TRAINER GUIDE BOOK

FOR INSTALLERS AND OPERATORS

OF

SOLAR PHOTOVOLTAIC SYSTEMS TRAINING

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CHAPTER ONE

1.1 The Development of Photovoltaics

Photovoltaic systems generate electricity directly from sunlight, based on the ***Photovoltaic Effect***. Such systems produce clean, reliable electrical energy without consuming fossil fuels, and can be used in a wide variety of applications.
This *Photovoltaic Effect* was best understood by Albert Einstein in 1905, a leading scientist in the early last century.
Solar cells are produced from silicon (e.g. out of sand) in a highly sophisticated process, resulting in solar cells, which later are assembled as solar panels.
Efficiency of solar cells is in the range of 10 to 15% for normal application in photovoltaic [PV] systems. In laboratory experiments, the efficiency is reaching 30%.
PV panels are delivering electric power as direct current (DC) and low voltage (Normally 12V). Other system outputs can be considered if feasible.

Solar cell efficiency is defined as the ratio of output electric power to the amount of power from the sunlight falling on the cell.

PV technology is being used in a large number of applications such as lighting, water pumping, telecommunication, refrigeration for health care, marine and air navigation, and other residential and commercial applications, as well as in devices like pocket calculators, watches etc.

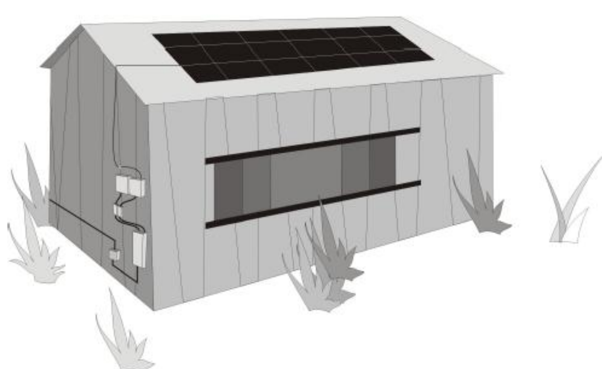


Figure 1.1: *Solar powered building*

1.2. Advantages of Photovoltaic Technology

Photovoltaic systems form a reasonable alternative to conventional power supply by generation systems based on conventional fossil fuel based technology (e.g. diesel gen sets, Kerosene lamps, dry cell batteries.

1.2.1. Reliability

Even in harsh environmental conditions, photovoltaic systems have proven their reliability. PV arrays provide stable power supply in situations where continuous operation of other technologies is critical.

Figure 1.2: *Photovoltaic system in harsh environmental conditions*

1.2.2. Durability

Crystalline PV cells available today show no degradation even after 25 years of use, while amorphous cells show degradation after some years. It is likely that future crystalline cells will last even longer.

Crucial for long lifetime of PV panels is a reliable framing protecting the cells against humidity and dust.

1.2.3. Low Maintenance Cost

Transporting materials and personnel to remote areas for equipment maintenance or service work is expensive. Since PV systems require only periodic inspection and occasional maintenance, these costs are usually less than with conventionally fuelled systems (such as diesel powered generators).

However, high investment costs are needed prior to installation and operation of PV systems

1.2.4. No Fuel Cost

Since no fuel source is required, there are no costs associated with purchasing, storing or transporting fuel.

However, batteries need attention, and have to be replaced after a couple of years.

1.2.5. Independence

PV systems can be operated in remote areas independently of national or local grids.

However, the energy service provided is rather limited, compared with grid connection or diesel gen sets, due to the high investment costs, urging the system size as small as possible.

Insolation is defined as the amount of solar radiation falling on a given area and is measured in Watt per square meter.

1.3. Photovoltaic System Components

Photovoltaic systems consist of several components:

PV Panel

A number of PV cells sandwiched between a glazing material and an encapsulating substrate, providing DC current at 12 V output voltage in normal cases

PV Array
A PV array is a combination of more than one panel. Sometimes the term *module* is used instead of *panel*.

Controller
It is also called charge controller and is used to regulate battery charging and discharging.

Battery
Battery is a storage device that stores electrical energy (DC) in the form of chemical energy.

DC Loads
Appliances (light bulbs, radio, TV, fans, motors, refrigerators, etc) powered by direct current are called DC loads.

AC Loads
Appliances (light bulbs, radio, TV, fans, motors, refrigerators, etc) powered by alternating current are called AC loads

1.4. Photovoltaic System Types

Photovoltaic systems can be designed according to system purpose: For example, many residential systems use battery storage to power appliances during the night. In contrast, water pumping systems often operate only during the day and require no electrical storage device. A large bigger commercial system would likely have an inverter to power AC appliances; whereas a small solar home system [SHS] in a remote village will power only DC appliances and wouldn't include an inverter. Some systems are linked to grid, while others operate independently.

1.4.1. Stand-Alone Systems

These systems contain all components, including the application (load), in a single package. Battery is an important component of such a system that can power loads at night or in cloudy weather. System loads can be powered by the batteries during the day or night, continuously or intermittently, regardless of weather. In addition, a battery bank has the capacity to supply high-surge (large amount of current) for a brief period, giving the system the ability to start electric motors.
Batteries form one of the most sensitive parts of a SHS. They store solar energy for providing energy service during low radiation (cloudy weather, at night).
Batteries are controlled by charge controllers in order to avoid overcharging and deep discharging, which would shorten the life time if the battery or even might destroy it
A charge controller is automatically disconnecting the module from the battery bank when it is fully charged. Moreover, charge controllers also disconnecting the load from the battery in case of reaching the level of deep discharge.

PRACTICAL WORK OF CHAPTER # 1

1. Show PV system components.

i. Show different components of PV system to the student i.e. PV module, battery, controller, inverter and AC and DC lights.

2. Show different types of PV systems.

i. Show a stand alone system [SHS] to the students.
ii. Show pictures of PV mini grids and PV pumping stations.

CHAPTER TWO

2. THE SOLAR RESOURCE

In this chapter, you will learn

a) The solar geometry regarding earth's latitude, azimuth, orientation and tilt angle.
b) Types of solar radiation.

2.1. Introduction

The term for solar radiation striking a surface at a particular time and place is insolation. When insolation is described as power, it is expressed as number of watts per square meter and usually presented as an average daily value for each month. On a clear day, the total insolation striking the earth is about 1,000 watts per square meter. However, many factors determine how much sunlight will be available at a given site, including atmospheric conditions, the earth's position in relation to the sun, and obstructions at the site.

2.2. The Solar Geometry

The earth's distance from the sun and the earth's tilt affect the amount of available solar energy. The earth's northern latitudes are tilted towards the sun from June to August, which brings summer to the northern hemisphere. The longer summer days and the more favourable tilt of the earth's axis create significantly more available energy on a summer day than on a winter day.

In the northern hemisphere, where the sun is predominantly in the southern sky, photovoltaic modules should point towards the southern sky to collect solar energy. Designers should optimize solar collection by positioning the array to take full advantage of the maximum amount of sunlight available at a particular location. Fortunately, the sun's path across the sky is orderly and predictable.

The site's latitude (the distance north or south of the earth's equator) determines whether the sun appears to travel in the northern or southern sky. For example, Islamabad, Pakistan, is located at approximately 33 degrees north latitude, and the sun moves across the southern sky. At midday, the sun is exactly true south.

2.2.1. Orientation

The sun's apparent location east and west of true south is called azimuth, which is measured in degrees east or west of true south. Since there are 360 degrees in a circle and 24 hours in a day, the sun appears to move 15 degrees in azimuth each hour (360 degrees divided by 24 hours).

Daily performance will be optimized, if fixed modules are faced true south. An array that deviates 15 degrees from true south will collect 90 percent of the sun's available energy on an average daily basis.

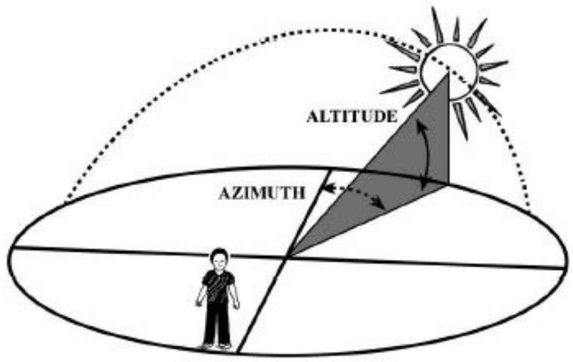


Figure 2.1: *Azimuth and altitude for all northern latitudes*

Local climate characteristics should be carefully evaluated and taken into consideration. For example, you can compensate for early morning fog by adjusting the photovoltaic array west of south to gain additional late afternoon insolation.

2.2.2. Tilt Angle

The sun's height above the horizon is called altitude, which is measured in degrees above the horizon. When the sun appears to be just rising or just setting, its altitude is 0 degrees. When the sun is true south in the sky at 0 degrees azimuth, it will be at its highest altitude for that day. This time is called solar noon.

A location's latitude determines how high the sun appears above the horizon at solar noon throughout the year. As a result of the earth's orbit around the sun with a tilted axis, the sun is at different altitudes above the horizon at solar noon throughout the year.

The highest average insolation will fall on a collector with a tilt angle equal to the latitude. You must consider specific seasonal use characteristics to optimize a system's performance.

The following list outlines the optimum tilt angle of a photovoltaic array for different seasonal loads.

a) Year-round loads: Tilt angle equals latitude.
b) Winter loads: Tilt angle equals latitude plus 15 degrees.
c) Summer loads: Tilt angle equals latitude minus 15 degrees.

Adjusting the tilt angle of the PV array seasonally can increase power production significantly for year-round loads.

Photovoltaic arrays work best when the sun's rays strike perpendicular (90 degrees) to the cells. When the cells are directly facing the sun in both azimuth and altitude, the angle of incidence is "normal". Figure 2.2 illustrates the effect of this tilt angle on available monthly insolation.

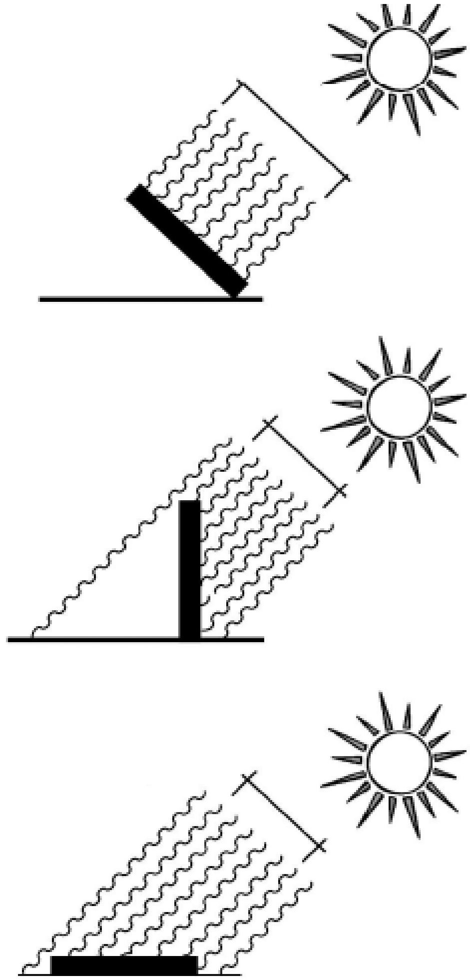


Figure 2.2: *Effect of tilt angle*

2.3. Types of Solar Radiation

Solar radiation received at the earth's surface can be divided into two types.

2.3.1. Direct Solar Radiation

The solar radiation that reaches the earth's surface without being diffused is called direct solar radiation.

2.3.2. Diffused Solar Radiation

As sunlight passes through the atmosphere, some of it is absorbed, scattered, and reflected by clouds (moisture and ice particles), particulate matter (dust, smoke, haze, and smog), and various gases. Solar radiation reaching the earth's surface finally is called diffused solar radiation. It has no special direction but comes from various directions at the same time. Due to that fact, one can realize that diffuse radiation is not causing shadow, as direct radiation does if obstacles are in its way.

Direct solar radiation produces more power than the diffused solar radiation when it strikes on PV modules, because direct solar radiation is much more intense than the diffused solar radiation. In cloudy weather conditions, diffused solar radiation will also produce power when it strikes on PV modules but amount of power will be less.

Key Points

1. On a clear day, the total insolation striking the earth is about 1,000 watts per square meter.
2. Designers should optimise solar collection by positioning the array to take full advantage of the maximum amount of sunlight available at a particular location.
3. Daily performance of fixed modules is optimised, if they are faced true south, which is the best generic orientation for locations in the Northern hemisphere.
4. Designers should evaluate the local climate characteristics before optimisation.
5. The highest average insolation will fall on a collector with a tilt angle equal to the latitude.
6. Photovoltaic arrays work best when the sun's rays strike perpendicular (90 degrees) to the cells.
7. In cloudy weather conditions, diffused solar radiation will also produce current when it strikes on PV modules but amount of current will be less.

PRACTICAL WORK OF CHAPTER # 2

1. To check the effect of orientation and tilt angle on PV panel output.

i. Place a PV panel at a tilt angle of 15 degrees (latitude near equator) with the help of an inclinometer and a compass facing true south or north.
ii. Measure the PV panel output i.e. open circuit voltage and short circuit current, with volt-ohm millimetre (VOM). Settings of VOM must be according to your requirements. For example, if you are checking open circuit voltage, the VOM must be set for DC volts of higher value than the open circuit voltage of PV panel.
iii. Record the readings.
iv. Now change the tilt angle from 33 to 70 degree and again record the readings.
v. In next step, keep the tilt angle equal to 33 degree but change the orientation from true south to true east and again record the readings.
vi. Compare the three readings with each other. You will find that
PV panel gave maximum output at tilt angle equal to latitude, i.e. 33 degree and facing true south.

Result: Orientation and tilt angle are very important to get maximum output from PV panel.

CHAPTER THREE

3. PHOTOVOLTAIC MODULES

In this chapter, you will learn

- The principle of photovoltaic phenomenon.
- Various components of a module that define the type of a module.
- Series circuits, parallel circuits and series and parallel circuits of modules to obtain required output voltage and current.
- Brief description of performance curve including maximum power point, open circuit voltage and short circuit current.
- Four major factors that affect the performance of the module.
- Use of blocking and bypass diodes in modules.

3.1. Photovoltaic Principle

Photovoltaic modules and arrays have proven to be reliable sources of electrical energy, but they must be properly designed for maximum effectiveness.

The basic unit of a photovoltaic system is the photovoltaic cell. Cells are electrical devices that convert sunlight into direct current electricity through the photovoltaic effect. Photovoltaic cells do not need moving parts to create electrical energy from the sun's energy. When sunlight strikes a cell, electrons are excited and generate an electric current that is carried through wires within the cell to an electrical circuit. They do not consume fuel and have a life span of at least 25 years. PV cells have the potential to take care of a significant amount of our electrical energy needs.

A module is an assembly of photovoltaic cells wired in series or parallel to produce a desired voltage and current. Like batteries, when PV cells are wired in series, the voltage is added while the current remains constant. Similarly when they are wired in parallel, the current is added while the voltage remains constant.

The PV cells are encapsulated within the module to protect them from weather and other environmental factors. Modules are available in a variety of sizes and shapes. Typically, they are flat rectangular panels that produce anywhere from 5 watts to over 200 watts. The terms "module" and "panel" are often used interchangeably, though more accurately a panel is a group of modules wired together to achieve a desired voltage. An array is a group of panels wired together to produce a desired voltage and current.

