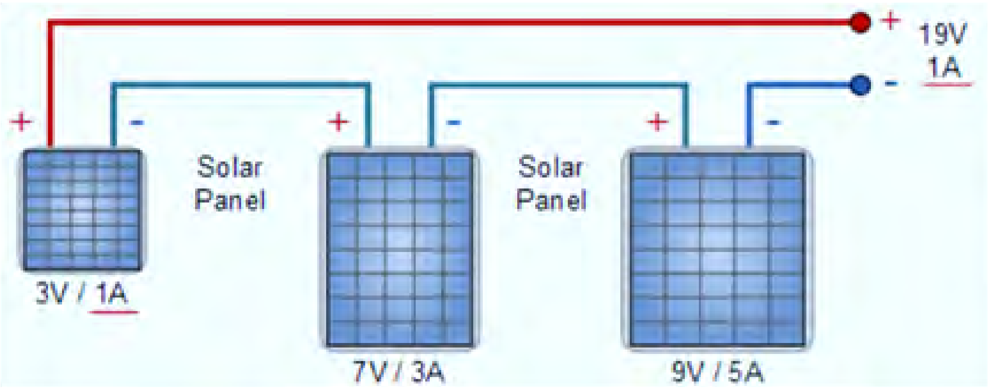

Fig. 3.5.4 Amperage of the system is limited to the lowest ampere value panel in the string

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4. Tools and Equipment Used for Solar PV Installation

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Unit 4.1 - Identification and Uses of Tools and Equipment Used for Solar PV Installation

SGJ/N0101, SGJ/N0102

Key Learning Outcomes

At the end of this module, you will be able to:

1. List the components of installation tool kit and safety equipment
2. Explain the function of measuring instrument used during a installation

UNIT 4.1: Identification and Uses of Tools and Equipment Used for Solar PV Installation

Unit Objectives

At the end of this unit, you will be able to:

1. List the components of installation tool kit and safety equipment
2. Explain the function of measuring instrument used during a installation

4.1.1 Tools and Tackles Required for Solar PV Installation

Important tools and consumables required to carry out installation work:

Table 4.1 Tools and Tackles

Tool Kit		
Ball Pin Hammer	Plumb bob	Line dori
Screw Driver	Measuring tape	Clamps
Nail puller	Drill machine	Digging bar
Measuring square	Utility knife	Spade
Hand saw (Frame with blade)	Chisel	PVC mallet
Spanner	Pliers (nose, side cutting, combination)	Filers (flat,round, triangle)
Crimping Tools		
Safety Equipment		
Safety Helmet	Safety Shoes	Safety Belt
Safety Goggles	Nose Mask	Reflective Jacket
Body Harness	Ear Plugs	Safety Hand Gloves
Measuring Instruments		
Spirit Level/Water Level	Multimeter	Clampmeter
Pyranometer	Vernier Callipers	Megger/Earth Tester
Sequence Meter	Wire Gauge	

1. **Double Ended Flat Spanner**

It is made from high grade steel, forged and accurately machined. Hardened and tempered to give long trouble free service. Provide with appropriate surface protection for rust prevention.

2. **Pyranometer**

Global irradiance is the amount of radiant energy (electromagnetic radiation from the sun) on a flat surface. It's important to measure irradiance to know how much power a solar project could potentially harvest from the Sun. The irradiance is measured in watts per square meter (W/m2). A pyranometer is designed to measure this irradiance from all directions.

3. **Double Ended Ring Spanner**

It is a Drop forged from high grade Chrome - Vanadium steel. Heat treated to give maximum strength and wear resistance. Good accessibility in confined spaces due to thin walled rings and are light and handy in use.

Slightly rounded handles sand blasted fit snugly in the hand and gives comfortable grip. Clearly marked facilities choice of right size.

Non damaging grip on the nut due to close wrench opening tolerances.

4. **Combination Pliers**

Combination pliers made from metal with insulators and it is used for gripping, holding, and cutting electrical wires and cables and even small nails. They are usually used by linemen in doing heavy tasks.

5. **Wire Stripper**

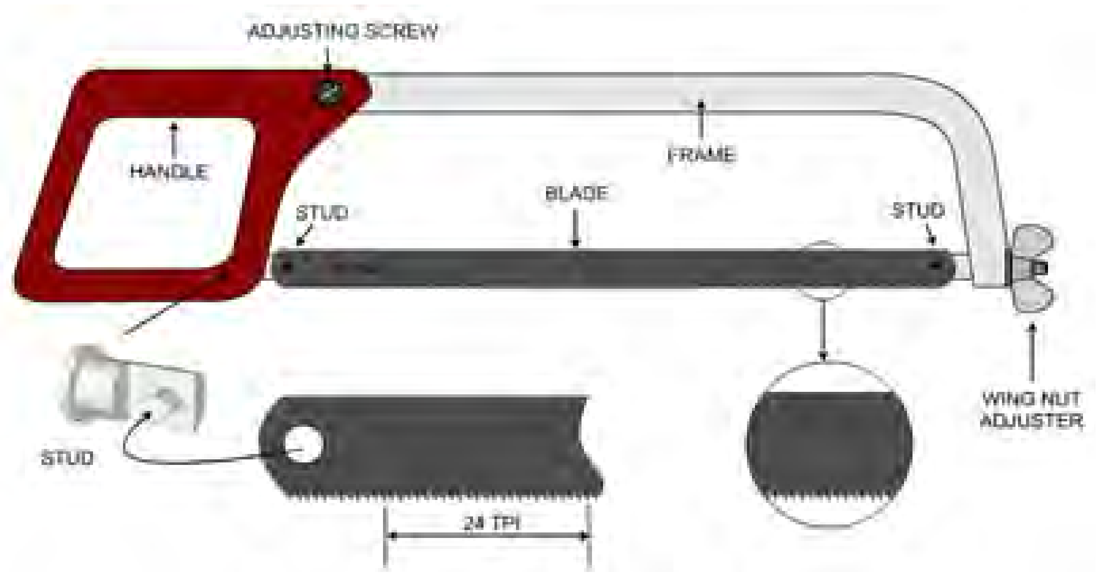
Wire stripper is a pair of opposing blades much like scissors or wire cutters. The addition of a center notch makes it easier to cut the insulation without cutting the wire.

6. **Electrician Knife**

This is used to remove insulation of wire and cables in low and high voltage transmission lines.

7. **Hand Saw Frame With Blade**

Hand saws typically have a relatively thick blade to make them stiff enough to cut through material. (The pull stroke also reduces the amount of stiffness required.) Thin-bladed handsaws are made stiff enough either by holding them in tension in a frame, or by backing them with steel or brass.



8. **Hand Crimping Tools**

A crimping tool is a device used to conjoin two pieces of metal by deforming one or both of them in a way that causes them to hold each other. The result of the tool's work is called a crimp. A good example of crimping is the process of affixing a connector to the end of a cable.

9. **Cable Cutter**

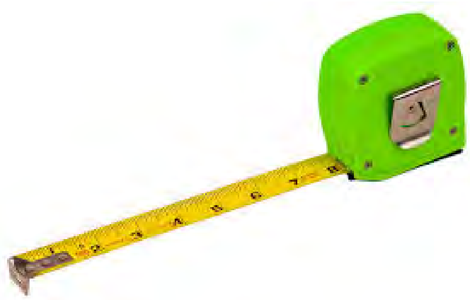
A cable cutter is a hand tool used for cutting thick electrical cable. Cable cutters and cable pullers are useful implements in several industries. These devices help to cut cables to length and pull cables through tight spots like walls and conduit. In other industries, heavy-duty cable cutters cut tensioning cables and a different type of cable puller helps to tighten the tensioning cables to the necessary tension.

10. **Screw Driver**

A screwdriver is a tool, manual or powered, for turning (driving or removing) screws. A typical simple screwdriver has a handle and a shaft, and a tip that the user inserts into the screw head to turn it. The shaft is usually made of tough steel to resist bending or twisting. The tip may be hardened to resist wear, treated with a dark tip coating for improved visual contrast between tip and screw—or ridged or treated for additional 'grip'. Handle are typically wood, metal, or plastic and usually hexagonal, square, or oval in cross-section to improve grip and prevent the tool from rolling when set down. Some manual screwdrivers have interchangeable tips that fit into a socket on the end of the shaft and are held in mechanically or magnetically.

11. **Measuring Tape**

A tape measure or measuring tape is a flexible ruler. It consists of a ribbon of cloth, plastic, fiber glass, or metal strip with linear-measurement markings. It is a common measuring tool. A tape measure or measuring tape is a flexible ruler. It consists of a ribbon of cloth, plastic, fiber glass, or metal strip with linear-measurement markings. It is a common measuring tool. Its design allows for a measure of great length to be easily carried in pocket or toolkit and permits one to measure around curves or corners.



12. **Centre Punch**

A center punch is used to mark the center of a point. It is usually used to mark the center of a hole when drilling holes. A drill has the tendency to "wander" if it does not start in a recess. A centre punch forms a large enough dimple to "guide" the tip of the drill. The tip of a centre punch has an angle between 60 and 90 degrees .When drilling larger holes, and the web of the drill is wider than the indentation produced by a centre punch, the drilling of a pilot hole is usually needed. An automatic centre punch operates without the need for a hammer

13. **Standard Wire Gauge In Round Shape**

Wire gauge is a measurement of how large a wire is, either in diameter or cross sectional area. This determines the amount of electric current a wire can safely carry, as well as its electrical resistance and weight per unit of length.

Wire gauge is applicable to both electrical and non-electrical wires, being important to electrical wiring and to structural cable

14. **Vernier Caliper**

The Vernier Caliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The example shown below is a manual caliper. Measurements are interpreted from the scale by the user. This is more difficult than using a digital vernier caliper which has an LCD digital display on which the reading appears. The manual version has both an Imperial and metric scale.

Manually operated vernier calipers can still be bought and remain popular because they are much cheaper than the digital version. Also, the digital version requires a small battery whereas the manual version does not need any power source.

How to read a measurement from the scales

EXAMPLE 1: The external measurement (diameter) of a round section piece of steel is measured using a Vernier caliper, metric scale.

Mathematical method

a. The main metric scale is read first and this shows that there are 13 whole divisions before the 0 on the hundredths scale. Therefore, the first number is 13.

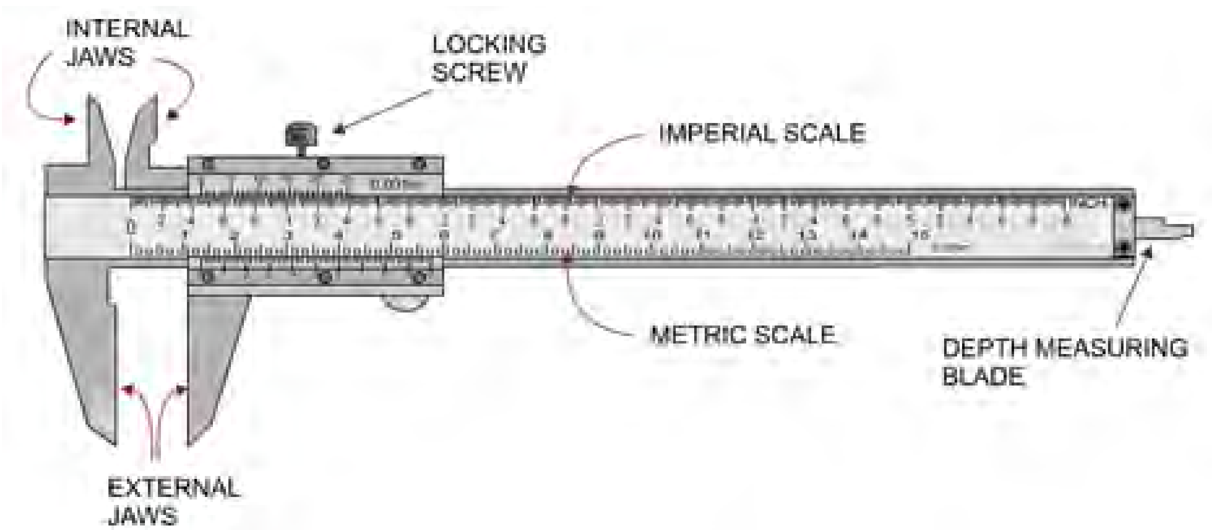
b. The' hundredths of mm' scale is then read. The best way to do this is to count the number of divisions until you get to the division that lines up with the main metric scale. This is 21 divisions on the hundredths scale.

c. This 21 is multiplied by 0.02 giving 0.42 as the answer (each division on the hundredths scale is equivalent to 0.02mm).

d. The 13 and the 0.42 are added together to give the final measurement of 13.42mm (the diameter of the piece of round section steel)

Shortcut method

Alternatively, it is just as easy to read the 13 on the main scale and 42 on the hundredths scale. The correct measurement being 13.42mm.



15. **Drill Machine**

Drill is a machine tool used for drilling the holes in solid materials like metal and wood with drill bit or driver bit. Drills are used in wide range of applications in metalworking, constructions and woodworking industries. The small drill is used for our household requirements to make holes on wall and materials. These are available in various sizes and power capacities. Drill is one of the oldest handy tools used from very beginning of the industrial era.

Types of Drills

Varieties of drills are manufactured as per the industrial needs. They are categorized based on different parameters like manual drills and automatic drill machines. Manual drills are referred as hand powdered drills used with hand pressure on the device/material to drill a hole. Manual drill variants are Bow drill, Gimlet, Breast drill and push drill etc. These are powered with electricity or compressed air known as electronic drill and pneumatic drill respectively. Drilling work is carried out at different locations with various types of drills including construction drill, wells drill, thermal drill etc. All drills have different applications of drilling from small to bigger size hole.

Pistol grip drill is commonly used in our daily work. Right angle drill is used in plumbing and electrical works. Hammer drill is similar to electrical drill with addition of hammer action on the same device. Rotary hammer drill is equipped with rotation mechanism used for drilling in solid constructions. Cordless drills with inbuilt rechargeable battery power are used where electrical supply is not reachable for drilling. Cordless drills consume high power. Thus need more spare batteries on charge during the drilling work to replace effectively on discharge of installed batteries.

16. **Plumb Bob**

A plumb bob or a plummet is a weight, usually with a pointed tip on the bottom that is suspended from a string and used as a vertical reference line, or plumb-line. It is essentially the vertical equivalent of a "water level".

17. **Sprit Level**

A spirit level, bubble level or simply a level is an instrument designed to indicate whether a surface is horizontal (level)/ vertical (plumb).

18. **Metal File**

Metal files these are hand tools having a series of sharp,parellel ridges or teeth.most files have a narrow,pointed tang at one end to which a handle can be fitted.

a) Flat Level File

Flat file is parallel in width and tapered in thickness, they are used for flat surfaces and edges.

b) Round File

It is also called rat-tail file which is gradually tapered and used for many tasks that require a round tool,such as enlarging round holes or cutting a scalloped edge

C) Triangular File

A triangular file is a specialized tool for trimming and sharpening edges. Its unique, three-sided design makes it a great tool for sharpening hard-to-reach places such as saw teeth.

19. **Hand Saw**

In woodworking and carpentry, hand saws, also known as "panel saws", "fish saws", are used to cut pieces of wood into different shapes. This is usually done in order to join the pieces together and carve a wooden object.

20. **PVC Mallet**

A PVC mallet is a kind of hammer,often made up of nylon, polycarbonate, or polystyrene.

The term is descriptive of the overall size and proportions of the tool, and not the materials it may be made of, though most mallets have striking faces that are softer than steel.

21. **Ball Peen Hammer**

A ball-peen (also spelled ball-pin) hammer, also known as a machinist's hammer, is a type of peening hammer used in metal working. It is distinguished from a cross-peen hammer, diagonal-peen hammer, point-peen hammer, or chisel-peen hammer by having a hemispherical head.

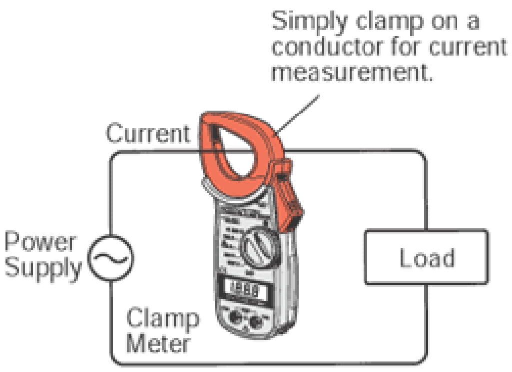
Uses: Though the process of peening (surface hardening by impact) has become rarer in metal fabrication, the ball-peen hammer remains useful for many tasks, such as striking punches and chisels (usually performed with the flat face of the hammer). The peening face is useful for rounding off edges of metal pins and fasteners, such as rivets.

22. **Fuse Puller**

A fuse puller is a tool used to insert and remove electrical fuses from their housing.

23. **Tong Tester AC/DC**

Pushing the large button at the bottom opens the lower jaw of the clamp, allowing the clamp to be placed around a conductor. An electrical meter with integral AC current clamp is known as a clamp meter, clamp-on ammeter or tong tester.



24. **Earth Tester**

The earth tester is a special type of ohm meter which sends A.C through earth and D.C through measuring instrument. the handle is made to rotate at a uniform speed .the direct indication of earth tester gives the earth resistance.

25. **Water Testing Instruments**

Water testing instruments and meters help you quickly and easily measure water quality.

26. **Earthing Rod**

Earthing is the electrical drain path for stray energy in an electrical circuit. Grounding is the most effective method of the Earthing. Inserting rods, plates, or strips the ground resistance can be reduced up to 22 %.

27. **Soldering Iron And Flux**

Common fluxes are: ammonium chloride or rosin for soldering tin; hydrochloric acid and zinc chloride for soldering galvanized iron (and other zinc surfaces); and borax for brazing, braze-welding ferrous metals, and forge welding.

28. **Phase Sequence Meter**

The Phase Sequence Indicator is used to determine the phase sequence (A-B-C or C-B-A) of three-phase voltages. (A-B-C is clockwise rotation) It is important that phase sequence is known prior to energizing electrical motors and other equipment, as incorrect connection could cause damage to the equipment.

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5. Site Survey for Solar PV Installation

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Unit 5.1 - Engaging with Customers
Unit 5.2 - Steps for Conducting a Load Assessment
Unit 5.3 - Steps for Conducting a Site Assessment
Unit 5.4 - Deriving a PV Solution from Customer Requirements

SGJ/N0101

Key Learning Outcomes

At the end of this module, you will be able to:

1. Use survey forms and questionnaire to accurately and completely record basic information about the customer such as name, address, household size, ownership of facility etc.
2. Assess the load and energy requirements of the customer
3. Create a layout diagram and mark relevant information to choose location for components of a PV system

UNIT 5.1: Engaging with Customers

Unit Objectives

At the end of this unit, you will be able to:

1. Describe different methods for engaging with customer and assessing customer needs
2. Assess customer expectations at a broad level with open and close ended questions
3. Explain the importance of doing load and site surveys

5.1.1 Key Methods for Gathering Customer Requirements

As a solar installer, you always have to keep the customer's need in mind. Your ultimate goal is to provide a PV system and ensure the customer's problem is solved and that the customer is satisfied.

To understand customer needs, you need to be clear what methods you will use and what specific questions you will answer with each of those methods.

A customer's requirements for a PV system can be understood by trying to answer 3 basic questions as shown in the figure below.

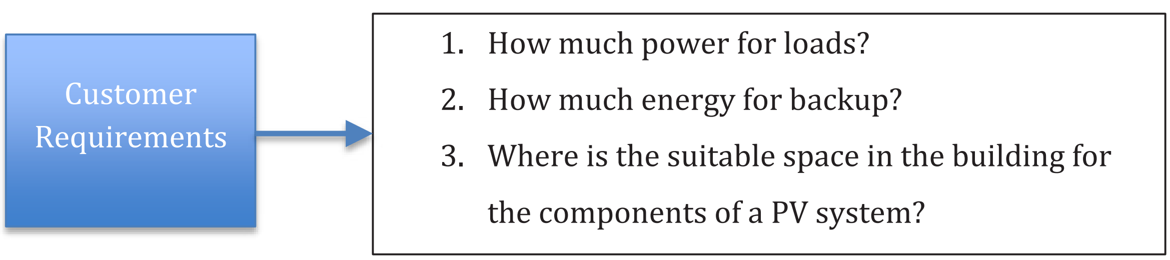


Fig. 5.1.1 Questions that underlie a user's PV requirements

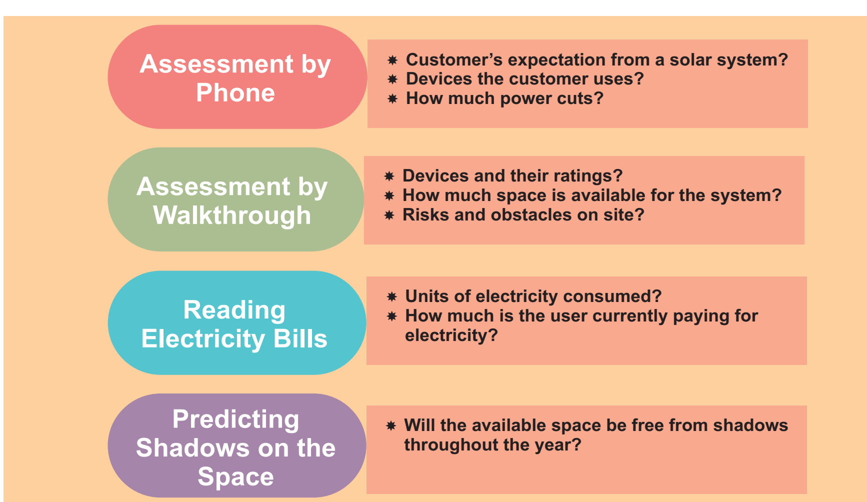


Fig. 5.1.2 Methods for gathering customer requirements and questions they should answer

Assessment by phone

An assessment by phone should yield useful information that will help you understand if solar PV is indeed the right option for this customer. You can use the following sample questions for this:

1. What devices do they typically use?
2. Do they use any heavy load devices such as air-conditioners or pumps?
3. Do they need to power part or all of their loads?
4. What is their estimated load size?
5. How many hours of power cut do they have?
6. How many hours of backup do they need?
7. At what time of the day and months are power cuts most frequent?

Assessment by walkthrough

Both load and site assessments can be done by walking through the building. You will learn the detailed steps in the next sub-section. When doing a load assessment, you are trying to gather information on both - the customer's power and energy requirements.

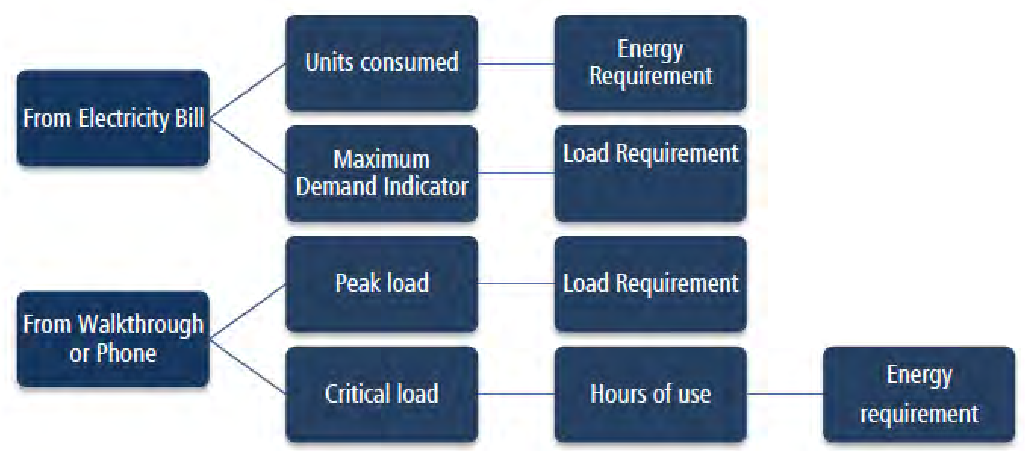


Fig. 5.1.3 Summary of methods to do load and site assessment

- Critical load – Loads that are absolutely essential to work during an outage
- Peak load – The maximum load that can occur when all devices are operated
- Units consumed – The kilowatt-hours of energy consumed by devices

Site Assessment - Shadow analysis and its importance

The sun does not shine at the same angle with change of time and seasons. The amount of energy received from the sun does depend on its position. Sun path refers to the seasonal-and-hourly positional changes of the sun (and duration of daylight) as the Earth rotates, and orbits around the sun. The relative position of the sun is a major factor affecting the overall performance of solar energy systems. So it is important to use special techniques to know if a spot on the roof will have shadows as the seasons change. Refer to the chapter on solar energy to get an understanding of sun path and how it causes shadows.

After performing the shading analysis carefully, you will be able to give accurate inputs to your design team. The design team will then be able to come up with a system that is custom-made for your client's location. This design will in turn be the most cost-effective.

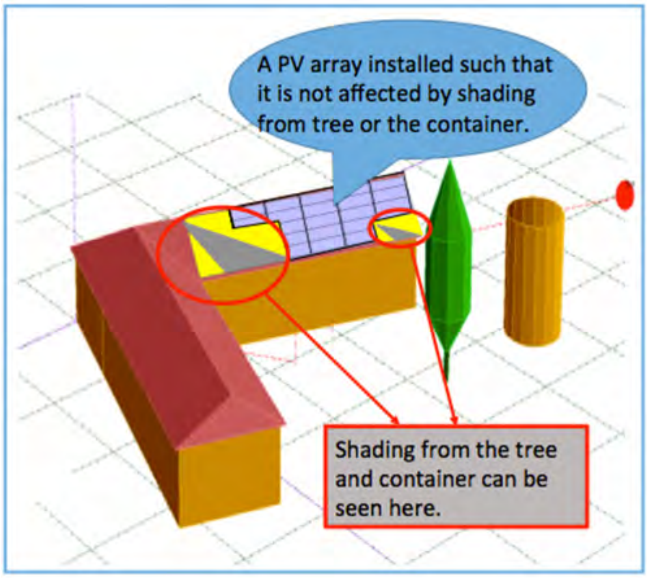


Fig. 5.1.4 Placement of PV array to avoid shading from surrounding objects

Fig. 5.1.5 PV array installations must be carried out after thorough consideration of possible shading objects surrounding the location

5.1.2 Benefits of Site Survey

As a PV installer, you will have to ensure that the system you install meets the customer's requirements in the best possible way. Load and site assessments are the primary means to achieve this objective.

A solar PV system powers electrical loads and charges batteries. So you need to find out how big is your customer's load and how much energy they need to store in batteries. The procedure to do this is called load assessment.

A PV system occupies space in a customer's home and most customers will not have unlimited space. Once you know the load and energy requirements of the customer, you also need to find out if enough space is available to satisfy these requirements. Finally, you need to check if the space available is appropriate for installing a PV system. Assessing the availability and suitability of the space for a solar PV system is called site assessment.

The final consequences of doing a proper load and site assessment are summarized below:

Table 5.1 Outcome expected on completion of site survey activities

Site Survey Activities	Some benefits of doing an accurate assessment
Load Assessment	■ Solar array and batteries are sized according to need ■ Critical loads are backed up ■ The customer's gets maximum value for money
Site Assessment	■ Components are placed in proper locations where they function without hindrance ■ Shadows do not fall on the arrays maximizing output ■ The area remains safe for humans and equipment

Notes

UNIT 5.2: Steps for Conducting a Load Assessment

Unit Objectives

At the end of this unit, you will be able to:

1. Use forms and checklists to gather information about a customer's load and energy needs
2. Record relevant data for average and peak power
3. Record energy usage from reading customer electricity bills
4. Represent load profile in a simple diagram and terms understandable to the average customer

5.2.1 Gather Load Information

Assume you are at a customer site and about to start load assessment. We will now follow a step-by-step procedure to perform a load and site assessment for any customer.

Step 1: Gather Important Details About the Customer

Decisions on the type of systems to be installed, depends on the profile of the customer. Use the form below to gather details of the customer.

	Question	Answer
1	Name and address of customer	
2	Type of customer	Residential/Commercial/Institutional
3	Type of locality	City/Town/Village
4	Current sources of power used	Electricity Grid/Diesel Generator/DC solar devices
5	• Current back-up sources used • Battery backup size, if any (in Ampere-hours)	• Yes/No • Battery back up
6	If grid is available, hours of power cuts experienced	

Fig. 5.2.1 Sample form for gathering customer information

Tips

- A residential customer is looking to install a system for his own household
- A commercial customer includes shops, offices and industries
- Examples of an institutional customer will be schools, colleges, hospitals or government buildings

- You will need to fill the data by asking your potential customer some questions and in some cases by observation
- This step is an opportunity to understand your potential customer better and gather as much information as possible about their needs and preferences. This will help in ensuring that you can later satisfy their needs in the best possible way

Step 2: Identify Devices and Their Ratings

To estimate peak load, you will have to identify all the major electrical devices and record their ratings. This will be the maximum load that will need to be powered by the solar system, assuming the customer has unlimited space and budget. In reality, many customers only want to ensure that certain critical loads are backed up using solar energy.

By walking through the building, you can create a table similar to the one shown below to list the devices and their power ratings.

Table 5.2 Identifying electrical loads in the building

Type of Load	Power	Total Number	Critical loads	Hours of use
AC Loads				
TV	60 W	1	1	3
Fan	60 W	5	2	6
Lamp	60 W	3	0	6
CFL	20 W	12	6	6
Desktop Computer	270 W	2	1	4
Laptop	50 W	2	0	2
Laser Printer	375 W	1	0	
Refrigerator	380 W	1	0	12
DC Loads				
Phone Charger	4 W	1	1	5
LED	5W	5	3	7

Tips

- You can usually find the wattage of most appliances stamped on the bottom or back of the appliance, or on its nameplate.
- If the wattage is not listed:
  - You can still estimate it by finding the current draw (in amperes) and multiplying that by the voltage used by the appliance.
  - Most appliances in the India uses 240 volts
  - The amperes might be stamped on the unit in place of the wattage. If not, find a clamp-on ammeter -- an electrician's tool that clamps around one of the two wires on the appliance -- to measure the current flowing through it. Take a reading while the device is running; this is the actual amount of current being used at that instant.
  - If measuring the current drawn by a motor, note that the meter will show about three times more current in the first second that the motor starts than when it is running smoothly.
- At this point, it is important to gather all information without making assumptions about the type of solution the customer will need such as AC or DC, grid-tied or off-grid system etc.

Step 3: Read the Electricity Bill

- Try to capture the bills of atleast the 3 most recent months
- Record the units consumed in each month
- Record the unit electricity charges mentioned in the bill
- Also, note the additional surcharges that have been applied by the distribution company. This will be useful when later explaining the payback to the consumer

Extract and record information as shown in the sample table below.

Table 5.3 Information recorded from electricity bill

Month	Units Consumed	Unit Rate Applied	Surcharges
May			
June			
July			

Meter Details in Annexure

Billing Details   **Current Period Charges (01-09-2014 to 30-09-2014)**

Fixed Charges (A)	Slab-wise Energy Charges				Slab-wise FPA/PPA		T O D		Srch@8% on (E=A+B+D+R)	Electricity Tax @ 5% (F)	Total Amount (A+B+C+D+E+F+G)
	Cons. Measrd During	Billed Units	Unit Rate	Amount(B)	PPAC% on B	Amount(C)	TOD% on B	Surg/Reht. Amount (D)			
6785.00 (1.00 Mth(s))	NORMAL(S)	772.00	8.50	6562.00					1653.65	749.82	23074.07
	OFFPEAK(S)	48.00	8.50	408.00			(25.00)	(102.00)			
	PEAK(S)	688.00	8.50	5848.00			20.00	1169.60			
PPAC on Fix Chg='G' 0.00											
	TOTAL ->	1508		12818.00		.00		1067.60			

Past Dues / Refunds / Subsidy

Arrears / Refunds		Late Payment Surcharge (LPSC)	Other Charges, if any *	Total Charges Payable	Rebate(R) / Subsidy*	Net Amount Payable
Amount	Period to which it relates					
0.00		0.00	3.31	23077.38	0.00/0.00	23077.38

nd prvbl.

Amount not immediately payable, if any.	Rs. 0.00	Reasons

Security Deposit with DISCOM	Rs.
Interest accrued for FY already adjusted in bill No. (generated for the period to).	Rs.
Interest for FY will be adjusted in your first bill to be generated in FY	

Bill Amount Payable

Rs. 23070.00

Due Date of Payment
20-10-2014

If payment is made after the due date, LPSC for the delay, shall be charged in the next bill.

Last payment Rs. 19020.00 received on 11-09-2014 Payment Accounted Upto. 28-09-2014

The connection shall be liable for disconnection on non payment of all dues(including arrears of previous bill(s)) by due date, after notice as per Section 56(1) of the Electricity Act, 2003.

Switch off lights and appliances from mains when not in use. This will conserve energy and reduce your electricity bill. ELCB is a safeguard against faulty internal wiring and prevents shock, fire and electrical accidents.Install ELCB for all loads.Installation is mandatory for load of 5 KW and above.ENERGY SAVED IS ENERGY PRODUCED.

Fig. 5.2.2 Sample electricity bill demonstrating consumption patterns of the customer during normal, peak and off-peak hours

Step 4: Assess Building Wiring

Branch Circuits

- As a site surveyor, it is very important for us to capture all the necessary details about home wiring. Understanding where and how each branch circuit operates is critical to performing any basic house wiring project.
- A branch circuit refers to the isolated areas of the home where panel board directs electrical currents.
- MCBs are used in the picture shown below. It's the reason one can cut power to one room while leaving the rest of the house operational.

Fig. 5.2.3 Miniature Circuit Board (MCB)

- We should make it a point to identify and capture all the normal and power loads
- In your home wiring layout, you can number all the MCBs installed at the site and then identify the loads controlled

by them. This can be represented in a tabular form. This information is very useful while designing the PV system for the site.

- Identify all the MCBs and their respective loads and represent the data in a tabular form as shown below.

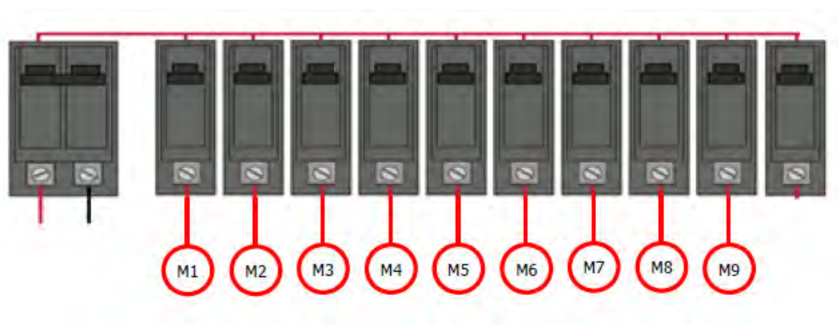
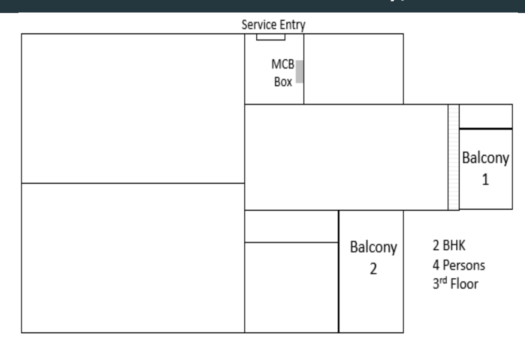


Table 5.4 Representation of MCBs and their respective loads.

MCB	Remarks	Electrical Load	Power Socket
M1	DR	TV, Incandescent Light Bulb	Yes (2)
M2	BR1		Yes (1)
M3	BR2	TV	Yes (1)
M4	Kitchen	Tube light, Fan, Laptops	Yes (3)
M5	Terrace	Light	Yes (1)

Identify the Service Entry, and draw a basic layout of home wiring marking locations such as Service entry, Panel



You have now captured enough information to later perform a load analysis.