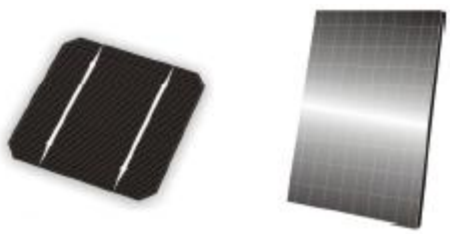


Figure 3.1: *Solar cell and solar panel*

3.2. Module Types

The following components of a photovoltaic module differentiate the various types of modules:
- Cell material
- Glazing material
- Hardware, frame, and electrical connections

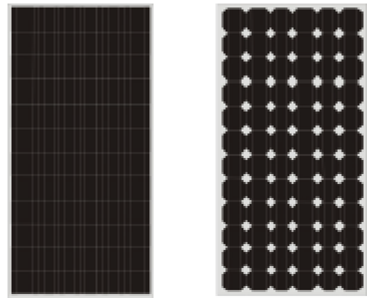
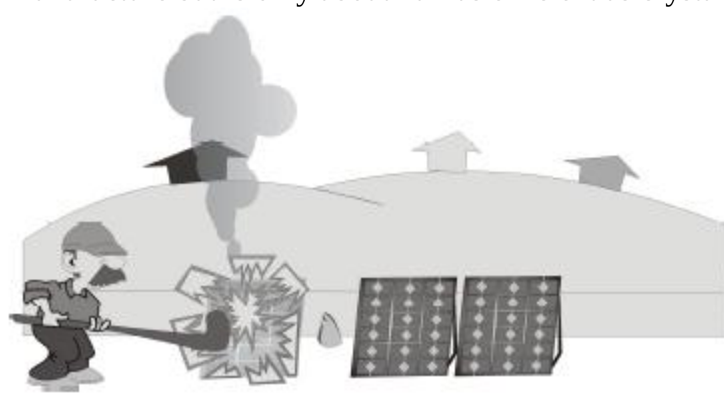


Figure 3.2: *Crystalline panel and amorphous panel*

The most important component is the cell material which is the composition of the silicon crystalline structure. The crystalline material can be grown as a single crystal (single-crystalline), cast into an ingot of multiple crystals (poly-crystalline), or deposited as a thin film (amorphous silicon). The two types of crystalline silicon cells perform similarly, although single crystalline cells are slightly more efficient than polycrystalline. Thin film or amorphous silicon is much more inexpensive to manufacture but is only about half as efficient as crystalline silicon cells.



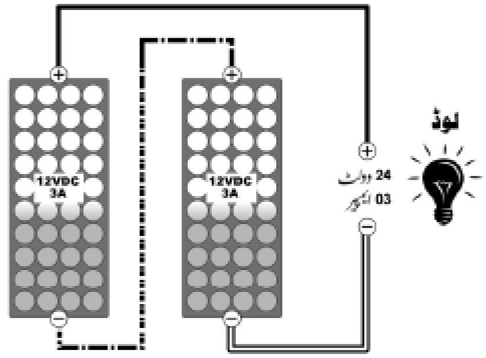
Do not hit the solar panel with any solid object; otherwise you will damage the solar panel.

3.3. Module Wiring

PV modules are a solar system's building blocks. While each module has a rated voltage or current, they are wired together to obtain a desired system voltage.

3.3.1. Series Circuits

When modules are connected in series, voltage adds. Series wiring maintains the current constant. Figure 3.3 shows two modules wired in series. Note that series wiring connections are made from the positive (+) end of one module to the negative (-) end of another module.



take 6V + 6 V=12V

Figure 3.3: *PV modules in series*

3.3.2. Parallel Circuits

When modules are wired in parallel, currents are added and voltage stays the same. To increase the current of a system, the modules must be wired in parallel. Figure 3.4 shows PV modules wired in parallel to get a 12V, 6amp system. Notice that parallel wiring adds the currents while maintaining the voltage constant. Also the parallel wiring connections are made from positive (+) to positive (+) and negative (-) to negative (-).

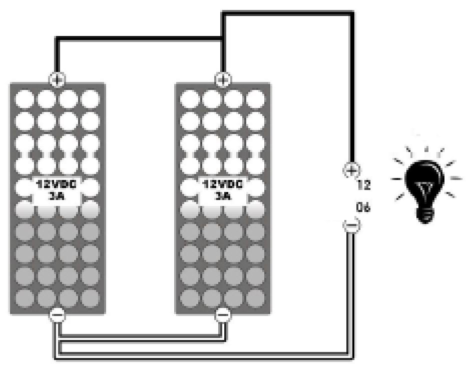


Figure 3.4: *PV modules in parallel*

3.3.3. Series and Parallel Circuits

Systems may use a mix of series and parallel wiring to obtain required voltages and currents. In Figure 3.5, four 12V, 3amp modules are wired. Strings of two modules are wired in series, increasing the voltage to 24V. Each of these strings is then wired in parallel, increasing the current to 6 amps. The result is a 24V, 6amp system.

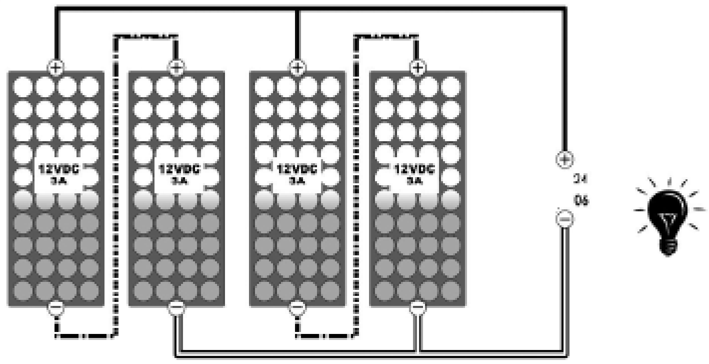


Figure 3.5: *PV modules in series and parallel*

3.4. Module Performance

The total electrical output (wattage) of a photovoltaic module is equal to its output voltage multiplied by its operating current.

The output characteristics of any given module are characterized by a performance curve, called an I-V curve that shows the relationship between current and voltage.

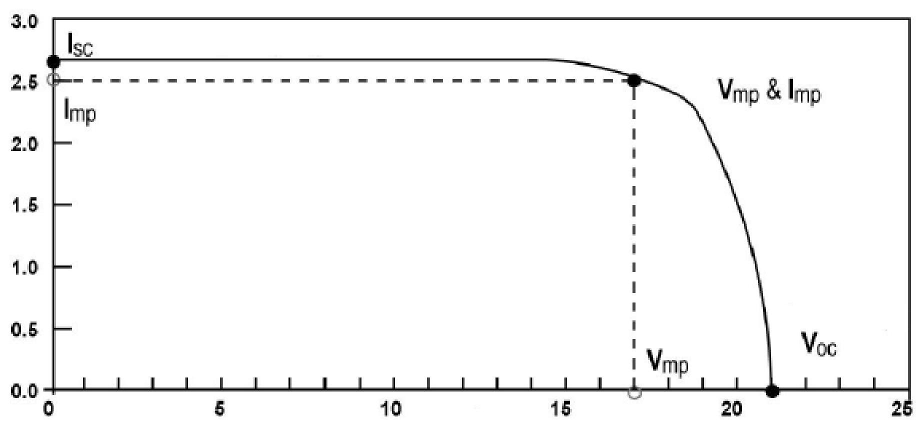


Figure 3.6: *Module I-V curve (12VDC nominal)*

Figure 3.6 shows a typical I-V curve. Voltage (V) is plotted along the horizontal axis. Current (I) is plotted along the vertical axis. Most I-V curves are given for the standard test conditions (STC) of 1000 watts per square meter sunlight (often referred to as one peak sun) and 25 degrees C (77 degrees F) cell temperature.

I-V curve contains three significant points: Maximum Power Point (representing both Vmp and Imp), the Open Circuit Voltage (Voc), and the Short Circuit Current (Isc).

3.4.1. Maximum Power Point

This point, labelled Vmp and Imp, is the operating point at which the maximum output will be produced by the module at operating conditions indicated for that curve. The voltage at the maximum power point can be determined by extending a vertical line from the curve downward to read a value on the horizontal voltage scale. The example in Figure 3.6 displays a voltage of approximately 17.3 volts at the maximum power.

The current at the maximum power point can be determined by extending a horizontal line from the curve to the left to read a value on the vertical current scale. The example in Figure 3.6 displays a current of approximately 2.5 amps at the maximum power point.

The wattage at the maximum power point is determined by multiplying the voltage at the maximum power point by the current at the maximum power point.

The power output decreases as the voltage drops. Current and power output of most modules drops off as the voltage increases beyond the maximum power point.

3.4.2. Open Circuit Voltage

This point, labelled Voc, is the maximum voltage achieved when no current is being drawn from the module. Since no current is flowing, the module experiences maximum electrical potential. The example in Figure 3.6 displays an open circuit voltage of approximately 21.4 volts. The power output at Voc is zero watts since there is no current.

3.4.3. Short Circuit Current

This point, labelled Isc, is the maximum current output that can be reached by the module under the conditions of a circuit with zero resistance or a short circuit.

The example in Figure 3.6 displays a current of approximately 2.65 amps. The power output at Isc is zero watts since the voltage is zero.

3.5. Factors of Module Performance

Major factors affect the performance of photovoltaic modules are as follows:

3.5.1 Load Resistance

A load or battery determines the voltage at which the module will operate. For example, in a nominal 12-volt battery system, the battery voltage is usually between 11.5 and 14 volts. For the batteries to charge, the modules must operate at a slightly higher voltage than the battery bank voltage.

When possible, system designers should ensure that the PV system operates at voltages close to the maximum power point of the array. If a load's resistance is well matched to a module's I-V curve, the module will operate at or near the maximum power point, resulting in the highest possible efficiency. As the load's resistance increases, the module will operate at voltages higher than the maximum power point, causing efficiency and current output to decrease.

Efficiency also decreases as the voltage drops below the maximum power point.

This relationship between the load and photovoltaic array is particularly significant when an inductive load, such as a pump or motor, is powered directly by the array. A control device that tracks the maximum power point may be used to continuously match voltage and current operating requirements of the load to the photovoltaic array for maximum efficiency.

3.5.2 Intensity of Sunlight

A module's current output is proportional to the intensity of solar energy to which it is exposed. More intense sunlight will result in greater module output. As illustrated in Figure 3.7, as the sunlight level drops, the shape of the I-V curve remains the same, but it shifts downward indicating lower current output. Voltage, although, is not changed appreciably by variations in sunlight intensity.

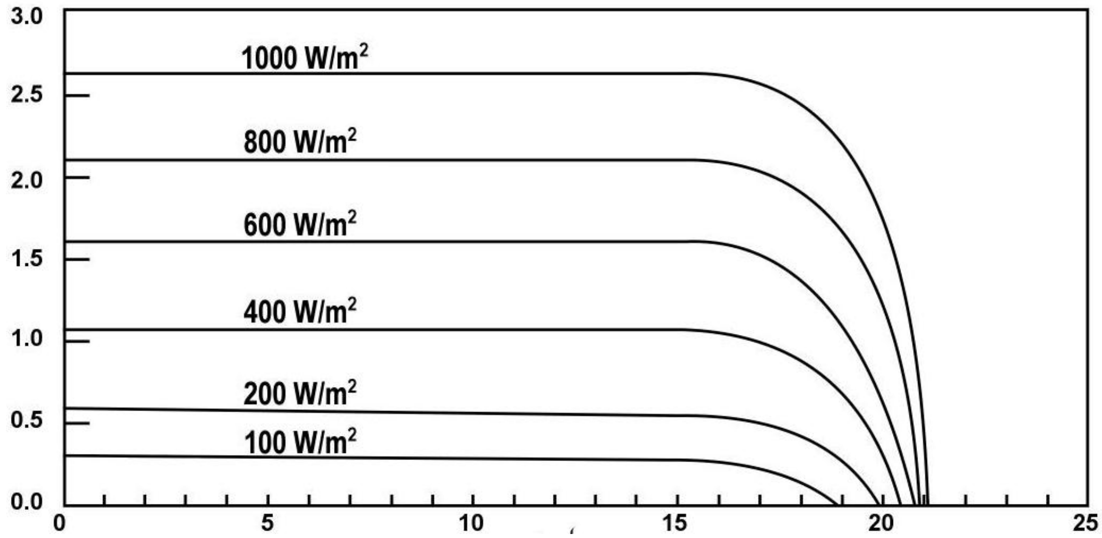


Figure 3.7: *Effect of sunlight intensity on module performance (12VDC nominal)*

3.5.3 Cell Temperature

As the cell temperature rises above the standard operating temperature of 25 degrees C, the module operates less efficiently and the voltage decreases. As illustrated in Figure 3.8, as cell temperature rises above 25 degrees C (cell temp, not ambient air temp), the shape of the I-V curve remains the same, but it shifts to the left at higher cell temperatures indicating lower voltage output.

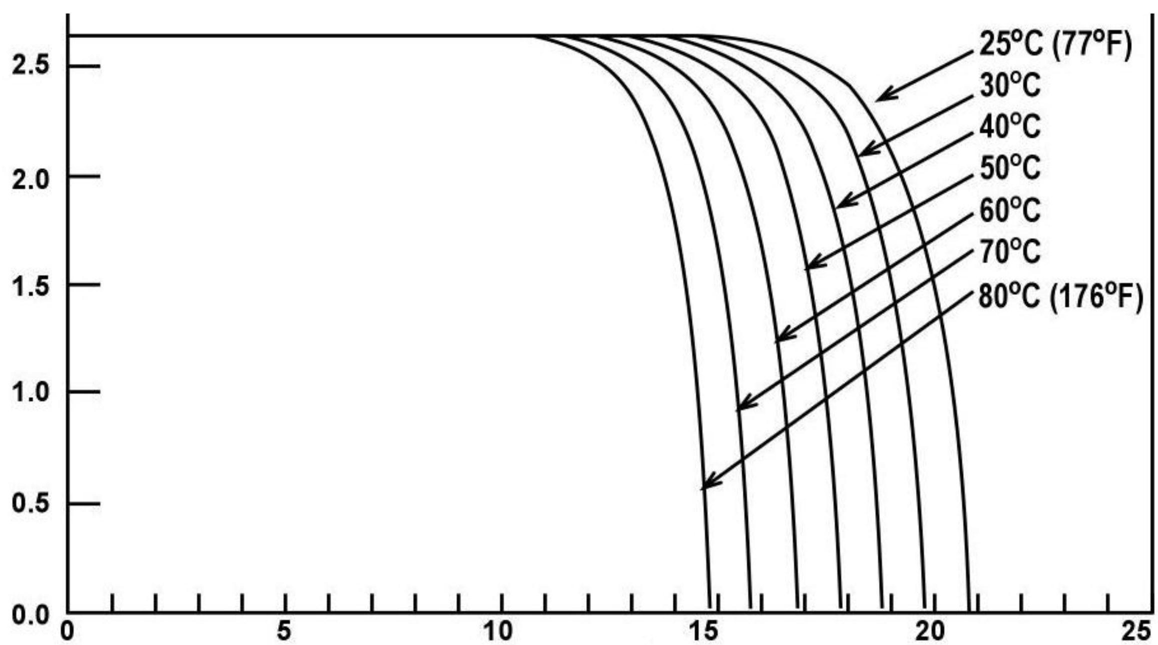


Figure 3.8: *Effect of cell temperature on module performance (12VDC nominal)*

Airflow under and over the modules is critical to remove heat to avoid high cell temperatures. A mounting scheme that provides for adequate airflow, such as a stand-off or rack mount, can maintain lower cell temperatures.

3.5.4 Shading

Even partial shading of photovoltaic modules will result in a dramatic output reduction. Some modules are more affected by shading than others. Figure 3.9 and Table 3.1 show the extreme effect of shading on one cell of a crystalline cell module. In Figure 3.9, one completely shaded cell reduces the module's output by as much as 75%. Some modules are less affected by shading than this example.

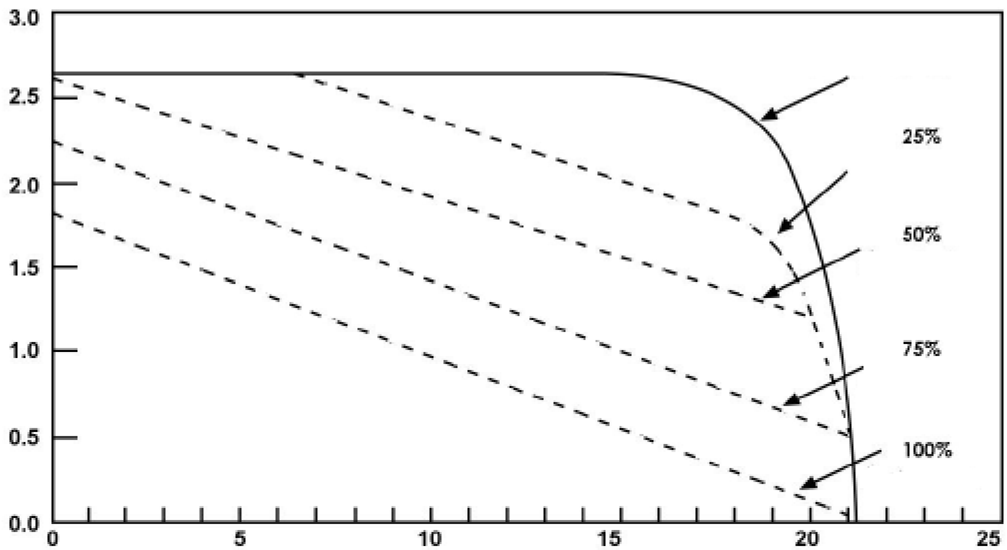


Figure 3.9: *Effect of shading on module performance (12VDC nominal)*

Locating shading obstacles at the site is an extremely important part of a site evaluation. An entire system's performance can be diminished by underestimating the effects of shading, even partial shading. Some manufacturers make use of bypass diodes within the module to reduce the effect of shading by allowing current to bypass shaded cells.

Table 3.1: *Effects of shading on module power*

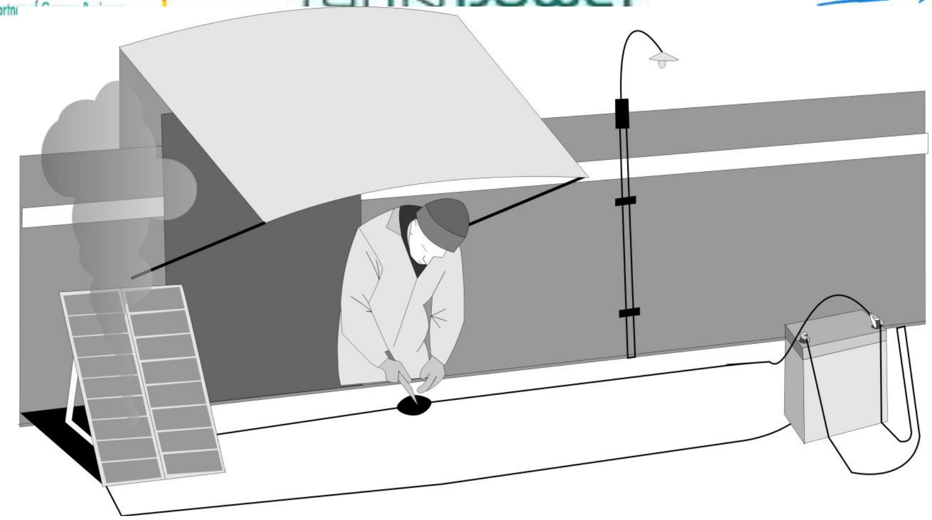
Percent of One Cell Shaded	Percent of Module Power Loss
0 %	0 %
25 %	25 %
50 %	50 %
75 %	66 %
100 %	75 %
3 cells shaded	93 %

Do not cover the solar panel with any opaque or semi-transparent material, otherwise you will loose the current and your appliances will be OFF.
The installation site should be such that the array is not shaded from 9 a.m. to 3 p.m. when there is maximum sun availability. If there is shading during this period, more modules will be needed to produce adequate power.

3.6. Diodes
A diode is a semiconductor device that allows electric current to pass in only one direction. In photovoltaic systems, diodes may be used for several functions as follows:

3.6.1. Blocking Diodes
This type of a diode is placed in the positive line between the modules and the battery to prevent reverse current flow from the batteries to the array at night or during cloudy weather. Some controllers already contain a diode or perform this function by opening the circuit.

3.6.2. Bypass Diodes
This type of a diode is wired within a module to divert current around a few cells in the event of shading. Typically several bypass diodes are pre-wired in a module, each in parallel with a set of cells.



Do not remove the blocking diode between the solar panel and the battery; it will damage your panel by reverse current flow.

Key Points

1. Photovoltaic cells convert sunlight into direct current through the photovoltaic effect. They do not have any moving parts and also do not use any fuel.
2. Single-crystalline silicon cell is slightly more efficient than poly crystalline but amorphous silicon cell is half as efficient as crystalline silicon cell. Amorphous silicon cell costs much less to manufacture than the crystalline silicon cell.
3. Voltage adds and a current remains constant when modules are connected in series while current adds and voltage remains constant when modules are connected in parallel.
4. Load resistance, intensity of sunlight, cell temperature and shading are the main factors that affect the performance of a module.
5. Blocking diode is placed in the positive line between the modules and the battery to prevent battery current from reversing its direction from the batteries to the array at night or during cloudy weather.
6. Bypass diode is wired in parallel with a few cells within a module to divert current around the cells in the event of shading.

PRACTICAL WORK OF CHAPTER # 3

1. To check the output of different types of modules.

i. Show mono-crystalline, poly-crystalline and amorphous type modules to the students.
ii. Place all modules at a tilt angle of 33 degree and oriented to true south.
iii. Measure the output of all three types of modules.
iv. Record the readings and compare them with each other.

Result: Mono-crystalline module is slightly more efficient than poly-crystalline; however, both mono and poly crystalline are significantly more efficient than amorphous modules.

2. To check the output of two PV panels connected in series.
i. Take two PV panels of same ratings.
ii. Measure the open circuit voltage and short circuit current of both panels.
iii. Record the readings.
iv. Now connect both PV panels in series by connecting +ve terminal of one panel to –ve terminal of the other panel.
v. Measure the open circuit voltage and short circuit current of this series connection.
vi. Record the readings and compare it with previous readings.

Result: Voltage adds up while current remains the same.

3. To check the output of two PV panels connected in parallel.
i. Take two PV panels of same ratings.
ii. Measure the open circuit voltage and short circuit current of both panels.
iii. Record the readings.
iv. Now connect both PV panels in parallel by connecting +ve terminals of both panels and –ve terminal of both panels with each others.
v. Measure the open circuit voltage and short circuit current of this parallel connection.
vi. Record the readings and compare it with previous readings.

Result: Voltage remains the same while current adds up.

4. To check the output of four PV panels connected in series and parallel.
i. Take four PV panels of same ratings.
ii. Make two series connections by connecting two PV panels in series each.
iii. Measure the open circuit voltage and short circuit current of the two series connections.
iv. Record the readings.
v. Now connect these two series connections into parallel connection by connecting +ve terminals and –ve terminals.
vi. Measure the open circuit voltage and short circuit current of this series and parallel connection.
vii. Record the readings and compare it with previous readings.
Result: Voltage adds up while current remains the same in a series connection.
Current adds up and voltage remains the same in a parallel connection. You can connect a number of panels in series and parallel to obtain required output.

5. To check the effect of intensity of sunlight on the panel output.
i. Place a PV panel at 33 degrees tilt angle facing true south.
Make sure that sun is shining brightly.
ii. Measure the open circuit voltage and short circuit current.

iii. Record the readings.
iv. Now place a semi-transparent cloth over the panel through which 40 to 50% of sunlight can pass and fall on the panel.
v. Measure the open circuit voltage and short circuit current and record the readings.
vi. Compare the readings.
Result: More intense sunlight results in greater module output current.
Decreasing sunlight results in lower current but no appreciable change in voltage

6. To check the effect of shading on the panel output.
i. Place a PV panel at 33 degree of tilt angle and facing true south. Make sure that the sun is shining brightly.
ii. Measure the panel open circuit voltage and short circuit current.
iii. Record the readings.
iv. Now shade a very small portion of PV panel.
v. Again measure the panel open circuit voltage and short circuit current and record the readings.
vi. Compare the readings.
Result: Output is greatly affected due to shading. You can compare your results with Table 3.1 in chapter 3.

CHAPTER FOUR

4. BATTERIES

In this chapter, you will learn

- Battery as a storage device.
- Battery types and their operation.
- Battery specifications necessary for designer to consider during design.
- Safety rules to insure proper and safe handling of batteries.
- Battery wiring to obtain desired voltage and amp-hours.

4.1. Introduction

Batteries store direct current electrical energy in chemical form for later use. In a photovoltaic system, the energy is used at night and during periods of cloudy weather. Batteries also serve as a portable power source for appliances, such as flashlights and radios. Since a photovoltaic system's power output varies throughout any given day, a battery storage system can provide a relatively constant source of power when the PV system is producing minimal power during periods of reduced insolation. Batteries can even power the loads when the PV array is disconnected for repair and maintenance. Batteries can also provide the necessary amounts of surge power required to start some motors.

Batteries are not one hundred percent efficient. Some energy is lost, as heat and in chemical reactions, during charging and discharging. Therefore, additional photovoltaic modules must be added to a system to compensate for battery loss.

There are several types of day-use systems that do not require batteries. A water pumping system can be designed to pump during the day to a storage tank.

Utility grid-connected photovoltaic systems do not necessarily require batteries, though they can be used as an emergency backup power source.

4.2. Battery Types and Operation

Many battery types and sizes are available. Smaller sizes, commonly used in flashlights or portable radios, are available in the "disposable" or “rechargeable” options. Rechargeable nickel cadmium batteries are commonly used for large standby loads, such as industrial applications, and small portable appliances.

These batteries may be re-charged using a solar or AC battery charger.

Manufacturers of nickel cadmium batteries claim that nickel cadmium batteries will last through 500 to 1000 charge/discharge cycles. A battery is charging when energy is being put in and discharging when energy is being taken out. A cycle is considered one charge-discharge sequence, which often occurs over a period of one day in residential photovoltaic systems.

The following types of batteries are commonly used in PV systems:

4.2.1. Lead-Acid Batteries

A lead-acid battery consists of a number of cells and each cell consists of three main parts which are contained in one of the compartments of the battery container as follows:

Positive and Negative Plates

A plate consists of a lattice type of grid of cast antimonial lead alloy which is covered with active material. The gird not only serves as a support for the fragile active material but also conducts electric current. Grids for the positive and negative plates are often of the same design although negative plate grids are made somewhat lighter.

Separators

These are thin sheets of a porous material placed between the positive and the negative plates for preventing contact between then and thus avoiding internal short circuiting of the battery. A separator must however be sufficiently porous to allow diffusion or circulation of electrolyte between the plates.

Electrolyte

It is typically dilute sulphuric acid that fills the cell compartment to immerse the parts completely.

The battery most commonly used for residential photovoltaic applications is the lead-acid battery, which closely resembles an automotive battery. Automotive batteries, however, are not recommended for PV applications because they are not designed to be "deep-cycled". They are designed to discharge large amounts of current for a short duration to start an engine and then be immediately recharged by the vehicle's alternator or generator. Photovoltaic systems often require a battery to discharge small amounts of current over long durations and to be recharged under irregular conditions. Deep cycle batteries can be discharged down as much as 80 percent state of charge. An automotive battery may last for only a few photovoltaic cycles under these conditions. In contrast, deep cycle lead-acid batteries suitable for photovoltaic applications can tolerate these conditions, and, if properly sized and maintained, they will last from three to ten years.

Lead-acid batteries are rechargeable, widely available, relatively inexpensive, and available in a variety of sizes and options. They are also commonly used, easily maintained, and reasonably long lived. Lead-acid batteries may be categorized into “vented” and “sealed” subcategories.

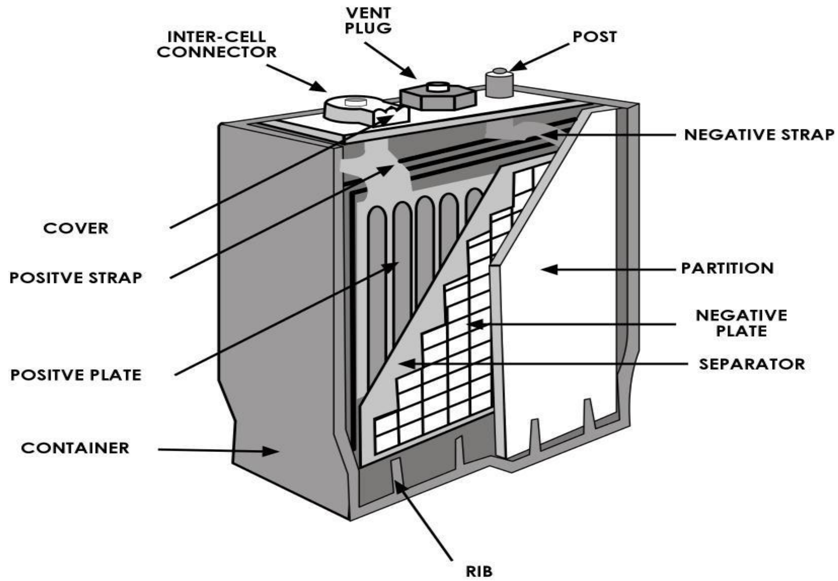


Figure 4.1: *Cut-away of a standard lead acid battery cell*

Vented Lead-Acid Batteries

Vented liquid lead-acid batteries are like automobile batteries. The battery is built from positive and negative plates, made of lead and lead alloy placed in an electrolyte solution of sulphuric acid and water. Figure 4.1 shows the cross-section of a common 12-volt liquid lead-acid battery containing 6 individual 2-volt cells. As the battery is charged and nears full charge, hydrogen gas is produced and vented out of the battery.

Water is lost when the battery vents waste gases, so it must be refilled periodically. Deep cycle batteries will last longer if protected from complete discharge. Controls with a low voltage disconnect (LVD) protect batteries from complete discharge. Like an automobile battery, less capacity is available when the battery is cold, whereas, higher temperatures provide greater capacity but shorten battery life.

Sealed Lead-Acid Batteries

Unlike liquid vented batteries, sealed batteries have no caps, and thus no access to the electrolyte. No water can be added to these batteries. They are not totally sealed - a valve allows excess pressure to escape in case of overcharging. This is referred to as a “valve regulated lead acid” battery (VRLA). Sealed batteries are considered maintenance free because you do not need to add water.

The main advantage of sealed batteries is that nothing spills out of them. This allows them to be safely transported and handled. They can be air-shipped in contrast to a commercial liquid lead-acid battery that needs to be shipped dry, and then activated on site by the addition of electrolyte. They also do not require periodic maintenance, such as watering. This makes them a good choice for very remote applications where regular maintenance is unlikely or not cost effective.

Sealed batteries cost more per unit of capacity compared to vented batteries.

They are susceptible to damage from overcharging especially in hot climates and have a shorter life expectancy than other battery types.

Most sealed batteries must be charged to lower voltages and at a lower ampere rate to prevent excess gas from damaging cells.

4.2.2. Alkaline Batteries

Alkaline batteries, such as nickel-cadmium and nickel-iron batteries, also have positive and negative plates in an electrolyte. The plates are made of nickel and cadmium or nickel and iron and the electrolyte is potassium hydroxide.

These batteries are often expensive. An advantage is that they are not as affected by temperature as other types of batteries. For this reason, alkaline batteries are usually recommended for commercial or industrial applications in locations where extremely cold temperatures (-50°F or less) are anticipated.

In residential PV systems, typically liquid lead-acid batteries are the wisest choice. They usually constitute a significant part of the total system cost. The majority of PV systems and components are designed to use lead-acid batteries.

Despite the safety, environmental, and maintenance issues, batteries are necessary to provide the needed flexibility and reliability to a home PV system.

4.3. Battery Specifications

A photovoltaic system designer must consider the following variables when specifying and installing battery storage system for a stand-alone photovoltaic system:

4.3.1. Days of Autonomy

Autonomy refers to the number of days a battery system will run a given load (application) without being recharged by the photovoltaic array or another source.

You must consider a system's location, total load, and types of loads to correctly determine the number of days of autonomy.

General weather conditions determine the number of "no sun" days, which is a significant variable in determining autonomy. In humid climates, three to four week cloudy periods can occur. It may be too costly to size a battery system capable of providing power in the most extreme conditions. Consequently, most designers usually opt for a design based on the average number days of cloudy weather or design with a hybrid approach adding a generator or wind turbine.

The most important factors in determining an appropriate autonomy for a system are the size and type of loads that the system services. It is important to answer several questions about each load.

- Is it critical that the load operate at all times?
- Could an important load be removed or replaced by alternatives?
- Is the load simply a convenience?

The general range of autonomy is as follows:

- 2 to 3 days for non-essential uses or systems with a generator back-up.
- 5 to 7 days for critical loads with no other power source.

4.3.2. Battery Capacity

Batteries are rated by ampere-hour (AH) capacity. The capacity is based on the amount of power needed to operate the loads and how many days of stored power will be needed due to weather conditions. Using a water analogy, you can think of a battery as a bucket, the stored energy as water and the AH capacity as the bucket size. The AH rating will tell you "how large your bucket is".

In theory, a 100 AH battery will deliver one amp for 100 hours or roughly two amps for 50 hours before the battery is considered fully discharged. If more storage capacity is required to meet a specific application requirement, then batteries can be connected in parallel. Two 100 amp-hour 12-volt batteries wired in parallel provide 200 amp-hours at 12 volts. Higher voltages are obtained through series wiring. Two 100 amp-hour 12-volt batteries wired in series provide 100 amp-hours at 24 volts.

Many factors can affect battery capacity, such as, rate of discharge, depth of discharge, temperature, controller efficiency, age, and recharging characteristics.