Notes

UNIT 5.3: Steps for Conducting a Site Assessment

Unit Objectives

At the end of this unit, you will be able to:

1. Identify shadow free areas for installation
2. Identify possible locations for array, battery and inverter
3. Identify cable routing options
4. Assess suitability of roof condition
5. Identify risks for human safety
6. Prepare site map and dimensioning plan
7. Carry out shading analysis

Step 1: Prepare Layout of Building

- Prepare a layout of the building with rooms
- Mark places available with shading for inverters and batteries
- Mark nearest points for MCB/ Electricity Meters

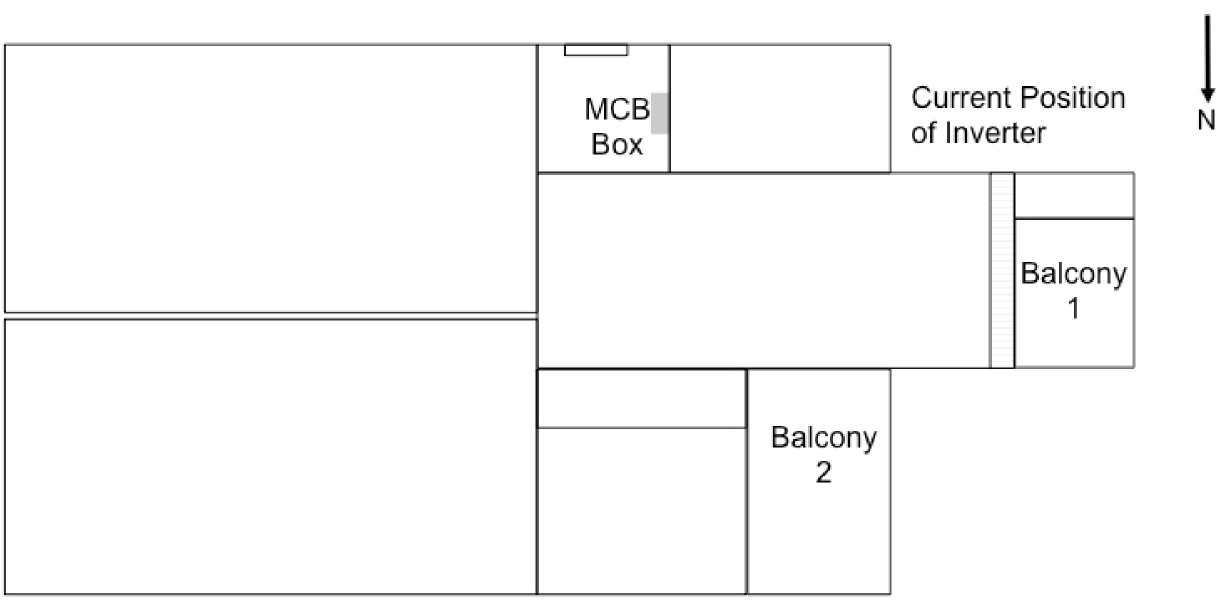


Fig. 5.3.1 Site assessment

Step 2: Prepare Layout of Roof; Take Pictures; Mark Dimensions

Marking site layout with dimensions on paper:

- Walk through the terrace and draw the layout
- Mark the dimensions and directions
- Mark the visible obstructions and measure their dimensions
- Enquire whether the obstructions can be moved or not
- Click multiple (from all angles) photographs of the roof
- Click and mark photographs of the most suited spot on the roof for installing PV array
- Take 2 or 3 of the most suitable available spots on the roof for installing PV array as a reference point, click photograph of obstacles in its North South East West directions

Fig. 5.3.2 Mark dimensions

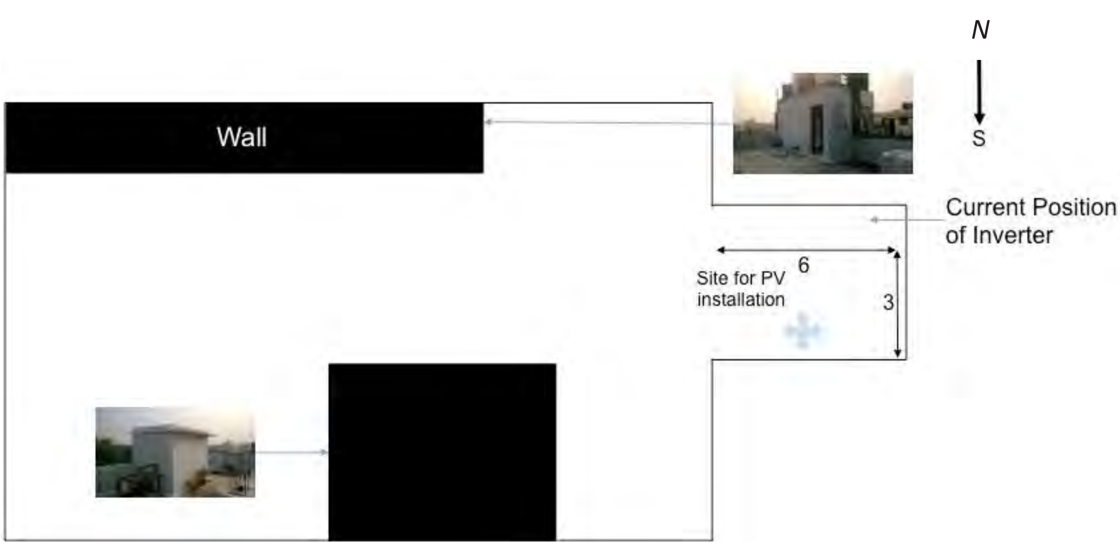


Fig. 5.3.3 Site layout (Roof)

Fig. 5.3.4 Front view with height of walls photo

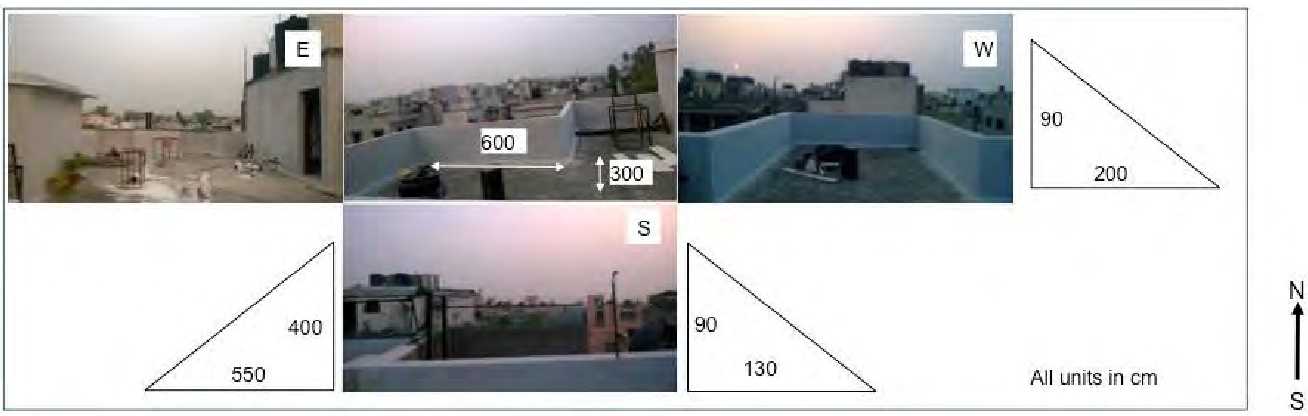


Fig. 5.3.5 Site photographs; Photo credit: AnthroPower Training Private Limited

- When marking locations for system components and cable routing, do keep the following in mind:
  - Inverter should be located in a room or shelter protected from sun and rain
  - Batteries should be kept in a room or shelter in a rack and the room should be ventilated.
  - If such space does not exist, you should enquire from the customer as to the possibility of constructing shelters for equipment
  - For cable routing, do keep in mind that the inverters should be kept as close as possible to the DC combiner box as DC side wire loss increases drastically with the length of the wire
  - Draw a rough sketch of how the cables will be routed and estimate the length of the wiring that may be required upto the switchboard

Step 3: Choose Spots Suitable for Shading Analysis

Before doing a shading analysis on a spot, ensure that the area is suitable by other criteria:

- Is it possible to easily carry the panels to the area?
- Is it as close as possible to the location of the DC combiner box and inverter?
- Assess area required for solar array, and identify shadow free locations on roof suitable for installation and nearest to the inverter wiring. Roughly 110 sq. ft. or 10 m2 per kW of area is required. Make a layout of the rooftop on a sheet of paper

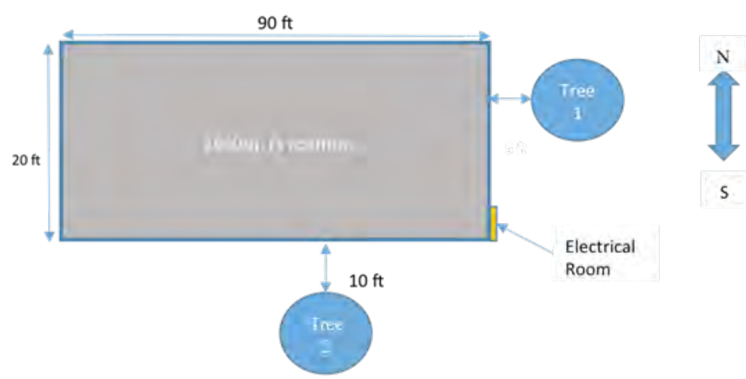
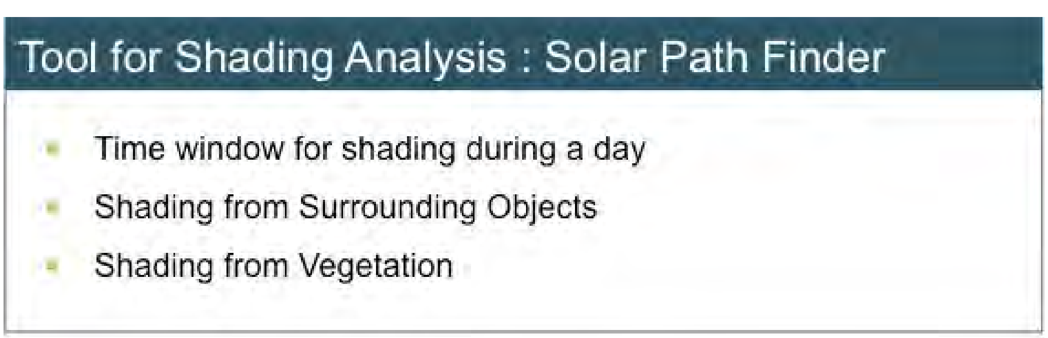


Fig. 5.3.6 Sample layout diagram of a rooftop

Step 4: Performing Shading Analysis

- Shading situations present a challenge for preparation of PV system implementation plans. Shading has a effect on system yield.
- Shading analysis tells us how much hours of sunlight, a selected location will receive in a given month of the year
- Similation programs are availiable which generally stimulate shading effects using horizon photographs of shade generating objects based on 3D simulation. There are various ways tools for doing shading analysis such as Solar Pathfinder, SunEye and paper tools. There are software simulation tools like PVSOL and PVsyst which are also used for doing shadow analysis and annual energy generation projections. Even the result from solar pathfinder and other instruments, is used as an input in the above solar simulation softwares for energy generation projections. Some of these tools are described below.



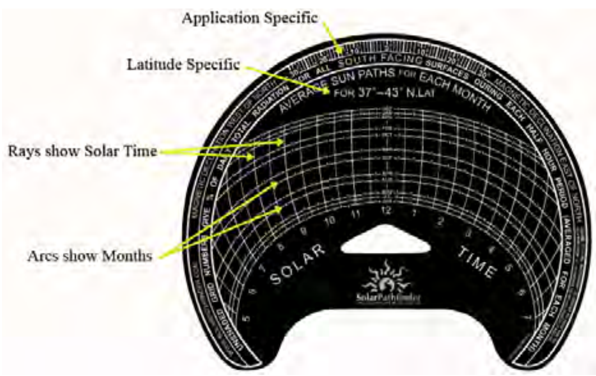


Fig. 5.3.7 Diagram of a Solar Path Finder

Fig. 5.3.8 Solar Path Finder

1. The solar path sheet shown below is specific to each latitude. You can obtain it from websites such as http://solardat.uoregon.edu/SunChartProgram.html
2. Each curved line represents the sun path of a specific month of the year. You can see that in the summer months, the path is wider.
3. When placed on a spot, the fish eye lens on the pathfinder projects a shadow on the solar path sheet (see diagram below)
4. Note the area below the marked black line as it shows the shading times for that day
5. You can use this to select the location with least shading. Shading during early morning and late evening and does not affect as much as any shading during 10A.M – 4 P.M.

Shading Analysis on a Sun Path Diagram

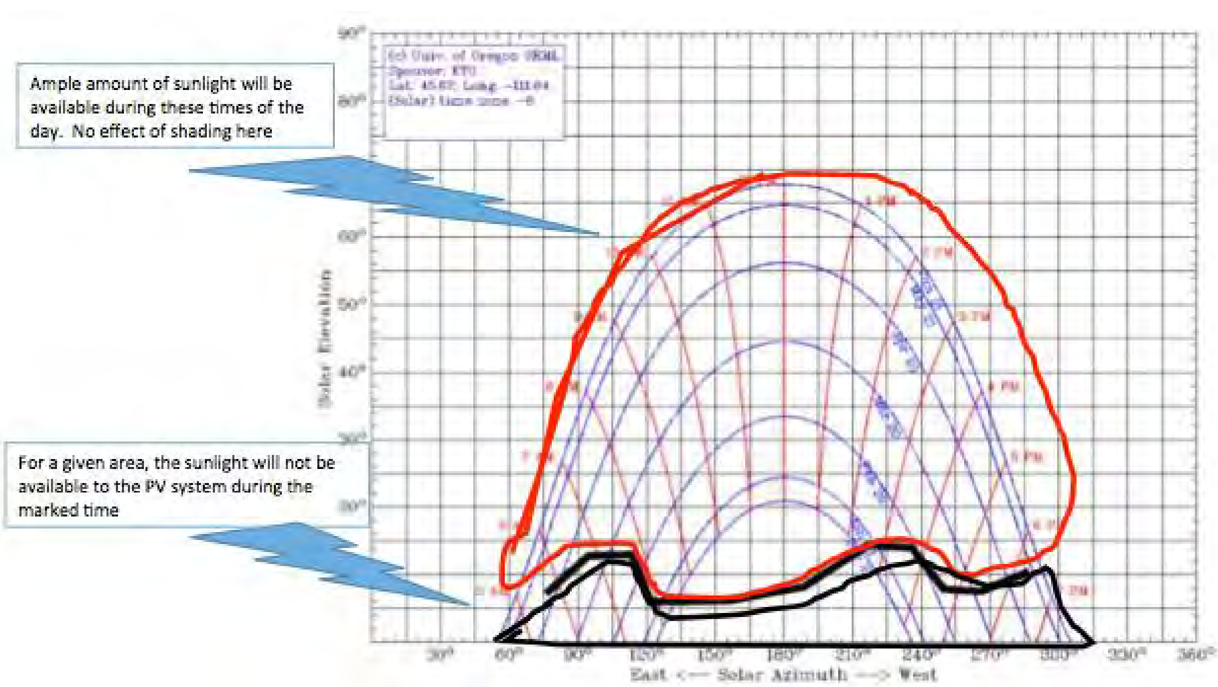


Fig. 5.3.9 Sunlight availability mapped on a sun path diagram during the entire day

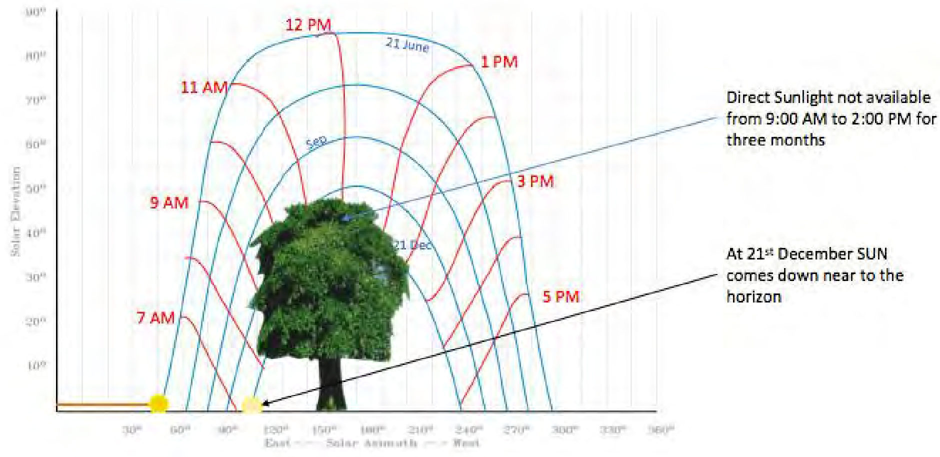


Fig. 5.3.10 Shading analysis carried out using sun path diagram

The SunEye tool also has a fish eye lens and does shadow analysis works on a similar principle as the Solar Pathfinder.

Illustrations from PVSOL - Shading Analysis

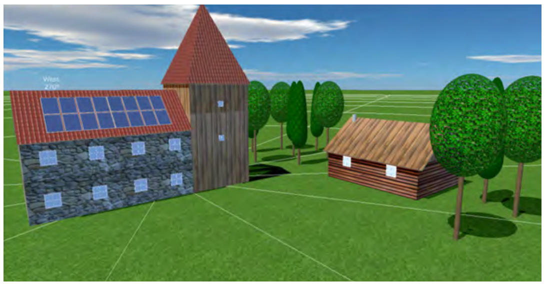


Fig. 5.3.11 Transport the client to the rooftop for visuals

Fig. 5.3.12 3D modelling of rooftop solar PV system

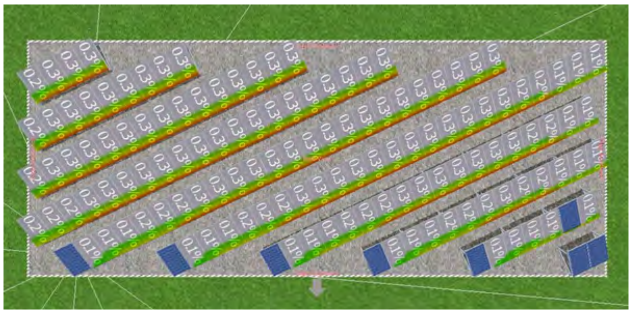


Fig. 5.3.13 Detailed shading analysis - Effect of shading on individual solar modules

Notes

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UNIT 5.4: Deriving a PV Solution

Unit Objectives

At the end of this unit, you will be able to:

1. Use the load and site survey data to map customer's need to the right type of solar system

5.4.1 Factors Deciding the Type of Solar PV System

You can use a decision table as shown below to choose the type of system that is the most appropriate to the gathered requirements.

Table 5.5 Decision table for choosing PV system type

Customer Requirement	PV System Type
• Lighting, mobile charging, small DC devices such as DC fans	DC off-grid system
• AC loads such as fans, CFLs, TV and Refrigerators • Very erratic or no grid supply. So backup requirement is high	AC off-grid system (stand-alone system)
• Grid is available with very little or no power cuts	Grid-tied system

Use of grid-connected solar PV system requires approval and NOC from electricity utility/Discom and should be supported by the state government policy

Exercise

Activity 1:

Draw a map of the rooms, the load in each room and the location of MCBs and switch boards in your building

Activity 2:

1. Look at 10 different electrical devices and note their wattage ratings in a table
2. Calculate the total energy consumed by these devices if they run continuously for 8 hours
3. For each device, write down the hours of usage for 3 periods: morning, afternoon and night
4. Now write the total load for each of these periods by adding the wattage of each device

Activity 3:

i. Take any electricity bill and note the following information:

- What was the unit consumption for the period?
- What were the electricity charges?

1. What information do you need to size the batteries correctly?
    a. Loads which are to be connected for backup
    b. Hours of usage of the loads
    c. Hours of power cut
    d. All of the above
2. What does peak load mean?
    a. The load when all devices are turned on at the same time
    b. The wattage rating of the largest load
    c. The load at night time
3. What does critical load mean?
    a. Loads which need to be backed up
    b. Loads which are running all the time
    c. Loads which run only sometimes
4. Which of these are important steps in site assessment?
    a. Drawing a layout of the roof space and marking areas available for the solar array
    b. Identifying shadow free areas
    c. Identifying locations for all components such as batteries and inverters
    d. All of the above
5. What is the purpose of shadow analysis?
    a. To observe shadow falling at a point at a specific time
    b. To determine when and for how long shadows may fall at a spot throughout the year
    c. To determine the movement of the sun
6. Why do shadows on a path change throughout the year?
    a. Because it is warmer during the summer
    b. The sun path across the sky changes
    c. The true south direction changes through the year
7. Which of these tools are used for shading analysis?
    a. Solar pathfinder
    b. Multimeter
    c. Tester
8. What is the criteria for choosing location of inverter?
    a. As close as possible to the solar array combiner box
    b. Free from shadows
    c. At the lowest height
9. What is the criteria for choosing location of the batteries?
    a. Shaded spot with good ventilation
    b. Free from shadows
    c. At the lowest height

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6. Procure Solar PV System Components

Unit 6.1 – Prepare Bill of Materials (BOM)

Unit 6.2 – Procurement of the Solar PV System Components

Unit 6.3 – Verification of Components on-Site

SGJ/N0102

Key Learning Outcomes

At the end of this module, you will be able to:

1. Prepare the Bill of Materials (BOM)
2. Procure the components as per market availability, design requirement and customer requirement
3. Verify the components after they are brought to site against specifications given in the BOM/customer requirement

UNIT 6.1: Prepare Bill of Material (BOM)

Unit Objectives

At the end of this unit, you will be able to:

1. Identify all major components of a Solar PV System
2. Define Bill of Material (BOM)
3. Preparation of BOM using Single Line Diagram & Civil drawings

6.1.1 Major System Components

The major components for solar PV system are solar charge controller, inverter, battery bank and loads (appliances) typically represented on the electrical diagram (SLD). Below some of the basic definitions of the solar components have been mentioned:

- PV Module – converts sunlight into DC electricity.
- Solar charge controller – regulates the voltage and current coming from the PV panels going to the battery and prevents battery overcharging and prolongs the battery life.
- Inverter – converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or feedback into grid line.
- Battery – stores energy for supplying to electrical appliances when there is a demand.
- Cables (AC and DC), mounting structures and its accessories, Junction boxes (AC - Distribution Box, DC - Distribution Box/String Junction Box/String Combiner Box/Array Junction Box)

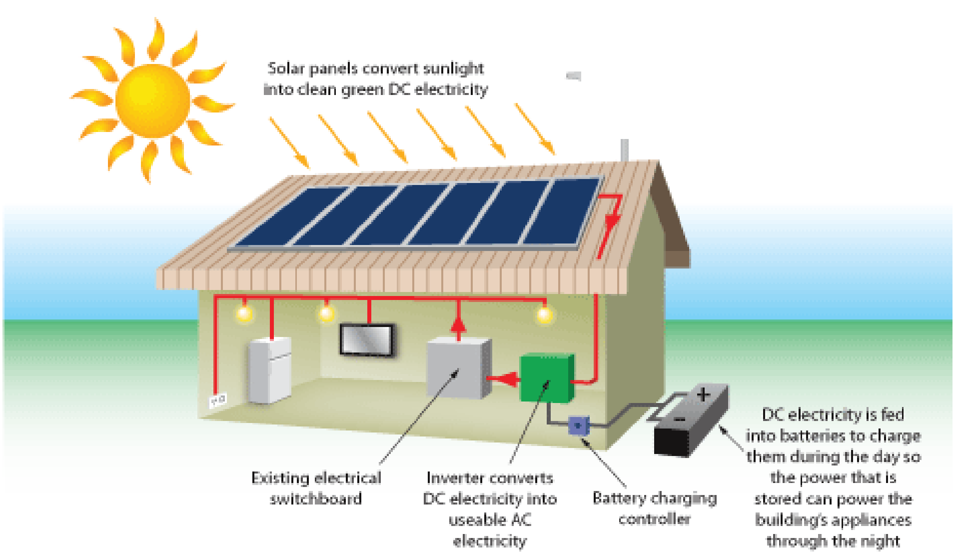


Fig. 6.1.1 Major system components

6.1.2 Prepare Bill of Material

A bill of material is a formally structured list for an object (semi-finished or finished product) which lists all the component parts of the object with the name, reference number, quantity, and unit of measure of each component. A bill of material can only refer to a quantity greater than or equal to one of an object. It is a product data structure, which captures the end products, its assemblies, their quantities and relationships.

There are usually two kinds of bills of materials needed for a product: engineering and manufacturing BOM. The engineering BOM normally lists items according to their relationships with parent product as represented on assembly drawings. But this may not be sufficient to show the grouping of parts at each stage of the production process nor include all of the data needed to support manufacturing or procurement. These requirements may force the arrangement of the product structure to be different in order to assure manufacturability. Thus, engineering and manufacturing will usually have different valid views for the same product.

A Bill of Materials is a product data structure which captures the end-products, its assemblies, their quantities and relationships. The structure of a part's list determines the accessibility of the part's information by various departments in a company. It also helps to determine the level of burden put on the computational device in searching for product information. In many companies the BOM is structured for the convenience of individual departments. This, however, engenders problems in other departments.

Bill of Material:

A Typical BOM format is shown below. Actual contents/ description shall be listed as per actual requirement.

Table 6.1 Form to tabulate BOM

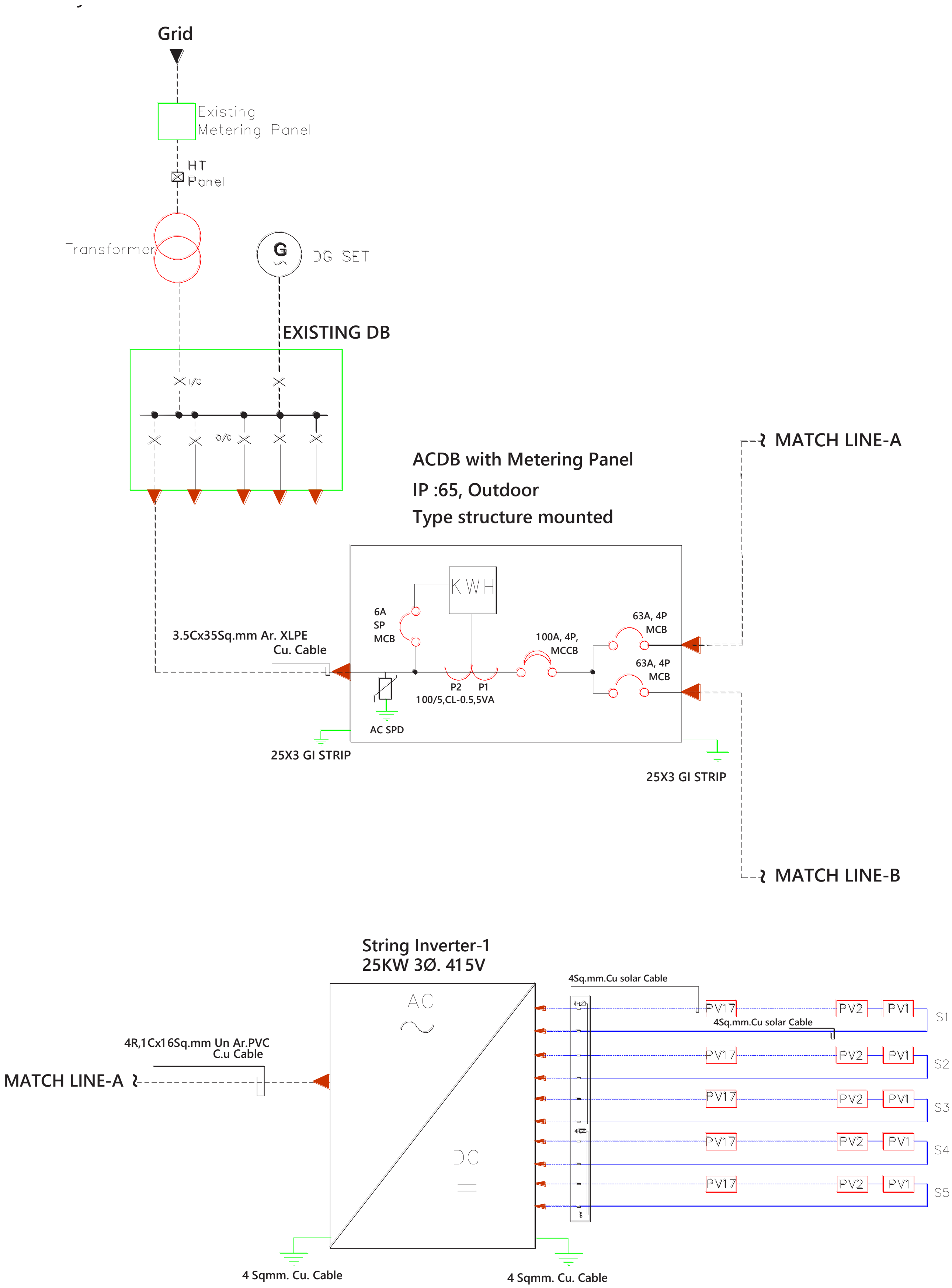
Bill of Materials/BOM					
Sl. No.	**Item**	**Description**	**Quantity**	**Cost**	**Remarks**

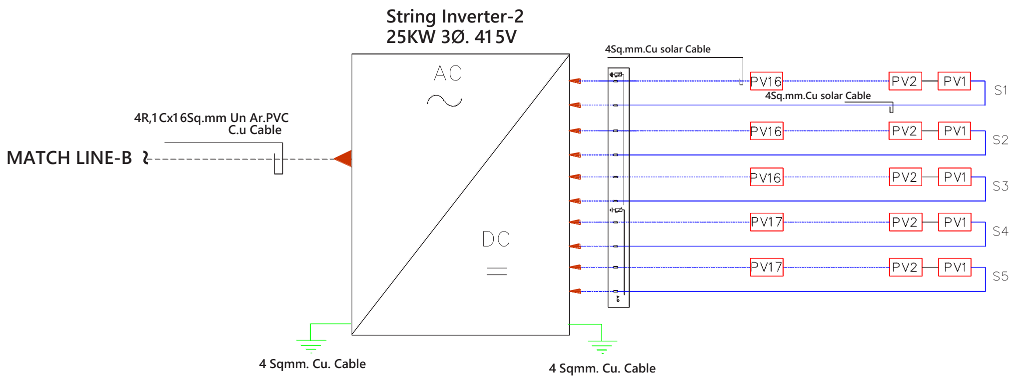
6.1.3 Prepare BOM from Single Line Diagram, Civil/Mechanical Drawings and Electrical Drawings

Let's understand the preparation of BOM of PV Solar system by taking a simple case (50KW Solar Power system). In order to fetch the BOM of any PV solar system, following design documents one generally (but not limited to these) used.

- Single Line Diagram
- Civil structural General arrangement drawing

A Single Line Diagram (SLD) or sometimes called One-line diagram is a simplified notation for representing an electrical system. Electrical elements such as circuit breakers, transformers, capacitors, bus bars, and conductors are shown by standardized schematic symbols. It is a form of block diagram graphically depicting the paths for power flow between entities of the system.


Grid
Existing Metering Panel
HT Panel
Transformer
G
DG SET
EXISTING DB
I/C
O/G
MATCH LINE-A
ACDB with Metering Panel
IP :65, Outdoor
Type structure mounted
KWH
6A SP MCB
63A, 4P MCB
100A, 4P, MCCB
63A, 4P MCB
3.5Cx35Sq.mm Ar. XLPE Cu. Cable
P2 P1
100/5,CL-0.5,5VA
AC SPD
25X3 GI STRIP
25X3 GI STRIP
MATCH LINE-B
String Inverter-1
25KW 3Ø. 415V
AC
DC
4Sq.mm.Cu solar Cable
4Sq.mm.Cu solar Cable
4R,1Cx16Sq.mm Un Ar.PVC C.u Cable
MATCH LINE-A
PV17 PV2 PV1 S1
PV17 PV2 PV1 S2
PV17 PV2 PV1 S3
PV17 PV2 PV1 S4
PV17 PV2 PV1 S5
4 Sqmm. Cu. Cable
4 Sqmm. Cu. Cable



Legends

S.No.	Symbol	Description
1.	PV	Modules
2.		String Inverter
3.		MCB
4.		MCCB
5.		Circuit Breaker
6.		CT
7.		AC SPD

Fig. 6.1.2 Single Line diagram for a 50KW solar PV system

Now let's start quantifying the items from above shown SLD

Table 6.2 Sample Bill of Materials

SAMPLE BILL OF MATERIAL (BOM)				
ELECTRICAL COMPONENTS				
SL.	**ITEM**	**DESCRIPTION**	**QTY**	
1	Modules	300Wp, As per specification	167	
2	Inverter	25 KW Capacity, as per specification	2	
3	ACDB Metering Panel	IP65, outdoor type structure mounted	1	
4	Cable	1C X 16 SQ.MM Cu, AR, PVC	AS REQUIRED	
5	Grounding Wire	4SQ.MM, Cu	AS REQUIRED	
6	Tool & Tackles	AS PER VENDOR RECOMMENDATION	-	
7	Consumables		LOT	

Now let's see the Civil/ structural drawing. Below figure shows the plan view of the system arrangement reflecting the distance between two footings/ base.

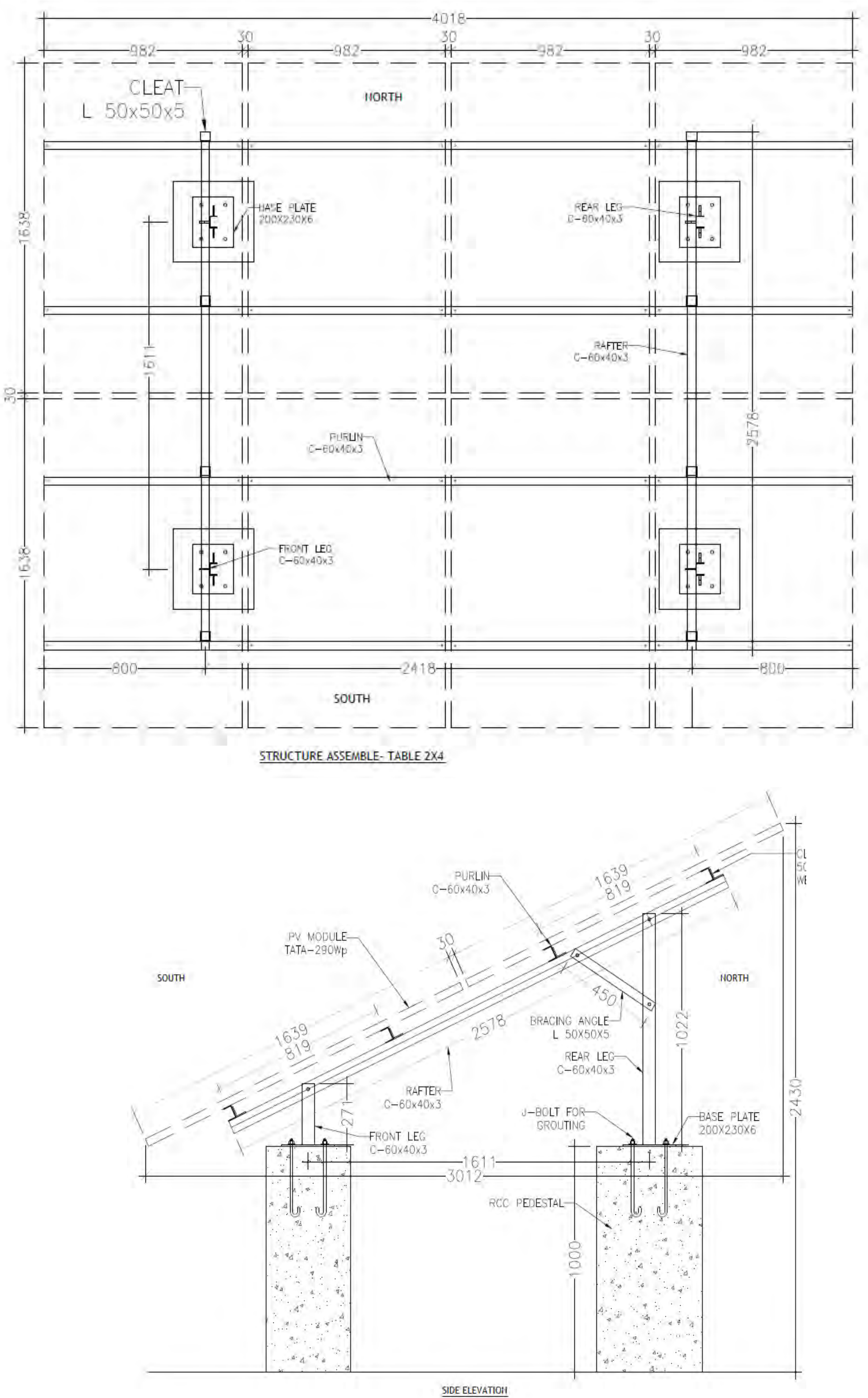


Fig. 6.1.3 Civil/Structural drawings from AutoCAD simulation

Thus, BOM for the civil items from above shown civil drawings are as follows:

Table 6.3 Sample Bill of Materials

SAMPLE BILL OF MATERIALS				
CIVIL STRUCTURAL COMPONENTS				
SL.	ITEM	DESCRIPTION	QTY	
1	Purlin	C-60X40X3 (mm); LENGTH: 4018 mm	16100	mm
2	Rafter	C-60X40X3 (mm); LENGTH: 2578 mm	5200	mm
3	Bracing Angle	L- 50X50X5 (mm); LENGTH: 450 mm	900	mm
4	Front Leg	C- 60X40X3 (mm); LENGTH: 271 mm	600	mm
5	Rear Leg	C- 60X40X3 (mm); LENGTH: 1022 mm	2100	mm
6	Cleat	50X50X5 (mm)	As Required	
7	Base Plate	200X230X6 (mm)	4	Nos.
8	J Type Bolt		16	Nos.
9	Bolt	M10	As Required	

Notes

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UNIT 6.2: Procurement of the Solar PV System Components

Unit Objectives

At the end of this unit, you will be able to:

1. Approach stores of the company or the market to place the requirement of the components as per BOM
2. Ensure that the quantity of modules/ panels, inverter and batteries match the Voltage requirement of the System
3. Identify the list variation in equipment specifications, if any
4. Document variation and submit to design team (if required) and obtain approval or revised drawings
5. Arrange for tools and consumables required for mounting the solar panels
6. List the statutory and the other requirements to dispatch the equipment at site
7. Ensure that only company recommended quality materials are used unless specified by customer
8. Ensure that all materials are QC passed
9. Complete all documentation with respect to procurement

6.2.1 Steps to be Followed for Procurement of Solar PV System Components

STEP 1: Approach stores of the Company with BOM & Specifications

Procurement for the components shall be done based on quantity mentioned in BOM & specification mentioned or attached with BOM. Below some specification of major components has been shown for reference only.

a. **Solar panel specification:** Following key specification (but not limited to these) must be taken into consideration for procuring the Solar panel.

- Rated Power at STC (Standard Test Conditions)
- Rated Power Tolerance (%)
- Temperature Coefficient
- Open circuit voltage
- Voltage at MPP
- Short Circuit Current
- Current at MPP
- Efficiency
- Module Dimensions
- Operating Temperature

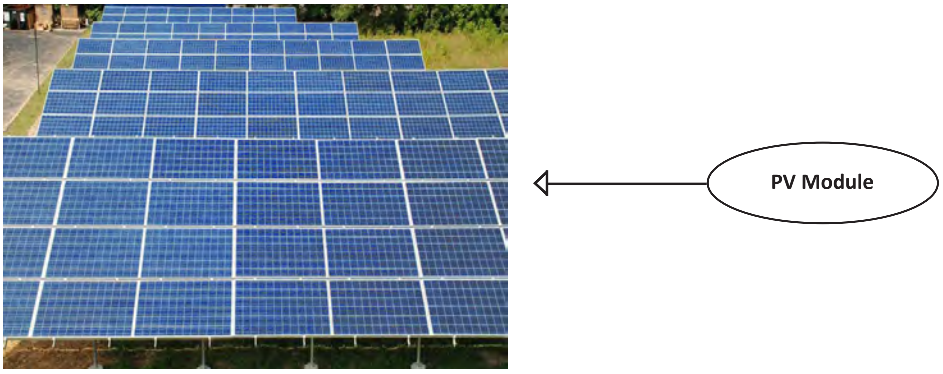

Fig. 6.2.1 Solar PV Module

Specification shown in below table is just for reference:

Table 6.4 Sample Specification sheet for a solar PV panel

SPECIFICATION SHEET										
Max Power Pmp (W)	10W	20W	40W	50W	75W	80W	100W	125W	150W	250W
Power Tolerence (+/-)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Max Power Voltage Vmp (V)	16.85	16.95	17.15	17.25	16.92	17	18	18.15	18.25	30.72
Max Power Current Imp (A)	0.59	1.18	2.33	2.9	4.43	4.71	5.56	6.89	8.22	8.14
Open Circuit Voltage Voc (V)	20.9	21	21.2	21.3	21.82	22.18	22.3	22.4	22.5	37.8
Short Circuit Current Isc (A)	0.65	1.29	2.55	3.17	4.92	5.11	6.1	7.4	8.85	8.63
Max. System Voltage VDC	600	600	600	600	600	600	1000/600	1000/600	1000/600	1000
Pm Temperature Coefficient	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.43
Isc Temperature Coefficient (mA/K)	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	0.04
Voc Temp Coefficient (mV/K)	-2	-2	-2	-2	-2	-2	-2	-2	-2	-0.32
Nominal Operating cell temp (Celcius)	45	45	45	45	45	45	45	45	45	45

b. **Inverter specification:** Following key specification (but not limited to these) must be taken into consideration for procuring the Inverters.