Fundamentally, the required capacity is also affected by the size of the load. If the load is reduced, the required battery capacity can also be reduced

Since it is easy to add photovoltaic modules to an existing photovoltaic system, a commonly held misconception is that the entire photovoltaic system is modular as well. However, manufacturers generally advise against adding new batteries to an old battery bank. Older batteries will degrade the performance of new batteries (since internal cell resistance is greater in older batteries) and could result in reduced system voltage when wired in series. In addition, if you were to add batteries to an existing system, you would probably add them in parallel to increase amp-hour capacity and maintain system voltage.

You should initially specify a slightly larger battery capacity than is needed because batteries lose their capacity as they age. However, if you greatly oversize the battery bank, it may remain at a state of partial charge during periods of reduced insolation. This partial charge state can cause shortened battery life, reduced capacity, and increased sulphating. Battery capacity should be determined by the overall load profile.

4.3.3. Rate and Depth of Discharge

The rate at which the battery is discharged directly affects its capacity. If a battery is discharged quickly, less capacity is available. Conversely, a battery that is discharged slowly will have a greater capacity. For example, a six-volt battery may have a 180 AH capacity if discharged over 24 hours. However, if the same battery is discharged over 72 hours, it will have a 192 AH capacity.

A common battery specification is the battery's capacity in relation to the number of hours that it is discharged. For example, when a battery is discharged over 20 hours, it is said to have a discharge rate of C/20 or capacity at 20 hours of discharge. If a battery is discharged over 5 hours, the discharge rate is C/5. Note that the C/5 discharge rate is four times faster than the C/20 rate. Most batteries are rated at the C/20 rate.

Similar consideration should be taken when charging batteries. Most lead-acid batteries should not be charged at more than the C/10 rate. If a battery were rated at 220 AH at the C/20 rate, charging it at a C/10 rate would equal charging at 22 amps (220 □□10).
Depth of discharge (DOD) refers to how much capacity will be withdrawn from a battery. Most PV systems are designed for regular discharges of 40 percent to 80 percent. Battery life is directly related to how deep the battery is cycled. For example, if a battery is discharged 50 percent every day, it will last about twice as long as if it is discharged 80 percent. Lead-acid batteries should never be completely discharged; even though some deep cycle batteries can survive this condition, the voltage will continually decrease. Nickel cadmium batteries, on the other hand, can be totally discharged without harming the battery and hold their voltage.

When the nickel cadmium battery is fully discharged it may reverse polarity, potentially harming the load.

4.3.4. Life Expectancy

Most people think of life expectancy in terms of years. Battery manufacturers, however, specify life expectancy in "number of cycles". Batteries lose capacity over time and are considered to be at the end of their life when 20 percent of their original capacity is lost, although they can still be used. When sizing a system initially, this should be considered.
Depth of discharge also affects the life expectancy of a battery. For example, a battery that experienced shallow cycling of only 25 percent depth of discharge (DOD) would be expected to last 4000 cycles while a battery cycled to an 80 percent DOD would last 1500 cycles. If one cycle equalled one day, the shallowly cycled battery would last for 10.95 years while the deeply cycled battery would last for only 4.12 years.
This is only an estimate. Some batteries are designed to be cycled more than once each day. In addition, batteries degrade over time, affecting life expectancy.

4.3.5. Environmental Conditions

Batteries are sensitive to the environment and are particularly affected by the temperature of that environment. Higher voltages are required for charging at lower temperatures (the opposite is true in warmer temperatures). Controllers with a temperature compensation feature can automatically adjust charge voltage based on a battery's temperature.
Manufacturers generally rate batteries at 77 degrees F (25 degrees C). The battery's capacity will decrease at lower temperatures and increase at higher temperatures. A battery at 32 degrees F may be able to achieve 65 to 85 percent of its fully rated capacity. A battery at -22 degrees F will achieve only 50 percent capacity. Battery capacity increases at higher temperatures.
Even though battery capacity decreases at lower temperatures, battery life increases and conversely at higher temperatures, the life of the battery decreases. Most manufacturers say there is a 50 percent loss in life for every 15 degrees F increase over the standard 77 degree temperature. Generally battery life and capacity tend to even out in most systems, as they spend part of their lives at higher temperatures, and part at lower temperatures.
Colder temperatures have other effects as well. In extremely cold environments, the electrolyte can freeze. The temperature at which a battery will freeze is a function of its state of charge.

When a liquid electrolyte battery is completely discharged, the electrolyte is principally water. The electrolyte in a fully charged battery is mainly sulphuric acid, which freezes at a much lower temperature.

Table 4.1 lists the freezing point at various states of charge. To maintain a constant temperature, lead-acid batteries can be placed in an insulated battery box. Nickel cadmium or sealed batteries are not as susceptible to freeze damage.

Table 4.1: *Liquid electrolyte freeze points, specific gravity and voltage*

State of Charge	Freeze Point	Specific Gravity	Voltage
100%	-57.2 °C	1.260	12.70
75%	-37.2 °C	1.237	12.50
50%	-23.3 °C	1.200	12.30
25%	-16.1 °C	1.150	12.00
0%	-8.3 °C	1.100	11.70

Regardless of temperature concerns, batteries should be located in a strong enclosure (a battery box). Since liquid electrolyte batteries produce explosive hydrogen gas during charging, the enclosure or area where the batteries are located should be well vented. Even though a battery box helps to contain the gases, other electric system components should be installed a reasonable distance away from the battery compartment. There are two reasons for this.

One, sparking from the electrical equipment could ignite the gases. Two, the gases are corrosive and will attack other system components. A battery enclosure should also be used to contain acid in case the batteries leak.

Always try to design systems with batteries as near as is safely possible to the loads and the array to minimize wire length, thereby, saving money on materials and reducing voltage drop.

The battery should be properly ventilated; otherwise excess heat can damage your battery.

4.3.6. Measuring State of Charge

A voltmeter or a hydrometer can be used to measure a battery's state of charge.

To properly check voltages, the battery should sit at rest for a few hours (disconnect from charging sources and loads).

Table 4.1 can be used to compare a 12V battery's voltage to its state of charge.

For a 24-volt system, multiply by 2, and for a 48-volt system, multiply by 4. For gel cell batteries, subtract 0.2 volts from the numbers in the table. Table 4.1 can also be used to determine a battery's state of charge by measuring the specific gravity of a cell with a hydrometer.

Gel Cell is a sealed type battery.

4.4. Battery Safety

Batteries used in photovoltaic systems are potentially the most dangerous system component if improperly handled, installed, or maintained. Dangerous chemicals, heavy weight, and high voltages and currents are potential hazards that can result in electric shock, burns, explosion, or corrosive damage.

You should observe the following safety rules to insure proper and safe handling, installing, maintaining, and replacing of photovoltaic system batteries.

Do's:

- Use proper tools when assembling cells.
- Remove any jewellery that can touch terminals while working around batteries.
- Design the battery area to be properly ventilated.
- Wear protective clothing (especially eye protection) while working on batteries.
- Have baking soda accessible to neutralize acid spills.
- Have fresh water accessible in case electrolyte splashes on skin or eyes. If an accident occurs, flush with water for five to 10 minutes, and then contact a physician.
- Keep open flames and sparks away from batteries.
- Discharge body static electricity before touching terminal posts.
- Disconnect battery bank from any sources of charging or discharging before working on batteries.
- Lift batteries from the bottom or use carrying straps.
- Use tools with insulated or wrapped handles to avoid accidental short circuits.
- Follow the manufacturer's instructions.
- Use common sense.

Prevent metals from falling on terminals of the battery, otherwise battery can catch fire.

Don’ts:
- Do not use metal hard hats or non-insulated tools around batteries to avoid possible shock.
- Do not lift batteries by their terminal ports or by squeezing the sides of the battery.
- Do not smoke near a battery.

Do not lift the battery from its terminals; you may get a strong shock.

4.5. Battery Wiring Configuration

Batteries need to be configured to obtain the desired voltage and amp-hours.

Using the design and battery parameters from the example, we can clearly see how a system’s batteries should be configured and wired. Two separate six-volt batteries rated at 200 AH each are wired in series to obtain 12V direct current and 200 AH. Two of these series strings are wired in parallel to achieve 12V direct current and 400 AH. Figure 4.2, Figure 4.3 and Figure 4.4 show examples of wiring configurations for 12V, 24V and 48V battery banks.

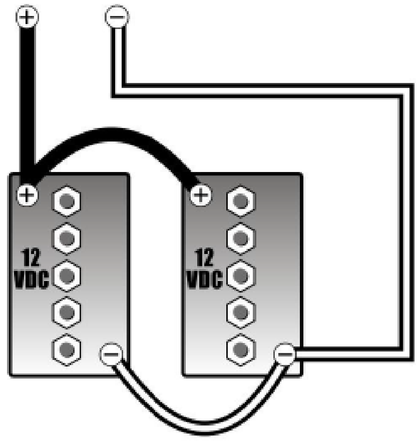


Figure 4.2: *12-volt battery configurations*

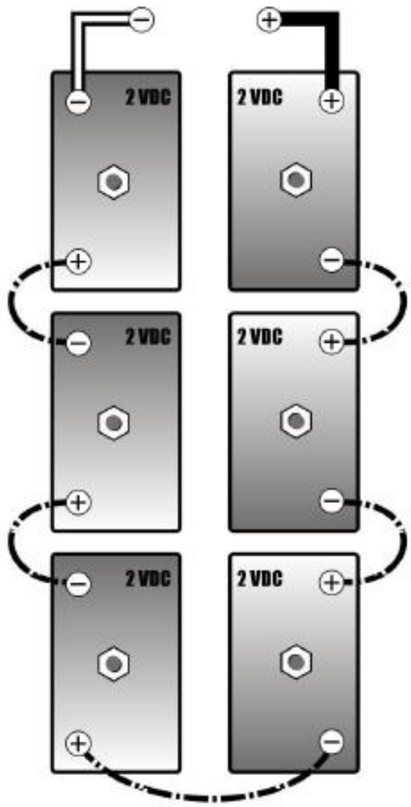


Figure 4.3: *24-volt battery configurations*

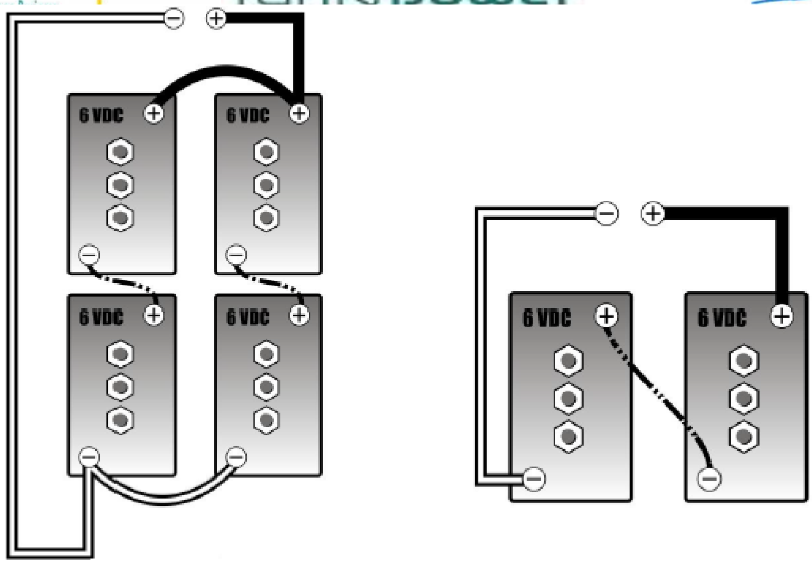


Figure 4.4: *48-volt battery configurations*

Key Points

1. Batteries store direct current electrical energy in chemical form for later use. In a photovoltaic system, the energy is used at night and during periods of cloudy weather.
2. Lead-acid batteries are rechargeable, widely available, relatively inexpensive, and available in a variety of sizes and options. They are also commonly used, easily maintained, and reasonably long lived.
3. Less capacity is available when Liquid Vented Lead-Acid battery is cold, and higher temperatures shorten its life.
4. Valve Regulated Lead-Acid batteries are considered maintenance free because you do not need to access the electrolyte. These batteries are spill-proof and cost more per unit of capacity compared to Liquid Vented Lead-Acid batteries.
5. A photovoltaic system designer must consider important variables including days of autonomy, battery capacity, rate and depth of discharge, life expectancy and environmental conditions when specifying and installing battery storage system for a stand-alone photovoltaic system.
6. Batteries used in photovoltaic systems are potentially the most dangerous system component if improperly handled, installed, or maintained. Safety rules have to be followed to insure proper and safe handling, installation and maintenance.
7. Batteries need to be configured and wired to obtain the desired voltage and amp-hour.

PRACTICAL WORK OF CHAPTER # 4

1. To show different types of batteries.

i. Show the students liquid vented lead-acid, sealed lead-acid and nickel-cadmium batteries and help them understand the physical differences between these batteries.

2. To measure the battery state of charge using voltmeter.

i. Disconnect the battery from charging source and loads and keep it at rest for few hours.
ii. Set the knob on the VOM for the proper voltage. To check the voltage of 12 V battery, knob should be set for more than 12 V on VOM.
iii. Check the voltage across the terminals of the battery.
iv. Record the reading and find the state of charge using Table 4.1.

Table 4.1 should be used for a 12-volt battery system. For a 24-volt system, multiply by 2, and for a 48-volt system, multiply by 4. For gel cell batteries, subtract 0.2 volts from the numbers in the table.

3. To measure the battery state of charge using hydrometer.

i. Wear safety glasses, rubber gloves, and a rubber apron. Have some baking soda handy to neutralize any acid spillage and have fresh water available for flushing purposes. If you get acid into your eyes, flush with water immediately for at least 10 minutes and obtain professional medical assistance.
ii. Insert the hydrometer inside the battery after opening its cap. Draw the electrolyte in and out of the hydrometer three times to bring the temperature of the hydrometer float and barrel to that of the electrolyte in the cell. Hold the barrel vertically so the float does not rub against its side.
iii. Draw some amount of electrolyte into the barrel. With the bulb fully expanded, the float should be lifted free, not touching the side, top, or bottom stopper of the barrel.
iv. Read the hydrometer with your eye level with the surface of the liquid in the hydrometer barrel. Disregard the curvature of the liquid where the surface rises against the float stem and the barrel due to surface tension.
v. Adjust the reading for the temperature of the electrolyte. Use the thermometer and directions for temperature compensation that come with the hydrometer.
vi. Compare the reading of specific gravity with Table 4.1 to find the state of charge of the battery.

Keep the float clean. Make certain the hydrometer is not cracked. Never take a hydrometer reading immediately after water is added to the cell. The water must be thoroughly mixed with the electrolyte by charging the battery before hydrometer readings are taken.

4. To make a 12 V battery bank by connecting them in series.

i. Take two 6-volts batteries.
ii. Connect the + terminal of one battery with the – terminal of other battery through a wire having ring terminal connectors at both ends.
iii. Batteries are connected in series. Now measure the voltage and current using VOM.

iv. Always check the knob setting of VOM before using it for a specific purpose.
v. Use the free +ve terminal of one battery and free –ve terminal of second battery to measure the voltage and current.

Result: Voltage is doubled while current remains constant. 12-volt battery bank in series is ready.

5. To make a 12 V battery bank by connecting them in parallel.
i. Take two 12-volts batteries.
ii. Connect the +ve terminal of first battery with the +ve terminal of second battery through wires having ring terminal connectors at both ends.
iii. Connect the -ve terminal of first battery with the -ve terminal of second battery through wires having ring terminal connectors at both ends.
iv. Take a red wire with a ring terminal connector at one end and connect it to one of the +ve terminals of batteries with ring terminal connector.
v. Take a black wire with a ring terminal connector at one end and connect it with one of the -ve terminals of batteries with ring terminal connector.
vi. Batteries are connected in parallel. Now measure the voltage and current using VOM.
vii. Always check the knob setting of VOM before using it for a specific purpose.
viii. Use the free ends of red and black wires to measure voltage and current.

Result: Voltage remains constant as 12 volts while current doubles. 12-volt battery bank in parallel is ready.

6. To make a 24 V battery bank by connecting them in both series and parallel.
i. Take four 12-volts batteries.
ii. Connect the +ve terminal of first battery with the -ve terminal of second battery through a wire having ring terminal connectors at both ends.
iii. Similarly connect the +ve terminal of third battery with the –ve terminal of fourth battery through a wire having ring terminal connectors at both ends.
iv. Now four batteries are connected, two each in series. In series, one +ve and one –ve terminal are free.
v. Now connect the +ve terminal of first series with the +ve terminal of second series through a wire having ring terminal connectors at both ends.
vi. Connect the -ve terminal of first series with the -ve terminal of second through a wire having ring terminal connectors at both ends.
vii. Take a red wire with a ring terminal connector at one end and connect it to one of the +ve terminals of parallel connection with ring terminal connector.
viii. Take a black wire with a ring terminal connector at one end and connect it with one of the -ve terminals of parallel connection with ring terminal connector.
ix. Both series are now connected in parallel. Now measure the voltage and current using VOM.
x. Always check the knob setting of VOM before using it for a specific purpose.
xi. Use the free ends of red and black wires to measure the voltage and current.

Result: Voltage doubles while current remains constant in series connection.

Voltage remains constant while current doubles in parallel connection. 24-volt battery bank in series and parallel is ready.

CHAPTER FIVE

5. CONTROLLERS

In this chapter, you will learn

- The function of a controller.
- Types of controllers and their use.
- Controller features especially over discharge protection and few optional features.
- Certain beneficial features before specifying a controller.

5.1. Introduction

The photovoltaic controller is a voltage regulator. The primary function of a controller is to prevent the battery from being overcharged by the array. Many PV controllers also protect a battery from being overly discharged by the DC load. A
PV charge controller senses battery voltage. When the batteries are fully charged, the controller will stop or decrease the amount of current flowing from the photovoltaic array into the battery. When the batteries are being discharged to a low level, many controllers will shut off the current flowing from the battery to the DC load.

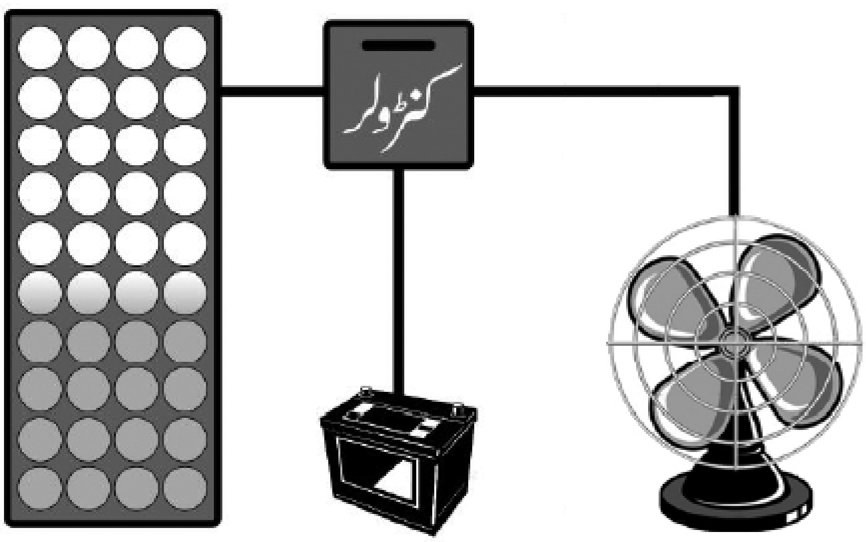


Figure 5.1: *Controller in a PV system*

5.2. Controller Types

Charge controllers come in many sizes, from just a few amps to as much as 60 amps; higher amperage units are available, but rarely used. If high currents are required, two or more PV controllers can be used. When using more than one controller, it is necessary to divide the array into sub-arrays. Each sub-array will be wired to its own controller and then they will all be wired to the same battery bank. There are three different types of PV controllers. They are:

5.2.1. Single-stage Controllers

Single-stage controllers prevent battery overcharging by switching the current off when the battery voltage reaches a pre-set value called the charge termination set point (CTSP). The array and battery are automatically reconnected when the battery reaches a lower preset value called the charge resumption set point (CRSP).

Single-stage controllers use a sensor to break the circuit and prevent reverse current flow (battery to array) at night, instead of using a blocking diode. These controllers are small and inexpensive. They generally do not require significant ventilation as the electronics inside does not produce much heat.

5.2.2. Multi-stage Controllers

These devices automatically establish different charging current levels depending on the battery's state of charge. The full array current is allowed to flow when the battery is at a low state of charge. As the battery bank approaches full charge, the controller releases lesser and lesser current to flow into the batteries.

This charging approach is said to increase battery life. As the charging current is reduced, heat is generated by the dissipation of excess power, requiring that multi-stage controllers be properly ventilated. These controllers generally have a relay type switch that prevents reverse "leakage" (battery to array) at night.

5.2.3. Maximum Power Point Tracking (MPPT) Controllers

A MPPT, or maximum power point tracker is an electronic device that optimizes the match between the solar array (PV panels), and the battery bank, utility power, DC motor, or DC pump. Most modern MPPT controllers provide 92-97% efficiency. There is a 20 to 45% power gain in winter and 10-15% in summer. Actual gain can vary depending on weather, temperature and battery state of charge.

5.3. Controller Features

In addition to preventing overcharging, controllers can have many other features that protect the batteries, provide a better user interface, and increase the flexibility of a PV system.

5.3.1. Over-discharge Protection

The second main function of charge controllers is to prevent batteries from being overly discharged. Like a parked car with its lights left on, photovoltaic system loads can easily over-drain batteries, dramatically shortening the life of the battery. Most photovoltaic systems provide protection for the battery against unmanaged discharge.

Controllers prevent over-discharging by:

Temporarily Turning OFF Loads

Turning off loads to prevent further battery discharge (until the photovoltaic modules or other power source recharge the battery to a minimum level) is called load management or load shedding and is accomplished using a low voltage disconnect (LVD) circuitry. If a controller performs load management, DC loads will automatically be shut down. Therefore, essential loads must be wired directly to the battery to avoid unplanned disconnection. In this case, battery over discharging can still occur since the controller has been bypassed. It is also important to remember that charge controllers only control DC loads. The inverter LVD needs to be programmed to disconnect the AC loads.

Activating Lights or Buzzers

Lights or buzzers may also be used to indicate low battery voltage and prevent cutting off critical loads. If the system is designed for critical loads, such as a vaccine refrigerator in a rural health clinic, warning lights or buzzers might be essential. However, since loads can keep running after the user is warned, there is always the risk of over-discharging and shortening battery life.

Turning ON a Standby Power Supply

Stand-by or auxiliary power sources, such as generators, can be used to prevent over-discharging. Some controllers automatically start the backup power source to recharge the battery bank when the batteries reach a low charge state. When the batteries are fully charged, the controller turns off the auxiliary power sources, and the photovoltaic system resumes its charging operation. In "grid connected" systems with battery backup, the conventional utility power creates a backup power supply.

5.4. Specifying a Controller

A photovoltaic system controller must match the system voltage. For example, a
12-volt controller is used in a 12-volt system and a 24-volt controller in a 24-volt system. Secondly, a controller must be capable of handling the maximum load current (amperage) that will pass through the controller. System designers should note that some loads might operate directly from the batteries or through an inverter and not pass through the controller. Thirdly, a controller must be able to handle the maximum PV array current. Use the maximum array amps at short circuit current (which is greater than the operating amps) plus a 25 percent safety margin to conservatively determine this figure.
Although there are numerous optional features, system designers should consider using controllers with the following features.

5.4.1. Lights

Indicator lights can tell users and service people how the system is operating.
Lights can indicate when the batteries are fully charged, when the battery voltage is low, or when the LVD has shut off the loads.

5.4.2. Meters

Meters are used to monitor system performance. A voltmeter can provide information on the health of the battery. Voltmeters that have a colour-coded, expanded scale are easily read and understood. Red is used to indicate LVD, yellow for caution, and green for a fully charged battery. When trained users report system problems, a voltmeter reading may tell the service person what is wrong. While voltmeters are inexpensive, they really measure battery "pressure" and can only indicate the true battery state-or-charge (SOC).

An array ammeter indicates if the PV array is working by measuring how much current is flowing. An ammeter on the load side tells users how much power the loads are drawing. Not only do meters allow users to learn about and maintain their system, but also, in case problems arise, users can accurately report the system's status to maintenance personnel.

5.4.3. Temperature Compensation

When battery temperature is less than 15 degrees C (59 degrees F) or more than 35 degrees C (95 degrees F), the charging voltage should be adjusted. Some controllers have a temperature compensation sensor to automatically change charging voltage.

Key Points

1. The photovoltaic controller is a voltage regulator that prevents the battery from being overcharged by the array.
2. Single-stage controllers use a sensor to break the circuit and prevent reverse current flow at night, instead of using a blocking diode. These controllers are small and inexpensive and do not require significant ventilation.
3. Multi-stage controllers automatically establish different charging currents depending on the battery's state of charge which is beneficial for battery life. These controllers need proper ventilation as they dissipate heat.
4. Maximum power point tracking controller optimises the match between the solar array (PV panels), and the battery bank, utility power, DC motor, or DC pump. They provide 92-97% efficiency.
5. Controllers prevent over-discharging by temporarily turning off loads, byactivating lights or buzzers or by turning on a standby power supply.
6. Designers should specify controllers with lights, meters and temperature compensation features.

CHAPTER SIX

6. INVERTERS

In this chapter, you will learn
- The function of an inverter.
- Inverter optimal features.
- Types of inverters and their use.
- Certain beneficial features before specifying an inverter.

6.1. Introduction

Alternating current is easier to transport over a long distance and has become the conventional modern electrical standard. Consequently, most common appliances or loads are designed to operate on AC. As you know, photovoltaic modules generate only DC power. In addition, batteries can store only DC power.
AC and DC are, by nature, fundamentally incompatible. Therefore, a "bridge" – an inverter - is needed between the two.
The fundamental purpose of a PV system inverter is to change DC electricity from PV modules (when connected with the utility grid) and batteries (in standalone or grid tied/battery backup) to AC electricity, and finally to power AC loads.
Inverters can also feed electricity back into the grid. Inverters designed to feed into the utility grid are referred to as grid-tied, line-tied, or utility-connected inverters. These inverters are used in large-scale PV power plants owned by utility companies that generate electricity for the grid, as well as in residential systems that feed electricity to the grid.

6.2. Inverter Features

A system designer should know the optimal features of an inverter when choosing one. Inverter features include the following:

High Efficiency

The inverter should convert 80 percent or more of the incoming DC input into AC output.

Low Standby Losses

The inverter should be highly efficient when no loads are operating.

High Surge Capacity

The inverter should provide high current required to start motors or run simultaneous loads.

Frequency Regulation

The inverter should maintain 50 Hz output over a variety of input conditions.

Harmonic Distortion

The inverter should "smooth out" unwanted output peaks to minimize harmful effects on appliances.

Ease of Servicing

The inverter should contain modular circuitry that is easily replaced in the field.

Reliability

The inverter should provide dependable long-term service with low maintenance.

Automatic Warning or Shut-off

The inverter should contain protective circuits that guard the system.

Power Correction Factor

The inverter should maintain optimum balance between the power source and load requirements.

Low Weight

The inverter should facilitate convenient installation and service.

Battery Charging Capability

Many PV systems have a backup AC power source, such as a generator, to charge the batteries. Battery charging capability on an inverter allows the generator to charge the batteries through the inverter (by converting the AC to DC at appropriate voltage) instead of through a separate battery-charging component.

Low cost

The inverter's price should fit the system budget.

6.3. Inverter Types

There are two categories of inverters. The first category is synchronous or linetied inverters, which are used with utility-connected photovoltaic systems. The second category is stand-alone or static inverters, which are designed for independent, utility-free power systems and are appropriate for remote photovoltaic installations. Some inverters may have features of both types to facilitate future utility-connected options.

Another classification for inverters is the type of waveform they produce. The three most common waveforms include the following:

6.3.1. Square Wave Inverters

These units switch the direct current input into a step-function or "square" AC output. They provide little output voltage control, limited surge capability, and considerable harmonic distortion. Consequently, square wave inverters are only appropriate for small resistive heating loads, some small appliances, and incandescent lights. These inexpensive inverters can actually burn up motors in certain equipment.

6.3.2. Modified Square Wave Inverters

This type of inverter switches DC input to AC output. These complex circuits can handle large surges and produce output with much less harmonic distortion. This style of inverter is more appropriate for operating a wide variety of loads, including motors, lights, and standard electronic equipment like TV and stereo.

However, certain electronic devices may pick up inverter noise running on a modified square-wave inverter. Also, clocks and microwave ovens that run on digital timekeepers will run either fast or slow on modified square wave inverters.

It is also not advised to charge battery packs for cordless tools on modified square wave inverters.

6.3.3. Sine Wave Inverters

Sine-wave inverters are used to operate sensitive electronic hardware that requires a high quality waveform. They have many advantages over modified square wave inverters. These inverters are specifically designed to produce output with little harmonic distortion, enabling them to operate even the most sensitive electronic equipment. They have high surge capabilities and can start many types of motors easily.

Sine wave inverters can also feed electricity back into the grid. Most utility connected inverters don't use a battery bank but instead connect directly to the public utility, using the utility power as a storage battery. When the sun is shining, electricity comes from the PV array via the inverter. If the PV array is making more power than is being used, the excess is sold to the utility power company through a second electric meter. If you use more power than the PV array can supply, the utility makes up the difference. Also, at night and during cloudy weather, all power comes from the grid.

6.4. Specifying an Inverter

When you are choosing an inverter for a stand-alone system, you should read and understand the specifications. Most inverters will list some, if not all, of the following ratings:

6.4.1. Watts Output

This indicates how many watts of power the inverter can supply during standard operation. It is important to choose an inverter that will satisfy a system's peak load requirements. The inverter must have the capacity to handle all the AC loads that could be on at one time. For example, a system user may wish to power a 1000-watt iron and a 500-watt microwave oven at the same time, a minimum of 1500 watts output would be required. However, system designers should remember that over-sizing the inverter could result in reduced system efficiency and increased system cost.

6.4.2. Voltage Input or Battery Voltage

This figure indicates the DC input voltage that the inverter requires to run, usually 12, 24, or 48. The inverter voltage must match the nominal PV system voltage.

As an inverter's maximum rated AC wattage increases, its DC input voltage also increases. It is common to find 1200-watt inverters with a 12-volt DC input, whereas 2400-watt, 12-volt inverters are rare.

6.4.3. Surge Capacity

Most inverters are able to exceed their rated wattage for limited periods of time.

This is necessary to power motors that can draw up to seven times their rated wattage during start-up. Consult the manufacturer or measure with an ammeter to determine surge requirements of specific loads. As a rough "rule of thumb" minimum, surge requirements of a load can be calculated by multiplying the required watts by three.

6.4.4. Frequency

This indicates how often electricity alternates or cycles. Most loads in Pakistan require 50 cycles per second (often expressed as 50 Hz). High quality equipment requires precise frequency regulation; variations can slowly damage equipment.

Inverters are available to produce the frequency needed for international applications.

6.4.5. Voltage Regulation

This figure indicates how much variability will occur in the output voltage. Better units will produce a near constant output voltage.

6.4.6. Efficiency

If you plan to operate the inverter frequently, a high efficiency unit is essential. Inverters may only be efficient when operated at or near their peak output, for example when a 300-watt inverter is used to power a 300-watt load. An inverter is often used to power loads at less than its rated capacity. Therefore, it is usually wise to choose a unit rated at a high efficiency over a broad range of loads.

Key Points

1. The fundamental purpose of a photovoltaic system inverter is to change DC electricity from PV modules (when connected with the utility grid) and batteries (in stand-alone or grid tied/battery backup) to AC electricity, and finally to power AC loads.
2. A system designer should know the optimal features of an inverter when choosing one. Those features are high efficiency, high surge capacity, frequency regulation, harmonic distortion, reliability, battery charging capability, low cost etc.
3. Square wave inverters are only appropriate for small resistive heating loads, some small appliances, and incandescent lights. These inexpensive inverters can actually burn up motors in certain equipment.
4. Modified square wave inverter is more appropriate for operating a wide variety of loads, including motors, lights, and standard electronic equipment like TV and stereo.
5. Sine wave inverters have high surge capabilities and can start many types of motors easily. They can also feed electricity back into the grid.
6. When specifying an inverter for stand-alone PV systems, certain features, watts output, voltage input, surge capacity, frequency, voltage regulation and efficiency, have to be considered.

CHAPTER SEVEN

7. PHOTOVOLTAIC SYSTEM WIRING

In this chapter, you will learn
- The power and the voltage drop due to wire size and wire length.
- Types of wires on the basis of the conductor and the insulation.
- How to choose the correct size of wire for different sections of PV systems.
- How to use the wire tables to select the appropriate wire size for specific application.
- The importance and use of circuit breakers, fuses and disconnects in PV systems.
- About grounding, types of grounding and complete grounding equipment.