- Type of Inverter
- AC Output capacity
- DC input voltage range
- Operating temperature range

The below specifications pertain to the standard branded SPV Module just for reference

Table 6.5 Sample Specification sheet for Inverter

SPECIFICATION SHEET						
Model	100W/200W/300W/400W/12V	500W/24V	750W/24V	1000W/24V	1500W/48V	2000W/48V
Rated Power	100W/200W/300W/400W	500W	750W	1000W	1500W	2000W
INPUT						
Nominal Input Voltage	12VDC	24VDC	24VDC	24VDC	48VDC	48VDC
Input Voltage Range (DC)	10.5-15.5VDC	21.0-31.0VDC	21.0-31VDC	42.0-62.0VDC	42.0-62.0VDC	42.0-62.0VDC
Battery Low Alarm	10.7 VDC	21.5VDC	21.5VDC	21.5VDC	43.0VDC	43.0VDC

Battery Low Shutdown	10.5 VDC	21.0VDC	21.0VDC	21.0VDC	42.0VDC	42.0VDC
Output						
Efficiency	85%					
Output Voltage	110VAC 50- Hz/220 VAC 50 Hz					
Voltage Regulation	+/-3% TO +/-10% RMS					
Output Waveform	Sine Wave form					
THD	<5%					
Overload	Above 110%					
Protection	Overload, Short Circuit, Reverse Polarity					
through DC fuse, over temperature						
General						
Operating Temp Range	0 deg C to 40 deg C					
Storage Temp Range	-20 deg C to 70 deg C					
Thermal Management/ Cooling	Controlled Forced air cooling					
Relative Humidity	0-95% Non Condensing					
Dimesions WxDxH (in mm)	200x361x85		240x380x100		250x450x125	250x450x125
Weight (kgs)	3.8		5.4	6	8	9
Indications	Low battery, Overload/ Short circuit, Inverter on					

c. **Charge controller specification:** Proper selection of Charge controller can make run the entire battery based PB system efficiently & longevity.

Solar charge controllers are rated and sized by the solar module array current and system voltage.

There are two types of charge controllers:

- Pulse width modulation (PWM)
- Maximum power point tracking (MPPT)

PWM solar charge controller: The PWM charge controller is a good low cost solution for small systems only, when solar cell temperature is moderate to high (between 45°C and 75°C).

Fig. 6.2.2 PWM solar charge controller, solar regulator 6A, 12V

Below is the technical specification:

Table 6.6 Sample Specification Sheet for a charge controller

Below is the technical specification

TECHNICAL SPECIFICATION	
Type	Series Regulators Common Negative
Technology	Microcontroller Based Control
System Voltage	240V
ELECTRICAL PARAMETERS	
Charging current	40 Amp
Solar Array	Single Array
Bulk Voltage	282 +/- 2V
	Adjustable 270 ~ 290 V
Absorption period	Hold battery voltage or bulk setting for a cumulative period of 1 hr
Float Voltage	270 +/- 2V
Indications	LED Indications for Bulk Mode, Float Mode, High Current, Low Battery
	High Battery, Array/ Battery Reverse Polarity
	Analog type voltmeter and ammeter with a selector
	switch for monitoring voltage of solar array/ battery and charge current
ENVIORNMENTAL PARAMETERS	
Operating Temperature	0 Deg C to + 40 Deg C
Storage Temperature	0 Deg C to + 55 Deg C
Relative Humidity	0~ 95% Non Condensing
Dimensions WxDxH (in mm)	400 x 475 x 151
Weight (in Kgs)	9.5

MPPT solar charge controller

The MPPT are most common these days and can gain you up to 30% more power than the PWM controllers. The MPPT controllers also allow the strings of panels to be connected in series for higher voltages, keeping the amperage lower and the wire size smaller, especially for long-wire runs to the PV array.

Fig. 6.2.3 MPPT 60 150 Charge Controller

Below is the technical specification just for reference:

Table 6.7 Sample specification sheet for an MPPT solar charge controller

TECHNICAL SPECIFICATION	
Type of Product	**MPPT With Load Charger**
Voltage(V)	**12 V - 24 V**
Current(A)	**20 A**
Application	**Off-grid and micro grid. Telecom grid solar system. Home lighting system and street lighting system.**
Product Warranty	**2 Years**

d. **Solar Cables:** Solar cables are the interconnection cables used in photovoltaic power generation. A solar cable interconnects solar panels and other electrical components of a photovoltaic system. Solar cables are designed to be UV resistant and weather resistant. It can be used within a large temperature range and are generally laid outside.

Cables are generally sold in 6, 30, 50 and 100 foot lengths, with a wire gauge size of AWG 10 (30-amp capacity) or AWG 12 (25 amps). They're also typically rated to handle either 600 or 1,000 volts.

Fig. 6.2.4 Solar Cable

e. **Solar batteries specification:** Deep-cycle, lead-acid batteries are widely used in renewable energy and grid-backup system, and are ideally suited for these applications because of their long, reliable life and low cost of ownership. There are many companies that sell deep-cycle lead-acid batteries, so it is important to understand the technologies and other performance factors that affect overall operation and battery life.

Some important factors are as below:

- Capacity- Battery capacity is important because it's a measure of the amount of energy stored in the battery.
- Voltage- the battery bank voltage must be considered to ensure it matches the system requirements. The battery bank voltage is often determined by the inverter specifications if installing a DC-to-AC system or by the voltage of the loads in a DC system
- Cycle Life- The most critical consideration is cycle life, which provides the number of discharge/charge cycles the battery can provide before capacity drops to a specified percentage of rated capacity. Batteries from different manufacturers may have the same capacity and energy content and be similar in weight. But design, materials, process and quality influence how long the battery will cycle

Below battery specification is just for reference:

Table 6.8 Sample Specification sheet for a Battery

SPECIFICATION SHEET									
Model	Nominal Voltage (V)	Nominal Capacity (AH)	Dimensions (mm)				Approx Weight (Kg)	Terminal Position	Terminal Type
			Length	Width	Height	Total Height			
Vendor Specific	2	100	103	206	355	409	12.6	G	M10
	2	150	103	206	355	409	15.3	G	
	2	200	103	206	355	409	17.2	G	
	2	250	124	206	355	409	20.8	G	
	2	300	145	206	355	409	24.3	G	
	2	350	124	206	470	525	26.9	G	
	2	420	145	206	470	525	31.5	G	
	2	500	166	206	470	525	36.1	G	

STEP 2: Identify and list the variation in equipment specifications, if any & submit to design team, if necessary.

Before placing the order for components, make ensure that the components which are going to be ordered are matching the design requirement. It is also standard procurement practices that get the list of variation or deviation from the Vendor itself with the proper technical justification for further evaluation by the design team (if required) & obtain the approval or revised drawings..

STEP 3: Arrange the Tools and consumables

Identify the Tools & Tackles (get special tools recommended by Vendor, if any) required for installing the solar panels. Below are listed some Tools & Tackles required for mounting the solar panels.

Table 6.9 Tools and Tackles required for Installation of Solar PV Panels

Solar path finder (evaluates the solar energy potential at a site	
Compass (not needed if you are using a solar pathfinder)	
Angle Finder	
Torpedo Level	
Chalk Line	

Hole Saw	
Torque Wrench	
Wire Strippers	
Cable Cutter	
Caulking Gun	

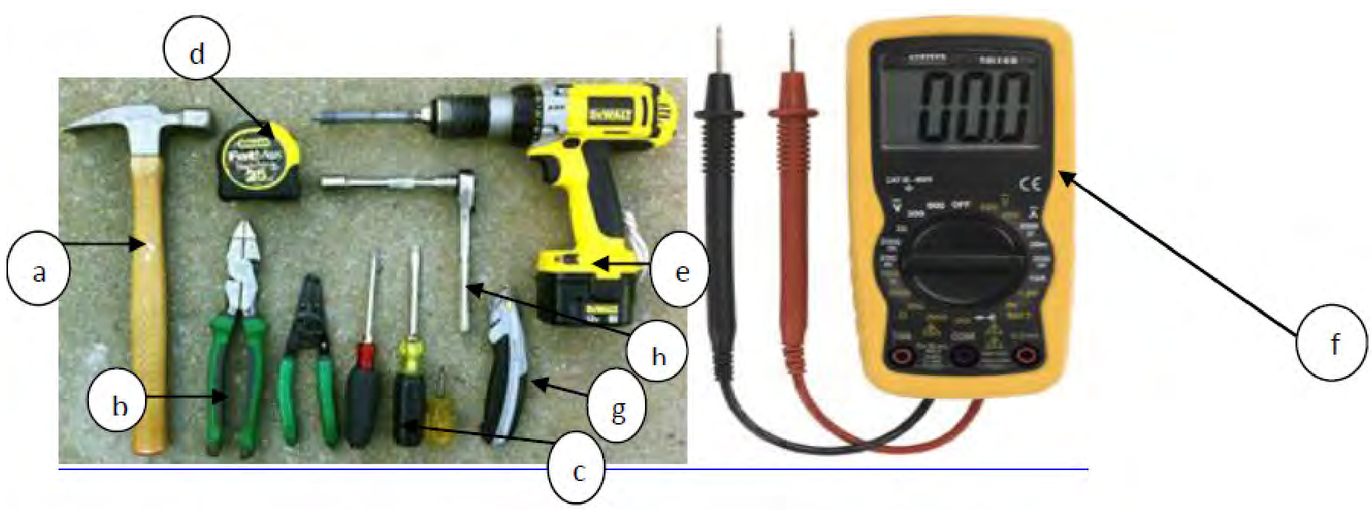

Fig. 6.2.5 Some pictures of Tools/ equipment

a. Hammer

b. Plier

c. Screwdriver

d. Measuring Tape

e. Driller

f. Multi-meter

g. Utility knife

h. Ratchet set

Consumables

a. Electrical tape

b. Cable ties

c. Cable clip

d. Silicon caulking

e. Bolts

f. Splice

g. Washer

h. Mounting clips

STEP 4: List the Statutory requirements / compliances required for the components

To obtain subsidies or participate in government schemes, registration of module types with the Indian Ministry of New & Renewable Energy (MNRE) is required. Only MNRE approved suppliers and modules types are entitled to the MNRE policy schemes & subsidies.

MNRE compliance requires conformity to latest standards by the Bureau of Indian Standards (BIS).

Major BIS standard for Solar PV module are:

- IS 14286 (adopts IEC 61215)
- IS 61701

Make sure the supplier confirms the statutory requirements according to customer before placing the order.

System Warranty: The majority of solar panels on today`s market come with a 25-year long warranty (also known as a performance guarantee). In most cases this means a guaranteed electrical production for 10 years at 90% of rated power output and 25 years at 80%.

STEP 5: Make sure all the material certificates are available with Supplier.

STEP 6: Complete all the required documentation w.r.t. Procurement.

Notes

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UNIT 6.3: Verify the Components on-Site

Unit Objectives

At the end of this unit, you will be able to:

1. Plan and receive the equipment at site
2. Ensure that all the components are handled and stored properly as per standard operating procedures
3. Check material received as per final BOM and ensure that the correct material for the job arrives on site and is damage free
4. Report and document the status of material received at site and take appropriate action for replacements, if any

6.3.1 Plan and Receive the Equipment at Site

Make ensure that before arrive the components at site, pre-installation works has been completed. If not, proper arrangement has been done for storage.

6.3.2 Material Handling

Make ensure that all the components are handled and stored properly as per standard operating procedures provide by supplier. It can be under sunshade, rain protected place. Make ensure electronics/ electrical components/ structural materials are placed properly at site.

Table 6.10 Some Dos & Don’ts of Solar PV Material Handling

Sl. No	Dos	Don'ts	Remarks
1	**Open the boxes carefully. Wrap the unpack box properly once the inspection is done. Follow Vendor provided storage procedure strictly.**	**Do not spread the parts/ materials on surface**	
2	**Always use gloves while handling hazard potential equipments like batteries**	**Never handle the equipment like batteries with bare hands as it contains acid.**	
3	**Wrap the nut & bolts properly.**	**Do not start using tools & tackles without proper knowledge**	

6.3.3 Check Materials Received on-Site

Most of the manufacturers bound some restrictions and deadlines when it subject to return or exchange the supplied items because of any reason, so it is always better to inspect immediately once the components arrived at site. Inspect all the components for sign of wear, poor seal, damage (take snapshots, if any). Make the report & document the status of material received at site.

Below is a check list for site verification, just for reference.

Table 6.11 Check list for site verification

Sl. no	Item to be checked/ verified after receiving the purchased components at Site.	Yes/ No	Remarks
1	Check Component qty as per final BOM		
2	Check Equipment and parts are properly labeled as required		
3	Make ensure that all the components received damaged free		
4	Check the all the require documents like Manufacturer operation and maintenance instructions, Manufacturers As built drawing, Catalogues, storage & handling procedure, list of deviation are received		
5	System warranty		
6	All QC inspection reports		
7	Certificates regulatory required as per local/ national		
8	Check the received accessories for mounting panels are compatible with the fabricated structures at site		
9	Check all the recommended tools & tackles are received		

Exercise

1. Explain the importance of preparing BOM for procurement of any item
2. Which type solar charge Controller is more efficient & why?
3. List out the typical design documents required for preparation of BOM

Activity 1:

Design & prepare the Bill of Material for Civil Structural quantity PV System.

Type of Installation: Tilted

No of PV Module: 8

Location Layout: Building Roof Top

Footings: Using Pedestal

Module Dimension: 1000 mm X 1600 mm

Activity 2:

Prepare the Specification sheet for PV module (75W)

7. Install Civil & Mechanical Parts of Solar PV System

Unit 7.1 – Get Equipment Foundation Constructed

Unit 7.2 – Install Mounting System

Unit 7.3 – Install Photovoltaic Modules

Unit 7.4 – Install Battery Bank Stand and Inverter Stand

SGJ/N0103

Key Learning Outcomes

At the end of this module, you will be able to:

1. Explain the types of footings used for civil installation
2. Get the equipment foundation constructed
3. Identify the various structural attachments used during installation
4. Explain the different types of mounting structures
5. Install mounting system
6. Install photovoltaic module
7. Install battery bank stand and inverter stand

UNIT 7.1: Get Equipment Foundation Constructed

Unit Objectives

At the end of this unit, you will be able to:

1. Identify type of footing required
2. Locate structural footings
3. Arrange for tools and consumables required for civil/mechanical installation
4. Get the concrete forms constructed to design specifications
5. Install mounting posts, roof attachments and anchors

7.1.1 Identify Type of Footing Required

The solar array of a PV system can be mounted on rooftops, generally with a few inches gap and parallel to the surface of the roof. If the rooftop is horizontal, the array is mounted with each panel aligned at an angle. If the panels are planned to be mounted before the construction of the roof, the roof can be designed accordingly by installing support brackets for the panels before the materials for the roof are installed. The installation of the solar panels can be undertaken by the crew responsible for installing the roof. If the roof is already constructed, it is relatively easy to retrofit panels directly on top of existing roofing structures.

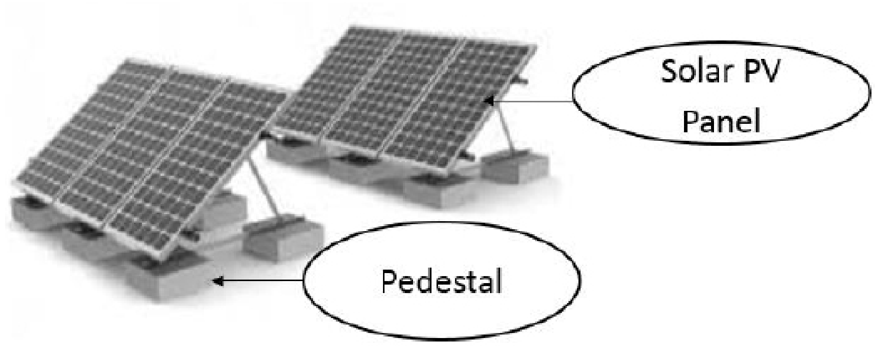


Fig. 7.1.1 Pedestal type of footing

The most preferred method is to construct a pedestal like footing to avoid any roof penetration. Type of footing required is entirely depends on the type of roof. In India generally two type of roof structure are common:

- Flat roof
- Slope roof

Type of Footings explained pictographically

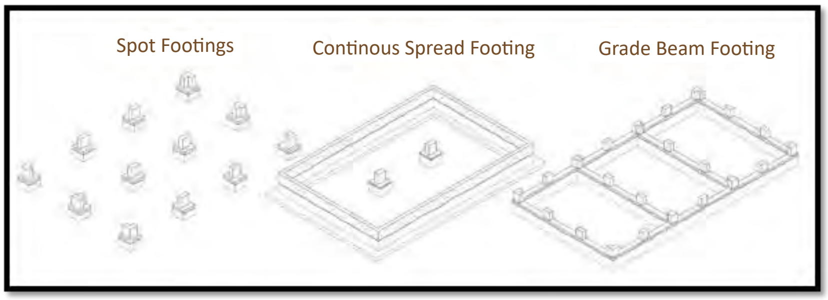
Installing PV panels onto roofs introduces hazards that can affect the structural integrity of the roof. Not only does the roof support the dead load of the PV system itself, but also external forces introduce structural loading. Outside installations expose the PV system and roof assembly to hazardous elements such as wind, hail, snow, debris, and extreme temperatures. The mounting structure should be such that the external environment factors do not reduce the life of the structure to less than 25 years.

Types of Footing:

a. Spot footings

b. Continuous spread footing

c. Grade beam footing



a. **Spot footing**

A spot or pad footing is used to support a single point of contact, such as under a pier or post. Typically, spot footing is of 2' by 2' square pad, 10" to 12" thick, and made with reinforced concrete rated to 3,000 to 5,000 pounds per square inch (psi) in compression.

b. **Continuous spread footing**

A continuous spread footing is commonly used to provide a stable base around the perimeter of a structure or between the front leg and the back leg of the structure. The footing thickness provides the strength needed to support the weight. The wider width of the footing base creates a large area to transfer this weight. The dimensions of a continuous spread footing vary according to the load placed on the footing, soil conditions, and the wind sustainability analysis. Typically, spread footings are frequently 16” to 24” wide, 6” to 16” thick, and made with reinforced concrete rated to 2,000 to 5,000 psi in compression.

c. **Grade beam footing**

A grade beam footing is a continuous reinforced-concrete member used to support loads with minimal bending. Typically, a continuous grade beam is frequently constructed by digging a trench at least 8” wide to the depth or creating the same height of footing above the roof, needed to span the distance between supports. Grade beam footings differ from continuous spread footings in how they distribute loads. The depth of a grade beam footing is designed to distribute loads to bearing points.

7.1.1.1 Flat Roofs

In roof-mounted systems on flat roofs, modules are mounted with the help of module mounting structure above the roofs. Modules are kept at a tilt angle using support structure. Method of securing mounts requires a considerable attention as PV modules have large area, wind forces must be taken into account. The structure of roof determines the type of footing. The ability of roof to handle the greater loads determines whether the system can be ballast mounted or must be fixed with respect to the roof (anchoring).

Ballast mounted

With ballast-mounted systems, the flat roof mounts are anchored without penetrating the roof. Concrete blocks, slabs or plinths are placed on the flat roof without any further fixing and the support frames are secured to these with screw anchors. For the concrete elements, it is possible to use standard building materials such as curbs, paving slabs or specially made foundation slabs. If necessary, matting should be laid beneath to protect the roof skin from sharp edges. Alternatively, the concrete weights can be inserted in channels on the support frame.

Anchoring

If it is not possible to use ballast-mounted systems for structural reasons, the PV array must be rigidly anchored to the roof construction. Here, the supporting frames are mounted on crossbeams that are secured either to the roof itself or to the roof parapet. Where the roofs waterproofing is penetrated, the anchorage points must be carefully sealed. When designing the layout, the number of penetration points should be reduced to a minimum. When refurbishing flat roofs, the anchoring can be particularly easily realized since the pressure points of the solar substructure can be sealed at the same time.

7.1.1.2 Slope Roof

The modules are fitted above the existing roof covering using a metal substructure. The metal structure to support the modules consists of three main components:

- Roof mounts
- Mounting rails
- Module fixings

Using the roof mounts, a rail system is anchored to the roof structure beneath the roof covering or is fixed directly to the roof cover itself (but only if the roof covering is structurally strong enough). The modules are fixed to the rails with system-specific fixing elements.

Tips

Before going for civil installation, it is always beneficial to collect some basic information such as type of roof, length & width of the array space, thickness of roofing material, distance between beams etc. It is important to ensure that the overall weight of the system is in line with structural allowance.

7.1.2 Locate Structural Footings

After identifying the type of footing, refer to the design to locate the structural footing. For your understanding, a sample design is shared below.

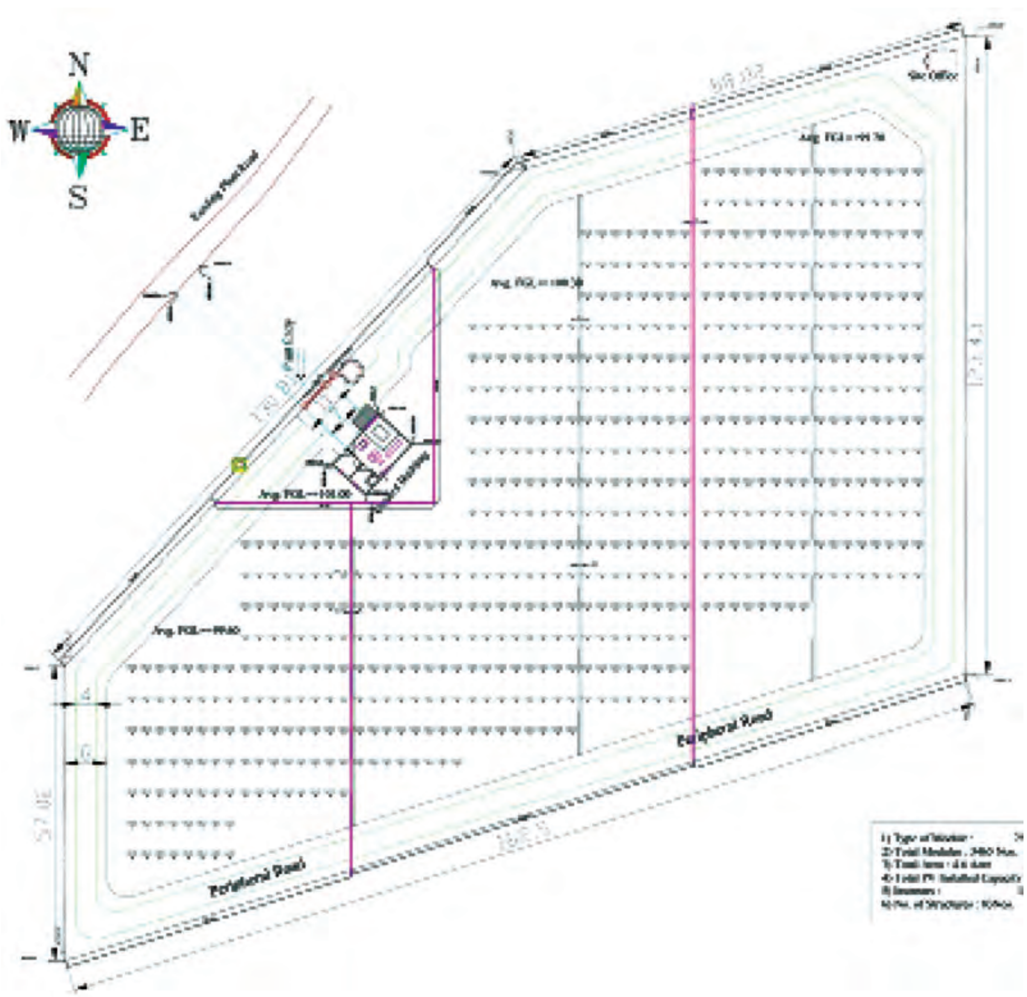


Fig. 7.1.2 Sample PV Array Layout Design

7.1.3 Arrange for Tools and Consumables Required for Civil/Mechanical Installation

Important tools and consumables required to do civil/mechanical work are:

Table 7.1 Tools and Tackles for Civil/Mechanical work

1. Hammer	6. Plumb bob	11. Line dori
2. Screw Driver	7. Measuring tape	12. Clamps
3. Nail puller	8. Drill machine	13. Digging bar
4. Measuring square	9. Utility knife	14. Spade
5. Hand saw	10. Chisel	15. Spirit Level

Some of the tools are shown below.

Fig. 7.1.3 Tools and Tackles for Civil/Mechanical work

7.1.4 Get the Concrete Forms Constructed to Design Specifications

Concrete forms need to be constructed as per the design. Roof is generally chipped where pedestal has to be made. The figure given below shows the side view of an RCC pedestal. (RCC stands for Reinforced Cement Concrete).

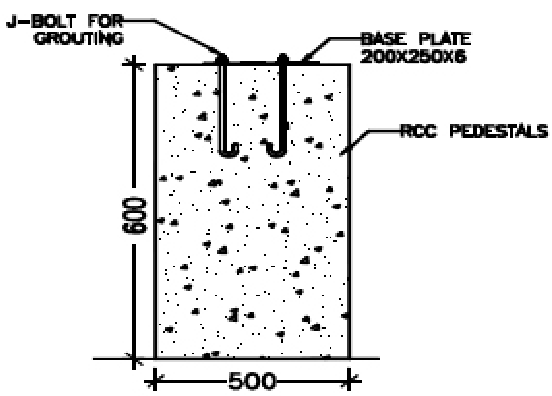
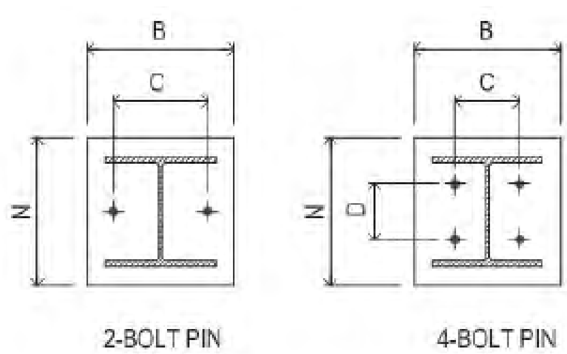


Fig. 7.1.4 Side view of an RCC pedastal

Once the pedestal is prepared as shown in the figure above, a base plate of size – 200x250x6 shall be fixed by using J type bolts. Below figure shows the base plates with different no of holes available in market.



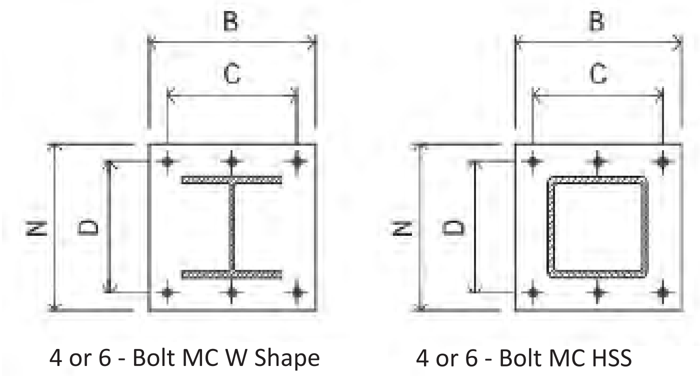


Fig. 7.1.5 Types of Base plates available in the market

A general concrete mixing ratio is shown in figure below.

Table 7.2 Concrete mixes and purpose

Type of Concrete	Proportion of Mix	Nature of Work
M5	1 : 5 : 10	Mass Concrete for heavy walls, foundation, footings
M7.5 M10	1 : 4 : 8 1 : 3 : 6	Mass concrete and foundations of less importance
M15	1 : 2 : 4	For general RCC works (slabs, beams, columns, etc.)
M20	1 : 1.5 : 3	Water retaining structures, piles and general RCC structures
M25	1 : 1 : 2	Heavily loaded RCC structure, long span slab, beams, etc.

7.1.5 Install Mounting Posts, Roof Attachments and Anchors

Installation of mounting post for fixed structures with legs

Foundation for supporting mounting structure can be constructed in accordance with site condition. For installing mounting post kindly refer to the design.

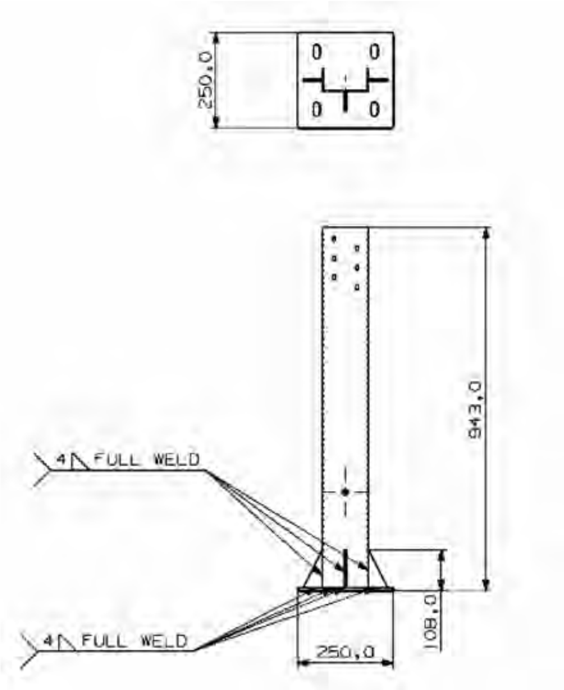


Fig. 7.1.6 Sample design for installing mounting post

Notes

UNIT 7.2: Install Mounting System

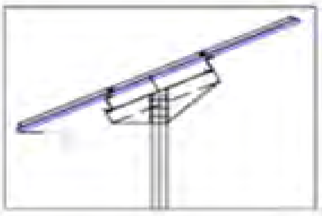
Unit Objectives

At the end of this unit, you will be able to:

1. Locate structural roof members and install structural attachments
2. Install module support/racking frame
3. Plumb and Level array structure
4. Install supplementary structural supports
5. Apply corrosion protection to cut surfaces
6. Apply Weatherproofing to avoid any seepage and penetrations
7. Install tracking system

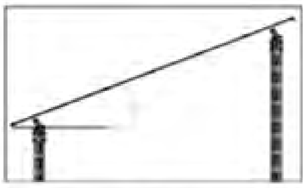
7.2.1 Different Types of Mounting Structures

1. Single Pole Static structures is designed to install quickly and provide a secure mounting structure for PV modules on a single pole. The module specific design reduces the number of components and provides for an easier assembly. It utilizes high strength welded steel components and corrosion resistant hardware for long term reliability. Seasonal adjustability for maximizing production can be provided for different tilt-angle settings and is a single person operation.



Single Pole Static structure

2. Double Pole Static Structure is designed with graded or flat ground systems in mind and are common for remote photovoltaic applications.



Double Pole Static structure

3. Pitched roof top mounting systems can easily mount PV modules on pitched roofs of varying types. The optimized system is simple: just click in, position, and fix. The designed rails are thinner therefore reducing cost significantly and continue to provide stability.

4. Rails and racks This is a flexible system for the parallel mounting of framed and unframed modules on all current types of trapezoidal metal sheet roofs. Fast and easy mounting is guaranteed due to the unique hook design of its fasteners. These fasteners are easily fixed to the side of the standing seam. The lateral position of the screws in the profiled sheet has a positive effect on the permitted tearing levels. It allows for easy adjustment and levelling of minor height deflections

5. Trapezoidal roof top mounting structure system can be individually adapted to the customer's requirements thanks to a variable tilt angle and several anchoring options, such as ballasting or fixation with roof penetration. It can be adjusted to fit even difficult roof conditions.

6. Single pole ground-mount system: is especially designed to reduce cost. It is suitable for both laminates and framed modules. The use of ramming posts and the parallel ground surface installation eliminates the need for additional excavation work. It makes the structure aesthetically pleasing and very economical – ideal for large projects. Adjusted to the respective project, different module layouts are available.

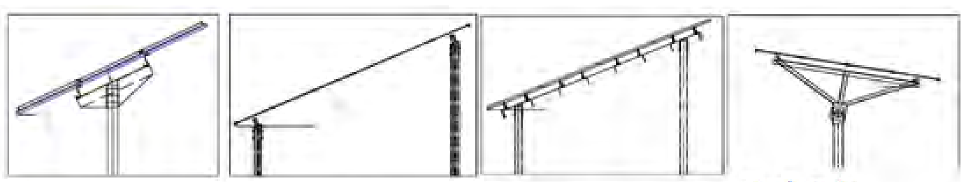
7. Single Pole with frames type of Module combines the advantages of a single-pole system and Double pole mounting Structure. As a result, maintenance work has been further reduced with the same number of modules.

   The system adapts easily to any terrain and space and the modules can be installed either in portrait or in landscape. The installation costs are extremely low due to the simple, functional design and the minimal number of tools required.

8. Double Static Concreted Pole is especially designed for application in difficult ground & soil conditions, e.g. landfill or disposal areas. The modules can be arranged in any number of rows and columns on the module table. It is an extremely low-maintenance system during its entire life span.

9. Pole top mounting structure gives maximum power production everywhere, without grid connection. The pole top provides the best possible decentralized solution. The system is particularly flexible and can be adjusted to local conditions for maximum performance. Mounted on a single post, the pole additionally acts as a theft protection. As with all the systems, it is made from high quality aluminum and stainless steel and therefore ensures long-life service without additional maintenance.

Snapshot: Types of mounting structures

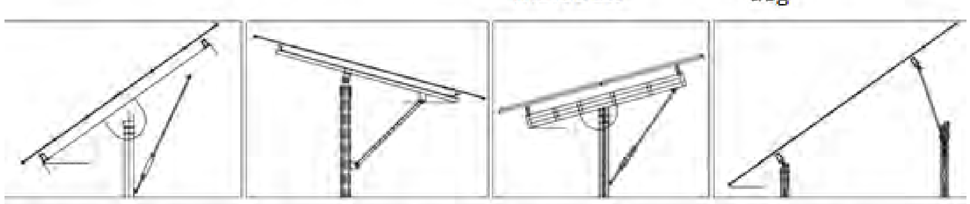


Single Pole Static structure

Double Pole Static structure

Double Pole Static structure with struts

Single Pole Seasonal titling structure (10 to 40 deg

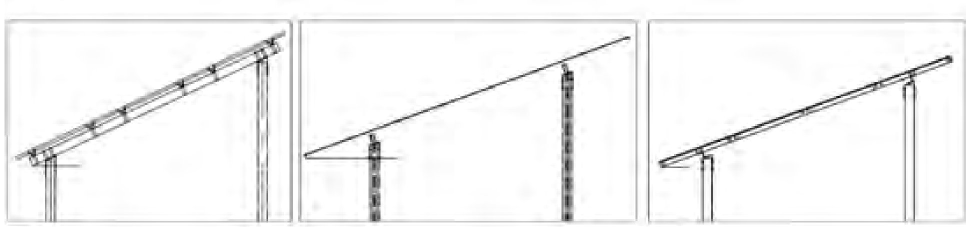


Seasonal structure with unique turn buckle mechanism titling

Seasonal structure with manual tilting

Seasonal tilting structure with turn buckle with struts

Double pole Seasonal tilting structure



Double Pole Static structure with struts

Double Pole Static structure without struts

Double Pole Static structure with beam

7.2.1 Installation of Mounting Structure

Installation of mounting structure is site and product specific. Refer design and user manual for installation. Typical steps for installation of mounting structure are given below:

1. Locate structural roof members and install structural attachments

Panel Rack: Panel racking in general, consists of rails/ rafters, roof mounts, fasteners like mid clamp, end clamp

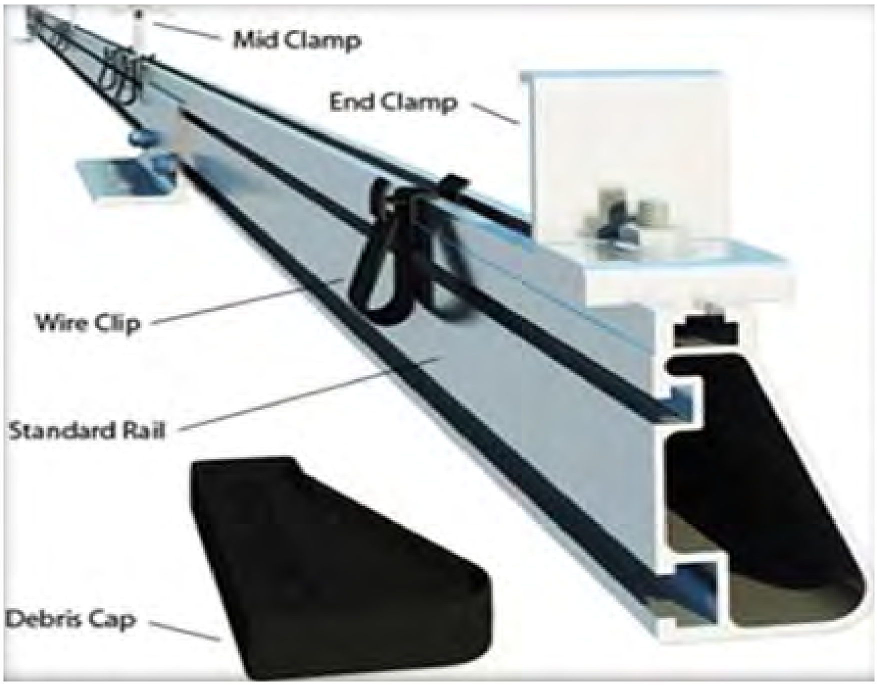
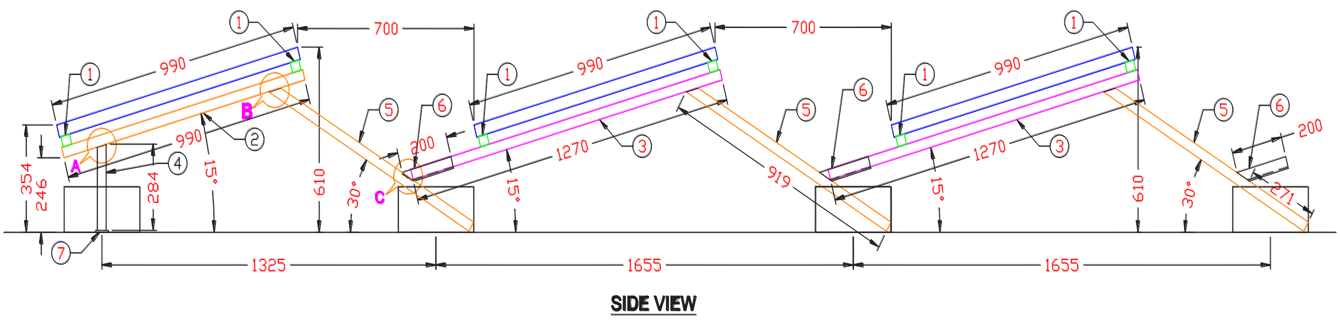


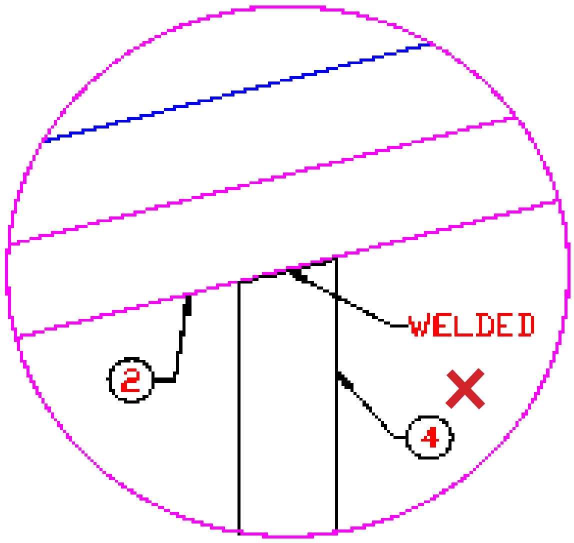
Fig. 7.2.1 Panel Racking - Rails/rafters, fasteners (clamps)

While rails hold your modules in place, footings, standoffs and other types of mounts secure the rails to the roof or other array base.