7.1. Introduction

Water flows easily through a large diameter pipe but not through a small pipe. If a water system is installed using pipes that are too small (diameter), water pressure will be lost in the pipes. By the time the water reaches the user, the pressure may be so low that not enough water comes out to be useful. The reason for the loss of pressure is that the small pipe has too high a resistance.

7.2. Power Loss due to Size

Current flowing through a wire is just like water flowing through a pipe. The smaller the wire, the more electrical pressure (volts) is needed to force a certain current (amperes) through the wire.

Too small wiring is a common reason for poor performance of solar PV systems.

It is important to understand that the wiring used for a 12 V or 24 V solar installations must be of much larger diameter than wire used to carry the same amount of power at 240 V from a city electrical system. Here is an example:

Suppose the total power is 120W

i. For a 240V system, current = 120W/240V = 0.5A

ii. For a 24V system, current = 120W/24V = 5A

iii. For a 12V system, current = 120W/12V = 10A

As you can see, for the same amount of power, lower voltage means much larger current and a thicker wire requirement.

To get this higher current, more batteries and panels must be installed, usually at extra cost. If you use very large wires, the voltage needed to push the electricity through the wires is low, but the cost of the wires is much higher. The best size of wire will compromise between the cost of larger wire with low voltage losses and the cost of the extra panels and batteries to overcome the losses from cheaper, smaller wire.

Figure 7.1: *Effect of size on power loss*

7.3. Power Loss due to Length

The longer a pipe, the more difficult it is to force water through it. To move a certain amount of water each day through a short pipe takes less pressure than, moving the water through a long pipe of the same size. To save power, pipes should be as short as possible.

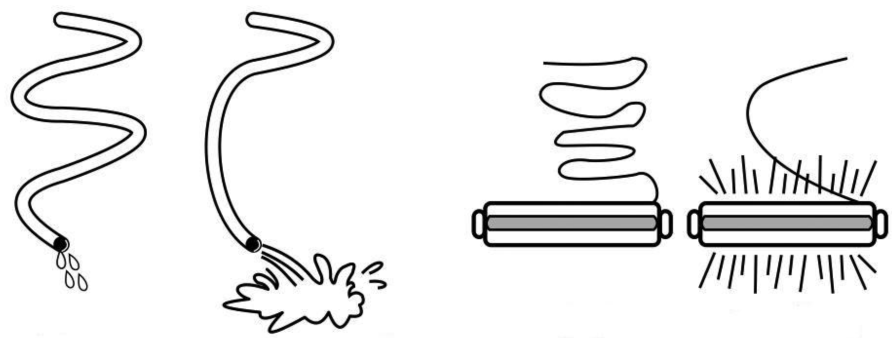


Figure 7.2: *Effect of length on power loss*

The same problem exists with solar PV systems. More electrical pressure (voltage) is needed to force a certain current (amperes) through a long wire than a short one of the same size. To get this increased voltage, more batteries and panels must be installed at extra cost. To save cost, wires should be kept as short as possible. Short wires save on wire cost and cause less power loss.

7.4. Voltage Drops from Wiring

The reason for the power loss in wire is its resistance (ohms). It takes force (volts) to push electricity through a wire and the more resistance the wire has, the more force must be used. The voltage needed to push electricity through a wire is called the voltage drop of the wire. It is called voltage drop because the voltage at the appliance end of the wire is lower than the voltage at the battery end by the amount needed to push the electricity through the wire. The wire resistance causes a drop in voltage.

It takes more force to push a lot of electricity through a wire than to push a small amount. Therefore, the voltage drop in a wire increases as the current (amperes) increases. The exact voltage drop of the wire equals the amperes being pushed through the wire times the wire resistance in ohms (Ohm's law).

An appliance requires a certain voltage and a certain number of amperes to work properly. The appliance determines the number of amperes that must flow in the wire connecting it to the battery. If the appliance cannot get enough amperes because the voltage is too low, it will not work properly and may be damaged.

7.4.1. Wire Length and Voltage Drop

Because wire resistance increases as wire length increases, the shorter the wire the better it is. If the voltage drop between the battery and an appliance is 2 V with a 10 m wire, shortening the wire to 5 m will cut the voltage drop in half to only 1 V. Not only does a shorter wire make more volts available to the appliance, it also cuts the cost of the wire, so a double advantage is gained.

7.4.2. Wire Size and Voltage Drop

Because wire resistance deceases as wire size (diameter) increases, the voltage drop in the wires goes down as wire size goes up. Doubling the size of the wire cuts the wire voltage loss in half. But doubling the wire size will increase the cost of the wire. One solution is to allow the wire to lose some voltage but not so much as to cause problems with the appliances.

7.5. Types of Wire

There are several types of wire. It is important to use the correct type of wire when installing a solar PV system. A bare or insulated conductor consisting of one or several strands used to transmit electric power from one place to another with maximum efficiency is called cable. The different sizes of wire commonly used are 14 SWG, 16 SWG, and 21 SWG where SWG stands for "standard wire gauge".

7.5.1. Conductor Type

The metal core that carries the electricity is called the conductor. Copper and aluminium metals are used as conductors.

Copper

Copper is the most commonly used material in cables. It has a high electrical and thermal conductivity. It is also cheaper as compared to other good conductors such as silver etc. Copper has a high resistance against corrosion, and can be easily jointed.

Aluminium

Aluminium conductor has an important role in electrical engineering especially in over head transmission system. Aluminium as a conductor is used where there would no chemical or corrosion agents. Although aluminium has only 61% of the conductivity yet it is widely used due to its less weight per unit volume. Weight per unit volume of aluminium is approx. 30% of that of copper.

Although wires are sometimes made with aluminium conductors, wire used for home and small commercial applications is always copper. Even if aluminium wire is available at no cost, never use it in house wiring because unless it is correctly installed with special connectors, which are difficult to obtain, it will not work well or last long.

For house wiring, solid copper wire is often used. It consists of a single solid copper conductor inside an insulating sleeve. Solid wire is usually the cheapest but it is inflexible and if bent back and forth enough times it will break.

Wire is often made up of many small strands of wires all bunched together inside the insulating sleeve. This is called stranded wire. Though each strand is very thin, enough strands are bunched together to make the total wire area equal to that of a solid wire. If each strand is 0.1 mm2 in size, then 25 strands will make a 2.5 mm2 wire.

The main advantage of stranded wire is its flexibility. The more strands in the conductor, the more flexible the wire. Most appliance power cords have a stranded wire. Very large electrical wires are also stranded because a single solid wire would be too difficult to bend.

Electrically, there is no difference between equal sizes of stranded and solid wire.

Solid wire is cheaper and good for permanent installations. Stranded wire is usually best for any application where the wire is not permanently fixed in place.

The current carrying capacity of cable depends upon the cross sectional area of the conductor and number of strands. The more the number of strands (overall cross sectional area) the higher will be the current carrying capacity.

The stranded formation of stranded conductors comprises 3, 7, 19, 37, 61, and 127 wires. For example, a 3/0.029 size of cable means that there are three conductors (strands) and each strand has a diameter of 0.029 inches. Similarly 7/0.044 means – 7 conductors of 0.044 inches diameter each.

7.5.2. Insulation

Insulation on a wire is mainly intended to prevent accidental electrical connections so that no electricity is lost through leakage to the material surrounding the wire. Insulation is also for safety. At the low voltages of a PV system, an electric shock is not likely but burns or a house fire can be caused if poorly insulated wires touch and cause a short circuit.

Another use of insulation in some wires is to combine several conductors into one unit. All electrical circuits require one wire going to the appliance from the power source and another wire returning. So it is common for house wiring to include two separate conductors combined into one insulating sheath. This is called two-conductor cable. Three conductors or more can also be combined into one insulating sheath. For PV systems two conductors are usually enough.

Multiple-conductor cable has two layers of insulation. The outside insulation holds the different wires together and the inside Insulation forms a layer around each individual wire. For house wiring, two conductor cable is more convenient to install than two single-conductor wires.

Insulation also protects the wires from damage. Special Insulation is needed for wires that will be buried or exposed to sunlight and the weather.

When buying wire, make sure that the insulation is right for the job. If the wire will be exposed to the weather, as when it is used for connecting solar panels, the insulation must be designed for exposure to sunlight and rain. Standard indoor house wiring will harden and crack open if exposed to sunlight for long periods. If the wire will be buried, the insulation must be designed to resist the fungus and moisture always present in the ground. Standard indoor house wiring will be ruined by long burial.

7.6. Choosing the Correct Size of Wire

Four tables are given in this chapter. These tables can be used to find a suitable size of wire to connect panels or appliances to batteries. Two of the tables are for use with 12 V systems and two are for 24 V systems. Before using a table, check that it is the right one for the voltage in your system.
Looking at the tables, three things must be known in order to choose the correct wire size:
 The voltage of the PV system battery (12 V or 24 V).
 The distance in metres along the path of the wire.
 The number of amperes that must flow through the wire to operate the appliance connected to it.
The battery voltage for most solar PV systems will be either 12 V or 24 V. If the voltage is not 12 V or 24 V these tables should not be used.
The length must be measured along the actual path the wire follows all the way to the battery.
To use the wire tables, first select the 12 V or 24 V table that fits your system.
There are two kinds of tables – exact size and standard size. Exact size table gives theoretical wire sizes and the wires may not be commercially available.
These tables are mainly used for large systems requiring wires larger than 4 mm2 or when one battery feeds more than one appliance.
Standard size tables show wire sizes that are commercially available. So when you use the exact size table and the wire size is not available then go to the standard size table to find the available wire.

7.6.1. Appliance to Battery

It is very easy to use the wire sizing tables when a single appliance is connected by a wire to the battery. First find the ampere rating or watt rating of the appliance. This is usually shown on the label although sometimes it can only be found on specification sheets packed with the appliance. The amperes used by an appliance can also be measured while it is in use with an ammeter.
Starting at the top left of the table, move down the watts or amperes column until you find the first row with the number of watts or amperes equal to, or higher than, the appliance rating.
Next, measure or closely estimate the total distance the wire must run between the battery and the appliance. Make sure that you allow for any extra wire that goes to switches, and the extra length needed to go around doors, windows or to make other detours.
Then, in the table, go across the row with the correct watt/ampere value until you reach a column for a wire length equal to, or longer than, the wire length you need.
Read the wire size in mm2 in the box where the wire length column and the watt/ampere row meet. You can use the wire size shown or a larger size. Never use a smaller size.

7.6.2. More than One appliance Connected to One Wire

It is not always the case that only one appliance is connected to a wire. Suppose you have three appliances connected to one wire. Suppose that

a. The first appliance is a television set that needs 60 W of power and is 2 m away from a 12 V battery.
b. The second appliance is a fan that needs 24 W and is 4 m from the battery.
c. The last appliance is a light that needs 13 W and is 7 m from the battery.

In this example, the wire is connected in three sections.

a. First section is from battery to appliance one (television),

b. Second is from appliance one to appliance two (television to fan),
c. Third section is appliance two to appliance three (fan to light).

The first section (battery to television) carries current not only for the television but also for the fan and light. The second section (television to fan) does not carry current to the television but carries it for both the fan and the light. The third section (fan to light) carries no current to either the television or the fan, but only for the light.

Step One

Use the table to find the exact wire size needed for each appliance if each appliance was connected by itself.

a. For the television that is 2 m from the battery and uses 60 W, a wire size of 0.80 mm2 is needed.
b. For the fan 4 m from the battery and using 24 W, a wire of 0.64 mm2 is needed.
c. For the 13 W light 7 m from the battery, a wire of 0.61 mm2 is needed.

Step Two

Combine the multiple wire sizes into one.

a. The wire from the battery to the television will have to be large enough to carry current to all three appliances. It will need to be 0.80 plus 0.64 plus 0.61 mm2, or 2.05 mm2.
b. The section of wire between the television and the fan will be carrying the current needed by the fan and the light so the minimum wire size needed in this section will be 0.64 plus 0.61 i.e. 1.25 mm2.
c. Finally, the section between the fan and the light will only be carrying current for the light, so that wire must not be smaller than 0.61 mm2.

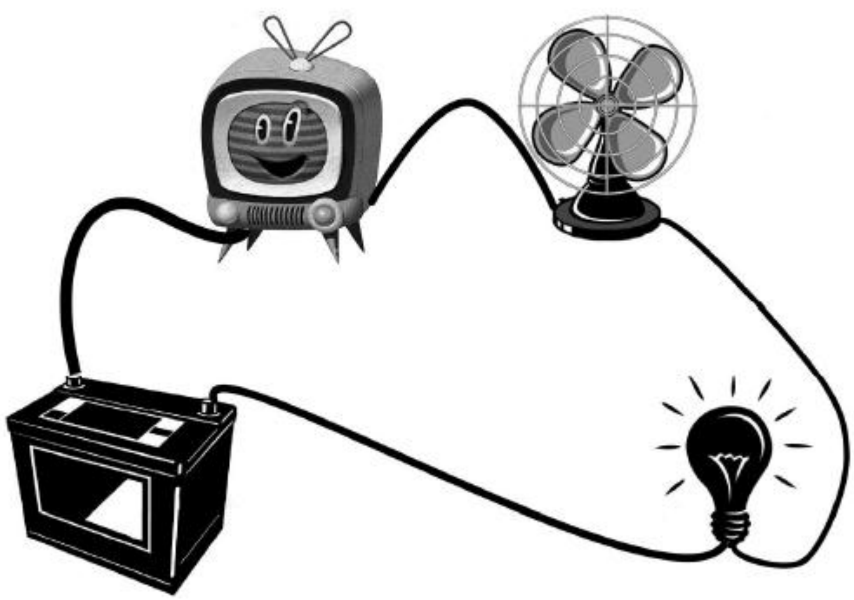


Figure 7.3: *More than one appliance connected to one wire*

While it is technically correct to connect the three appliances using the three different wire sizes, the largest of the three sizes is usually used for all the connections. In this case, the smallest acceptable size would be 2.5 mm2.

This method can be used for any number of appliances by dividing the circuit into the same number of sections as there are appliances.

7.6.3. Appliance with Motors

The watt or ampere rating on an appliance shows its electricity use in normal, continuous operation. For example, a refrigerator may show a power requirement of 60 W at 12 V. This means that when it is running continuously, it will need to receive 5 A of current from the battery. Electric motors, however, require extra current to start. When an electric motor is first turned on it may require several times the amperes it uses when running. The voltage drop in the wire increases as the amperes through the wire increases. Therefore, a motor that is starting and drawing extra amperes from the battery may cause such a large voltage drop in the wire that it can cause problems with the appliance. This is particularly true when the battery is partially discharged and its voltage is low. To prevent this problem, wires running to appliances with motors (refrigerators, washers and pumps, for example) should be sized for at least twice as many watts or amperes as the appliance normally requires when running.
If the table shows a wire size larger than is available, several smaller wires can be combined into one large one. So if the table shows 10 mm2 wires, four 2.5 mm2 wires can be run together from the battery to the appliance.

7.6.4. Panel to Battery Connections

Problems of voltage drop can occur in wires connecting solar panels to batteries.
The number of amperes that the wire must carry is not constant. It changes with the amount of charge in the battery and the brightness of the sun. The wire size should be large enough to pass the maximum amperes that the panels can produce. The maximum panel amperes are often printed on the panel or in the panel specifications sheet as the Isc of the panel. If the actual maximum panel amperes are not known, remember that watts equal volts time amperes. So the panel peak amperes will be its peak watts divided by its voltage. As almost all solar panels are designed to charge 12 V batteries, if you divide the peak watts by 12, you will usually get a reasonable estimate of the peak amperes. Thus a 72Wp panel (peak watt rating as shown in the panel specification) could be expected to provide a maximum ampere output of 72 W divided by 12 V, or 6 A.
Note that when you double the distance that the wire must run, you have to double the size of the wire to keep the voltage loss the same. This means that you can use the table for longer wire than listed. If you need to know the size of wire to run for 30 m, you can look in the table for the size of wire to run for 15 m and double the size.

7.6.5. Different Systems for Cable Size

To calculate the size of a cable there are two systems – English and Decimal.
In English system the conductor diameter is given in inches. For example, 3/0.029" means that there are three conductors and the diameter of each conductor is 0.029 inches. In the Decimal system the diameter is given in millimetres (mm). For example 1/1.13 stands for one conductor of 1.13 mm diameter. Table 7.1 shows different sizes of cables and their current ratings.