Note: Most preferred material for rails is aluminium & SS fasteners. Aluminium makes the structure light while SS fasteners are strong and durable

In below figure, detail module support structural has been shown with dimensions for better understanding of panel rack arrangement.





Welding should be avoided on site as it causes the structure to rust in a short time. That is why nut and bolt mounting structures are being used now.

View A

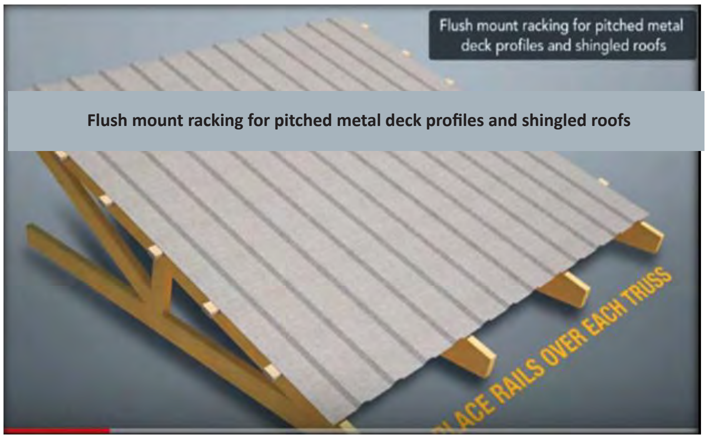
Fig. 7.2.2 Panel racking arrangement - side view of module support structure

Labels

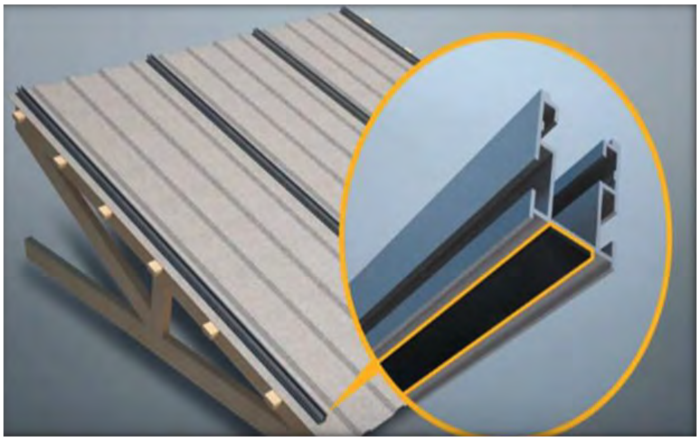
1. Purlin
2. Rafter-1 (based on length)
3. Rafter-2 (based on length)
4. Front Leg
5. Back Angle
6. Angle
7. Base Plate & Jointing Plate
8. Bolts

7.2.2 Installation of Roof Attachment and Anchors for Flat Roof Structures

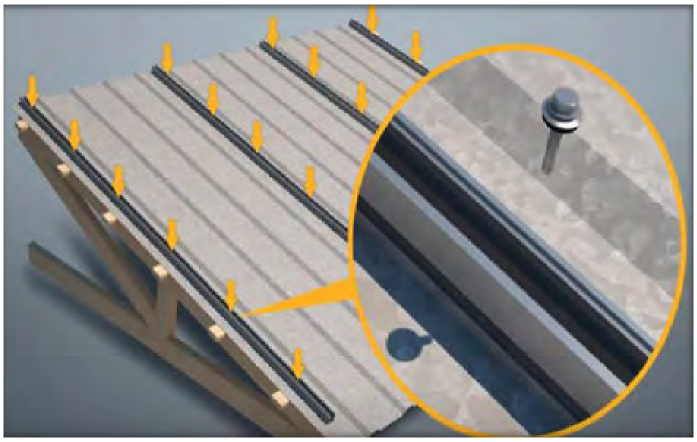
Step by Step method for fixing module over structural frame, Plumbing & Level the array structure or any secondary structural support, if required due to weight of the system



STEP 1: Place rails over footings

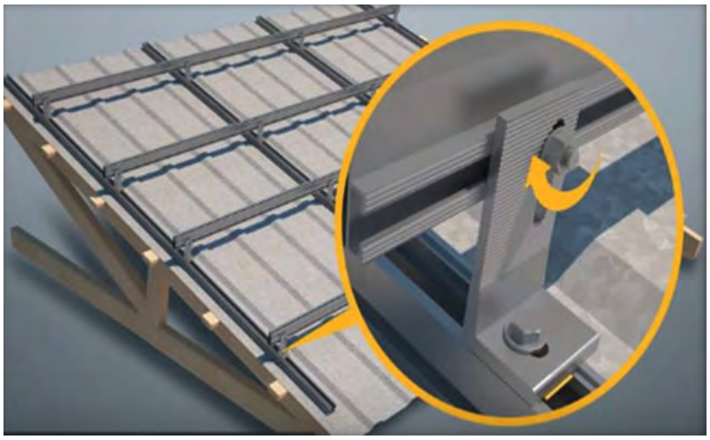


STEP 2: Place the Purlins over rails/ rafters

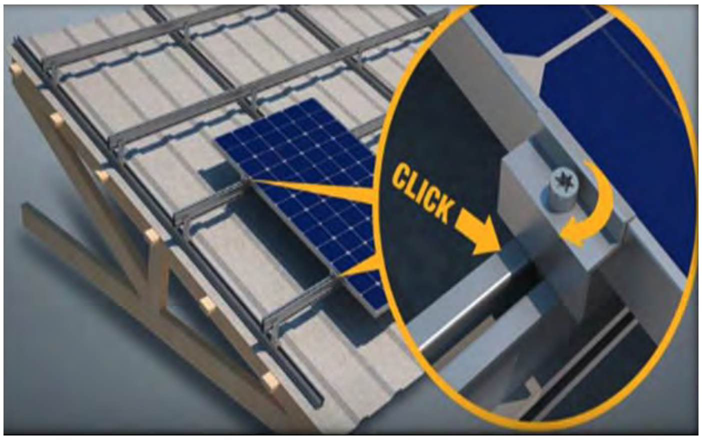


STEP 3: Fix the Purlins over rafters

STEP 4: Fix the Clamps



STEP 5: Fix the purlin with clamp to make elevation from roof



STEP 6: Now fix the PV modules & Level it over elevated structure

7.2.3 Apply Corrosion Protection to Cut Surfaces & Weather Proofing Material to Avoid Any Seepage & Penetration

Use the structure applied with corrosion resistant material like Hot Dip Galvanized after fabrication steel, or stainless steel materials. This will increase the structure life significantly.

Below figure shows the plan view of the system arrangement reflecting the PV module arrangements

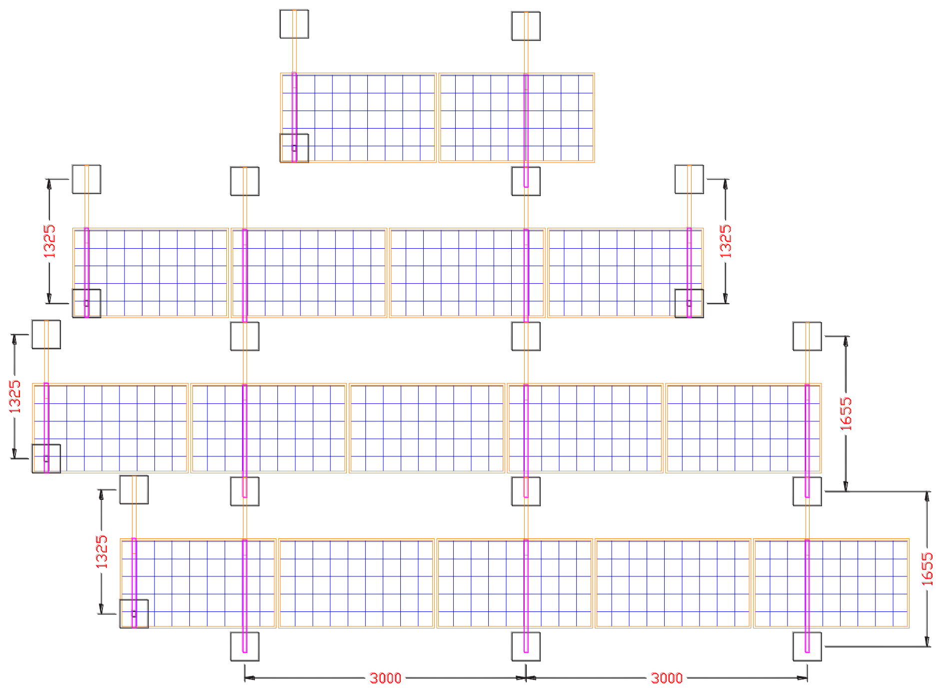


Fig. 7.2.3 Plan view of the PV system arrangement

7.2.4 Installation of Roof Attachment and Anchors For Slope Roof Structures

For installation of PV module on pitched roofs roof hooks or anchor are used. Various types of roof hooks and anchors are available depending on the roof structure. Below are some examples of hooks used for the roofing tiles.

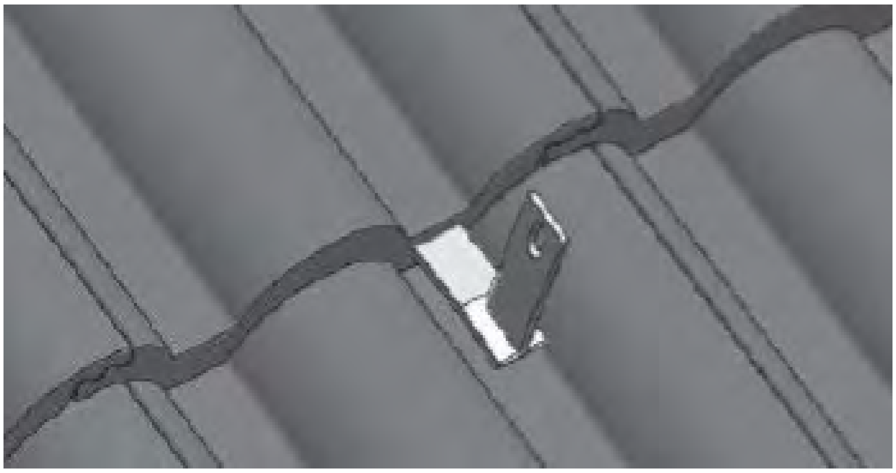
Fig. 7.2.4 Roof hook/anchor for roofing the tiles

Process of installing roof hooks

STEP 1: Remove tiles from hook location.

STEP 2: Fasten the hook to rafter using screws

STEP 3: Put tile back on its position



Hanger bolt fastener set is used for mounting on roofs with fiber cement corrugated and trapezoidal corrugated covering.

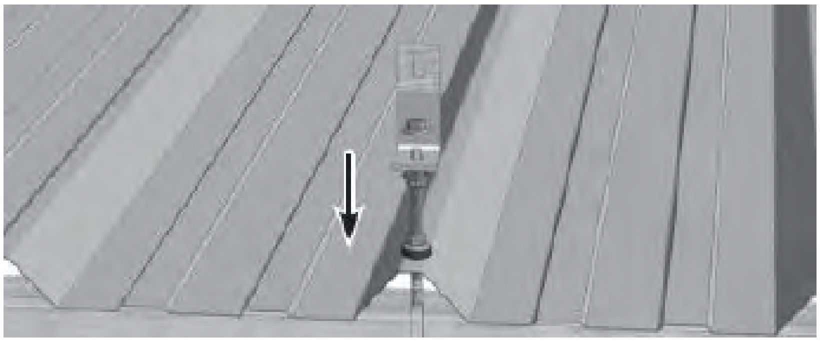
Installation

STEP 1: Drill wood structure and covering

STEP 2: Screw in hanger bolt

STEP 3: Place rubber seal and spacer, screw nut on and tighten

STEP 4: Mount flange



STEP 5: Install module support/racking frame

STEP 6: Plumb and Level array structure

STEP 7: Install supplementary structural supports

STEP 8: Apply corrosion protection to cut surfaces

STEP 9: Apply Weatherproofing to avoid any seepage and penetrations

Tips

Following key points must be taken into consideration for installing the PV components:

- Mounting Installation should not impact on the waterproofing of the building.
- Installation should be strong enough to withstand wind, snow, rain effect.
- Material used for installation should be corrosion resistance or sufficiently treated to prevent corrosion.

Notes

UNIT 7.3: Install Photovioltaic Module

Unit Objectives

At the end of this unit, you will be able to:

1. Unpack PV modules
2. Inspect module for physical damage
3. Test PV modules' electrical output
4. Install the modules as per layout diagrams
5. Secure module wiring
6. Fasten modules to structure
7. Torque module fasteners

7.3.1 Installation of PV Module

General Safety

- It is recommended that installation, wiring, and maintenance of PV modules must be done by licensed and trained persons
- Understand all instructions and information related to PV modules prior to handling and installing a PV modules
- Cover surface of PV modules with an opaque material during installation to avoid the electrical shock
- Do not disconnect operational modules
- Do not concentrate artificial sunlight on modules using lenses or mirrors
- Do not use any light sources other than natural sunlight and general illumination for power generation
- Check the polarity of the wiring before installing
- Only use equipment, connectors, wiring and support frames suitable for solar electric systems
- Wear appropriate protection and take all necessary precautions to prevent electric shock, especially when DC voltage exceeds 30 VDC

Storage And Unpacking

- Do not remove original packing until you are ready to install PV modules.
- Store the packaged PV modules in a clean, dry area with relative humidity below 85% and ambient temperatures between -20°c and 40°c.
- Do not load more than the permissible maximum number of pallets on top of each other.
- Two people are required to unpack modules from the packing box. When handling modules always use both hands.
- Do not use a knife to cut the zip-ties, but use wire cutting pliers.
- Do not place modules directly on top of each other.

Module Handling

- Wear insulated gloves while handling the module.

- Inappropriate transportation and installation can cause breakage of the module hence prevent that.
- Module should not be lifted by holding the junction box or cable.
- Avoid placing anything onto the module or pressing the surface of the module.
- Prevent falling of any object onto the module.
- Must not drop the module.
- Back of the module should not be exposed to direct sunlight.
- Avoid using metal ornaments while module handling.
- Installing or handling of modules should be prevented in wet or strong windy conditions.

7.3.2 Module Mounting

Two methods are generally used for mounting PV modules on structures.

Module mounting by using bolts

Generally the frame of any module has 4 x 9mm mounting holes, ideally placed to optimize the load handling capability, to secure the modules to supporting structure.

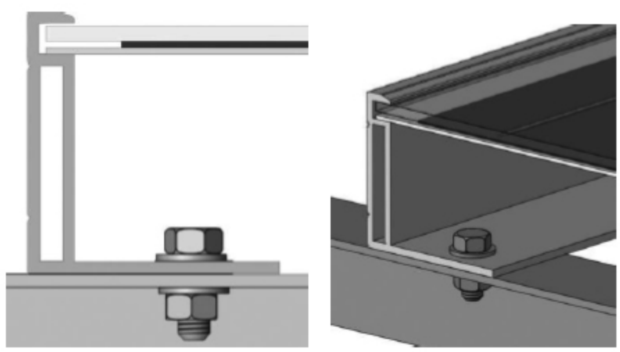


Fig. 7.3.1 Module mounting by using bolts

Module mounting by using clamps

Use at minimum 4 clamps to fix modules on the mounting rails. Modules clamps should not come into contact with the front glass and must not deform the frame. Be sure to avoid shadowing effects from the module clamps.

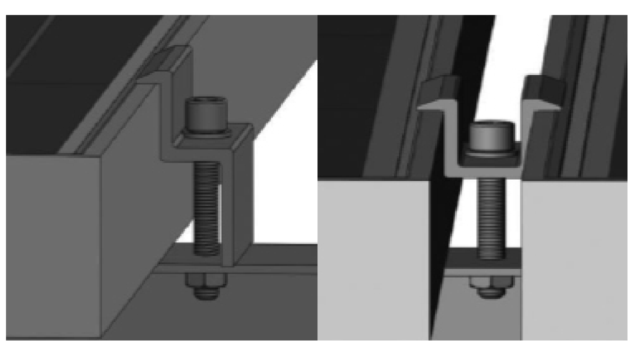


Fig. 7.3.2 Module mounting by using clamps

7.3.3 Instruction On Module Interconnection

- To avoid mismatching it is recommended to measure the electrical parameters of modules with larger power tolerances (> 5 per cent) before installation in order to make sure that modules with same MPP currents are interconnected in string.
- In a system same types of modules should be used.
- Module that have connecting cables with single-pole touch-proof plug connectors are quicker and easier for connecting them together.
- Polarity of the cables must be checked while connecting the modules together and with the PV array combiner/ junction box as reverse polarity can cause short circuit thereby damaging bypass diodes and the inverter's input stage.
- Module generates power during the day time only, plug connectors must not be disconnected under loading condition. If one requires, to disconnect them, then after installation, first of all switch off the inverter and then trip the DC circuit breaker (if fitted).
- Under open-circuit voltage condition the plug connectors can be disconnected from the modules.
- In modules without preassembled module connection cables:
  - On connecting lead strip the insulation to roughly 16mm.
  - Without metal end sleeves connect securely in spring clamp terminals.
  - Remember strain relief and correctly implement water-proof cable feed through.
  - Before the cable entry point into the module junction box form a drip loop.
  - Seal the box cover properly so that it is waterproof.
- Wiring should be done only by the qualified installers and as per local codes and regulations.
- Modules are connected in series by plugging the positive plug of one module into the negative socket of the next module. In series connection the operating voltage of individual modules will be added to get the increased output voltage. Make sure that the contacts are corrosion free, clean and dry before the connection of modules.

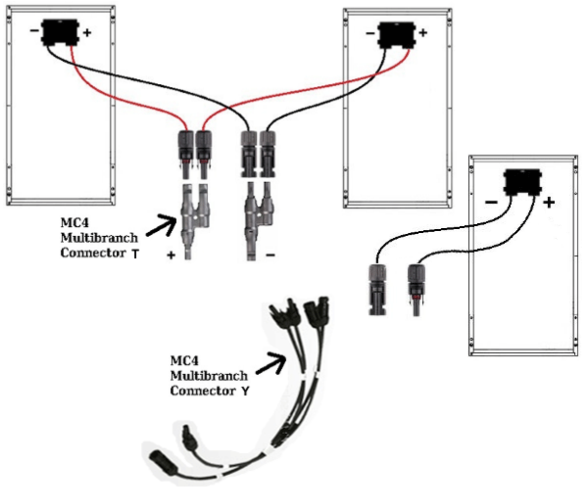


Fig. 7.3.3 Connection of PV moudles using MC4 connectors

Grounding

- Proper grounding or earthing must be provided to all module frames and mounting racks as per National Electrical Code.

- For grounding all the module frames and the metallic structural members are bonded together by using a proper grounding structure. The conductor used for grounding may be copper, copper alloy, or other material which is acceptable for use as an electrical conductor per National Electrical Codes.
- Connection to the earth is made by the grounding conductor using a proper earth ground electrode

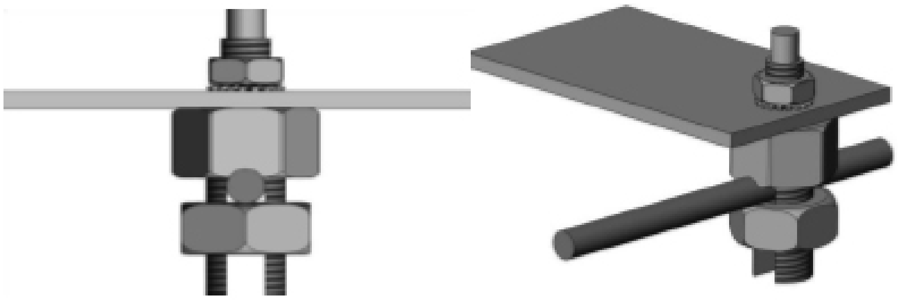


Fig. 7.3.4 Grounding of modules using earth ground electrode

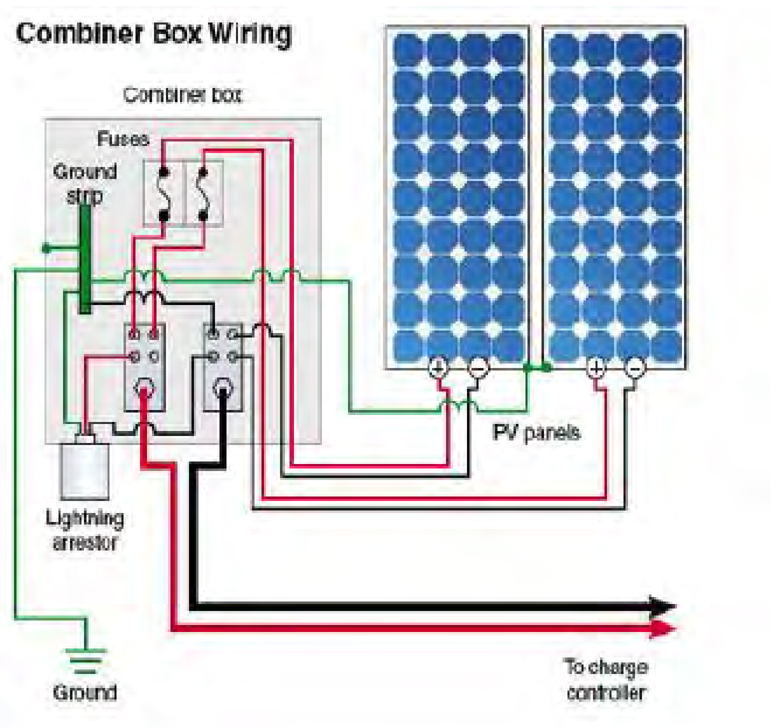


Fig. 7.3.5 Schematic diagram of grounding Solar PV Panels

Notes

UNIT 7.4: Install Battery Bank Stand and Inverter Stand

Unit Objectives

At the end of this unit, you will be able to:

1. Install battery bank stand and battery spill containment as per drawings / manuals
2. Install inverter stand as per drawings / manuals

7.4.1 Install Battery Stand and Inverter Stand

A battery storage power plant is a form of storage power plant, which uses batteries on an electrochemical basis for energy storage. Unlike common storage power plants, such as the pumped storage power plants with capacities up to 1000 MW, the benefits of battery storage power plants move in the range of a few kW up to the low MW range - the largest installed systems reach capacities of up to 36 MWh. Small battery storage called solar batteries with few kWh storage capacity, are mostly in the private sector operated in conjunction with similarly sized photovoltaic systems to daytime bring revenue surpluses in yield poorer or unproductive hours in the evening or at night, and to strengthen their own consumption. Sometimes battery storage power stations are built with flywheel storage power systems in order to conserve battery power. Flywheels can handle rapid fluctuations better.

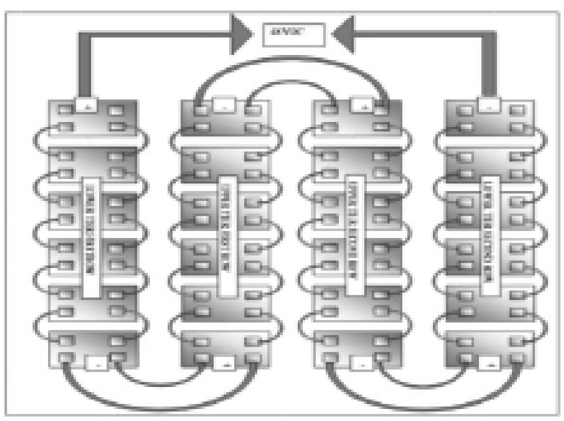


Fig. 7.4.1 System of interconnected batteries

Batteries can be installed by using racks or surface mounted with spill container as shown in below pictures.

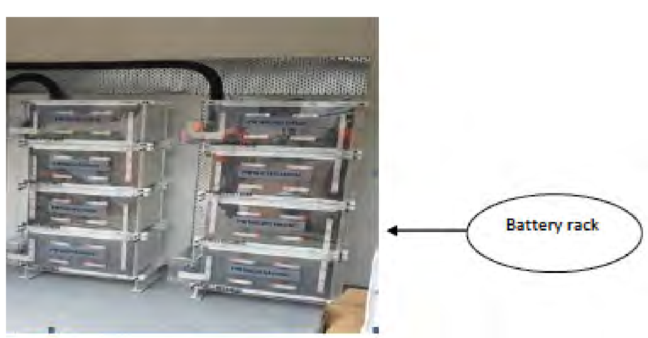


Fig. 7.4.2 Battery bank installed using racks with spill containers

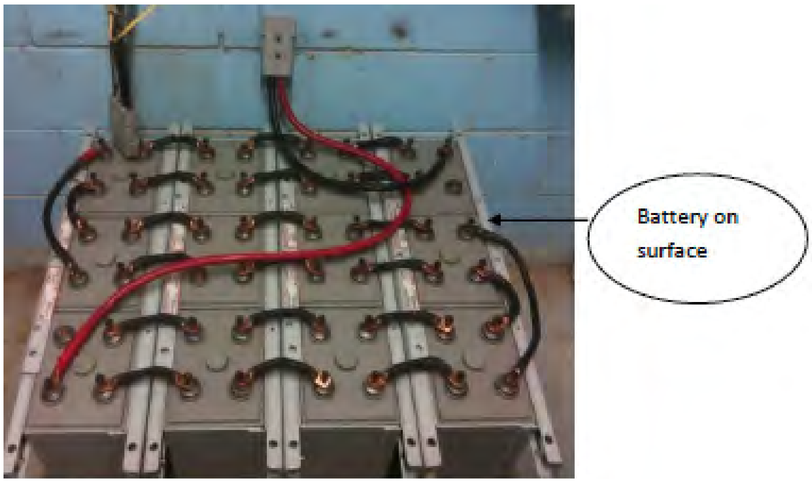


Fig. 7.4.3 Ground mounted battery installation

7.4.2 Inverter Stand

A solar inverter, or converter or PV inverter, converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network. It is a critical balance of system (BOS)–component in a photovoltaic system, allowing the use of ordinary AC-powered equipment. Solar power inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection

Solar inverters may be classified into three broad types

- Stand-alone inverters, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection.
- Grid-tie inverters, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.
- Battery backup inverters, are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.
- Grid Tied or grid connected Inverters are supplied with mounting brackets & commonly installed near the PV module on structure outside or rack nearby battery area. The inverter should be located out of afternoon sun. Mount canopy for sunshade & rain protection. In below figure, inverter has been installed by using support of column structure. It can be mounted on wall also using brackets.

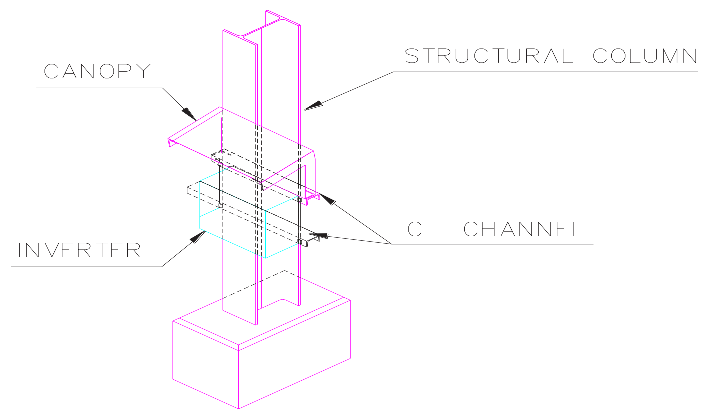


Fig. 7.4.4 Support structure for installation of inverter

Exercise

1. Which is the most preferred material for using rails
2. List out any two corrosion control methods for materials.
3. List out the methods and material used for waterproofing.

Activity 1:

Draw the Module wiring connection diagram using MC4 connectors for 16 modules

Activity 2:

Elaborate the step by step installation for wall mounted inverter using brackets.

Notes

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8. Installation of Electrical Components of Solar Photovoltaic Systems

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Key Learning Outcomes

At the end of this module, you will be able to:

1. Prepare for Solar Installation
2. Install Electrical components
3. Install Conduits and Cables
4. Get the Grounding Systems Installed
5. Install Battery Bank (as required)

UNIT 8.1: Prepare for Solar Installation

Unit Objectives

At the end of this unit, you will be able to:

1. Implement the site safety plan and maintain clear work area.
2. Clarify the maximum working voltage
3. Select required Personal Protective Equipment (PPE)
4. Measure current and voltage on equipment before proceeding with work
5. Inspect and demonstrate the use of electrical installation toolkit
6. Inspect and maintain safety equipment
7. Inspect and maintain testing equipment
8. Demonstrate situational awareness

8.1.1 Implement the Site Safety Plan and Maintain Clear Work Area

- Identify working area for installation of solar power plant.
- Make sure that there should not be debris, substances or any other things laying down in working area.
- All the scrap material should be stored in a place away from the working area on the roof.
- Proper spacing should be maintained between working area and storage area to take out any material safely.
- Make sure that there should be proper exit and entry for bringing or take out the installation materials.
- Separate working area with a fence.

Fig. 8.1.1 Clear site area before installation

- Make sure that all persons on site are equipped with proper personal protection equipment (PPE).
- Check whether all the workers have right PPE for the job or not.
- Provide necessary first aid facilities.
- Make sure that there should be fire precaution equipment such as fire extinguishers.
- Ensure that existing power lines (buried or overhead) are identified and associated safe systems are of workplace.

8.1.2 Clarify the Maximum Working Voltage

Before starting installation of electrical components, kindly check design for maximum working voltage. Select personal protective equipment in accordance with the maximum working voltage. All the workers should be aware of maximum working voltage.

8.1.3 Select Required Personal Protective Equipment (PPE)

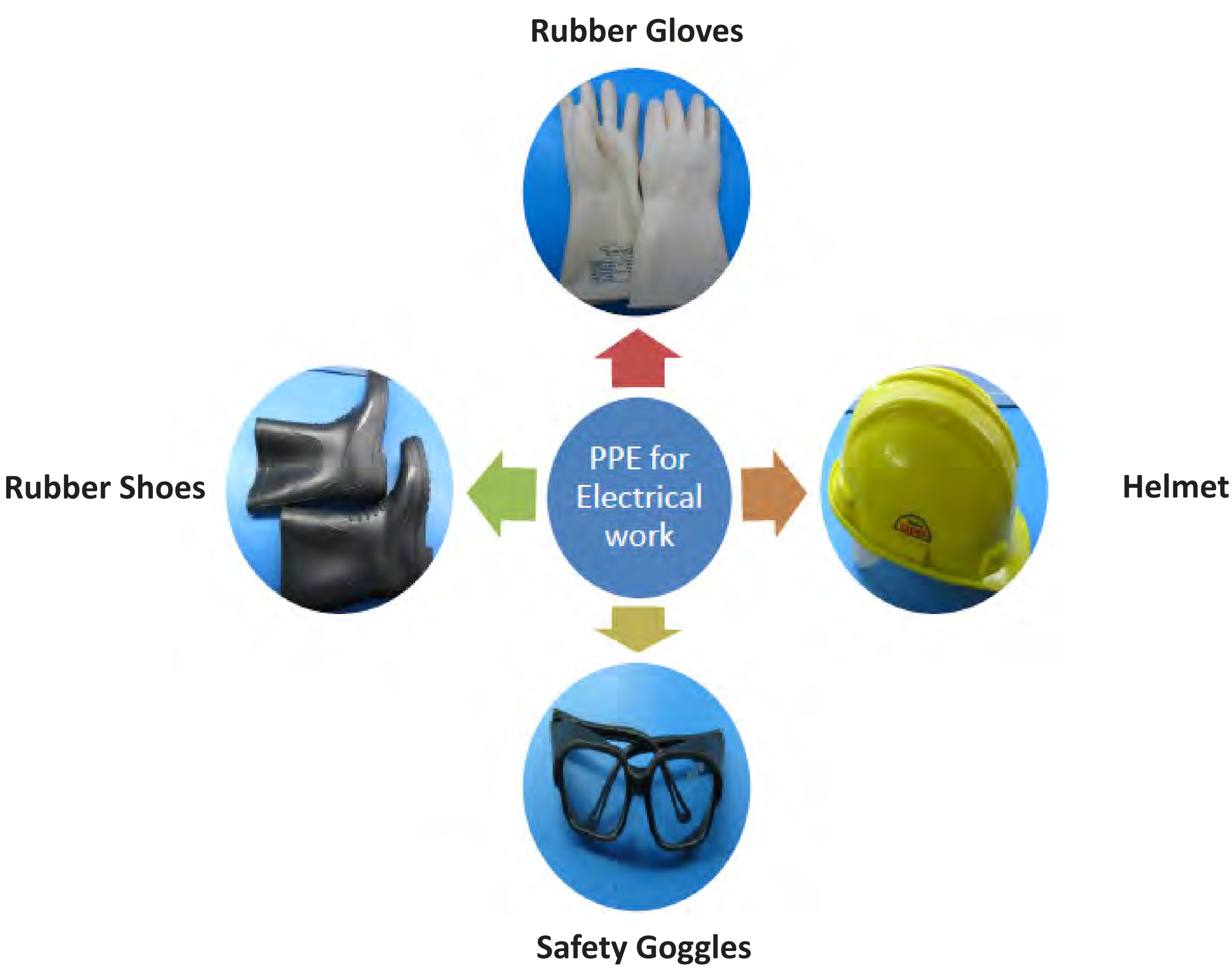


Fig. 8.1.2 Personal Protective Equipment (PPE) for Electrical Work

8.1.4 Inspect and Demonstrate the Use of Electrical Installation Toolkit

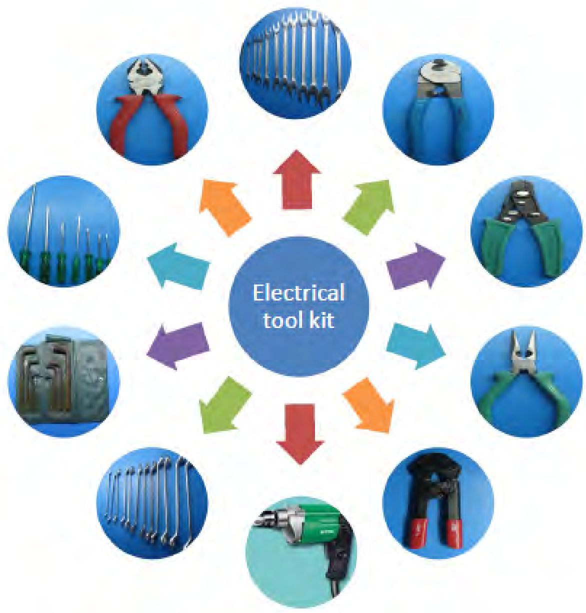


Fig. 8.1.3 Electrical Tool Kit

Tool kit required for the electrical installation is shown above. Make sure the availability of these equipment before starting installation work. It may be tough to get tools, extra parts and equipment while on-site. For this reason, before leaving for the installation site, make check lists of all the materials and tools needed. This list should be carefully cross checked before departing. Make sure availability of design and location information. Some instrument requires power supply to operate (Drill machine etc.). Ensure that you will get power supply at the installation site.

8.1.5 Inspect and Maintain Testing Equipment

Testing equipment which are necessary to do the installation are shown below. These equipment's are (From top in clockwise direction):

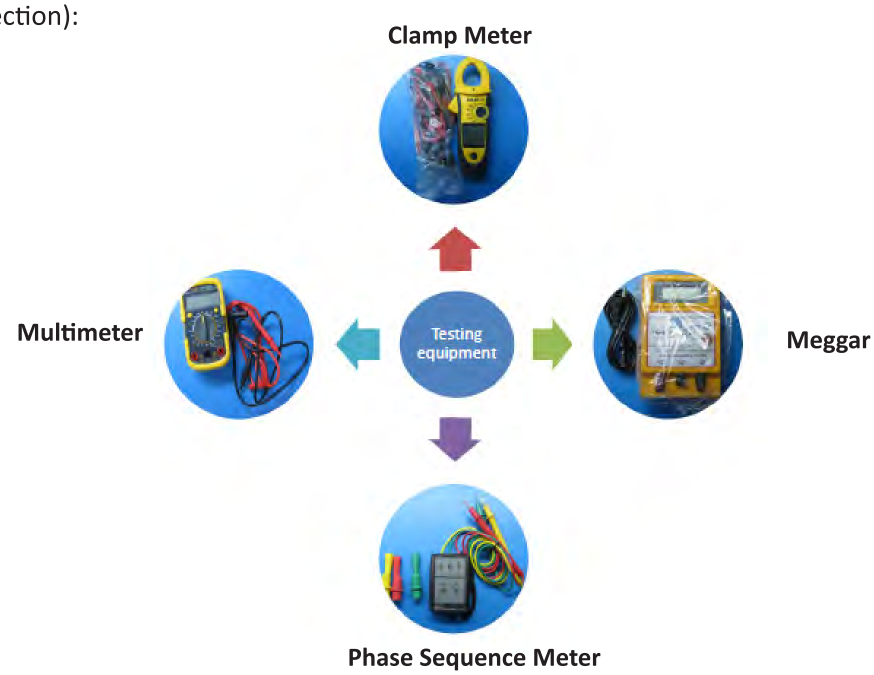


Fig. 8.1.4 Testing equipment

Ensure that all testing equipment's are in working condition. All the installer needs to be familiar with the use of the testing instrument. Multimeter are very crucial in performing various tests like continuity test, polarity teat, voltage measurement.