Table 7.1: *Cable sizes and current arranging capacity*

Serial No.	Conductor Size	Capacity (Amp)
1	1/0.044” or 1/1.131 mm	11
2	3/0.029” or 1/1.38 mm	13
3	3/0.036” 0r 1/1.78 mm	16
4	7/0.029” or 7/0.85 mm	21
5	7/0.036” or 7/1.04 mm	28
6	7/0.044” or 7/1.35 mm	34
7	7/0.064” or 7/2.14 mm	56
8	19/0.044” or 19/1.53mm	77

7.7. Over-current Protection

Every circuit must be protected from electrical current that exceeds the wire's current carrying ability. Two types of over-current protection are:

7.7.1. Circuit Breakers

When the current exceeds a fuse or circuit breaker's rated amperage, the circuit will open and stop all current flow. Circuit breakers must be DC rated if used in direct current circuits. Many circuit breakers commonly used in AC circuits are not suitable for DC systems unless rated specifically for that purpose. A breaker without an adequate DC rating will soon burn out its contact points.

7.7.2. Fuses

Fuses consist of a wire or metal strip that will burn through when a specified maximum current passes through the fuse. This opens the circuit and protects the wire. Fuses, like circuit breakers, must be DC rated if placed in DC circuits. A fuse that has "blown" must be replaced, while a circuit breaker may simply be reset.
When a fuse blows or circuit breaker trips, first of all, determine the cause, then replace the fuse or reset the circuit breaker to avoid damaging the PV system wiring or starting a fire. Common causes of fuse failure from excess current are:

- Overload: Operation of too many loads on the same circuit.
- Short circuit or ground fault: Caused by faulty wiring or equipment.

Fuses and circuit breakers are always connected in series with the circuit.

7.8. Disconnects

Each piece of equipment in a PV system, such as inverters, batteries, and charge controllers, must be able to be disconnected from all sources of power.
Disconnects must satisfy the following items:

- They can be switches or circuit breakers.
- They need to be accessible.
- They must not have any exposed live parts.
- They must plainly indicate whether they are in the opened or closed position.
- They must be rated for the nominal system voltage and available current.

  Circuit breakers designed in the system for over-current protection can be used as disconnects. Fuses are not considered disconnects unless they are switched fuses.

7.9. Grounding (Earthing)

The following are the reasons to ground:

- To limit voltages due to lightning, line surges or unintentional contact with higher voltage lines.
- To stabilize voltages and provide a common reference point being the earth.
- To provide a path in order to facilitate the operation of over-current devices.

7.9.1. How Does Grounding Gives Protection

When a live conductor comes in contact with exposed metal, i.e., body of the equipment already connected to earth, due to low resistance of earth path a heavy current flows in the earth path via the supply conductors. This heavy current operates the protection device, i.e., fuse or circuit breaker and the faulty circuit is isolated thus preventing the risk of shock or fire that can occur due to this fault.

The operation (efficiency) of the protection device depends upon the resistance of the grounding system, i.e., lower the overall resistance of the grounding system, more efficient will be the protection device. It is, therefore, recommended that the overall resistance of the grounding system should not be more than one ohm.

There are two specific ways we ground a system; equipment grounding and system grounding. It is important to know the difference between the two.

7.9.2. Equipment Grounding

Equipment grounding provides protection from shock caused by a ground fault and is required in all PV systems. A ground fault occurs when a current-carrying conductor comes into contact with the frame or chassis of an appliance or an electrical box. A person who touches the frame or chassis of the faulty appliance will complete the circuit and receive a shock. The frame or chassis of an appliance is deliberately wired to a grounding electrode by an equipment grounding wire through the grounding electrode conductor. The wire does not normally carry a current except in the event of a ground fault. The grounding wire must be continuous, connecting every non-current carrying metal part of the installation to ground. It must bond or connect to every metal electrical box, receptacle, equipment chassis, appliance frame, and photovoltaic panel mounting. The grounding wire is never fused, switched, or interrupted in any way.

7.9.3. System Grounding

System grounding is taking one conductor from a two-wire system and connecting it to ground. It should be used for all systems over 50 volts. In a DC system, this means bonding the negative conductor to ground at one single point in the system. Placing this grounding connection point as close as practicable to the photovoltaic source better protects the system from voltage surges due to lightning.

7.9.4. Size of Equipment Grounding Conductor

The size of the equipment grounding wire depends on whether or not the system has ground-fault protection.

If the system has ground-fault protection, the equipment grounding conductors can be as large as the current carrying conductors, the positive and negative wires.

If the system does not have ground-fault protection, the equipment grounding wire must be sized to carry no less than 125% of the PV array short circuit current. For example, if your PV array has a short circuit current of 30 amps, the equipment grounding wire would have to be sized to handle at least 37.5 amps (30 amps x 1.25).

7.9.5. Size of Grounding Electrode Conductor

The DC system grounding electrode conductor, which is the bare copper wire connecting grounded conductor (the negative wire) and/or equipment grounding conductor to the grounding electrode (the ground rod), cannot be smaller than 16 mm2 aluminium or 10 mm2 copper.

7.9.6. Grounding Electrode and its Installation

Because all PV systems must have equipment grounding, regardless of operating voltage, PV systems must be connected to a grounding electrode. This is usually done by attaching the equipment grounding wire to a copper rod or galvanised iron or copper plates, via a grounding electrode conductor. In case of galvanized iron, the size of earth plate should not be less than 2ft x 2ft x1/4 inches, and that of copper not less than 2ft x 2ft x 1/8 inches. Copper plates are extensively used nowadays because copper plates are more effective and cheaper to install. PV systems often have AC and DC circuits where both sides of the system can use the same grounding electrode. Some PV systems may have two grounding electrodes, one electrode for the AC system and one electrode for the DC system at the array. If this is the case, these two grounding electrodes must be bonded together.

To achieve best results, it is necessary to bury the earth plate well below water level. The plate should be installed vertically in the ground and should be surrounded by a bed of one foot of charcoal mixed with lime packed hard. Coke or salt should never be used as these have corrosive effects especially on copper. For greater safety two or three plates should be buried in parallel, keeping them at least 10 ft apart.

If water level is too far below the surface, i.e., 40 ft or more; then bury plate at least 10 ft below the surface and artificial dampness should be provided.

Grounding electrode conductor is connected to earth electrode buried in earth and the other end is connected to the point where the equipment grounding conductor meets.

Key Points

1. The best size of wire will compromise between the cost of larger wire with low voltage losses and the cost of the extra panels and batteries to overcome the losses from cheaper, smaller wire.
2. Wires should be kept as short as possible. Short wires save on wire cost and cause less power loss.
3. It takes more force to push a lot of electricity through a wire than to push a small amount. Therefore, the voltage drop in a wire increases as the current (amperes) increases.
4. Solid wire is usually the cheapest but it is inflexible and if bent back and forth enough times it will break.
5. The main advantage of stranded wire is its flexibility. The more strands in the conductor, the more flexible the wire.

6. To choose the correct size of wire from wire tables, you should know the voltage of the PV system battery, the distance in meters along the path of the wire and the number of amperes that must flow through the wire to operate the appliance connected to it.
7. Every circuit must be protected from electrical current that exceeds the wire's current carrying ability. Circuit breakers and fuses are used in PV system for over-current protection.
8. Grounding is applied to limit voltages due to lightning, line surges or unintentional contact with higher voltage lines, to stabilize voltages and provide a common reference point.

Table 7.2: *12 V exact size table – for sizing wire to multiple appliances or for connecting solar panels*

Appliance Load or Panel W_p		Distance between Battery and Load (m)														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
W_p or W	A	Exact wire size for no more than a 0.5 V voltage drop (mm^2)														
6	0.5	0.04	0.08	0.12	0.16	0.20	0.24	0.28	0.32	0.36	0.40	0.44	0.48	0.52	0.56	0.60
10	0.8	0.07	0.13	0.20	0.27	0.33	0.40	0.47	0.53	0.60	0.67	0.73	0.80	0.87	0.93	1.00
12	1.0	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80	0.88	0.96	1.04	1.12	1.20
13	1.1	0.09	0.17	0.26	0.35	0.43	0.52	0.61	0.69	0.78	0.87	0.95	1.04	1.13	1.21	1.30
15	1.3	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
18	1.5	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.20	1.32	1.44	1.56	1.68	1.80
20	1.7	0.13	0.27	0.40	0.53	0.67	0.80	0.93	1.07	1.20	1.33	1.47	1.60	1.73	1.87	2.00
22	1.8	0.15	0.29	0.44	0.59	0.73	0.88	1.03	1.17	1.32	1.47	1.61	1.76	1.91	2.05	2.20
24	2.0	0.16	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60	1.76	1.92	2.08	2.24	2.40
28	2.3	0.19	0.37	0.56	0.75	0.93	1.12	1.31	1.49	1.68	1.87	2.05	2.24	2.43	2.61	2.80
30	2.5	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60	2.80	3.00
32	2.7	0.21	0.43	0.64	0.85	1.07	1.28	1.49	1.71	1.92	2.13	2.35	2.56	2.77	2.99	3.20
34	2.8	0.23	0.45	0.68	0.91	1.13	1.36	1.59	1.81	2.04	2.27	2.49	2.72	2.95	3.17	3.40
36	3.0	0.24	0.48	0.72	0.96	1.20	1.44	1.68	1.92	2.16	2.40	2.64	2.88	3.12	3.36	3.60
38	3.2	0.25	0.51	0.76	1.01	1.27	1.52	1.77	2.03	2.28	2.53	2.79	3.04	3.29	3.55	3.80
40	3.3	0.27	0.53	0.80	1.07	1.33	1.60	1.87	2.13	2.40	2.67	2.93	3.20	3.47	3.73	4.00
45	3.8	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00	3.30	3.60	3.90	4.20	4.50
50	4.2	0.33	0.67	1.00	1.33	1.67	2.00	2.33	2.67	3.00	3.33	3.67	4.00	4.33	4.67	5.00
55	4.6	0.37	0.73	1.10	1.47	1.83	2.20	2.57	2.93	3.30	3.67	4.03	4.40	4.77	5.13	5.50
60	5.0	0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00	4.40	4.80	5.20	5.60	6.00
65	5.4	0.43	0.87	1.30	1.73	2.17	2.60	3.03	3.47	3.90	4.33	4.77	5.20	5.63	6.07	6.50
70	5.8	0.47	0.93	1.40	1.87	2.33	2.80	3.27	3.73	4.20	4.67	5.13	5.60	6.07	6.53	7.00
75	6.3	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00	5.50	6.00	6.50	7.00	7.50
80	6.7	0.53	1.07	1.60	2.13	2.67	3.20	3.73	4.27	4.80	5.33	5.87	6.40	6.93	7.47	8.00
85	7.1	0.57	1.13	1.70	2.27	2.83	3.40	3.97	4.53	5.10	5.67	6.23	6.80	7.37	7.93	8.50
90	7.5	0.60	1.20	1.80	2.40	3.00	3.60	4.20	4.80	5.40	6.00	6.60	7.20	7.80	8.40	9.00
100	8.3	0.67	1.33	2.00	2.67	3.33	4.00	4.67	5.33	6.00	6.67	7.33	8.00	8.67	9.33	10.00
110	9.2	0.73	1.47	2.20	2.93	3.67	4.40	5.13	5.87	6.60	7.33	8.07	8.80	9.53	10.27	11.00
120	10.0	0.80	1.60	2.40	3.20	4.00	4.80	5.60	6.40	7.20	8.00	8.80	9.60	10.40	11.20	12.00
130	10.8	0.87	1.73	2.60	3.47	4.33	5.20	6.07	6.93	7.80	8.67	9.53	10.40	11.27	12.13	13.00
140	11.7	0.93	1.87	2.80	3.73	4.67	5.60	6.53	7.47	8.40	9.33	10.27	11.20	12.13	13.07	14.00
150	12.5	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00
160	13.3	1.07	2.13	3.20	4.27	5.33	6.40	7.47	8.53	9.60	10.67	11.73	12.80	13.87	14.93	16.00
170	14.2	1.13	2.27	3.40	4.53	5.67	6.80	7.93	9.07	10.20	11.33	12.47	13.60	14.73	15.87	17.00
180	15.0	1.20	2.40	3.60	4.80	6.00	7.20	8.40	9.60	10.80	12.00	13.20	14.40	15.60	16.80	18.00
190	15.8	1.27	2.53	3.80	5.07	6.33	7.60	8.87	10.13	11.40	12.67	13.93	15.20	16.47	17.73	19.00
200	16.7	1.33	2.67	4.00	5.33	6.67	8.00	9.33	10.67	12.00	13.33	14.67	16.00	17.33	18.67	20.00
220	18.8	1.47	2.93	4.40	5.87	7.83	8.80	10.27	11.73	13.20	14.67	16.13	17.60	19.07	20.53	22.00
240	20.0	1.60	3.20	4.80	6.40	8.00	9.60	11.20	12.80	14.40	16.00	17.60	19.20	20.80	22.40	24.00
260	21.7	1.73	3.47	5.20	6.93	8.67	10.40	12.13	13.87	15.60	17.33	19.07	20.80	22.53	24.27	26.00
280	23.3	1.87	3.73	5.60	7.47	9.33	11.20	13.07	14.93	16.80	18.67	20.53	22.40	24.27	26.13	28.00
300	25.0	2.00	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	22.00	24.00	26.00	28.00	30.00

Table 7.3: *12 V wire sizing table - standard wire (metric)*

Load		Distance between Battery and Load (m)																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
W	A	Standard Size Wire needed (mm²)																			
6	0.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
10	0.8	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
12	1.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
13	1.1	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
15	1.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
18	1.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
20	1.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4
22	1.8	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4
24	2.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4
28	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	4
30	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	4	4
32	2.7	2.5	2.5	2.5	2.5	2.5	2.5	2.5	25.	2.5	2.5	2.5	4	4	4	4	4	4	4	6	6
34	2.8	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	6	6	6
36	3.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	6	6	6	6
38	3.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	6	6	6	6	6
40	3.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	4	6	6	6	6	6
45	3.8	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	6	6	6	6	6	6	6
48	4.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	6	6	6	6	6	6	8	8
50	4.2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	4	6	6	6	6	6	6	8	8
55	4.6	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	6	6	6	6	6	6	8	8	8	8
60	5.0	2.5	2.5	2.5	2.5	2.5	2.5	4	4	4	4	6	6	6	6	6	8	8	8	8	8
65	5.4	2.5	2.5	2.5	2.5	2.5	4	4	4	4	6	6	6	6	8	8	8	8	8	10	10
70	5.8	2.5	2.5	2.5	2.5	2.5	4	4	4	6	6	6	6	8	8	8	8	8	10	10	10
72	6.0	2.5	2.5	2.5	2.5	2.5	4	4	4	6	6	6	6	8	8	8	8	10	10	10	10
75	6.3	2.5	2.5	2.5	2.5	2.5	4	4	4	6	6	6	6	8	8	8	8	10	10	10	10
80	6.7	2.5	2.5	2.5	2.5	4	4	4	6	6	6	6	8	8	8	8	10	10	10	12	12
84	7.0	2.5	2.5	2.5	2.5	4	4	4	6	6	6	8	8	8	8	10	10	10	12	12	12
85	7.1	2.5	2.5	2.5	2.5	4	4	4	6	6	6	8	8	8	8	10	10	10	12	12	12
90	7.5	2.5	2.5	2.5	2.5	4	4	6	6	6	6	8	8	8	10	10	10	12	12	12	12
96	8.0	2.5	2.5	2.5	4	4	4	6	6	6	8	8	8	10	10	10	12	12	12	14	14
100	8.3	2.5	2.5	2.5	4	4	4	6	6	6	8	8	8	10	10	10	12	12	12	14	14
108	9.0	2.5	2.5	2.5	4	4	6	6	6	8	8	8	10	10	12	12	12	14	14	14	16
110	9.2	2.5	2.5	2.5	4	4	6	6	6	8	8	10	10	10	12	12	12	14	14	14	16
120	10.0	2.5	2.5	2.5	4	4	6	6	8	8	8	10	10	12	12	12	14	14	16	16	16
130	10.8	2.5	2.5	4	4	6	6	8	8	8	10	10	12	12	14	14	14	16	16	18	18
140	11.7	2.5	2.5	4	4	6	6	8	8	10	10	12	12	14	14	14	16	16	18	18	20
150	12.5	2.5	2.5	4	4	6	6	8	8	10	10	12	12	14	14	16	16	18	18	20	20
160	13.3	2.5	2.5	4	6	6	8	8	10	10	12	12	14	14	16	16	18	20	20	22	22
170	14.2	2.5	2.5	4	6	6	8	8	10	12	12	14	14	16	16	18	20	20	22	22	24
180	15.0	2.5	2.5	4	6	6	8	10	10	12	12	14	16	16	18	18	20	22	22	24	24
190	15.8	2.5	4	4	6	8	8	10	12	12	14	14	16	18	18	20	22	22	24	26	26
200	16.7	2.5	4	4	6	8	8	10	12	12	14	16	16	18	20	20	22	24	24	26	28
220	18.3	2.5	4	6	6	8	10	12	12	14	16	18	18	20	22	22	24	26	28	28	30
240	20.0	2.5	4	6	8	8	10	12	14	16	16	18	20	22	24	24	26	28	30	32	32
260	21.7	2.5	4	6	8	10	12	14	14	16	18	20	22	24	26	26	28	30	32	32	32
280	23.3	2.5	4	6	8	10	12	14	16	18	20	22	24	26	28	28	30	32	32	32	32
300	25.0	2.5	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	32	32	32	32

PRACTICAL WORK OF CHAPTER # 7

1. To check the voltage drop due to length and size of the wire.

i. Take a light and note down its wattage; calculate current by dividing wattage by voltage.

ii. Select the optimum wire size from wire tables given at the end of chapter 7 for connecting the light with the battery. To use the table you need length of the wire and the desired current, as calculated above.

iii. Connect the light with the battery through a switch.

iv. Turn ON the light and measure the voltage at the light end.

v. Now measure the voltage at the battery and compare it with the voltage measured at light end.