Notes

UNIT 8.2: Install Electrical Components

Unit Objectives

At the end of this unit, you will be able to:

1. Select the location of DC Combiner Box
2. Install DC combiner box along with disconnect protections
3. Install DC energy meters
4. Confirm battery bank location and install batteries
5. Prepare battery terminals and install battery interconnection cables
6. Terminate fine stranded cables
7. Test final assembled battery polarity and voltage
8. Install charge controller (if required)
9. Install inverter
10. Install utility required disconnects
11. Install AC Combiner Box
12. Connect the solar system to the distribution box or transformer
13. Proper labeling of the components

8.2.1 Select the Location of DC Combiner Box

- Choose a mounting location which is suitable for dimensions and weight of Combiner Box
- Combiner Box should be mounted on a firm and stable surface
- Combiner Box should be mounted in a location that can be reached all times
- Do not install Combiner Box with a forward tilt or horizontally
- Vertical installation is preferred
- During installation PV modules must be covered

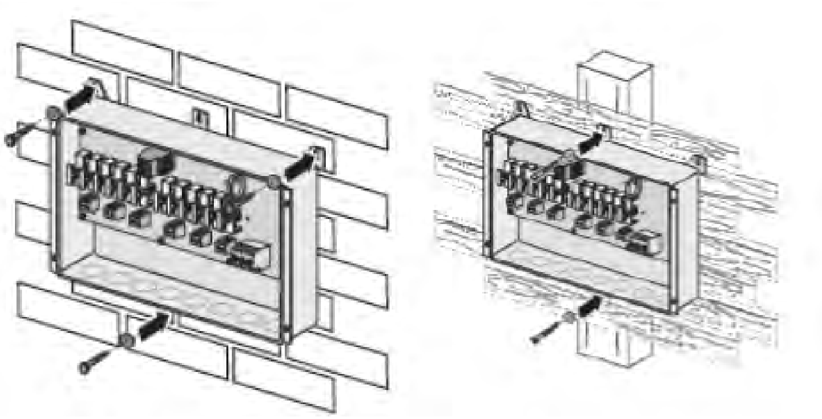


Fig. 8.2.1 Wall & structure mounting of DC Combiner Box

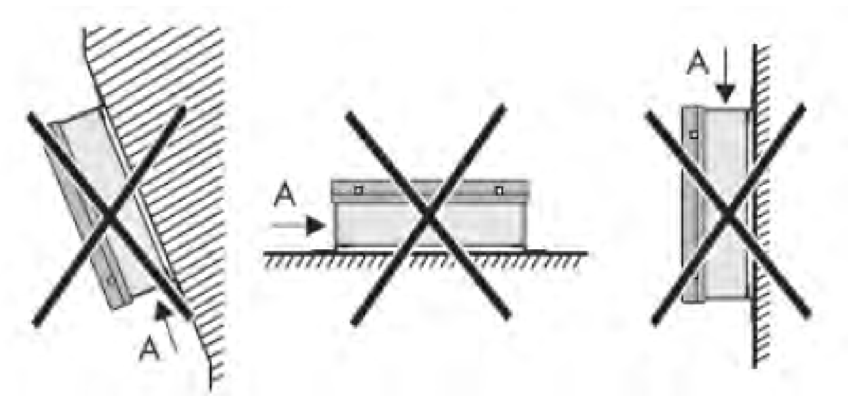
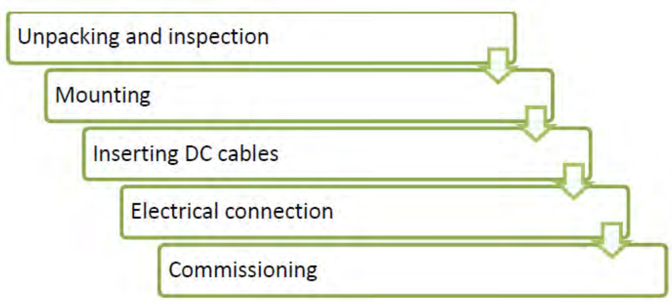


Fig. 8.2.2 Wrong mounting of DC Combiner Box (SMA)

8.2.2 Install Dc Combiner Box Along With Disconnect Protections

Follow below steps for Installation of DC combiner box:



Unpacking and Inspection

It is essential to sensibly examine the shipping box and contents before the installation for any damage of equipment. In case of any damage report the damage instantly to dealer and to the shipping company.

Mounting of DC Combiner Box step by step

- Put the Combiner Box at the mounting position on the wall.
- Aligned the Combiner Box.
- Through the mounting holes mark the mounting position.
- Drill the mounting holes that are marked by removing the Combiner Box.
- Place the wall anchors.
- Put Combiner Box on the wall. Align the drilled holes with the mounting holes.
- Through the mounting holes of the Combiner Box insert the screws. Clockwise tighten the screws.
- Make sure that the Combiner Box is attached securely to the wall.

For inserting DC cables, electrical connections refer to the section.

DC disconnect switch

DC circuits consist of two wires—a positive and a negative. In most PV systems, one of these wires is grounded (like a neutral in an AC system). Which of the two wires is grounded is specified by the solar panel manufacturer. The more common application is a negative ground, and the location of this bond is usually found at the inverter. As per the National Electrical Code (NEC) Section 690.5(A), only the current-carrying ungrounded conductor should be switched. Thus, in a negative-grounded system, only the positive wire is switched.

Installation

Use appropriate hardware to mount DC disconnect switch on surface. For mounting refer to mounting of DC Combiner Box.

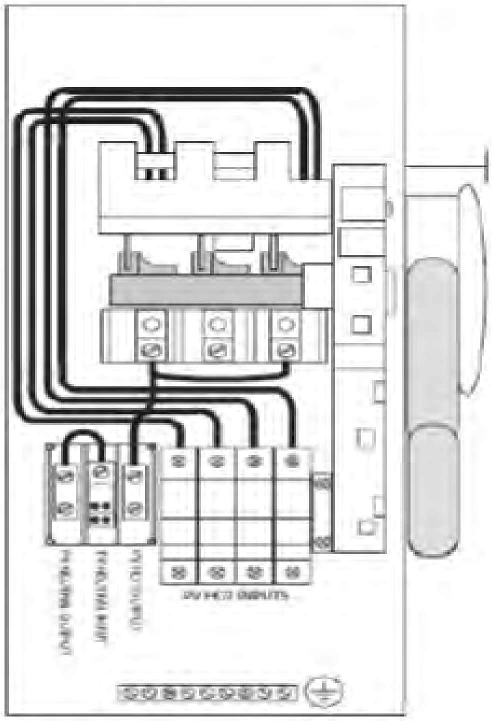


Fig. 8.2.3 DC combiner box

8.2.3 Install DC Energy Meters

Use appropriate hardware to mount DC disconnect install energy meter as shown in the figure below.

Fig. 8.2.4 Solar energy meter

8.2.4 Confirm Battery Bank Location and Install Batteries

While choosing the battery location following things should be keep in mind:

- Room should be ventilated and cool.
- **Nearness to array:** in order to reduce voltage drop batteries should be located as close as possible to the array. The size of the cable is generally large enough to carry the charge current from the module with 2 or less than 2% voltage drop.
- **Ventilation:** The battery room must have proper ventilation as batteries emit explosive gases during charging which must be allowed to escape. Try to put a 'No Smoking Zone' sign in the room.
- **Accessibility:** Access for easy state-of-charge measurement and cleaning, but only for trained persons.
- **Temperature:** Batteries should be located at a low temperature as above 40°C (104°F) the lifetime and performance of battery will get reduced. Prevent battery from sun exposure.
- **Battery boxes:** Batteries should be kept in a vented box to prevent children and animals from injuring themselves and to prevent accidental short circuits. Moreover, avoid placing battery directly on the floor as moisture or accidental puddles can increase self-discharge rates.
- **Security and safety:** Locate batteries in a safe and secure environment. Battery rooms should be locked to prevent children, animals and any kind of theft.

8.2.5 Prepare Battery Terminals and Install Battery Interconnection Cables

To minimize contact resistance, it is important that the lead terminals of the batteries be cleaned of any oxidation that may have occurred during transportation and storage. It is most convenient to clean them prior to placing them on the rack. Lightly brush the terminal contact surface areas with a brass bristle brush, or the equivalent, and then apply a light coating of the special antioxidant grease, such as NO-OX-ID or NCP-2, to the surfaces to protect the lead terminal from further oxidation.

If there is only one battery, attach the cables to the battery terminals and tighten the screw. If there is more than one battery, make sure that they are properly arranged in series or parallel as per design. Example of connecting two batteries in series by using interconnection cable is shown below.

To connect cable to terminal first strip cable by crimping tool and attach a suitable cable termination connector and then connect cable to terminal. For cable termination see section 1.3.4

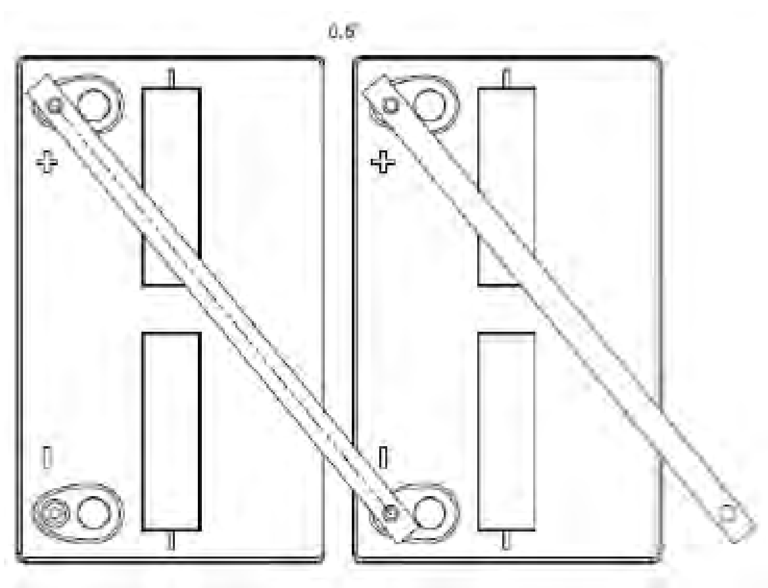


Fig. 8.2.5 Battery interconnection

8.2.6 Confirm Battery Bank Location and Install Batteries

Making secure connection with fine-stranded cables or flexible conductors

- Electrical standards require flexible, fine-stranded cables to be terminated only with terminal lugs or connectors identified for use with fine-stranded cables.
- Connectors are commonly used with solid, B- or C-Code cables, they are not recommended for fine-stranded cables because the mechanical connection can cause breakage of the fine strands, resulting in overheating.
- For the connection of fine-stranded cables, flexible-conductor cables are generally used, normally known as flex cable. Fine-stranded cables are often used by Photovoltaic system installers because of its flexibility.
- Flex cable has to be selected with the proper connectors, lugs and terminals as well as the proper method for installing these connectors for secure and problem free termination.

8.2.7 Test Final Assembled Battery Polarity and Voltage

After doing battery final battery interconnection, perform battery polarity test to ensure that connection are as per design. For all the series connected batteries check the open circuit voltage. The open circuit voltage should be equal to multiplication of total number of batteries to open circuit voltage of individual battery. If measured voltage is not equal to the expected voltage then check connection once again. One possible reason could be the reverse polarity of battery connection. Similarly perform voltage measurement for parallel connected batteries. For this arrangement voltage will be equal to one battery voltage.

8.2.8 Install Inverter

Follow these steps to install inverter.

Choosing Inverter Location

Inverter should be installed at a place where people can't reach frequently because during operation the surface temperature is very high and can cause a potential burn hazard. Ensure that the temperature of location should be in the range of -25 to +65 degree.

Mounting Inverter

The mounting process of inverter varies from inverter to inverter.

Mounting of inverters included following steps:

- First of all check the dimensions and knockout locations.
- Put bracket on the wall and mark the position of holes by using a pencil.

- Drill the hole locations by using drill machine.
- Mount the bracket to the wall using the screws.
- Ensure that screws are fully tight.
- Make sure that there is adequate clearance around the inverter for secure and optimal working.
- During mounting of inverter on a vertical surface like wallboard, wood siding, concrete wall or pole assembly. Make sure that the mounting surface or structure can support the inverter's weight i.e. 26 kg/58 lb along with the weight of its wiring and conduit. While mounting the inverter onto the wallboard either supporting material like plywood is required or securing of mounting screws in order to support the wall studs.
- Lift the inverter to the wall and engage the back of the inverter to the brackets. Check that the product is fully secured on to the wall bracket.

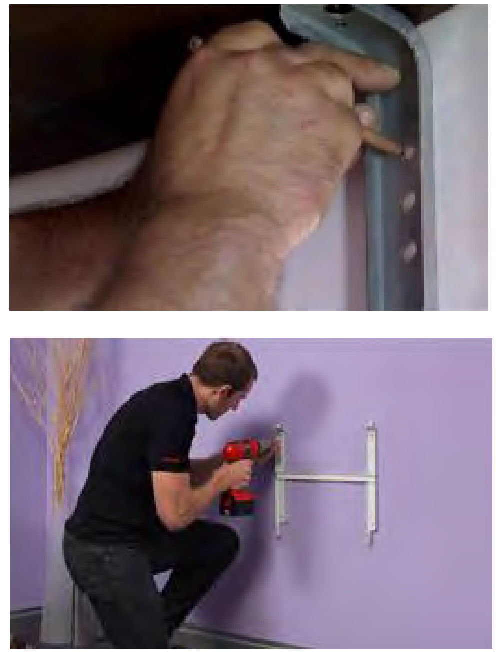


Fig. 8.2.6 Installation of Inverter mounting structure

8.2.9 Install Utility Required Disconnects

Install AC disconnect switch

This disconnect is located between the inverter and the home's main service panel. In particular, you'll have two "hot" conductors (in addition to a neutral) running from the inverter to the main service panel that will pass through this disconnect. Mount AC disconnect switch as per design. For mounting procedure kindle refer to mounting of DC Combiner Box.

Install double pole circuit breaker

Install the double pole circuit breaker on the existing breaker panel. Locate the double pole circuit breaker horizontally using your hand. For mounting procedure kindle refer to mounting of DC Combiner Box.

8.2.10 Install AC Combiner Box

An AC distribution box shall be mounted close to the solar grid inverter. For mounting refer to the procedure of mounting DC Combiner Box.

Notes

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UNIT 8.3: Install Conduits and Cables

Unit Objectives

At the end of this unit, you will be able to:

1. Prepare conduit and cable routing plan
2. Select the correct cable type, color, and gauge
3. Support and secure conduit
4. Install the cables for modules, inverter and other components
5. Terminate cables
6. Check cables for continuity
7. Complete proper labeling of conduits and cables

8.3.1 Prepare Conduit and Cable Routing Plan

Preparing cable conduit step by step:

STEP 1

STEP 2

STEP 3

STEP 4

STEP 5

STEP 6

STEP 7

STEP 8

Step 1

Detect the knock out stamping (KO) sized in order to fit the chosen connector

↓

Step 2

Against the inner-most KO's stamped edge press the edge of a screwdriver and push the KO away from the wall of the box by pressing.

↓

Step 3

To fully remove twist the KO to and fro by fingers or pliers

↓

Step 4

From the connector remove the locknut

↓

Step 5

Place the connector into the opening from the outward of the box

↓

Step 6

Onto the connector twist the locknut

↓

Step 7

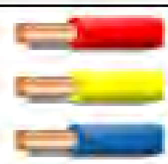
In order to keep screws reachable hold the connector in place while hand tightening the locknut.

Step 8

Place the wire, pipe or cable into the connector and firm with screws supplied on the body of the connector

8.3.2 Select the Correct Cable Type, Color, And Gauge

To enable wires to be easily and safely identified, all common wiring safety codes mandate a color scheme for the insulation on power conductors. In a typical electrical code, some color-coding is mandatory, while some may be optional. Phases could be identified as being live by using colored indicator lights: red, yellow and blue and for neutral shows as black color and for ground denotes as green color.

	Phases	Neutral	Protective earth/Ground
Standard wire insulation colors			

Factors to be consider

- Material: Cable material properly insulated to protect against fire and shock.
- Maximum voltage rating: It indicates the maximum voltage the wire can bear.
- Gauge: It indicates wire size. The most common gauges are 10, 12 or 14. Larger numbers represent smaller sizes or gauges of wire.

8.3.3 Install the Cables for Modules, Inverter And Other Components

Step by step process of installing cables from modules to invert through the different components

STEP 1: Connect modules together

STEP 2: lay down cables upto DC combiner box

STEP 3: Insert cables into DC combiner box

STEP 4: Insert cables into DC disconnect switch

STEP 5: Wiring to DC energy meter

STEP 6: Wiring to inverter

STEP 7: Wiring to AC disconnect switch

STEP 8: Wiring to AC combiner box

STEP 1: Connect modules together

Modules are connected by using MC4 connecter. All the PV modules are connected in series or in parallel as per the design. To determine how many PV modules are in series and how many are in parallel please refer to the design.

Fig. 8.3.1 Module interconnection

There may be a greater distance from one side of the panel string to the combiner box than from the opposite side of the panel string depending upon the location of the combiner box. In this case, to allow both ends to reach the combiner box you will have to cut the extender cable at a spot so that both cut ends reach the combiner box with a little slack to work with.

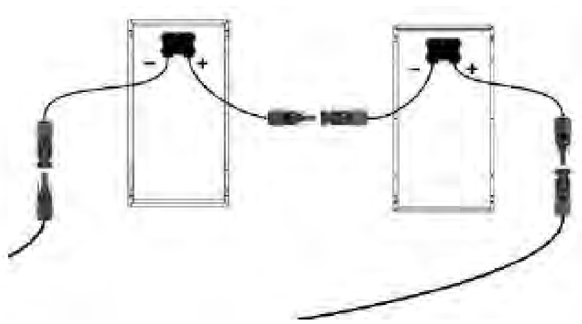


Fig. 8.3.2 Diagram for connection of PV modules

STEP 2: Lay down cables up to DC Combiner Box

All the string cables from the PV modules are brought to the next component i.e. DC combiner box. It is not suggested to lay down the cables openly since UV content in solar radiation affects the life of cables. So cable trench or cable tray is used to carry cables up to next components. All cables should be stacked together firmly by using cable ties.

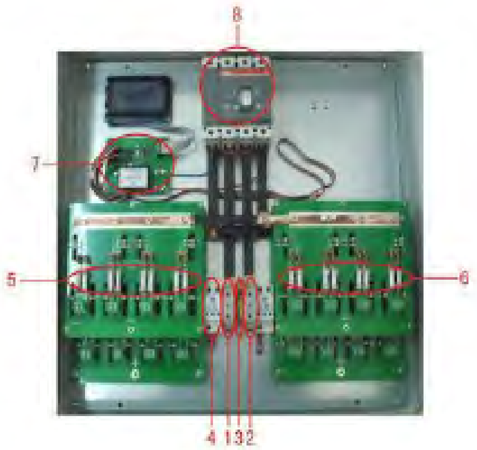
Fig. 8.3.3 Proper stacking of cables together using cable ties

STEP 3: Insert cables into DC combiner box

- For inserting string first make sure how many strings are required to be inserted referring to your design
- Open the Combiner Box
- For the cable conduits, break out the required number of knockouts needed
- Separate conduit is needed for each string cable
- Insert the cable conduit into the holes
- Pull the cable conduits to tighter them

Electrical connection

- Determine a suitable fuse rating to protect wiring and equipment referring to your design.
- Connect equipment grounding
- Connect PV modules
- Insert string fuses
- Connect negative string to appropriate location
- Connect positive string to appropriate location
- Connect the output wires and leave them for inverter connection



1. **DC Positive Pole Combine Output**
2. **DC Negative Pole Combine Output**
3. **Grounding Terminal**
4. **DC 1000V SPD**
5. **DC Positive Pole Fuse**
6. **DC Negative Pole Fuse**
7. **Communication Metering Board**
8. **DC Circuit Breaker**

Fig. 8.3.4 A typical combiner box connection area

Connect equipment grounding

The grounding in PV systems must be installed in accordance with the requirements of the National Electrical Code.

Steps of connecting grounding to DC combiner box

- Strip the cable roughly by 0.3 inches (i.e.8 mm).
- With the help of a flat-head screwdriver open the screw terminals completely by turning them counterclockwise, into the screw terminal plug the stripped cable.
- Clockwise tighten the screw terminal.

Fig. 8.3.5 Cable striping by using crimping tool

STEP 4: Insert cables into DC disconnect switch

When PV negative is ground, PV positive wire conductors are wired into the fuse holder terminals marked "PV Hot Inputs". PV negative conductors are wired into the terminal block to the left of the fuse holders marked "PV Neutral Input.

When PV positive is ground, PV negative wire conductors are wired into the fuse holder terminals marked "PV Hot Inputs". PV positive conductors are wired into the terminal block to the left of the fuse holders marked "PV Neutral Input".

STEP 5: Wiring to DC energy meter

Bring wires from the DC disconnect switch and make connection with energy meter. Make sure polarity of cables is right while making connection in energy meter.

STEP 6: Wiring to inverter

Connecting negative strings

- Strip the cable roughly by 0.3 inches (i.e.8 mm).
- With the help of a flat-head screwdriver open the screw into the screw terminal terminals completely by turning them counterclockwise, plug the stripped cable.
- Clockwise tighten the screw terminal.

Repeat above connecting procedure to make connection for positive strings Input terminal), DC positive and DC negative (output terminals).

STEP 7: Wiring to AC disconnect switch

Place the red wire at the bottom of the screws at the back of the breaker. Place the black wire at the bottom of the screw located behind the breaker. Tighten the screws so that the wires are securely in place. Attach the white wire to the neutral bar of the breaker panel. This part of the breaker panel can be found to the right side or left side of the breakers. Attach the white wire under a set of screws which are on the neutral bar as well. Tighten the screws to secure the wires. The bare copper wire should be connected to the ground bar which holds the copper and green ground wires.

STEP 8: Wiring to AC combiner box

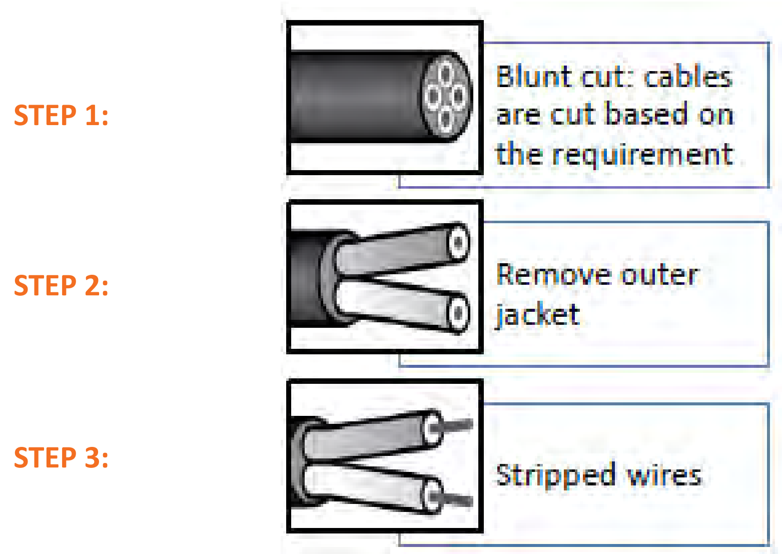
The AC distribution box shall be of the thermos-plastic IP65 DIN rail mounting type and shall comprise the following components and cable terminations:

- Incoming 3-core / 5-core (single-phase/three-phase) cable from the solar grid inverter
- AC circuit breaker, 2-pole / 4-pole
- AC surge protection device (SPD), class 2 as per IEC 60364-5-53
- Outgoing cable to the building electrical distribution board

Fig. 8.3.6 AC distribution box (AC MCB for AC isolation, Surge protection device and Input side fuse protection

8.3.4 Terminate Cables

Steps for cable termination:



Termination connectors

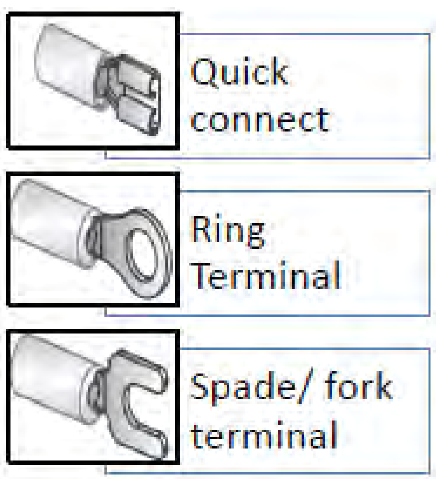


Fig. 8.3.7 Types of termination connectors

Mostly ring terminal is used where cables are connected by using screw and bolts.

8.3.5 Check Cables for Continuity

The continuity of cable conductors is checked by using a meggering test. For maintenance purpose of the cable this test should be carried out periodically.

Continuity test:

Tools and Equipment required

- Multimeter
- Wire nipper
- Screw driver test
- Box spanner

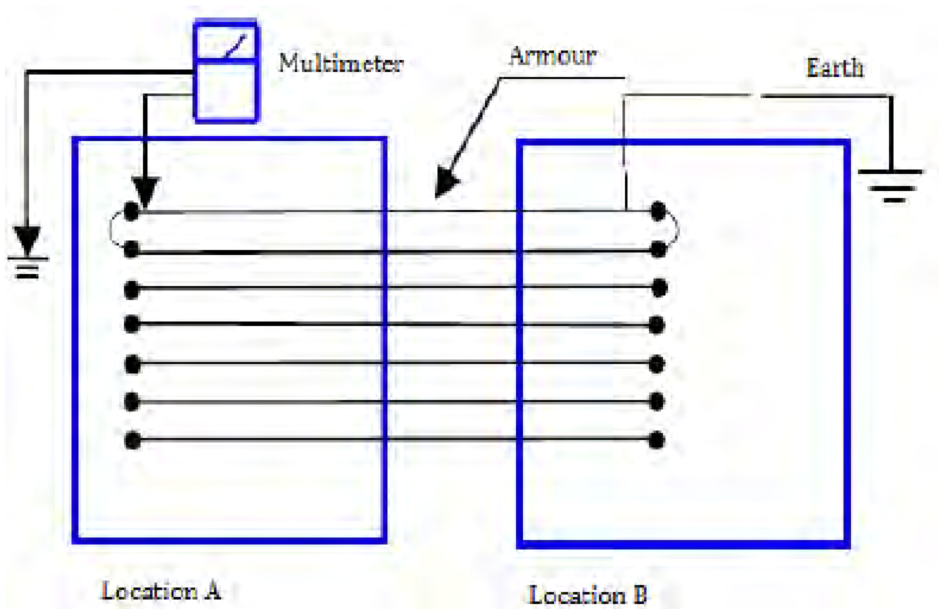


Fig. 8.3.8 Electrical diagram for continuity test

This test is done to confirm whether the core under test is electrically connected or showing break between both ends.

Procedure of testing:

1. At Location A place the knob of Multimeter to check the resistance at the range of 200 ohms.
2. Connect one probe of multimeter to the end of the cable conductor to be tested and other probe to earth as shown in the above figure.
3. At Location B guide staff to connect earth to same conductor of the cable.
4. Connect earth to armour too if the earth is light at both the ends.
5. Deflection in the needle of multimeter indicates that the conductor under the test is OK that is continuous without any break.
6. Then with reference to the tested conductor test continuity of other conductors also for example to test second conductor ,connect one probe of Multimeter to tested conductor at Location A and other probe to second conductor. Guide the staff at the Location B to short both the conductor i.e. second conductor and the tested conductor.
7. The continuity of all other conductors will be tested like that.

8.3.6 Proper Labeling of Conduits and Cables

In solar power plant lots of cables are there. Labeling of cables plays a crucial role during maintenance. In DC side generally there are only two cables after Combiner Box, whereas after modules there are number of cables. If we do not provide adequate labeling at each cable, it can lead to wrong connections. After modules all strings must be labeled as string 1, 2 and so on. After DC combiner box cable labeling can be done on color basis or number basis. Generally color coding is applied since there are only two wires, one is positive and other is negative. For positive wire red color is used for labeling and for negative wire black color is used.

UNIT 8.4: Get the Grounding Systems Installed

Unit Objectives

At the end of this unit, you will be able to:

1. Locate underground hazards, if any
2. Determine grounding conductor size
3. Get the grounding system installed for modules/mounting system and inverters
4. Get the Bonding done for all electrical equipment's and apply anti – oxidant material

8.4.1 Determine Grounding Conductor Size

Refer to your design, to know the type of material, size of grounding conductor, type of grounding. After getting all information proceed with the grounding procedure explained in the next section.

8.4.2 Get the Grounding System Installed For Modules/Mounting System and Inverters

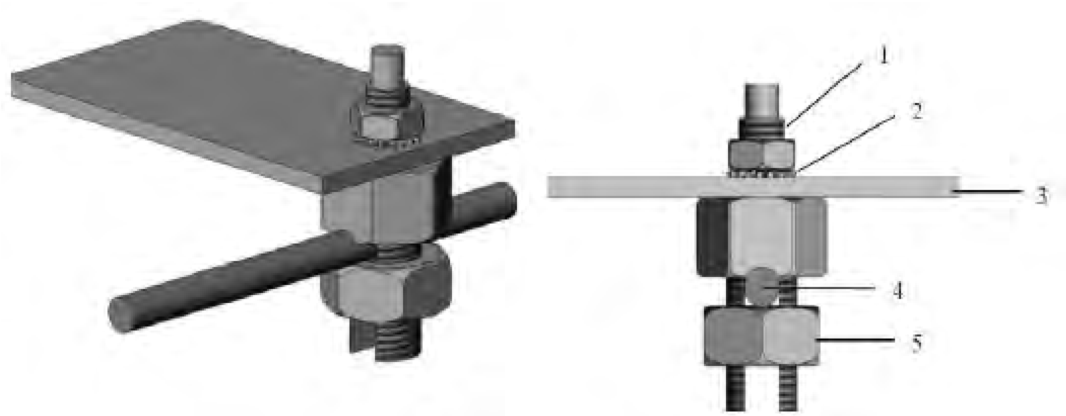
Grounding of PV modules

All module frames and mounting racks must be properly grounded in accordance with appropriate respective National Electrical Code.

Proper grounding is achieved by bonding the module frame(s) and all metallic structural members together continuously using a suitable grounding conductor. Grounding conductor or strap may be copper, copper alloy etc. The grounding conductor must then make a connection to earth using a suitable earth ground electrode.

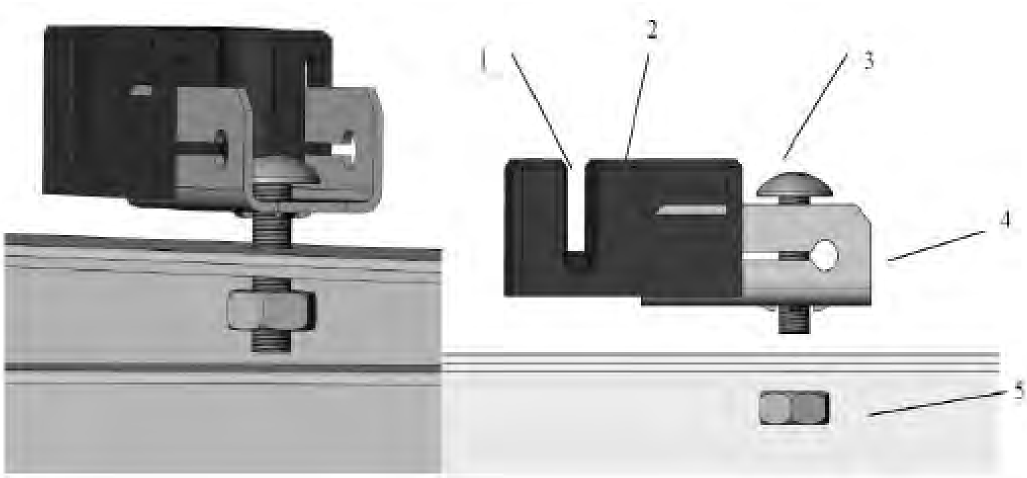
General grounding methods for PV modules:

Method 1



Number	Description
1	Wire bolt
2	Mounting wash hex nut
3	Aluminum frame
4	4 to 16 mm 2 cable
5	HEX nut

Method 2



Number	Description
1	Wire slot (available for 4-6 mm2 cable)
2	Slider
3	Bolt
4	Base
5	Nut

Grounding of DC Combiner Box

Grounding of inverter

The inverter must be connected to the ground from the inverter ground bar. To ground inverter follow procedure of grounding DC Combiner Box.

After connecting all the grounding wires to the component, follow these steps to make a connection of wire to earth. Before starting get following information from the design.

- Pit size
- Material size (rod or plate or any other material size)

Steps to make a connection of wire to earth

- Dig a pit (for size refer to the Design)
- In vertical position bury an appropriate copper plate or rod (as per design) in that pit
- From two different places on earth plate tight earth lead (The conductor wire connected between earth continuity

conductor and earth electrode or earth plate is called Earthing joint or Earthing lead.) through nut bolts.

- With each earth plate use an earth leads (in case of two earth plates use two earth leads) and tighter them.
- Grease the joints to protect it from corrosion.
- Bring all the wires in a metallic pipe from the earth electrode(s). Ensure that the metallic pipe is 1ft (30cm) above the ground surface.
- Around the earth plate put a 1ft (30cm) layer of powdered charcoal (powdered wood coal) and lime mixture in order to maintain the moisture condition.
- To connect the wires tightly to the components use thimble and nut bolts. No two components should be earthed from the same place and the electrodes should be separated with a distance at least 10 ft. (3m).
- Metallic parts of all installation and earth continuity conductor which is connected to the body should be connected tightly to the earth lead.
- Finally test all the earthing system using an earth tester. If everything is according to the plan, then fill the pit with soil. For earthing the maximum allowable resistance is 1Ω. If the resistance is more than 1 ohm, then increase the size (not length) of earth lead and earth continuity conductors.
- For better earthing system keep the external ends of the pipes open and hydrate it frequently in order to maintain the moisture condition around the earth electrode.

Various specifications recommended by Indian Standards for earthing are:

- An earthing electrode should not be installed close to the building which installation system is being earthed at least more than 1.5m away.
- The earth resistance should be low enough to cause the flow of current sufficient to operate the protective relays or blow fuses. It's value is not constant as it varies with weather because it depends on moisture (but should not be less than 1 ohm).
- Earth wire and earth electrode will be made up of same material.
- Always place the earthing electrode vertically inside the earth or pit in order to prevent its contact from all the different earth layers.

Fig. 8.4.1 Connection of ground wire to metallic part of a building

8.4.3 Get the Bonding Done For All Electrical Equipment's and Apply Anti – Oxidant Material

All the individual component grounding must be bonded to each other. This is also "recommended practice" of IEEE Standard 1100-1999. for the bonding conductor size refer to your design.

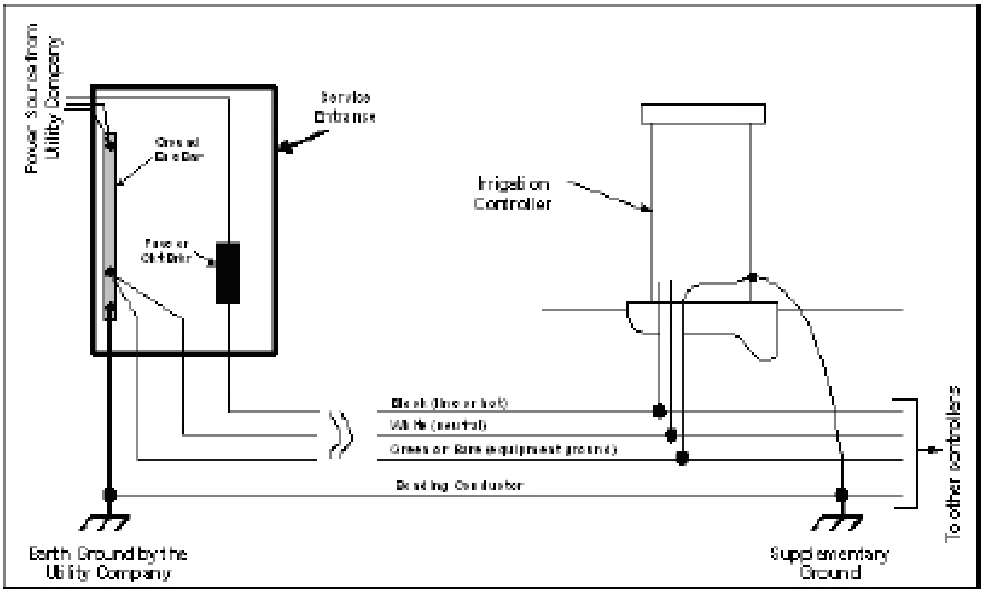


Fig. 8.4.2 Sample design reference for grounding

Notes

UNIT 8.5: Install Battery Bank

Unit Objectives

At the end of this unit, you will be able to:

1. Confirm and install battery bank enclosure/racks.
2. Install battery spill containment (if required).
3. Install batteries and Prepare battery terminals (e.g., clean).
4. Install battery interconnection cables and apply anti-oxidant material
5. Terminate fine stranded cables.

8.5.1 Confirm and Install Battery Bank Enclosure/Racks

Refer to the design to know whether design includes battery rack system or not. If it includes then note down which type of rack system is it.

Fig. 8.5.1 Battery Bank enclosures/racks

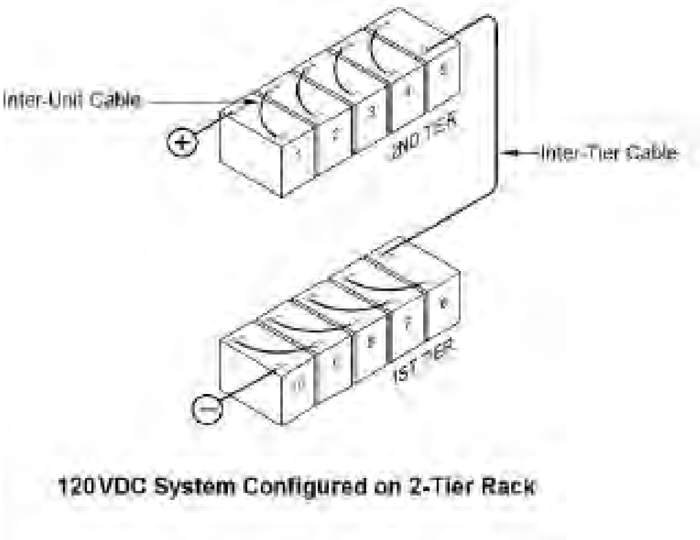
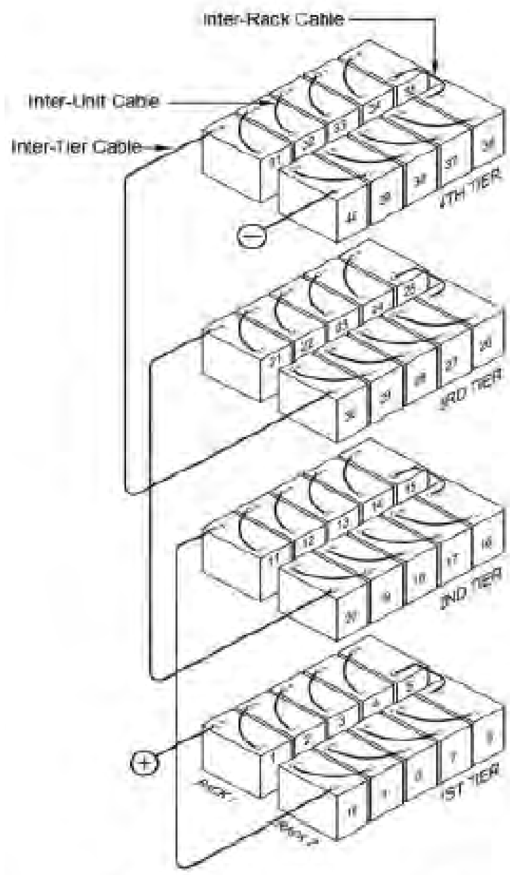


Fig. 8.5.2 Arrangement of batteries on rack systems



480VDC System Configured on
(2) 5 Wide, 4 Tier Racks

8.5.2 Install Battery Spill Containment (If Required)

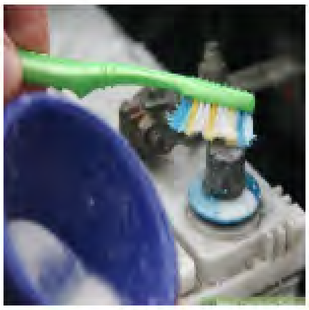
Refer the design for spill containment and install it as per manufacturer instruction.

8.5.3 Install Batteries and Prepare Battery Terminals

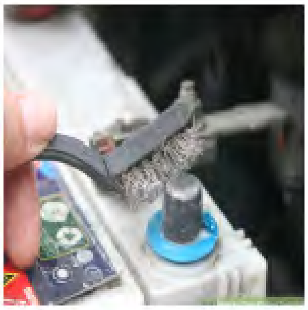
For installation of batteries refer to section 1.2.4. Make battery terminal clean before connection. Cleaning process is given below.

STEP 1: Make your cleaning agent

STEP 2: Apply the paste

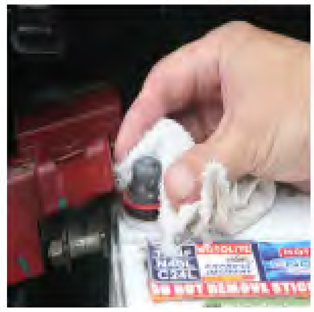


STEP 3: Scrape off deposits



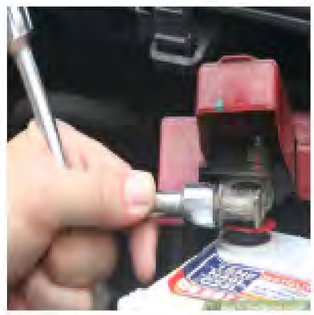
STEP 4: Rinse

STEP 5: Dry



STEP 6: Prevent future corrosin

STEP 7: Replace the clamps



8.5.4 Install Battery Interconnection Cables and Apply Anti-Oxidant Material

For installation of battery interconnection cable refer to the section 1.2.5. As mention above diagram apply antioxidant material at the interconnection.

Case study of a 10 kW solar power plant

Crystalline photovoltaic modules are mounted with the help of rail mounting structure on rooftop of a building. Ballasted foundations are created to hold mounting structure firmly.

Fig. 8.5.3 MC4 connecters are used to connect PV modules together

Fig. 8.5.4 MC4 connector

Cable trays are used to carry DC cables from PV panels to the inverter.

Fig. 8.5.5 Cable tray

DC cables from PV panels are inserted into inverter by using cable conduit.

Fig. 8.5.6 Cable conduits

AC output cables from inverter are fed to the AC distribution box

Fig. 8.5.7 Inverter and AC distribution box

From AC distribution box AC cables are fed to utility distribution box with the help of cable tray.

Fig. 8.5.8 Cable tray

Exercise

1. Demonstrate the use of electrical installation toolkit to the trainee.
2. Inspection and testing of measuring equipment like multimeter, clamp on meter, Earth tester etc.
3. Activity on the installation of DC combiner box. All the following steps must be performed by Learner:-
   - Selection of mounting location from design sheet.
   - Mounting of equipment
   - Prepare cable conduit
   - terminate cables and connect suitable cable terminator
   - Insert cables
   - Make electrical connection to equipment
4. Activity on installation of inverter. All the following steps must be performed by Learner:-
   - Selection of mounting location from design sheet.
   - Mounting of equipment
   - Prepare cable conduit
   - terminate cables and connect suitable cable terminator
   - Insert cables
   - Make electrical connection to equipment
5. Activity on battery interconnection for the following arrangement:
   - Series connection in batteries
   - Parallel connection in batteries
   - Combination of series and parallel connection in batteries
6. Perform battery polarity test
7. Perform cable continuity test
8. Install grounding system for inverter, SPV modules, DC combiner box

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9. Test & Commission Solar PV System

SGJ/N0105

Key Learning Outcomes

At the end of this module, you will be able to:

1. Test the Solar PV System installation by carrying out inspection and using necessary tools for the same, resulting in documentation of the report
2. Commission the Solar PV System as per manufacturer's instructions and document any changes, anomalies and/or modifications to the system design

UNIT 9.1: Tools and Accessories Required for Testing

Unit Objectives

At the end of this unit, you will be able to:

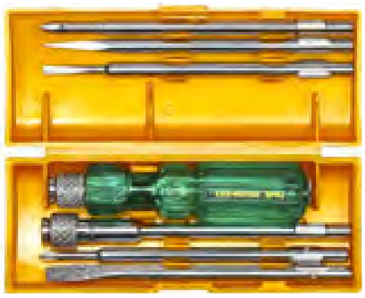
1. Identify and use the different tools to carry out measurement of system's electrical and mechanical parameters

9.1.1 Tools to Be Used

1. Required safety equipment (safety goggles, hand gloves, safety equipment for climbing roof, etc.) and first aid kit
2. A multi-meter (Ohm meter and voltmeter)
3. A DC clamp on ammeter
4. An AC clamp on ammeter
5. A sun pathfinder or solar sitting device
6. A hydrometer/ battery load tester
7. A measuring tape/ digital distance meter
8. An angle measuring equipment
9. A screw driver set
10. A flash light
11. A notebook
12. A camera
13. Testing and commissioning worksheets

Table 9.1 Important tools required for testing of PV system

		
Multimeter	**Clamp Meter**	**Hydrometer**

		
Screwdrivers	**Nut drivers**	**Crimping tool set**
		
Compass	**Sun Pathfinder**	**Angle gauge**
		
Battery Safety accessories	**Battery water filler**	**Battery Maintenance kit**

Important to Note

- Use relevant worksheet for inspection and testing given in this chapter
- Conduct the tests on a clear sunny day
- Commissioning should begin at the PV array so that if there are any issues with the wiring it can be rectified before the inverter is switched on and prevent damage to the inverter.
- Before commissioning a system, the installer should ensure:

- All strings are in segments to prevent accidental arcs (i.e. leave one of the module interconnections open).
- All fuses are removed.
- All circuit breakers and isolators are in the 'off' position (including the AC and DC isolators at the inverter).
- That the inverter is turned off.

Notes

UNIT 9.2: Overall System Inspection

Unit Objectives

At the end of this unit, you will be able to:

1. Perform visual inspection
2. Inspect mechanical, civil and electrical installation components

9.2.1 Assess Array Location

- PV array shall be free from shadow in all days of the year – use sun path finder
- There should be safe and convenient access for array maintenance (cleaning)
- Array shall be protected from animals and vandalism
- There should be ample space for air flow on the back side of the array
- Aesthetic of the building or premises shall be taken into account
- Array should not be located far from the charge controller/ inverter/ battery

Fig. 9.2.1 Shadow free installation on Howrah Municipal Corporation Building

Photo Credit: GSES

Fig. 9.2.2 Incorrect site selection for array installation

Photo credit: GSES

9.2.2 Check Equipment Location

- Check if all controls, power conditioning equipment and instruments are installed in such a way that access is controlled.
- Check if all electrical disconnect switch or circuit breaker are installed in such a way that access is controlled.

Fig. 9.2.3 Access to inverter is controlled

Photo credit: GSES

Fig. 9.2.4 Inverter and control equipment installed in a control room

Photo credit: CREDA

9.2.3 Check Battery Location

- Batteries should be located in a dry location
- Batteries should not be in contact with cold surfaces such as concrete

- The battery should be enclosed in a container or box or room that allows for proper ventilation and should have safe and easy access for maintenance and replacement;

Fig. 9.2.5 Location of batteries in a well ventilated room

Photo credit: CREDA

Fig. 9.2.6 Batteries kept in a box, container and rack

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UNIT 9.3: Testing of Solar Array

Unit Objectives

At the end of this unit, you will be able to:

1. Verify system grounding and measure insulation resistance
2. Check continuity of the system and Verify polarity.
3. Measure DC voltages and currents for each string and array for proper operation of the system
4. Verify inverter operation including anti-islanding performance and measure AC system values.
5. Verify calibration of Data Acquisition System.
6. Verify workmanship and demonstrate proficiency in using tools
7. Preparation of the Inspection report and take appropriate action

9.3.1 Overview of Testing Methods and Parameters

STEP 1: Check the physical condition of the photovoltaic array for any physical damage. Module frames should be straight with no corrosion.

STEP 2: All modules should be unshaded throughout the day. 'Spot' shading of a few cells or modules in the entire array must be eliminated.

Fig. 9.3.1 Spot shading causes hot spot and may damage a module

STEP 3: Check all the mounting hardware for loose fasteners or connections to the mounting surface.

STEP 4: Conduit and connections must all be tight and undamaged.

Fig. 9.3.2 Properly managed PV array cable

Photo credit: GSES

STEP 5: Visually check all conduit and wire insulation for damage.

STEP 6: Check junction boxes for loose or broken

STEP 7: Make sure all wiring is secured, by gently but firmly pulling on all connections.

STEP 8: Check if array wirings are readily accessible to un-authorized personnel.

Fig. 9.3.3 Poor quality conduit and unprotected cable can be easily damaged

Photo credit: GSES

STEP 9: Check all strings for the continuity, appropriate voltage and, lastly, polarity.

STEP 10: If the voltages of the strings are not within 5% of VOC, or are not what you would expect for the number of modules and weather conditions, you need to investigate this before proceeding further.

How to Conduct a Continuity Test

STEP 1: Turn the dial to Continuity Test mode With the test probes separated, the multimeter's display will show OL and Ω.

STEP 2: First insert the black test lead into the COM jack. Then insert the red lead into the V Ω jack.

STEP 3: Connect the test leads across tested string in open circuit condition.

STEP 4: The digital multimeter (DMM) beeps if a complete path (continuity) is detected. If the string is not connected the DMM will not beep.

STEP 5: Switch OFF the multimeter

How to Test Voltage and Polarity

STEP 1: Turn the dial to appropriate DC Voltage range

STEP 2: First insert the black test lead into the COM jack. Then insert the red lead into the V Ω jack.

STEP 3: Connect the test leads across tested string in open circuit condition.

STEP 4: The digital multimeter display the open circuit voltage and if polarity is wrong it will show a negative sign on the display

STEP 5: Switch OFF the multimeter

STEP 11: Polarity should also be checked in the junction box (if present) as it is easy to reverse the polarity here.

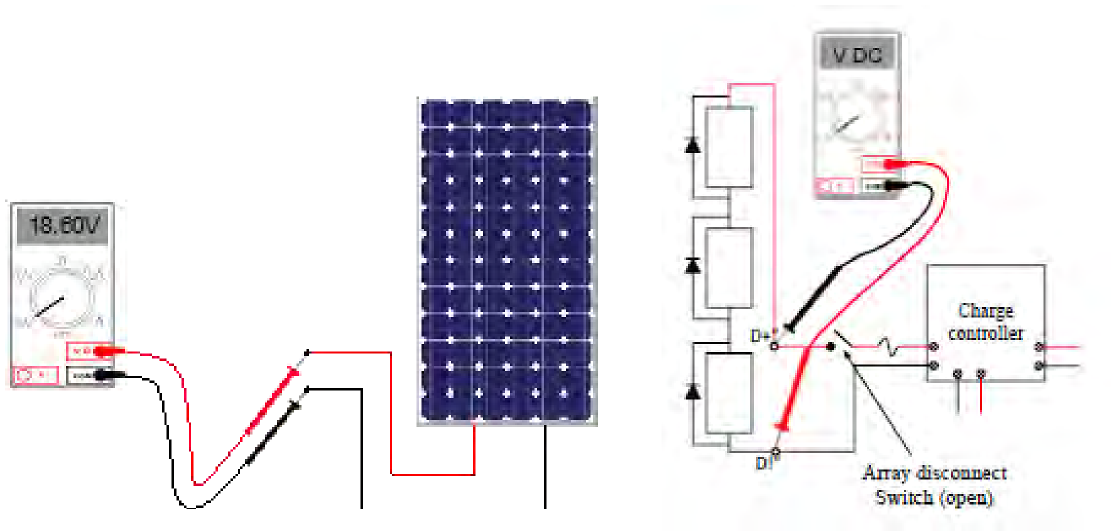

Fig. 9.3.4 Measuring module and string open cercuit voltage

Photo credit: GSES

STEP 12: Record the results on the worksheet at the end of this manual

Wrong polarity **Correct polarity**

Fig. 9.3.5 Checking of reverse polarity using a clamp-on meter (Voltmeter)

Photo credit: GSES

Attention!!

Always remember that loose connection and wrong polarity can cause fire in PV system, completely damaging the system and property.

Fig. 9.3.6 Fire breaking out at the site of a solar PV system

Notes

UNIT 9.4: Wire and Earthing Continuity Tests

Unit Objectives

At the end of this unit, you will be able to:

1. Perform continuity tests and tests for earthing and lightning protection

9.4.1 Continuity Tests

Follow the same procedure as mentioned above to test continuity cable.

1. Once the tests at the array are complete, continuity should be confirmed from the array to the PV array DC isolator
2. Check the continuity between the inverter and the inverter AC isolator (applicable to a grid connected system)
3. Check the continuity between the kWh meter and the inverter AC isolator (applicable to a grid connected system)
4. Measure the voltage of the grid on the output of the inverter AC isolator (applicable to a grid connected system)

9.4.2 Tests for Earthing and Lightning Protection

At this time, turn off (open) all disconnect switches.

Use an ohmmeter to check the continuity of the entire grounding system.

1. Make sure that all module frames, metal conduit and connectors, junction boxes, and electrical components chassis are earth grounded.
2. Using a DC voltmeter, check the polarity of all system components and wiring.
3. If plastic conduit is used, make sure a grounding wire has been run through it to provide continuous grounding.
4. If metal conduit is used, the conduit itself functions as the ground conductor, where allowed by code. If not allowed by code, a grounding wire must be used.

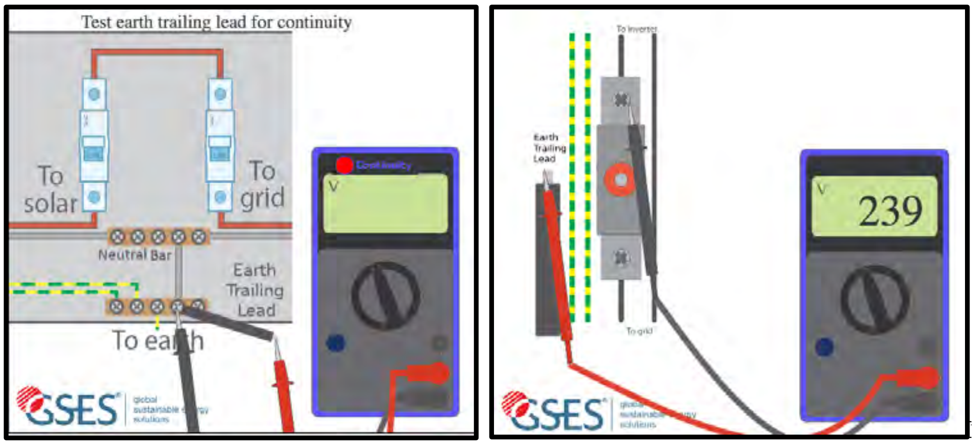

Fig. 9.4.1 Earth continuity and leakage test

Illustration credit: GSES

UNIT 9.5: Testing of Charge Controller

Unit Objectives

At the end of this unit, you will be able to:

1. Inspect the charge controller by referring to manufacturer specifications

9.5.1 Steps to be Followed

1. Follow the manufacturer's instructions, if available, for the specific charge controller in the system.
2. Check all terminals and wires for loose, broken, corroded, or burnt connections or components.
3. Check all displays, LED indicators and status monitoring system are in operation
4. Check that overcharge protection and under charge protection of charge controller is functioning correctly.
5. If charge controller is equipped with a temperature compensation device, check whether temperature probe is functioning correctly
6. Make sure there are no loose strands of multi-strand wire. These can short out on other terminals or other wires' loose strands.

Fig. 9.5.1 Testing of charge controller

Testing procedure for shunt charge controllers (12V system):

STEP 1: Set multimeter to appropriate DC voltage range to measure the voltage between the array positive and array negative (terminals).

STEP 2: Measure the DC voltage between the battery positive and battery negative terminals on the controller. If the controller is operating properly, it should be between 13.5 and 14.5 volts per module in series.

Testing procedure for series charge controllers:

You will require a DC portable adjustable power supply of suitable voltage range to carry out this test.

Step 1: Disconnect all wiring from the controller, except the temperature compensation probe, if the controller has one. Set the power supply to zero volts.

Step 2: Connect the power supply and DC voltmeter (Multimeter set at DC voltage) to the controller's + and - "array" input terminals.

Step 3: Watching the meter, slowly increase the power supply voltage until it is equal to the nominal voltage rating of the charge controller.

Step 4: Continue to increase the voltage until the meter reads one-half volt above the charge termination setting of the controller. At this point, the "charging" LED should go off. Record the charge termination voltage and compare with manufacturer's data sheet.

Step 5: Turn the power supply voltage back to zero, then move the meter and power supply to the + and - "battery" terminals on the charge controller. Slowly increase the Voltage. At first, the low voltage disconnect LED may be off. Once you supply enough voltage to operate the controller, but are still below the low voltage disconnect setting, the LED should be on. When the voltage is higher than the disconnect setting, the LED should go off. The voltage at which the LED comes on is the low battery reconnect voltage and should be recorded and compared with the manufacturer's data sheet.

Since many charge controllers have a time delay on load reconnection, it may be necessary to leave the power supply connected for a few minutes. The time required varies with the model of charge controller.

Testing procedure for Pulse charging

If the charge controller has a pulse charging feature, follow the same steps as described in testing procedure for series charge controller except modify step 4 as follows:

Turn the power supply voltage up very slowly. As the voltage approaches the charging termination setting, the controller should start pulse charging. The controller is trying to pulse voltage into the batteries. The charging LED should be flashing on and off. If the controller has a fully charged LED, it should be off.

Note that some controllers pulse so fast that you can not see the flashing of the LED.

Testing procedure for Multistage charge controller

For this test, an ammeter will be needed, as well as the voltmeter. Set the ammeter for the highest setting first, then change settings downward. During the test the current flow will range from amps to milliamps. Connect the ammeter to the controller's "battery" terminals.

Follow the same steps as described in testing procedure for series charge controller except modify step 4 as follows:

Turn the power supply voltage up very slowly. At first, the current flow should be a few amps. As the voltage approaches the charging termination setting, the controller should start "trickle" charging at a few hundred milliamps.

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UNIT 9.6: Testing of Batteries

Unit Objectives

At the end of this unit, you will be able to:

1. Identify types of baterries
2. Inspect the condition of batteries
3. Test the electrolyte for its state of charge using a Hydrometer

9.6.1 General Conditions

1. The tops of the batteries should be clean and dry. Caps should all be in place and secure.
2. All wiring connections should be secure.
3. Confirm that there are no shelves, hooks, or hangers above the batteries.
4. Check the electrolyte level of every cell in every non-sealed battery. It should always be above the top of the plates, but below the tops of the battery cases.
5. Ventilation systems must be functional.
6. Label each battery with a number for the battery and numbers for each cell.

9.6.2 Determine State of Charge with a Hydrometer

A hydrometer describes the state of charge by determining the specific gravity of the electrolyte. Specific gravity is a measurement of the density of the electrolyte compared to the density of water.

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.

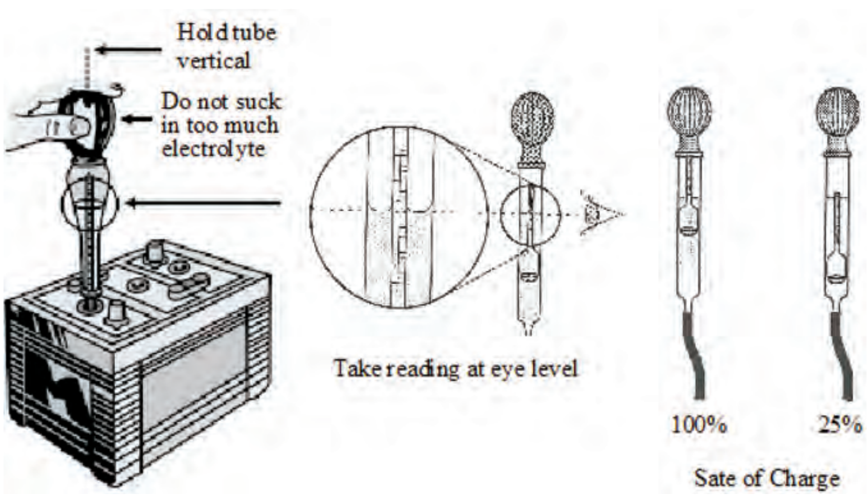

Fig. 9.6.1 Measurement of state of charge using a hydrometer

1. To use a hydrometer, squeeze the bulb while the inlet tube is still above the electrolyte level. Lower the hydrometer into the electrolyte and gradually release the bulb to suck in electrolyte.

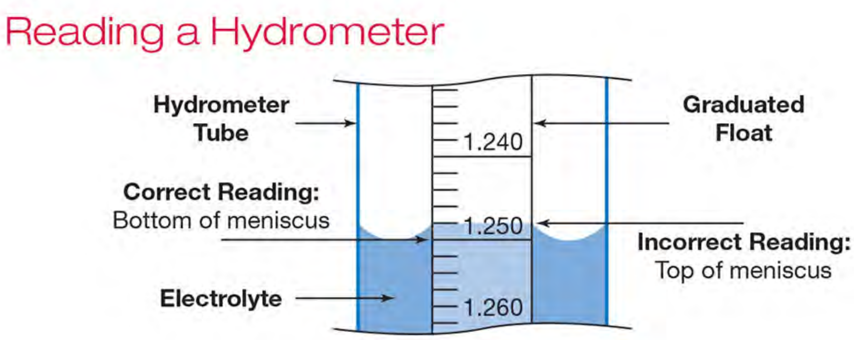

Fig. 9.6.2 Reading a hydrometer

2. When emptying the hydrometer, slowly squeeze the bulb with the inlet just above the electrolyte level, but still inside the battery cell. These methods reduce the chances that electrolyte will spurt out of the battery or the hydrometer.
3. At the first cell being checked, fill and drain the hydrometer with electrolyte three times before pulling out a sample. This brings the hydrometer to the same temperature as the electrolyte.
4. Take a sample of electrolyte and allow the bulb to completely expand. Hold the hydrometer straight up and down, so the float is not touching the sides, top, or bottom of the tube.
5. Look straight across the electrolyte level to read the float, as shown in Figure above. Ignore the curve of electrolyte up onto the sides of the hydrometer.
6. Record the specific gravity of each cell on a copy of the sheet provided at the end of this manual.

Table 9.2: Specific gravity to corresponding battery state of charge

Electrolyte Temperature (oC)	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

UNIT 9.7: Start–up Procedures

Unit Objectives

At the end of this unit, you will be able to:

1. Verify labeling of solar PV system.
2. Initiate startup procedures as per manufacturer instructions and record energy meter reading at startup
3. Measure and record voltage of energy storage system
4. Record and repair any anomalous conditions.
5. Document design changes, if any

9.7.1 Start-up of Standalone System

1. Start the inverter and make sure the inverter is actually coming on by turning on an AC load.
2. Measure and record the current draw of the inverter in both idling and operating states.
3. Measure and record the voltage drop between the inverter and battery on the positive and negative leg while under load. Measure the current draw simultaneously and use this to calculate the resistance to arrive at the loss between the battery and the inverter.

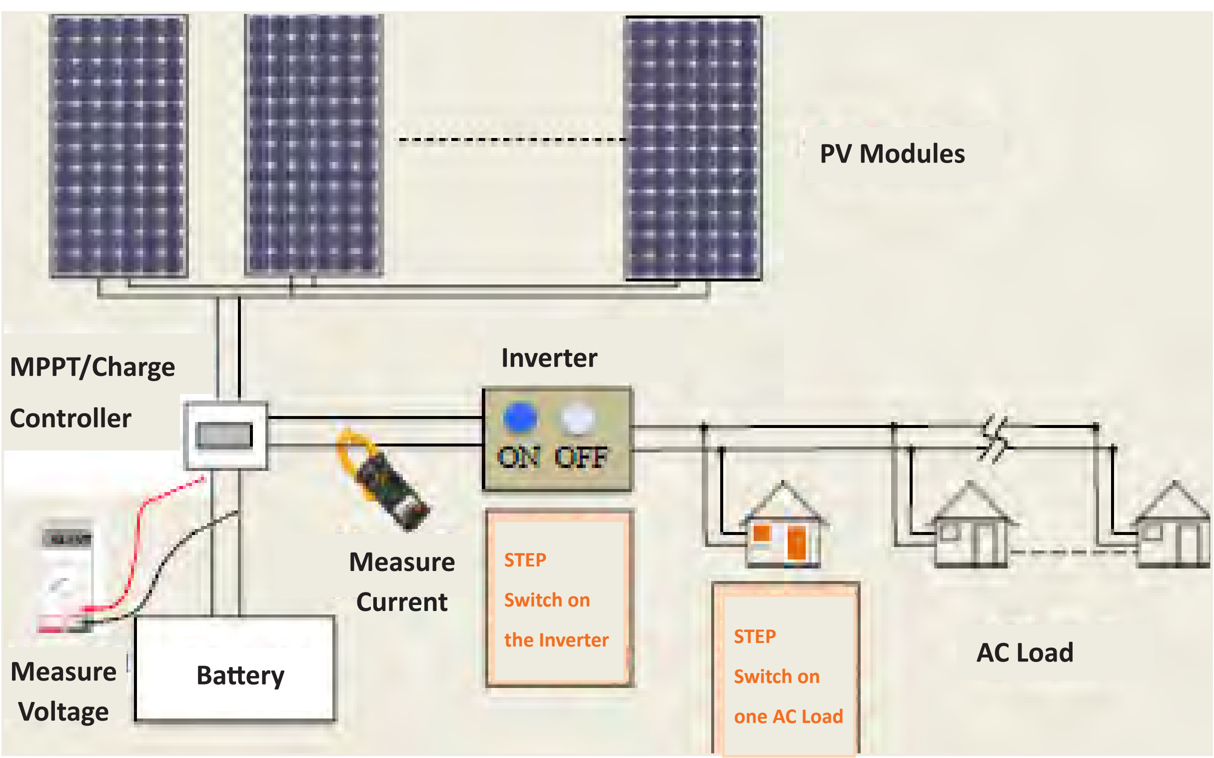

Fig. 9.7.1 Start up of standalone PV system

Illustration credit: GSES

9.7.2 Start-up of Grid Connected System

1. If inverter has an on/off switch ensure that it is in the off position.
2. After you have completed all other tests, refer to the inverter's system manual and follow the start-up procedure.
3. Typically this will involve turning on the PV array DC isolator followed by inverter AC isolator.
4. Check and confirm that the solar array is feeding power onto the grid.
5. If you do not have a display meter use a clamp on ammeter to measure either the AC or DC current.
6. Measure the DC input voltage and confirm that it is within operating limits of the inverter
7. Measure the AC output voltage.
8. If a kWh meter exists in the system, confirm that the inverter is producing the expected power output with respect to available DC power.

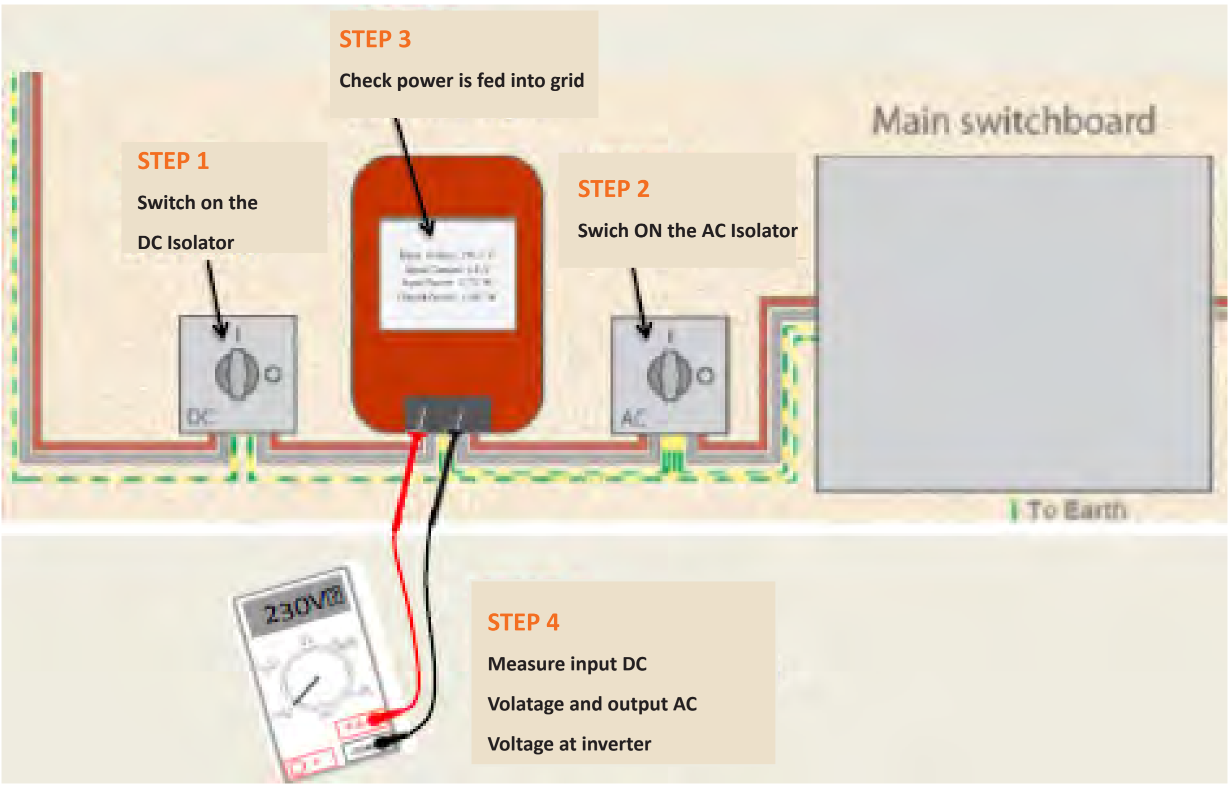

Fig. 9.7.2 Start up of grid connected inverter

Illustration credit: GSES

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UNIT 9.8: Unintentional Islanding Functionality Test

Unit Objectives

At the end of this unit, you will be able to:

1. Perform the Unintentional Islanding Functionality Test for the solar PV system

9.8.1 Unintentional Islanding Functionality Test

(Final test for grid connected PV system)

1. Conduct this test after the system has been operating correctly for a few minutes.
2. This test must be conducted during noon time in a sunny day.
3. PV system shall produce more than 20% of the rated output of the PV array or the inverter – whichever is less.
4. If there is more than one inverter, tests should be carried out for each inverter.

Test 1: Inverter Must Cease Supplying Power Within Two Seconds of a Loss of Mains

STEP 1: Keep DC supply from the solar array connected to the inverter.

STEP 2: Place the voltage probe in the inverter side of the AC main switch.

STEP 3: Turn OFF the AC main switch through which inverter is connected to grid.

STEP 4: Measure the time taken for the inverter to cease attempting to export power with a timing device and record.

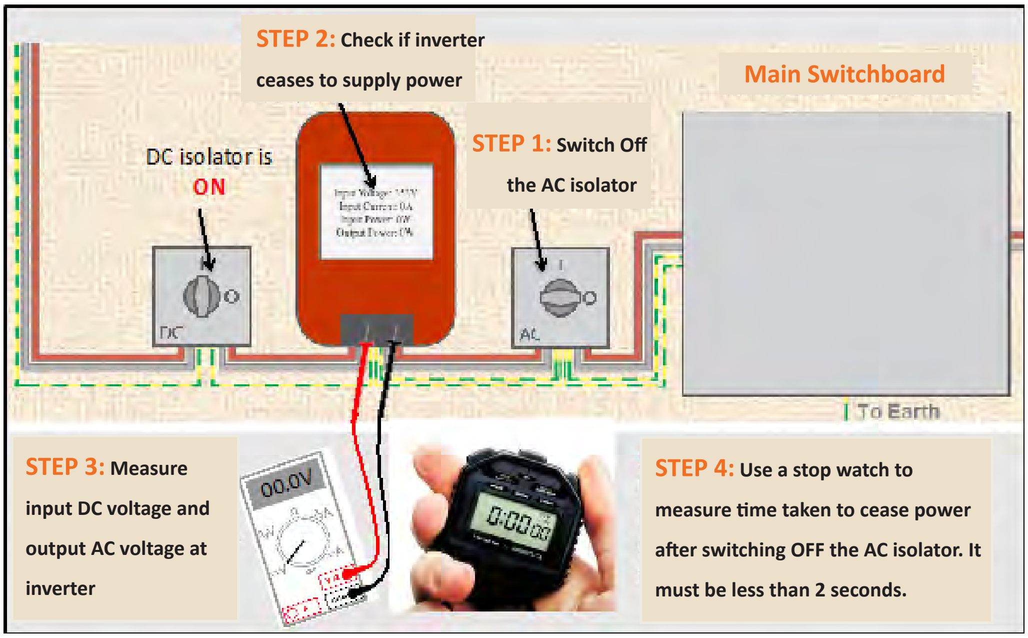

Fig. 9.8.1 Unintentional islanding functionality test 1

Illustration credit: GSES

Test 2: Inverter Must not Resume Supplying Power Until Mains have Been Present for More than 60 Seconds

STEP 1: Keep DC supply from the solar array connected to the inverter.

STEP 2: Place the current probe in the inverter side of the AC main switch.

STEP 3: Turn ON the AC main switch through which inverter is connected to grid.

STEP 4: Measure the time taken for the inverter to re-energise and start export power with a timing device and record.

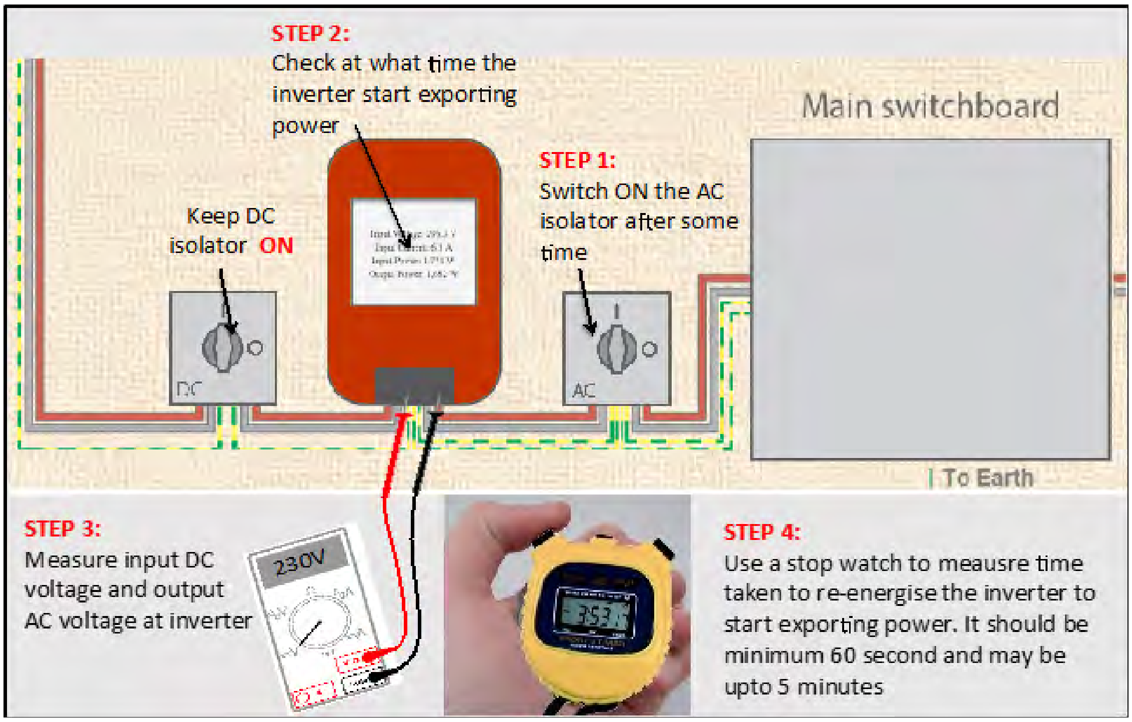

Fig. 9.8.2 Unintentional islanding functionality test 2

Illustration credit: GSES

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UNIT 9.9: Sample Inspection Record Sheets

Unit Objectives

At the end of this unit, you will be able to:

1. Know about the sample inspection record sheets

9.9.1 Sample Inspection Record Sheets

All questions in the record sheet below shall be answered YES or NO.

If answer is NO, explanation shall be given for each "NO" and remedial action to be taken as per the instruction given in his chapter. If deviation is unavoidable you must report your supervisor or engineer and raise your concern.

Table 9.3 Sample inspection record sheet

Overall system Inspection	
Array Location:	
1. Is the PV array free from shadow in all days of the year?	
2. Is the PV array having access for maintenance?	
3. Is the PV array protected from animals and vandalism?	
4. Is the PV array having ample space for air-cooling?	
Equipment Location:	
5. Is the access to inverter battery and other equipment controlled?	
6. Is the access to disconnect switch or circuit breaker are controlled?	
Battery Location:	
7. Is battery bank located in a dry location?	
8. Are batteries are in contact with cold surfaces such as concrete?	
9. Are batteries are placed in a box/ rack or inside a room?	
Testing of Solar Arrays:	
10. Is there any physical damagae to any PV module?	
11. Is there any corrosion in the structure?	
12. Is there any spot shading on any module during noon time?	
13. Is there any loose fasteners or connections to the mounting surface?	
14. Are all conduit and connections tight and undamaged?	
15. Are all conduits and wire insulations undamaged?	
16. Are all junction boxes physically intact and tight?	
17. Did all wiring pass the pulling tests?	
18. Is there any wire that is readily accessible to any person?	
19. Did all individual string pass the continuity test?	
20. Did all individual string pass the open circuit voltage test?	

21. Did all individual string pass the polarity test?	
22. Are the voltages of the strings within 5% of VOC ?	
23. Is polarity in the junction box correct?	
24. Did the cable from PV array to the DC isolator pass continuity test?	
Wiring and earthing continuity tests:	
25. Did all cables pass continuty tests?	
26. Did earthing cable pass continuty tests?	
27. Are all metallic part in the system bonded correctly?	
28. Did all system components and wiring pass polarity tests?	
29. Is the resistance test using megger successful?	
Testing of Charge Controllers:	
30. Did you check the charge controller as per manufacturer's procedure?	
31. Did you check all terminals and wires for loose connection in CR?	
32. Did you check functionality and display of and indicators of CR?	
Testing of Batteries:	
33. Are batteries kept dry and vents are clear and clean?	
34. Are all connections in battery bank secured?	
35. Is electrolyte level of the batteries appropriate?	
36. Is ventilation system in battery bank room working?	
37. Did you level all battery with specific number?	
38. Did you note state of charge of all the cells of the batteries?	
Unintentional islanding functionality test:	
39. Did the system pass the TEST 1?	
40. Did the system pass the TEST 2?	

Exercise

1. Name few tools and equipments required for testing of PV systems
2. How will you perform visual inspection?
3. How do you know that a PV mounting structure is correctly installed and foundations are appropriate?
4. How will you test continuity of a PV string?
5. How will you verify that grounding system of a PV power plant is adequate? What instrument you will require for that?
6. What will you measure when you check polarity? What could be the consequences of connecting DC cables with wrong polarity?
7. A PV system has 4 strings connected to the inverter. Each string has 10 modules (Voc = 37V) connected in series. While testing, you found that open circuit voltage of three strings is 370V and one string is 333V. What might be the reasons for that?

8. Explain the steps for testing the charge controller.
9. Explain steps to start up a standalone inverter.
10. Explain steps to start up a grid-connected inverter.
11. How will you perform unintentional islanding functionality test? How will you measure time during these tests?
12. How will you check if inverter display is providing correct data?
13. Demonstrate how to use a hydrometer correctly.
14. Demonstrate how to measure state of charge of a flooded electrolyte lead acid battery.
15. Demonstrate continuity test for cable and earthing system.
16. Demonstrate how to prepare Inspection Record Sheet.
17. You have seen a fire alarm sign in a battery room where smoking and taking naked flame is prohibited. What is the risk of fire in a battery room

Notes

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10. Maintain Solar Photovoltaic System

Unit 10.1 – Tools Required for Maintenance

Unit 10.2 – Preventive Maintenance of PV System

Unit 10.3 – Troubleshooting and Maintenance

ELE/N6001

Key Learning Outcomes

At the end of this module, you will be able to:

1. Clean the solar panels periodically
2. Inspect the solar PV system periodically
3. Troubleshoot to identify faults in the system
4. Report and document completion of work
5. Follow quality and safety procedures

UNIT 10.1: Tools Required for PV System Maintenance

Unit Objectives

At the end of this unit, you will be able to:

1. Identify the tools and equipment required for maintenance of PV system

10.1.1 List of Tools for Maintenance Activities

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

Table 10.1: List of tools and materials required for O&M of solar systems

Tools required for PV system maintenance		
First aid kit	Needle nose pliers	Compass
System service logbook	Linesman pliers	Flashlight
Datasheet & O&M manual	Diagonal cutters	Sun Pathfinder
This manual	DC soldering iron	Safety goggles
Paper/Pencil	Hacksaw	Rubber gloves
Multimeter	Battery terminal cleaner	Combination square
Clampon ammeter	Battery terminal puller	Small container
Hydrometer	Clamp spreader	Caulking gun
Screwdrivers	Utility knife	Needle nose pliers
Nut drivers 1/4in and 5/16in	Hammer	Wire strippers
Measuring tape (25m)	Cell water filler	Crimping tool
Angle measuring device	Cleaning brush	

10.1.2 Maintenance Schedule and Logbook

- An equipment logbook incorporating the maintenance schedules will be provided to the technicians
- A loose leaf folder can be used as the system log book with individual sheets added for each item.
- Log books are useful because the historical information they contain can show changes over time, as well as abnormal variations from the usual, indicating a problem in the making.

Table 10.2: Maintenance schedule and logbook

		
First aid kit	**Flash light**	**Cauliking gun**
		
Multimeter	**Clampon ammeter**	**Hydrometer**
		
Screwdrivers	**Nut drivers**	**Crimping tool set**
		
Compass	**Sun pathfinder**	**Angle gauge**

		
Battery safety accessories	**Battery water filler**	**Battery maintenance kit**

Figure: Important tools required for testing of PV system

10.1.3 Important to Note

Use relevant worksheet for inspection and testing given in this chapter

- Conduct the tests on a clear sunny day
- Commissioning should begin at the PV array so that if there are any issues with the wiring it can be rectified before the inverter is switched on and prevent damage to the inverter.
- Before commissioning a system, the installer should ensure:
    - All strings are in segments to prevent accidental arcs (i.e. leave one of the module interconnections open).
    - All fuses are removed.
    - All circuit breakers and isolators are in the 'off' position (including the AC and DC isolators at the inverter).
    - That the inverter is turned off.

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UNIT 10.2: Preventive Maintenance of PV System

Unit Objectives

At the end of this unit, you will be able to:

1. Perform the weekly, monthly and annual maintenance of the PV modules, PV Array, batteries, inverter, wiring system, earthing and lightning protection components
2. Monitor interaction of the solar PV system with the grid

10.2.1 What is a Maintenance Schedule?

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

Table 10.3: Sample Maintenance Schedule

Sl. No.	Maintenance Work	Frequency
1	Ensure security of the power plant	Day-to-day
2	Inspect and clean the PV modules from dust and other dirt like bird's dropping etc. as and when required	Weekly
3	Monitor power generation and export	Daily (Remotely)
4	Keep the inverters clean to minimize the possibility of dust ingress	Quarterly
5	Ensuring all electrical connections are kept clean and tight.	Half-yearly
6	Check mechanical integrity of the array structure	Annually
7	Check all cabling for mechanical damage	Annually
8	Check output voltage and current of each string of the array and compare to the expected output under the existing conditions	Annually
9	Check the operation of the PV array DC isolator	Annually

10.2.2 PV Module Maintenance

Performance of a PV system is highly affected when solar modules are not kept clean. Studies show that energy generation of a PV system can go down up to 20% or more if modules are not cleaned regularly. It is recommended to the modules are inspected on weekly basis and as and when required should be cleaned from dust and bird dropping etc.. Areas that are generally dusty and polluted would require more frequent inspections and cleaning.

How to clean PV modules?

- Inspect the site prior to cleaning work is performed. Note any hazardous conditions and danger.
- Cover all electrical equipment, i.e. inverters and combiner boxes, beneath area to be cleaned with covers prior to cleaning.
- Inspect surface of solar modules prior to cleaning. All accumulated dirts to be removed from module surface.

- Use ladder wherever required to reach surface of solar modules to be cleaned.
- Use a wiper with a sponge or brush to clean modules. Use clean water at minimal pressure. No chemicals or abrasive cleaning shall be applied to clean solar modules.

Fig. 10.2.1 Cleaning of modules using a wiper

- Use of hard water for long time will damage the modules by forming a coating on the modules. Avoid using water with hardness more that 200ppm.
- It is advisable to condition the module cleaning water through water softener prior to application. This will minimize mineral deposit on the module.
- If dirt like bird droppings cannot be removed easily use brush with soft bristle to remove such dirt.
- Perform cleaning in early morning or wait until evening, to avoid thermal shock to glass.
- Perform washing only when modules are not in direct sunlight, when the sun is positioned below the horizon.

Fig. 10.2.2 Cleaning modules using a mop

Check PV modules for physical damage:

- Inspect array for broken modules at least once in a year.
- If there is any broken module report to the supervisor or engineer and replace it with appropriate module.
- To replace the broken solar module isolate the string by switching OFF DC isolator at the string and remove the broken module. Replace with a correct module and connect. In case if there is no DC isolator on individual string,

switch OFF the main AC isolator between mains and inverter, then switch of the array DC isolator and replace the broken module.

Fig. 10.2.3 Broken module in a PV array

Check PV modules for performance:

- Check output voltage and current of each string of the array and compare to the expected output under the existing conditions.
- Verify output from the array (Isc and Voc and if possible Imp and Vmp)

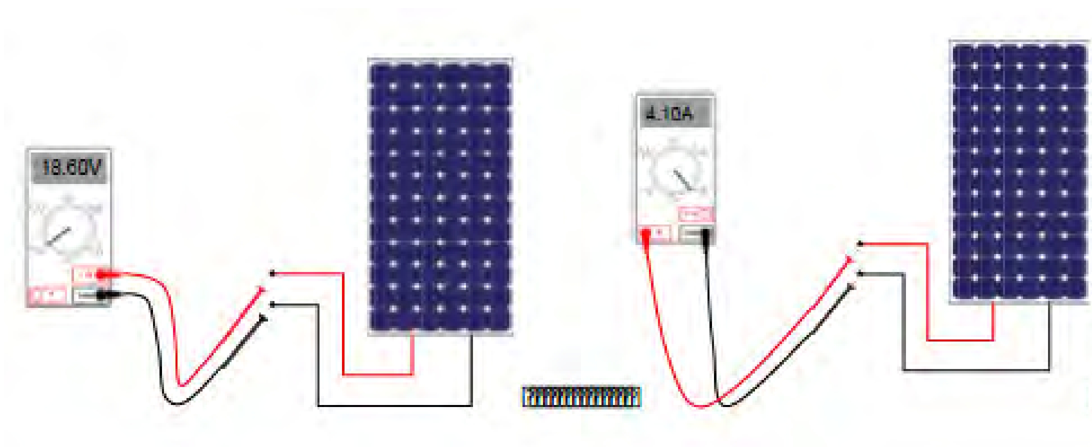

Fig. 10.2.4 Checking current and voltage of PV modules

Picture credit: GSES

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.

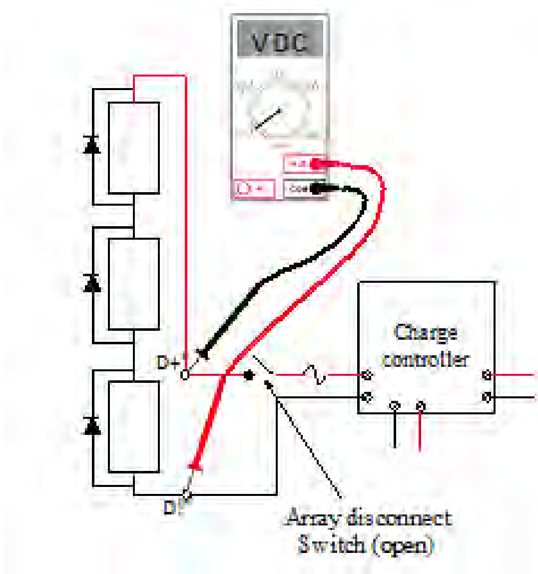

Fig. 10.2.5 Measuring the open circuit voltage of array

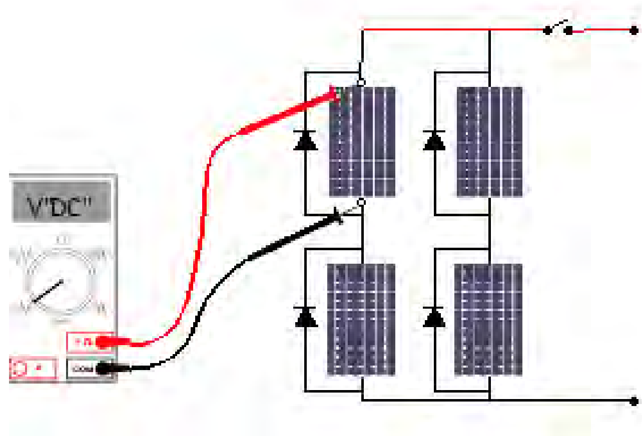

Fig. 10.2.6 Measuring the open circuit voltage of module

Picture credit: GSES

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.

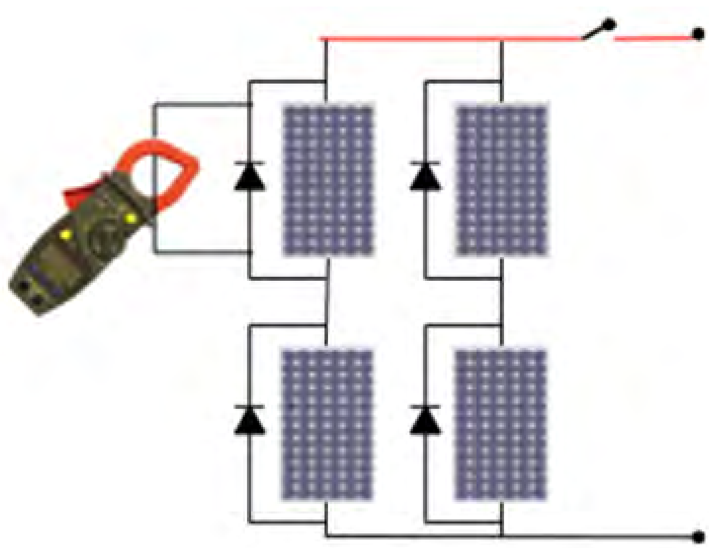

Fig. 10.2.7 Measuring module short circuit current

Picture credit: GSES

10.2.2 Monitor Power Generation

Monitor power generation and export to grid in case of a grid-connected system. This can be done by observing and recording daily energy generation report sent automatically by the inverter communication system. If the inverter communication system do not work, report it to the supervisor or engineer.

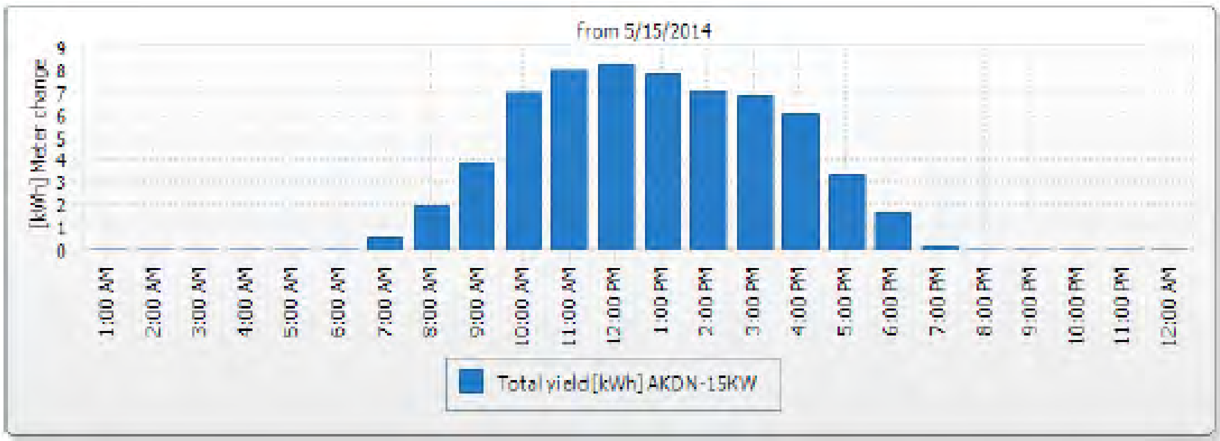

Fig. 10.2.8 Daily report of energy generation from a grid connected inverter

10.2.3 Maintenance of Batteries

Weekly maintenance of batteries:

- Clean the battery terminals, surface and surrounding clean
- Observe battery state of charge (SOC) using hydrometer
- In case of VRLA battery use voltmeter to measure voltage to check corresponding SOC.

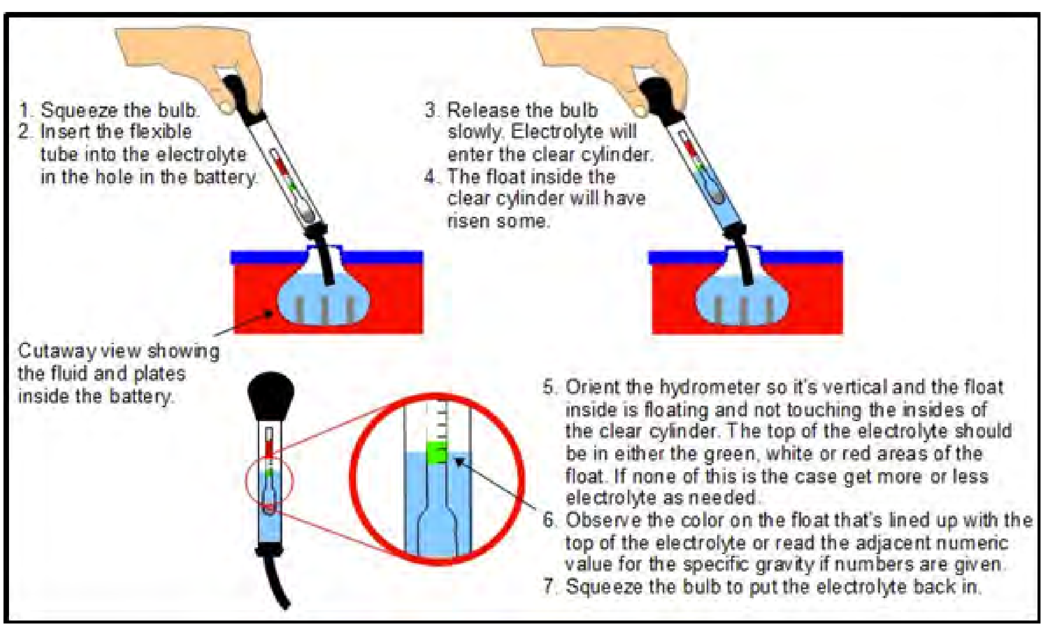

Fig. 10.2.9 Maintenance of battery by testing the electrolyte

Table 10.4: 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	1Z52	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 used check electrolyte level and top up if required. Wipe electrolyte residue from the top of the battery

Fig. 10.2.10 Top up of batteries

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

Fig. 10.2.11 Cleaning of batteries terminals to avoid corrosion and loose connections

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

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. This procedure is discussed in details in unit 6.6.

Determine state of charge through actual load test:

Use a DC voltmeter (or a multi-meter)

1. Operate the system loads from the batteries for five minutes. Turn off the loads and disconnect the batteries from the rest of the system.
2. Measure the voltage across the terminals of every battery

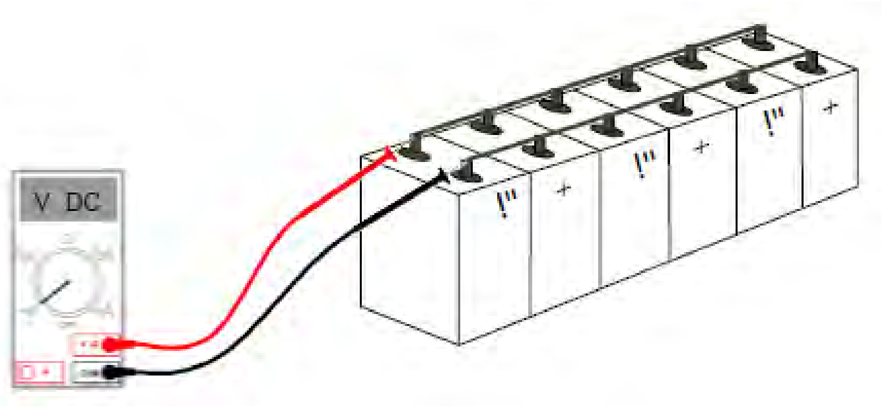

Fig. 10.2.12 Battery load tests using a multimeter (Voltmeter)

Photo credit: GSES

Table 10.5: Open circuit voltages and corresponding states of charge for deep cycle lead acid batteries during a load test

Open Circuit Voltages		State of Charge	
2 Volt Battery	6 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%

10.2.4 Maintenance of Inverter

Inspection and maintenance of Inverters:

- Remove dust or dirt, inspect system wiring for poor connections.
- 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.
- Look if any object blocks inverter room ventilation and restricts free airflow for natural cooling of inverter. Remove such obstruction or object.

Fig. 10.2.13 Inverter maintenance

10.2.5 Maintenance of Cables, Connectors And Switches

- 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.

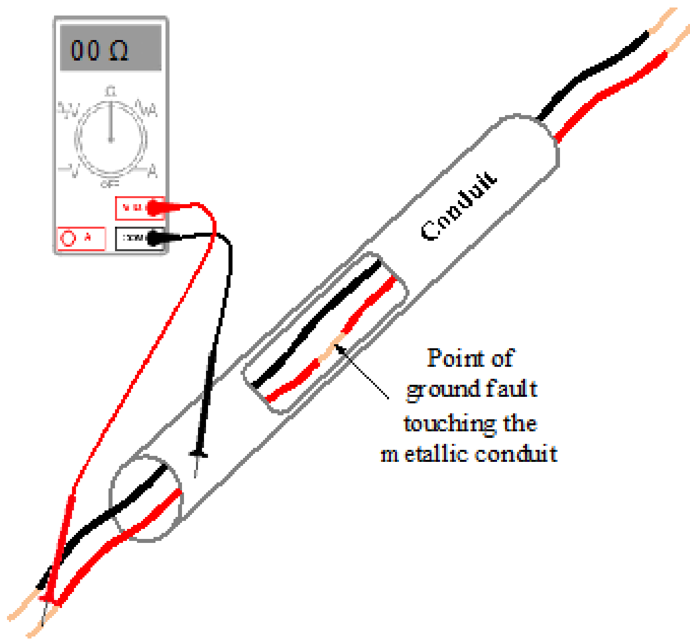

Fig. 10.2.14 Finding a ground fault

Picture credit: GSES

- Check the operation of the PV array DC isolators
- Check array wiring for physical damage and wind chafing

Fig. 10.2.15 Physically damaged wires

- Check array mounting hardware for tightness and corrosion

Fig. 10.2.16 Array mounting hardware to be checked

Inspection and maintenance of Earthing and Lightning Protection:

- Use an ohmmeter of multimeter 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.

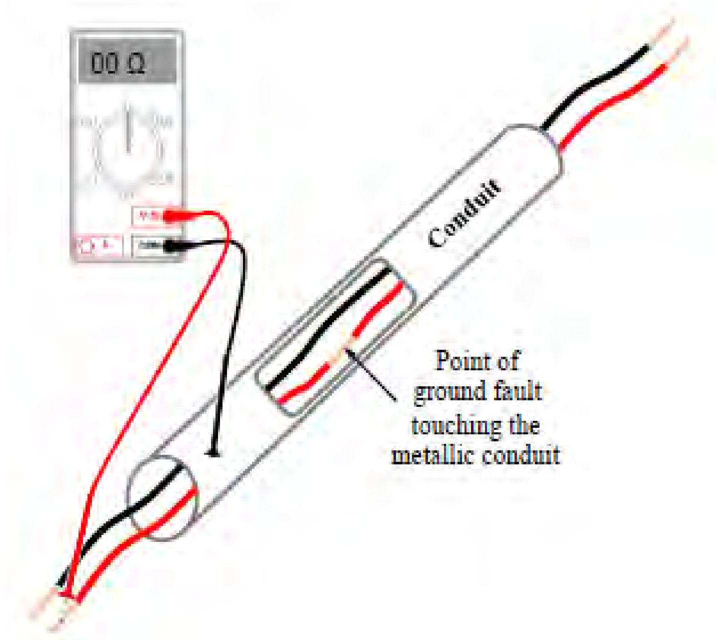

Fig. 10.2.17 Finding a ground fault

Picture credit: GSES

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UNIT 10.3: Troubleshooting and Maintenance

Unit Objectives

At the end of this unit, you will be able to:

1. Identify the faults in the system when there is an interruption in power generation
2. Perform regular checks like looking for dust, shade, etc., which might interrupt power output
3. Check current output for each string and identify the string which gives a low / undesired power output
4. Identify the faulty module in the string by shading the modules and checking the output using ammeter reading
5. Perform sequentially the standard troubleshooting activity to identify faults when there is power supply interrupting the grid
6. Check for working conditions of fuses and circuit breakers
7. Check the service panel connections
8. Check the cables and ensure that there is no damage
9. Check the wire connection to inverter and identify for any damage in wire connection
10. Inform the inverter service technician if there is a circuit board level fault for further repair
11. Escalate the issue to superiors if faults cannot be identified

10.3.1 Guidelines for Troubleshooting

The following guidelines are presented for troubleshooting of generic solar photovoltaic system.

Table 10.6: Solar PV System - Troubleshooting guidelines, check-list and recommended action

Symptom	Check	Action
Load does not operate at all	Check if switches are turned off or are in the wrong position	Put all switches in correct position
	Check if system circuit breakers or fuses are blown	Reset circuit breaker or replace fuse
	Check if load is too large for the system	Reduce load size
	Check if there is shadow on solar array	Remove shadow
	Check if weather is cloudy	Wait till weather is sunny and battery gets charged
	Check if load itself is defective	Repair or replace load
Load operates poorly or not at all	Check voltage drop in the system due to small and long wire	Use bigger wire
	Check if system is overloaded	Reduce load size or operating time
	Check if there is a ground fault or a defective diode	Correct ground faults or defective didoes

	Check if wiring or connections are loose, broken burned, or corroded	Repair or replace damaged wiring or Connections.
	Check if there is any short-circuit	Repair short circuits
	Check if small "phantom" load keeps inverter idling, draining battery	Turn off phantom load or replace it with one not requiring PV power
	Check if wiring polarity is reversed	Correct wiring polarity

10.3.2 Troubleshooting with Batteries

Table 10.7: Batteries - Troubleshooting guidelines, check-list and recommended action

Symptom	Check	Action
Battery voltage remain low	Check if load is too large	Reduce load size
	Check if load operates too long	Reduce operating time
	Batteries are too cold	Insulate battery enclosure
	Check if there is shadow	Remove shadow
	Check if weather is cloudy for several days	Wait till weather is sunny and restrict use of load
	Check if load it is defective	Repair or replace load
Battery do not accept charge	Check if load is too large	Reduce load size
	Check if load operates too long	Reduce operating time
	Check if there is shadow	Remove shadow
	Check if weather is cloudy for several days	Wait till weather is sunny and restrict use of load
Low electrolyte level	Check if battery is overcharged	Add distilled water
Voltage loss overnight even when no loads are on	Check if blocking diode is faulty	Replace diode
High water loss due to overcharging	Check if batteries are overcharged	Repair or replace charge controller
Electrolyte leakage	Check if battery container is broken or leaking	Replace battery/Report dealer/manufacturer
When Battery voltage constantly remain high	Check if charge controller is removed of faulty	Replace the charge controller with lower charge termination setting
	Check if battery capacity is too small for array	Increase battery capacity
	Check if charge controller is misadjusted	Adjust charge controller

10.3.3 Troubleshooting with Charge Controllers

Table 10.8: Charge controllers - Troubleshooting guidelines, check-list and recommended action

Symptom	Check	Action
Erratic controller operation and/or loads being disconnected improperly	Timer not synchronized with actual time of day	Either wait until automatic reset nest day or disconnect array wait 10 seconds and reconnect array

	Electrical "noise" from the inverter	Connect inverter directly to batteries, put filters on load
	Low battery voltage	Repair, replace battery
Erratic controller operation and/or improper load disconnection	High surge from load	Use large wire to load or add batteries in parallel
	Otherwise faulty charge controller, possibly from lightning damage	Repair or replace charge controller and check system grounding
	Adjustable low voltage disconnect set incorrectly	Reset low voltage setting
	Load switch in wrong position on controller	Reset switch to correct position
	Charge controller has low voltage disconnect feature	If necessary replace charge controller with one with a low voltage disconnect feature
Fuse to array blows	Array short circuited with batteries still connected	Disconnect batteries when testing array's short circuit current
	Current output of array too high for charge controller	Replace charge controller with one with a higher rating
Fuse to load blows	Current draw of load too high for charge controller	Reduce load size or Increase charge controller size
	Surge current draw of load too high for charge controller	Reduce load size or Increase charge controller size

10.3.4 Troubleshooting with Inverters

Table 10.9: Inverters - Troubleshooting guidelines, check-list and recommended action

Symptom	Check	Action
No output from the inverter	Check switch, fuse or circuit breaker open, blown or tripped or wiring broken or corroded	Close switch, replace or reset fuse or circuit breaker or repair wiring or connections
	Check low voltage disconnect on inverter or charge controller open	Allow batteries to recharge
	Check if there is time delay on inverter start-up from idle	Wait a few seconds after starting loads
Loads operating improperly	Excessive current draw by load	Reduce size or loads
	Defective inverter	Replace inverter/report to dealer/ manu-facturer
Motors operating at wrong speeds	Inverter not equipped with frequency control	Replace inverter with one equipped with frequency control/report to dealer/ manufacturer
Inverter circuit breaker trips	Load operating or surge current too high	Reduce size of loads or replace inverter with one of larger capacity/report to dealer/manufacturer
Inverter DC circuit breaker trips	Inverter capacitors not charged up on initial start up	Report to dealer/manufacturer

10.3.5 Troubleshooting with Solar PV Arrays

Table 10.10: Solar PV Array - Troubleshooting guidelines, check-list and recommended action

Symptom	Check	Action
No current from array	Check switches, fuses or circuit breaker open, blown or tipped or wiring broken or corroded	Close switches, replace fuses, reset circuit breakers, repair or replace damaged wiring
	Check if module is damaged or broken	Report
No voltage from array	Check switches, fuses or circuit breaker open, blown or tipped or wiring broken or corroded	Close switches, replace fuses, reset circuit breakers, repair or replace damaged wiring
	Check if module is damaged or broken	Report
Array voltage low	Some modules shaded	Remove source of shading or relocate the array
	Some array interconnections broken or corroded	Repair interconnections
	Defective bypass or blocking diode	Repair defective diodes
	Some modules damage or defective	Replace affected modules
	Full sun not available	Wait for sunny weather
	Modules are dirty	Clean modules
	Array tilt or orientation incorrect	Correct tilt/ orientation
	Check if module is damaged or broken	Report
	Some modules in series disconnected	Reconnect
	Bypass diode defective	Replace diodes
	Wiring from too long or small	Use large wire
	Check if module is damaged or broken	Report
Array current is low	Check if full sun is not available	Measure current at noon
	Check if modules are dirty	Clean modules
	Check if array tilt or orientation incorrect	Correct tilt/orientation
	Check if battery is fully charged	Wait till battery is charged
	Check if module is damaged or broken	Report
	Check if array is not giving expected load current at full sun	Report

Exercise

1. Name few tools and equipments required for maintenance of PV systems.
2. How often do you need to clean the solar modules and what time of the day you should clean them?
3. How often batteries require topping up and what type of water will you use?
4. During inspection you observe that state of charge of the batteries are very low for long period. What might be the reason and how do you diagnose it?
5. How do you check if modules are working satisfactorily?

6. What might be the consequence of shorting the batteries and how will you avoid that?
7. What are the safety resources required for battery maintenance?
8. What is catalytic recombination cap/ ceramic vent plug and how is it fixed?
9. Why you should not use detergent to clean PV modules?
10. What happen if you use hard water to clean the modules for long time?
11. How will you clean sticky dirt from the modules?
12. What equipment you will use to check if there is shadow possibility in any point of time in a year?
13. How will you check for the conditions of mounting and its stability to hold solar panels?
14. How do you identify faults in a PV system when there is an interruption in power generation?
15. How do you monitor performance of a PV system?

Notes

11. Maintain Personal Health and Safety at Project Site

Unit 11.1 - Establish and Follow Safe Work Procedure

Unit 11.2 - Use and Maintain Personal Protective Equipment (PPE)

Unit 11.3 - Identification and Mitigation of Safety Hazards

Unit 11.4 - Work Health and Safety at Heights

SGJ/N0106

Key Learning Outcomes

At the end of this module, you will be able to:

1. Establish and follow safe work procedure
2. Use and maintain personal protective equipment
3. Identify and mitigate safety hazards
4. Demonstrate safe and proper use of required tools and equipment
5. Identify work safety procedures and instructions for working at height

UNIT 11.1: Establish and Follow Safe Work Procedure

Unit Objectives

At the end of this unit, you will be able to:

1. Identify corporate policies required for workplace safety
2. Identify requirements for safe work area and create a safe work environment
3. Identify contact person when workplace safety policies are violated
4. Provide information about incident/violation
5. Identify the location of First Aid materials and administer first aid

11.1.1 Basics of Work Safety During Solar PV Installations

A Solar PV System is to be installed as per the safety standards, installation and building codes applicable for that particular location. The installer must be well versed with the organization's safety policy. These considerations include:

1. Maintaining a safe work area
2. Safe methods of using tools and equipment
3. Safety of Personnel, which includes knowledge of Personal Protective Equipment (PPE)
4. Awareness of electrical and non-electrical hazards and how to mitigate them

General Requirements of a safe work area

- The work site must not be cluttered. This increases the chances of tripping or falling, especially on sloped roofs/ surfaces.
- The access and exit arrangements should be safe and clear of obstacles.
- Communication arrangements should be adequate.
- Lighting should be adequate to allow safe working. Lighting in a work area may be a temporary arrangement cabled into the area requiring additional protection against possible trip induced falls. Whenever possible, natural lighting should be provided in the work area during inspection.
- The tools must not be left unsecured as they may cause obstructions or fall off the roof, injuring someone below.
- The rooftop is an outdoor location. In case, the location is extremely hot because of the sun, adequate precaution should be taken to avoid sun-burns, exhaustion and de-hydration by use of sunscreen, wear light colored clothes and keep drinking a lot of water.
- Maintain a First Aid Kit to mitigate accidents involving personnel or any other person who may be in the vicinity (say, the customer)

Table 11.1: Example of danger signs on components

Sign No.	Example Signs
1	PV Array d.c. Junction Box. Danger - contains live parts during daylight.
2	Do not disconnect d.c. plugs and sockets under load - turn off a.c. supply first.
3	PV array d.c. isolator. Danger - contains live parts during daylight.
4	Inverter - Isolate a.c. and d.c. before carrying out work.
5	PV system - main a.c. isolator.

11.1.2 First Aid Kit

In spite of all precautions/ preventions, there are chances of hazards. So, a PV Installer should always be aware of the mitigation measures to be taken if some mishap occurs. Following are the important mitigation measures that should be taken after the occurrence of hazards:

1. Maintain composure and separate victim from cause of hazard
2. Wash the injuries/ wounds with clean water
3. Apply First Aid on burns/ injuries/ wounds
4. Apply Sodium Hydroxide (NaOH) solution when burns are due to battery's acid
5. Take the injured person to Medical room or a safe place
6. Look for the Supervisor/ Team leader
7. Call the Doctor/ Medical Officer

Never Wash Burns With Water

Tips

1. You must be able to use tools and sources of information for referring to general guidelines over and above the compliances specified by the organization. Some of these safety standards are specified in codes by the Occupational Safety and Health Administration (OSHA)

Table 11.2: Common tool hazards

S.No.	Type of Hazard	Why it happens
1	Loss of eye/vision	Using striking tools without eye protection.
2	Puncture wounds	Using a screwdriver with a loose handle which causes the hand to slip.
3	Severed fingers, tendons and arteries	Using the wrong hammer for the job and smashing a finger.
4	Broken bones	Using a small wrench for a big job and bruising a knuckle.

Notes

UNIT 11.2: Use and Maintain Personal Protective Equipment (PPE)

Unit Objectives

At the end of this unit, you will be able to:

1. Identify the requirements of safe work
2. Implement the safe work flow procedure
3. Use and maintain Personal Protective Equipment (PPE)
4. Safely handle and carry out proper usage of tools/ equipment
5. Do proper tagging and markings

11.2.1 Importance of Personal Protective Equipment: PPE

Workplace hazards that could cause injury include the following:

- Intense heat
- Impacts from tools, machinery, and materials
- Cuts
- Hazardous chemicals

Fig. 11.2.1 General PPE guidelines

Ensure:

- Protect against specific hazard(s) encountered by employees
- Comfortable to wear
- Must not restrict vision or movement
- Durable and easy to clean and disinfect
- Must not interfere with the function of other required PPE

11.2.2 Eye/Ear Protection

For Employees who use spectacles, they must use

- Goggles that can fit comfortably over corrective eyeglasses without disturbing their alignment
- Goggles that incorporate corrective lenses mounted behind protective lenses

		
Safety Glasses / Goggles		**Ear Plugs**

11.2.3 Head Protection

Protection from:

- Objects might fall from above and strike them on the head
- They might bump their heads against fixed objects, such as exposed pipes or beams
- They work near exposed electrical conductors

Head Protection Criteria

In general, protective helmets, or hard hats, should:

- Resist penetration by objects,
- Absorb the shock of a blow,
- Be water resistant and slow burning,

Fig. 11.2.2 Safety Helmet/Hard Hat

11.2.4 Foot and Leg Protection

Some of the potential hazards that would require foot and leg protection include:

- Heavy objects such as barrels or tools that might roll onto or fall on employees' feet
- Sharp objects such as nails or spikes that might pierce the soles or uppers of ordinary shoes
- Molten metal that might splash on feet or legs
- Hot or wet surfaces
- Slippery surfaces

Foot and Leg Protection Choices

- Safety Shoes. These have impact-resistant toes and heat-resistant soles that protect against hot work surfaces common in rooftop installation areas.
- May have metal insoles to protect against puncture wounds

- May be designed to be electrically conductive for use in explosive atmospheres
- May be designed to be electrically nonconductive to protect from workplace electrical hazards

Fig. 11.2.3 A pair of ISO 20345:2004 compliant S3 safety boots

Fig. 11.2.4 Non-Protective Footwear

11.2.5 Hand and Arm Protection

- Use proper hand gloves – 'Electrically Insulated Gloves' – for handling electrical connections
- Two kinds of gloves are commonly used: PVC Gloves and Cotton Gloves

Fig. 11.2.5 Right way: Use protective hand gloves

Fig. 11.2.6 Wrong way: Use of bare hands

11.2.6 Safety Belt/Body Harness and Overalls (Full Body Suit)

Safety Belt/Harness provides the following support:

1. Personal protection against falling from high structures
2. Enables comfortable working position with protection against slipping or imbalance
3. Climbing to a location which is inaccessible from inside the building/household using an anchorage and suspension line

Overalls/protective PVC coated jackets provide protection from:

1. Extreme or harsh weather conditions
2. Injury from sharp tools to the body
3. Chemicals/fluids which should not come in contact with the body

Fig. 11.2.7 Safety harness

Fig. 11.2.8 Full body suit and safety harness

Fig. 11.2.9 Safety jacket

Personal Protective Equipment

Fig. 11.2.10 Snapshot of all PPE

Tips

1. A PV Installer should always keep in mind that safety at site refers to:
   - Safety of the PV Installer himself
   - Safety of others at the site
   - Safety of all tools/ equipments used at site
   - Safety of whole PV installed set up

Notes

UNIT 11.3: Identification and Mitigation of Safety Hazards

Unit Objectives

At the end of this unit, you will be able to:

1. Identify environmental hazards associated with photovoltaic installations
2. Identify electrical hazards
3. Identify personal safety hazards or work site hazards and Mitigate hazards

11.3.1 Overview

Any photovoltaic system is designed to fulfill a specific load requirement. Almost all grid-connected PV arrays use hundreds of PV modules having both series and parallel connection to generate large amount of electrical power. Operating voltages may be greater than 600 Vdc and currents may be hundreds of amperes!!! Many Off-grid PV systems have lesser number of modules but they use battery bank to store energy. Generally, each unit of battery is of 12 Vdc and can produce currents which can be hazardous causing severe burns.

Types of Hazards associated with PV installations

The safety considerations during an installation can be understood with respect to the various kind of hazards which could exist. These are broadly classified in the following flowchart:

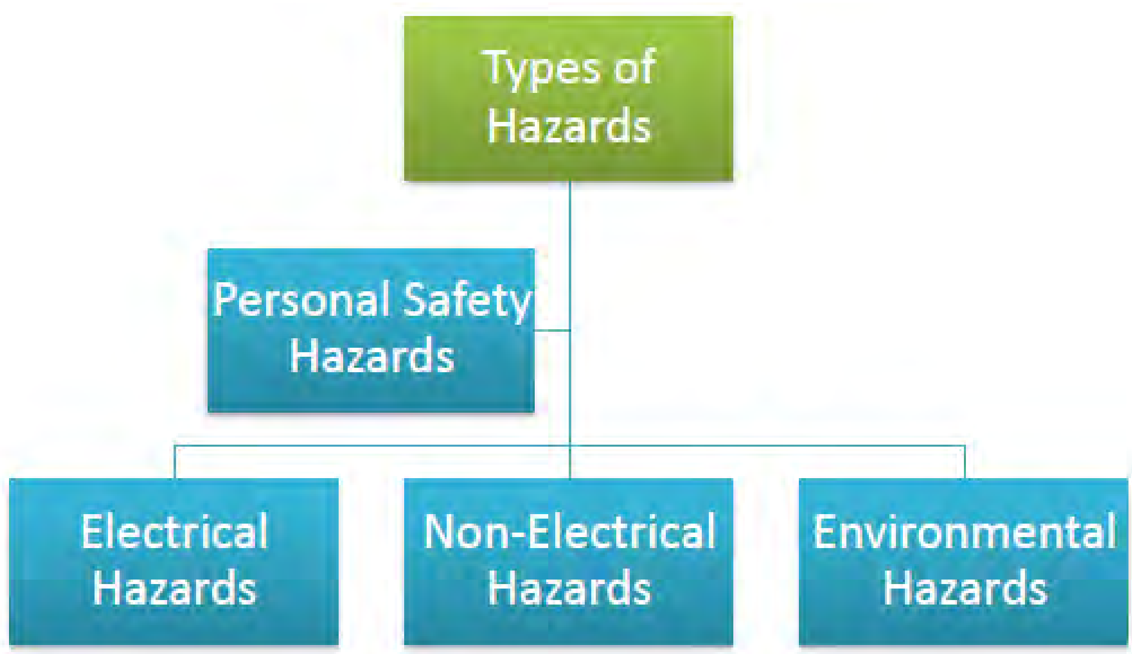


Fig. 11.3.1 Types of hazards associated with Solar PV Installations

11.3.2 Personal Safety Hazards

This has been elaborately covered in the previous unit on "Use and Maintain Personal Protective Equipment (PPE)".

Electrical

Environment Safety Hazards

Non-electrical hazards

There is an improper opinion among many persons that no one can get hurt while working on a small solar PV system. But the reality is not so. One can get injured while working on any configuration of PV system. Thus, safety should be the first and foremost point to be kept in mind.

Some common non-electrical hazards are as follows:

1. Exposure to sunlight because
   - PV systems are installed at the locations where the radiation is very good and no shading exits. This may cause severe sun burns (especially in the summer seasons)
2. Bites of Insects, Snakes and other Vermin because
   - Spiders and other insects often inhabit the junction boxes
   - Snakes use the shade built by the PV array
   - Ants are also found under PV arrays or near battery storage boxes
   - Some wasps build nests in the array framing
3. Cuts and Bumps because
   - Most of the PV systems include metal framing, junction boxes, cables, nuts and bolts, etc
   - Many of PV installation components have sharp edges and can injure you if you are not cautious
4. Falls and Strains when working at height because
   - Walking with heavy loads for installation in remote areas
   - During strong winds, PV module behaves like a wind-sail and can make you fall from ladder
5. Burns due to high metal temperature because
   - Metallic surfaces which are left in sun can attain higher temperatures (~ 80 °C) which can cause burns
   - Concentrating solar PV system can also cause burns

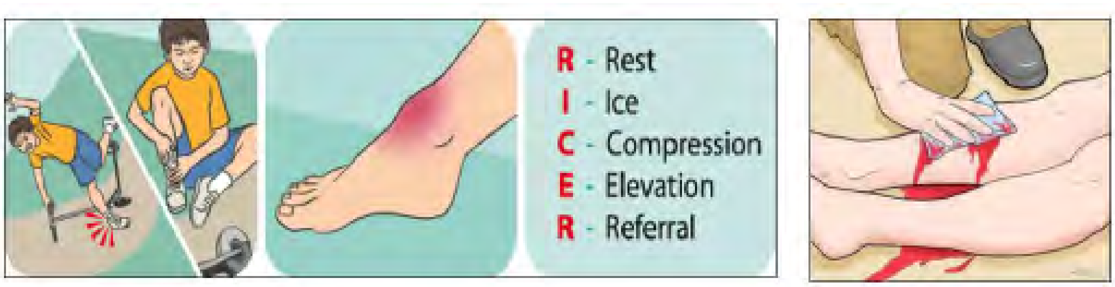


Fig. 11.3.2 Safety hazards: burns and cuts

11.3.3 Electrical Hazards

The most common electrical mishaps lead to electrical shocks or/ and burns, contraction of muscles and other severe injuries linked with falling after the electric shock. These injuries can take place anytime during the entire process of PV installation. It is difficult to estimate the severity of electrical injury because the resistivity of human body varies from thousand ohms to several thousand ohms. This variation in resistivity depends upon the skin moisture at the time of accident. Even a very less current (of order mA) is also sufficient to cause damage. A list of DC and AC current (in mA) and their linked-up electric shock hazards are given below:

Table 11.3: Electrical hazards associated with particular AC and DC levels

Reaction After The Electric Shock	CURRENT	
	DC	AC
Perception: tingle, warmth	6 mA	1 mA
Shock: retain muscle control, reflex may result into injury, burns	9 mA	2 mA
Severe Shock: lose in muscle control, can't let-go, severe burns, asphyxia	90 mA	20 mA
Ventricular Fibrillation: may cause death	500 mA	100 mA
Heart Frozen: temperature of human body rises, death occurs in minutes	Greater than 1 A	Greater than 1 A

Any type of electrical shock is always painful and a minor injury is often provoked by the reflex action of jumping back away from the cause of the electrical shock.

ATTENTION!!!

If a PV array is having more than two modules, then, an electric shock hazards should be supposed to exist

11.3.4 Battery Hazards

Battery hazards

Any PV system with battery/ battery bank is a potential hazard. The major areas of concern are:

1. Electrical burns
   - Shorting the terminals of any typical battery of a PV system may cause severe burns and even death also (electric shock can occur even at low battery voltage)
2. Acid burns
   - Acid of any type of battery can create burns if it get in touch with uncovered skin
   - Battery acid's contact with human eye can result into blindness
3. Fire or Gas explosion
   - Most of the batteries used in solar PV installations release Hydrogen gas during their charging
   - This is a flammable gas and can cause gas explosion and fire.

Fig. 11.3.3 How to lift a battery without causing injury to back/spine

11.3.5 Inverter Hazards

Inverter should be installed at a place where people can't reach frequently because during operation the surface temperature is very high and can cause a potential burn hazard. Ensure that the temperature of location should be in the range of -25 to +65 degree.

11.3.6 AC Power Hazards

If AC power output is required, then PV inverter is needed to be installed for the conversion of DC power from PV array/ modules to AC power. PV inverter operates at high voltage both at the input and the output ends, therefore, there is enough current to cause electric hazards. Hence, use of PPE is very critical for personal safety.

11.3.7 Preventive Measures to be Taken by a PV Installer

A PV Installer should always be cautious at site and follow safety measures. In this section of book, the preventive measures are detailed in accordance with the installation procedure.

Following are the general preventive measures that should be taken by a PV Installer throughout the PV system installation:

- Identify and understand the companies policies required for work place safety
- Identify the individual to contact if some accident happens
- Identify the requirements of safe work
- Implement the safe work flow procedure
- Use and maintain Personal Protective Equipment (PPE)
- Know the location of First Aid box

- Read and understand the proper usage of tools/ equipments
- Do proper tagging and markings of equipment
- Add labels or warning signs wherever required for the benefit of technicians as well as customer

11.3.8 Mitigation Measures to be Taken After the Occurrence of Hazards

In spite of all precautions/ preventions, there are chances of hazards. So, a PV Installer should always be aware of the mitigation measures to be taken if some mishap occurs. Following are the important mitigation measures that should be taken after the occurrence of hazards:

STEP 1: Rush towards the First-Aid place

Never Wash Burns With Water

STEP 2: Apply First Aid on burns/ injuries/ wounds

STEP 3: Apply Sodium Hydroxide (NaOH) solution when burns are due to battery's acid

STEP 4: Take the injured person to Medical room

STEP 5: Look for the Supervisor/ Team leader

STEP 6: Call the Doctor/ Medical Officer

Types and use a Fire Extinguisher?

Fig. 11.3.4 Some common fire classifications

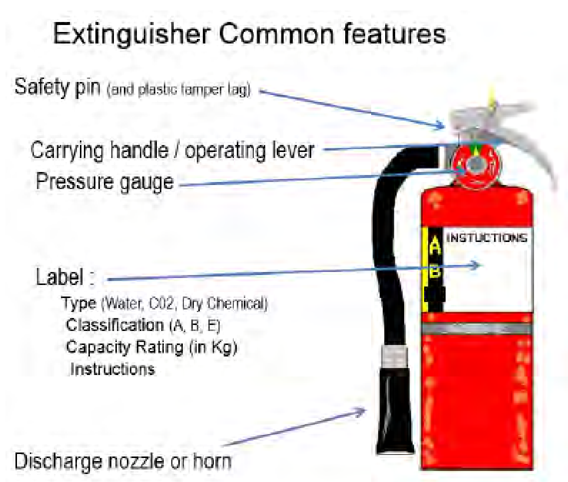


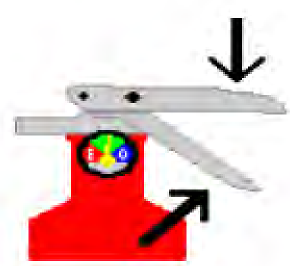
Fig. 11.3.5 Extinguisher common features

Steps to operate fire extinguishers:

STEP 1: Pull the Pin

STEP 2: Aim Low at the Fire

STEP 3: Squeeze the Lever



STEP 4: Swipe from Side to Side Slowly

Tips

Work safety is a full-time responsibility of every worker at the site. Practicing work safety includes:

- Clean job area
- Good work habits
- Proper knowhow of equipment and their respective use
- Awareness of all types of hazards and measures to avoid them
- Knowledge of location and usage of First Aid
- Periodic review of the work safety procedures

Notes

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UNIT 11.4: Work Health and Safety at Heights

Unit Objectives

At the end of this unit, you will be able to:

1. Check access from ground to work area to ensure it is safe and in accordance with requirements
2. Reassess risk control measures, as required, in accordance with changed work practices and/or site conditions and undertake alterations
3. Inspect/install fall protection and perimeter protection equipment ensuring adequacy for work and conformance to regulatory requirements
4. Identify approved methods of moving tools and equipment to work area and minimize potential hazards associated with tools at heights
5. Select and install appropriate signs and barricades
6. Place tools and materials to eliminate or minimize the risk of items being knocked down
7. Dismantle safety Power Plant in accordance with sequence and remove from worksite to clear work area

11.4.1 Safe Means of Accessing the Site and Minimize Potential Tool Hazards

Fig. 11.4.1 Warning line

Warning Lines

Fig. 11.4.2 Lanyard, lifeline and roof anchors

Fig. 11.4.3 Understanding the correct way to use a body harness

Fig. 11.4.4 Improper Placement of Tools

Tips

- Perform regular maintenance
- Use right tool for the job
- Inspect all tools before use
- Use the right personal protective equipment (PPE)
- Report to your supervisor any unsafe tool

Reassess risk control measures, as required, in accordance with changed work practices and/or site conditions and undertake alterations.

- The first safety rule to keep in mind when working with photovoltaic panels or other PV components is; always stop working in bad weather.
- Never work when it's raining, immediately after rain or in wet or slippery conditions or with wet tools.
- PV panels can be blown around by the wind or a storm which can result in you falling or damage to the PV system.
- Do not apply pressure on PV photovoltaic panels by sitting or stepping on them or they might break and cause bodily injury, electrical shock or damage to the solar panels. Also never drop anything on the PV panels.
- Make sure your entire PV system is properly and safely earth grounded to prevent electrical shock and injury.
- Cover your photovoltaic solar panels with an opaque material during wiring to stop or prevent electricity production.
- Do not use artificial or magnified light on the photovoltaic solar panels
- Inspect all your power tools to ensure that they are working safely prior to starting the installation of your PV system
- Always get a second person to securely hold ladders as you climb and use rubber latter mats to prevent the ladder from slipping.

11.4.2 Inspect/Install Fall Protection

Fall Protection Equipment

Fall protection equipment is used in situations where a potential to fall cannot be avoided. Equipment used will both protect the fall and absorb some energy of the fall. Examples would be the traditional harness plus lanyard incorporating energy absorbance, safety nets, air bags.

Fall protection systems

- A fall protection system should be fitted such that there is adequate clearance for it to deploy, and to prevent the installer from hitting an obstruction or the ground before the fall is stopped.
- Many recognized practices specify either a guardrail system, safety net system, or personal fall protection system to protect the installer when exposed to a fall of 1.8 m or more from an unprotected side or edge.
- Fall protection procedures should provide for a rescue to be carried out if the installer is left suspended from the working place.
- Safety nets or airbags should be located as close as possible to the working level to enhance their effectiveness.
- Safety nets should be installed as close as practicable under the walking/working surface on which surveyors are working.

Fig. 11.4.5 Guardrails

A fall protection system should not be used in a manner:

i. Which involves the risk of a line being cut

ii. Where its safe use requires a clear zone (allowing for any pendulum effect)

iii. Which otherwise inhibits its performance or renders its use unsafe

Fig. 11.4.6 Safety Nets for High-Rise buildings

11.4.3 Use of Safety Signs

General Safety Signs

Fig. 11.4.7 General safety signs

Prohibitory Safety Signs

Fig. 11.4.8 Prohibitory safety signs

Exercise

1. Select and identify the right PPE for doing the electrical installation of a Solar PV system
2. Select and identify the right PPE while working at height
3. Select the right type of fire extinguisher for electrical fire
4. Demonstrate the use a fire extinguisher
5. Demonstrate and explain the importance of all the Personal Protective equipments

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12. Customer Orientation for a Solar PV System

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Unit 12.1 – Demonstrate Working Principle of the Solar PV System

Unit 12.2 – Hand Over Documentation on the Use of the System

SGJ/N0107

Key Learning Outcomes

At the end of this module, you will be able to:

1. Explain the functioning of the system to a customer along with procedures for start-up, shutdown and maintenance
2. Explain what customers should expect from a PV system
3. Explain documentation that needs to be preserved by the customer

UNIT 12.1: Demonstrate Working Principle of the Solar PV System

Unit Objectives

At the end of this unit, you will be able to:

1. Demonstrate start-up and shut-down procedures
2. Demonstrate maintenance and safety procedures to the customer
3. Explain what the customer can expect from the system under normal and abnormal conditions

12.1.1 Demonstrate Start-up and Shutdown Procedures

Once commissioned, a PV system does not need to be shut down and started up under regular operation. The customer needs to shut down and start up the system under specific circumstances as described below:

- There is any malfunction that can be observed in the inverters or batteries such as unusual noise, overheating, fumes etc.
- The customer finds voltage fluctuations in your electricity supply and is not sure of the reasons
- There is a safety event related to the PV system or to the general electrical wiring in the facility
- The customer is instructed to switch off the system by the service provider

A customer will need to understand the system with a simple block diagram and locate the specific switches that need to be turned off or on. The diagram below shows the shutdown sequence in a simple block diagram understandable to the customer.

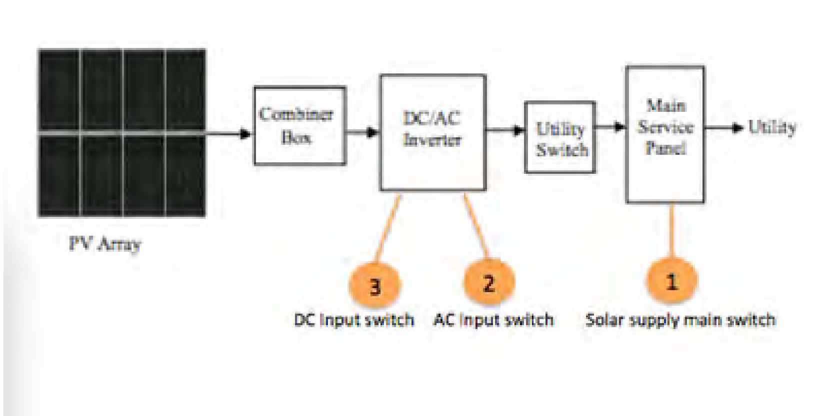


Fig. 12.1.1 Shut down sequence

Shut down sequence

Step 1: Switch off the solar supply main switch in the main service panel

Step 2: Switch off the AC input or AC isolator switch on the solar inverter

Step 3: Switch off the DC input switch, which connects to the solar array

The start up procedure will operate in reverse. It is extremely important to follow the above mentioned shutdown sequence because the probability of arcing is more at DC breaker than at AC breakers. So the AC breakers are switched off first to isolate load and reduce the generated current. This is safer and also leads to increased life of the protection devices used in the circuit.

12.1.2 Explaining System Maintenance to the Customer

Note: The normal operation of the PV system is automatic and does not require any intervention by the customer! However, following basic procedures to clean the PV modules is essential for good performance of the system. Some tips for this are described below:

Fig. 12.1.2 Clean without stepping on the panels or placing heavy objects on them

12.1.3 Explain What the Customer Should Expect From the System

There may be significant variation in how the system performs under varying conditions such as rain, fog and sunshine. You should be ready to provide answers to questions or doubts customers may have. Here are a few of them:

1. **How many back up hours should I expect from the system?**
    - Explain how many backup hours the system is designed for if there is full sun shine
    - Explain how many cloudy days will fully discharge the batteries under expected load
    - Explain how fog can affect the backup hours
2. **How much savings will I realize from the system?**
    - Explain that month to month output from the system will vary based on seasons and weather
    - Explain what is the estimated yearly savings in electricity they can expect. This should be available from the initial design and payback calculations done by the design team
3. **How will I get service if there is a problem?**
    - Provide numbers to call if there is a problem
    - Provide numbers to call if there is an emergency such as electric shock or fire
    - Explain the cost of receiving service
    - Explain what costs are covered by warranties and which ones are not

4. **How much will the system benefit me financially?**

   The customer may ask this question at the time of sales or even at the time of handover. You should be prepared to explain and work out the monthly benefit roughly. If it is a battery-backed system, calculate the amount of energy used daily from the batteries, using the following formula:

   Energy used daily from batteries =

   (Ampere-hour rating of the battery bank) X (Voltage of the bank) X (Depth of Discharge)

In an off-grid system, this energy should be provided entirely by the solar array, which is a free and renewable source. So the money saved will be the cost of the current energy sourced used for backup. It could be grid power or diesel power.

In a grid-tied system, the customer is offsetting the use of grid power using solar power. A simple way to calculate savings is to multiply the average expected output from the solar array by the cost of grid power. You should consult the data captured during site survey to do these calculations.

Note that the above methods are approximate and do not include a number of variables such as the cost the customer may be paying to service the loan taken for a solar system. You should consult an engineer or manager for a precise calculation of financial benefits and payback for the customer.

Notes

UNIT 12.2: Hand over Documentation on the Use of the System

Unit Objectives

At the end of this unit, you will be able to:

1. Deliver all relevant documentation to the customer

12.1.2 Hand Over Documentation On the Use of the System

Hand over documentation and explain the importance of each document to the customer, as listed in the table below:

Table 12.1: Important documents and their significance

	Document	Purpose
1	A layout diagram (see Fig 4 below)	• Shows where different components are located for the customer's specific installation. Useful when an engineer or technician arrives for general maintenance or troubleshooting
2	Single line diagram (See fig 5 below)	• Shows the design of the system. Useful when an engineer or technician arrives for general maintenance or troubleshooting
3	Approvals and permits (varies depending on state and distribution company) • Related to subsidies • Related to grid connection • Related to structure	• Approval may be needed from a certified chartered engineer for building structural integrity. • Subsidy application documents which will vary based on the state government process • Subsidy approval document, if received • The local utility will have to approve any connection to the grid supply for the case of a grid-tied system. Such approval has to be kept ready for renewal at the appropriate time
4	Product documentation • Invoices for all products purchased • Ratings and data sheets of all products purchased • Warranties of all products	• Very essential to get a replacement when a product malfunctions
5	Service documentation • Invoice of the installation and O&M service provider along with contact details	• Very essential to ensure the right level of service is received

- Service contract with the installation and maintenance provider. This should include the following details:
  - At what intervals will scheduled maintenance be performed?
  - What scheduled maintenance procedures are included in the contract?
  - What will be the response time when there is a service outage?
  - What sort of system problems will incur an additional cost for the customer?

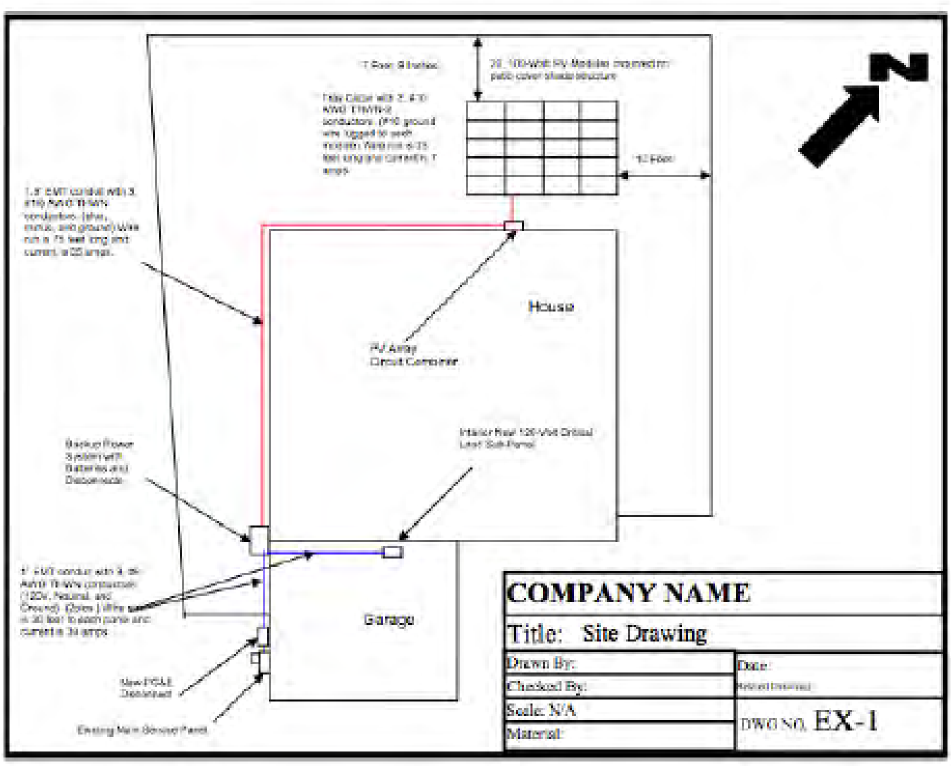


Fig. 12.2.1 Sample layout diagram

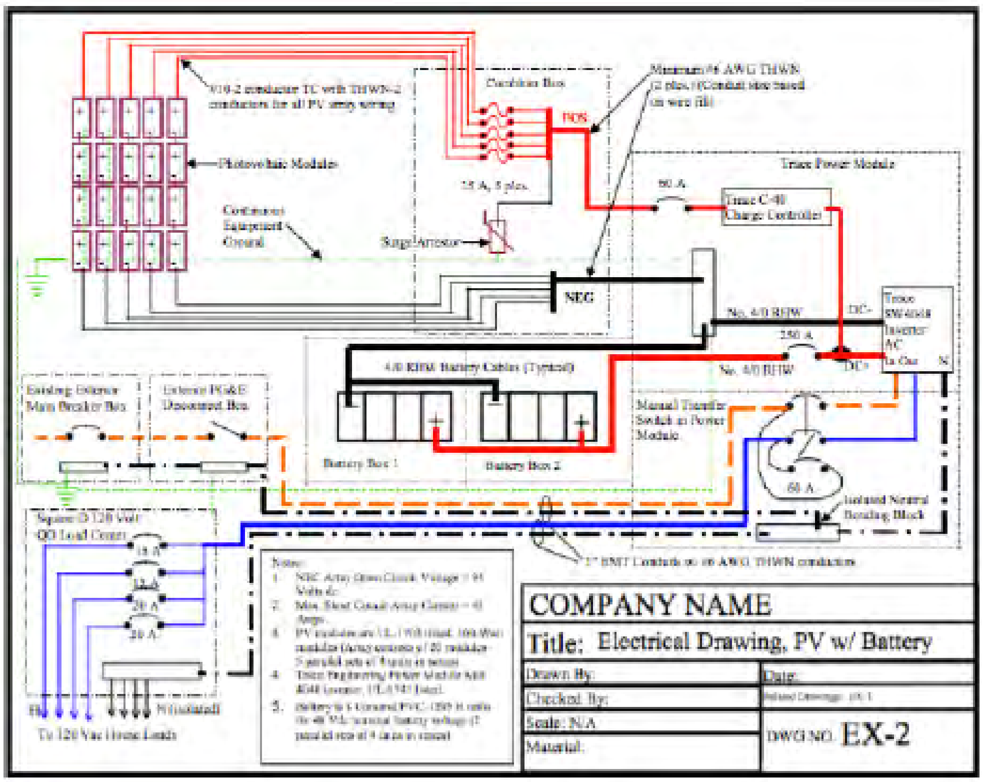


Fig. 12.2.2 Sample single line diagram

Exercise

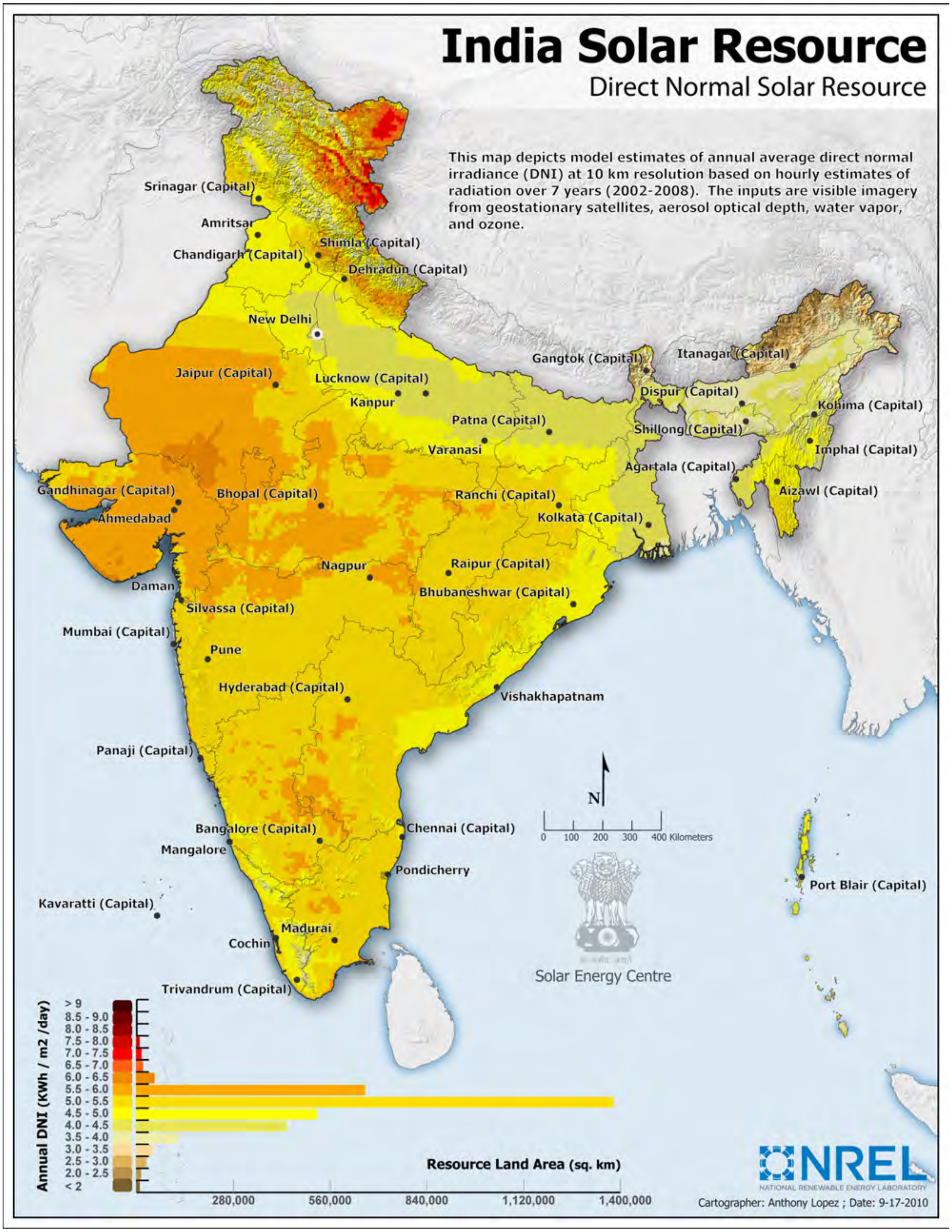
Activity 1: Make a list of all the safety and maintenance activities you will communicate to your customer

Activity 2: Prepare a draft service contract for your customer detailing the maintenance activities which will be provided to them. Make sure that you cover all the relevant details highlighted in the table provided for you in this unit.

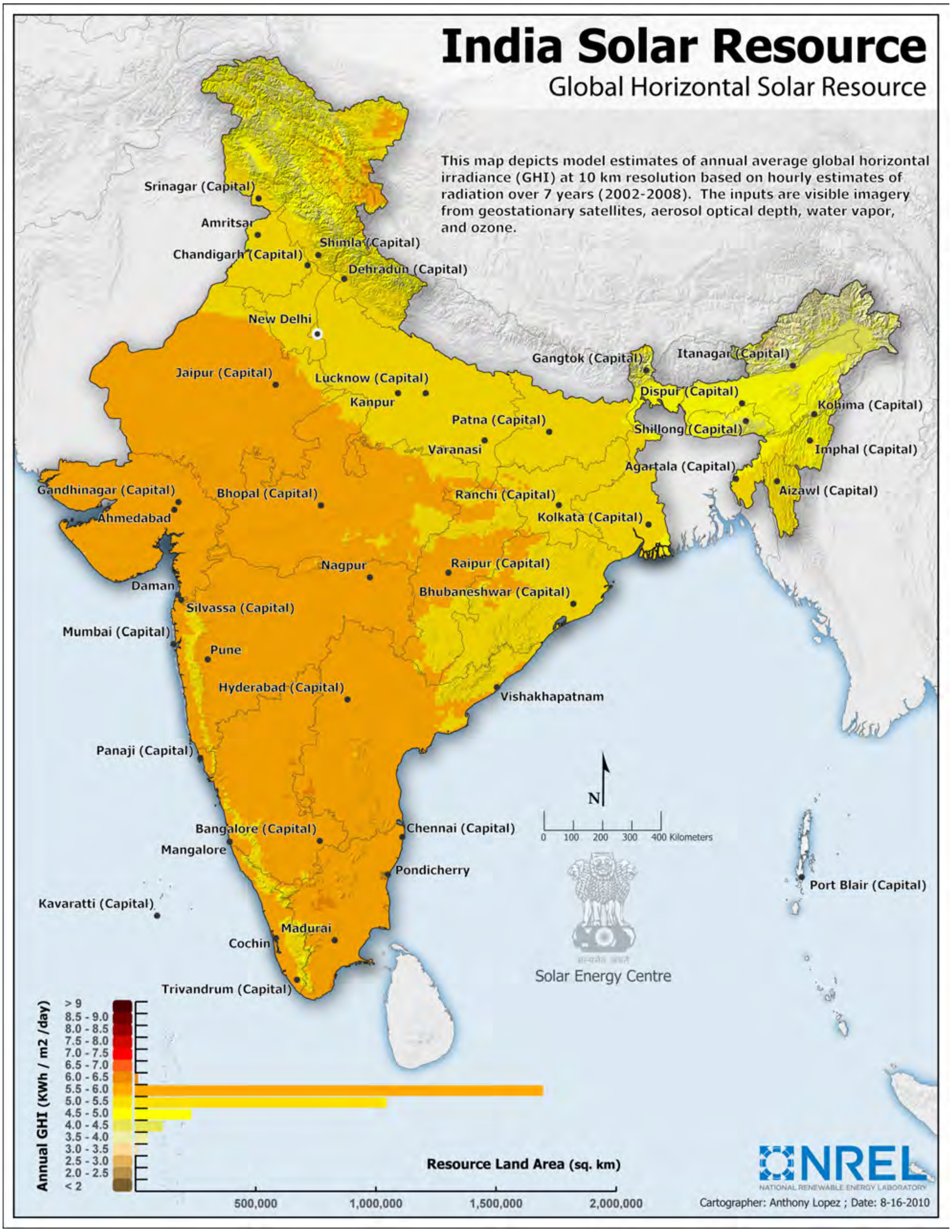
1. Why does the customer need to know how to start up a solar PV system?
   - b. There can be overheating of the inverter or battery
   - c. There can be random voltage fluctuations in the electricity supplied
   - d. There can be a problem with the wiring of the system
   - e. All of the above
2. Why is it important to file or document all the invoices and warranties related to a purchase?
   - c. There can be a problem with the working of the system or a component.
   - d. This is required for any potential replacement or servicing of the system or a component
   - e. This will ensure better after sales service and lead to greater customer satisfaction.
   - f. All of the above

14. Annexures

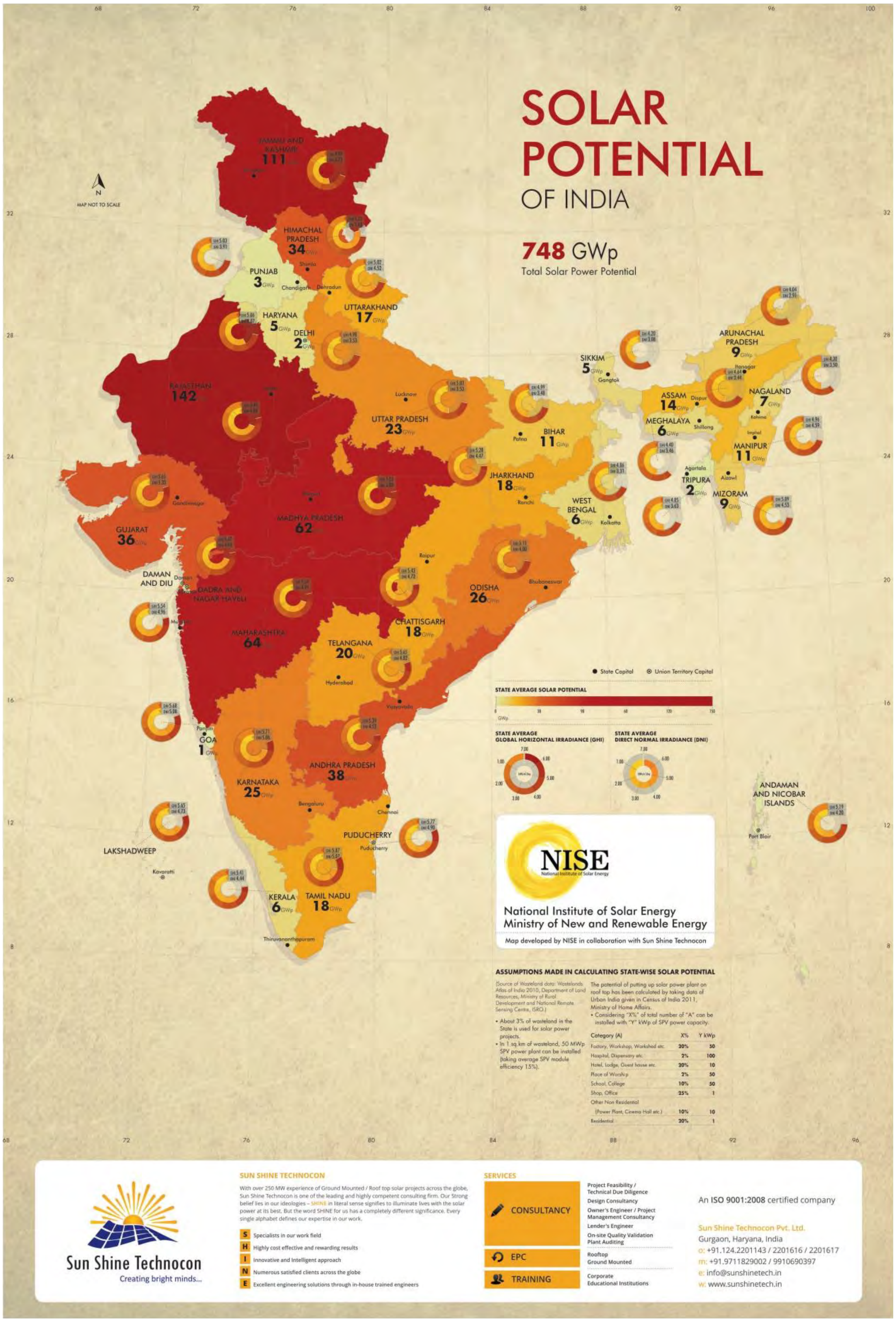
Annexure 1: Direct Normal Solar Resource



Annexure 2: Global Horizontal Solar Resource



Annexure 3: Solar Potential of India: 748 GWp



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