Result: If voltage drop is below or equal to 0.5 V for 12 V DC system or 1 V for 24 V Dc system, then wire selected is right. If the voltage drop is more than the specified values, then the selected wire is wrong.

2. To check the voltage drops if two appliances are connected to battery through one wire.

i. Take two lights of different wattage.
ii. Select wire A from exact wire tables given at the end of chapter 7 for larger power light for a distance of 10 metres from battery.
iii. Select wire B from exact wire tables given at the end of chapter 7 for smaller power light for a distance of 5 metres from the larger power light.
iv. Add the thickness of the two wires and select wire C. You will need to select wire C from the standard wire tables that is close to the sum of thicknesses as wires are sold based on standard wire tables.
v. Connect the larger power light with battery with wire C.
vi. Connect the smaller power light with the larger power light with wire B. (wire B will also need to be a standard size wire close to the size obtained in step ii)
vii. Turn ON the lights and measure the voltage at both ends of lights.
viii. Now measure the voltage at the battery end.
ix. Compare the readings with each other.

Result: If voltage drop from battery to larger power light and from larger power light to smaller power light is below or equal to 0.5 V for 12 V DC system or 1 V for 24 V Dc system, then wires selected are right. If the voltage drop is more than the specified values, then the wires selected are wrong.

3. To check the voltage drop of panel to battery connected wire.

i. Take a PV panel and find its short circuit current.
ii. Select a wire from wire tables given at the end of chapter 7 to connect this PV panel to battery for 15 metre distance and current equal to short circuit current.
iii. Connect the panel with battery using charge controller.
iv. Allow the battery to be charged by the PV panel.
v. Measure the voltage at the panel end and note it down.
vi. Now measure the voltage at the battery end and compare it with previous reading.

Result: If voltage drop is below or equal to 0.5 V for 12 V DC system or 1 V for 24 V DC system, then wire selected is right. If the voltage drop is more than the specified value, then the wire selected is wrong.

4. To check the tripping of a circuit breaker.

i. Take a DC rated circuit breaker and install it between the appliance and the battery.
ii. The ampere rating of the circuit breaker should be less than the current rating of the appliance.
iii. Turn ON the appliance (may be a light).

iv. The circuit breaker will trip as the appliance drawn current will be more than the current rating of the circuit breaker.

Result: The breaker is tripped because of higher current. This shows that you have to use the circuit breaker whose current rating is higher than the current rating of the circuit where it is going to be used.

8. SIZING PHOTOVOLTAIC SYSTEM

In this chapter, you will lean
 About penalty area which is important to know before optimisation of the PV system design.
 Six steps of sizing with an example.

8.1. Introduction

Stand-alone photovoltaic power systems are low maintenance, versatile solutions to the electric power needs of any off-grid application. They provide electric power for telecommunication stations and water pumping systems throughout the world. Twentieth-century comforts and conveniences can now be provided to remote homes via photovoltaic systems. These self-contained power stations have proven to be a reliable, cost-effective alternative to conventional power, and frequently replace the noisy, unreliable generators that most remote homes currently use.
Sizing a residential photovoltaic power system is not particularly complex. This chapter illustrates a six-step process to accurately size a system based on the user's projected needs, goals, and budget. Sizing a system includes the following steps:
1. Estimating the electric load
2. Sizing and specifying batteries
3. Sizing and specifying an array
4. Specifying a controller
5. Sizing and specifying an inverter
6. Sizing system wiring
This method is not fixed for a product, but rather will result in generic product specifications for the system. The method uses climatic data specific to a location and energy data specific to the user's needs.

8.2. Design Factors

More people would utilize photovoltaic power systems if it were not for the high initial cost. System designers must try to minimize the initial system costs by maximizing the system's energy efficiency. Efficient energy use lowers initial system cost. For example, reducing the electric lighting load by 75 percent, perhaps by shifting from incandescent to fluorescent lights, will reduce the number of modules and batteries needed for the system. Eliminating module shading by relocating the mounting system doesn't cost any money and can increase the system's efficiency. Inefficiency caused by excessive voltage drop in the system's wiring can be reduced with proper wire sizing. Intelligent advance planning doesn't cost anything and can drastically reduce a system's initial cost.
In general, designers should consider the following factors when trying to optimise a system:

Sitting

The site should be clear of shade to avoid loss in efficiency.

Orientation
The array orientation with respect to true south and proper inclination is critical for maximizing annual photovoltaic output based on local climatic conditions.

Mounting Options
The optimal mounting system can maximize insolation gain.

Modules
PV modules should be selected according to the system's parameters.

Wiring
System wiring should be designed to minimize voltage drop and provide protection from the environment.

Controllers
The controller must operate a system efficiently while meeting the needs of the user.

Battery Storage
The battery bank must be sized to the specific installation.

Loads
The system loads determine the size of the system and should be minimized by intelligent planning.

8.3. Sizing Methodology
The photovoltaic system sizing methodology is divided into six steps that should be completed sequentially.

8.3.1. Electric Load Estimation
First of all, you complete the electric load estimation by inputting the load, volts, amps, and usage information for each of the loads in a system. Upon completion, you will know the total connected watts (AC and/or DC) and the average daily load (AC and/or DC). If the loads vary significantly on a seasonal or monthly basis or are of a critical nature, use the highest values in designing the system.
Now that you have determined the average amp-hour per day load, the next step is designing an adequate battery bank.
Quantity of Fluorescent Lights = 1
Required Voltage = 12V DC
Required Current = 1.67amp DC
Power = 12x1.67
= 20 Watts DC
Daily Use = 4 hrs/day

Weekly Use = 6 days/wk
Average Daily Load of Light = (20x4x6) / 7
= 68.57 Watt-Hours DC
Quantity of Incandescent Lights = 3
Required Voltage = 12V DC
Required Current = 0.97amp DC
Power = (12x0.97) x 3
= 35 Watts DC
Daily Use = 5 hrs/day
Weekly Use = 5 days/wk
Avg. Daily Load of Incandescent Lights = (35x5x5) / 7
= 125 Watts-Hours DC
Total DC Connected Watts = 55 Watts
Average DC Daily Load = 68.75+125
= 193.57 Watts-Hours
Total AC Connected Watts = 0
Average AC Daily Load = 0

8.3.2. Battery Sizing

Divide the watt-hours calculated in step 1 by the DC system voltage to arrive at the average amp-hour per day load.
Average Amp-Hours per Day = 193.57 / 12 = 16.13 amp-hour/day
To factor in autonomy, multiply the average amp-hour per day Load by the desired days of autonomy to determine the required battery capacity. Divide this total by the discharge limit, or the battery's maximum depth of discharge, a number less than 1.0, to determine the total required battery capacity.
Days of Autonomy = 3
Battery Discharge Limit = 0.30
Required Battery Capacity = (16.13x3) / 0.3
= 161.3AH
At this point, you must select a particular battery to be used in the system and use the specifications for that battery. Divide the total required battery capacity by the battery amp-hour capacity supplied by the manufacturer to determine the number of batteries in parallel needed.
Battery AH Capacity = 55AH
No. of Batteries in Parallel = 161.3 / 55
= 3
Dividing the DC system voltage by the given battery voltage gives you the number of batteries to be connected in series.
Battery Voltage = 12V
DC System Voltage = 12V
No. of Batteries in Series = 12 / 12
= 1
Multiply batteries in series by batteries in parallel to obtain total batteries required.
Total No. of Batteries = 3x1
= 3

8.3.3. Array Sizing

To begin sizing the array, you must increase the average daily load (amp-hour) to account for the inefficiency of the batteries and controller that have been selected. Divide the average amp hour per day load by the estimated battery energy efficiency, commonly 0.8.

Battery Efficiency = 0.80

Average Load (step 2) = 16.13 amp-hours

Average Peak Amperes = 16.13 / 0.8 = 20.16

Then divide this number by the peak sun hours per day available. The resulting figure is the array peak amps.

Peak Sun Hours per Day = 4.5 Hours

Average Peak Amperes of Array = 20.16/4.5

= 4.48 amp-hours / day

At this point, you must select a particular PV module for the system and use the specifications for that module to complete further calculations.

Divide array peak amps by peak amps per module. The resulting number is the required modules in parallel.

Peak Amperes per Module = 2.23 amp/module

No. of Modules in Parallel = 4.48 / 2.23

= 2

To determine the required modules to be connected in series, divide DC system voltage by the nominal module voltage.

Nominal Module Voltage = 12V

DC System Voltage = 12V

No. of Module in Series = 12 / 12

= 1

Next, multiply modules in series by modules in parallel to determine the total modules required.

Total No. of Modules = 2x1

= 2

8.3.4. Controller Specifications

To begin, multiply module short circuit current by modules in parallel from Step 3.

Then multiply this by a safety factor of 1.25. The resulting figure is the array short circuit amps that the controller must handle under a short circuit condition.

Module Short Circuit Current = 2.4 amps

Array Short Circuit Current = 2.4x2x1.25

= 6 amps

Controller Current = 6 amps

At this point, you must select a controller for the system. Using the array short circuit amps and the manufacturer's specifications for the desired type of controller, find a controller with controller array amps or charging current that meets the required array short circuit amps. Also consider the other controller features.

Divide the DC total connected watts from Step 1 to calculate the maximum DC load amps the controller will be required to handle. Compare this figure to the manufacturer's specifications for load amperage.

DC Total Connected Watts = 55 Watts
DC System Voltage = 12V
Maximum DC Load Current = 55 / 12
= 4.58 amps
Controller Load Current = 6amps

8.3.5. Inverter Specifications

Divide the total connected watts that will be used simultaneously by the DC system voltage to calculate the maximum direct current amps continuous. This value will be used to size the wire from the battery to inverter.
AC Total Connected Watts = 0
DC System Voltage = 12V
Maximum DC Continuous Current = 0 / 12
= 0
Determine the maximum surge watts required. Remember that electric motors can require from three to seven times their rated wattage during start-up. Using these figures and the manufacturer's specifications for the desired type of inverter, find an inverter that meets the system's wattage specifications, budget, and other requirements, such as a sine-wave inverter for solid-state equipment.

8.3.6. System Wire Sizing

Refer to Chapter 7 for the system wire sizing.

Key Points

1. Sizing a residential photovoltaic power system is not particularly complex.
It is a six-step process to accurately size a system based on the user's projected needs, goals, and budget.
2. Designers should consider the important design factors when optimising a system.
3. Six steps sizing methodology should be completed sequentially.

9. PHOTOVOLTAIC SYSTEM APPLICATIONS

In this chapter, you will learn

- Lighting, lamp types and their efficiencies.
- Water pumping, terms used in water pumping, pump types, storage and delivery.
- PV-generator hybrid system and its advantages.

9.1. Lighting

Lighting is an essential element in most lifestyles, and electricity or natural day lighting generally provides it. In many of our villages, kerosene lamps are used.

Today, many different light sources are available, which makes choosing the correct energy-efficient light source much more difficult. A wide variety of attractive, economical lighting options are available in 12-volt and 24-volt direct current and 120-volt and 220-volt alternating current types, making photovoltaic powered lighting a feasible choice for many homeowners.

New types of lamps with electrical and light output characteristics far superior to the familiar incandescent and fluorescent lamps are also available now. The following sections describe the common lamp types and their applications. This information will help you determine the type of lamp to use for a specific application.

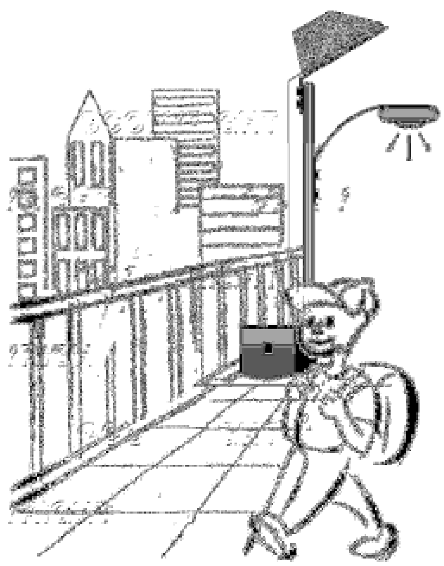


Figure 9.1: *Solar street light*

9.1.1. Lamp Efficiency

When selecting a lamp type, efficiency is an important consideration, but it should not be the only criteria used. In most cases, a more efficient light source can be substituted for a less efficient source with little or no loss in visibility.
Lamp efficiency is measured in lumens per watt. Lumens are a measure of the light output from the lamp. If a lamp produces more lumens from each watt of electrical energy input, it is more efficient.

9.1.2. Lighting Load Estimates
You should use the standard estimating procedure for electrical loads. The procedure is explained in electric load estimation of sizing methodology in chapter 7.

9.1.3. Lamp Types
Lamps designed for indoor applications are divided into the following categories:
Incandescent Lamps
Incandescent lamps are the most commonly used even though they have the poorest efficiency or lowest lumens per watt rating. In typical incandescent lamps, electricity is conducted through a filament that resists the flow of electricity, heats up, and glows. The popularity of the incandescent lamp is due to the simplicity of its use and the low initial cost of both lamps and fixtures.
Incandescent lamps are available in many wattage ranges, in 120-volt and 220-volt AC and 12-volt DC.
The efficiency of l20-volt and 220-volt AC incandescent lamps generally increases as the lamp wattage increases. Thus, one higher wattage lamp can be used instead of two lower wattage lamps, which saves on both energy and fixture costs. For example, one 100-watt general service (GS) lamp produces more light, 1740 lumens, than two 60-watt GS lamps, 860 lumens each for a total of 1720 lumens. This is not necessarily true for 12-volt DC lamps.

When choosing or recommending a lamp, you should remember that shocks, vibrations, and voltage variations could shorten the life of incandescent bulbs.

Fluorescent Lamps
Fluorescent lamps are the second most widely used light source. They are found in homes, stores, offices, and industrial plants. The sizes range from 4 to 215 watts. Generally, lamp efficiency increases with lamp length.
Fluorescent lamps generally work in both AC and DC systems. Excellent 12-volt
DC and 24-volt DC fluorescent lamps are now widely available.
Homeowners should remember to avoid using fluorescents in extremely cold environments because these lamps may have difficulty in starting.

Light-Emitting Diode (LED) Lamps
A light-emitting diode (LED) is a semiconductor device that emits light. LED lamps are now used as a replacement for incandescent light bulbs and fluorescent lamps in which white LEDs are grouped together to form a light source. LED lamps are moderately efficient with average 32 lumens per watt (lm/W) of output, and new technologies promise to deliver up to 80 lm/W. The

long lifetime of LEDs make them very attractive. They are also more mechanically robust than incandescent light bulbs and fluorescent tubes.
Currently, LED lighting is becoming more available for household use but is relatively expensive, although costs are decreasing. LED flashlights, however, already have become widely available.
LEDs are now well established in applications such as traffic signals and indicator lamps for trucks and automobiles. High output LED fixtures suitable for building lighting applications are beginning to appear on the market with system output of up to 56 lumens per watt, which is comparable to fluorescent systems.
LEDs produce more light per Watt than do incandescent bulbs; this is useful in battery powered devices.

LEDs have an extremely long life span: upwards of 100,000 hours, twice as long as the best fluorescent bulbs and twenty times longer than the best incandescent bulbs.

9.2. Water Pumping

Photovoltaic power systems are used to pump water throughout the world. The simplest method of water delivery – gravity – is not possible in many locations.
Manual pumps are a common method of water transfer worldwide, but cannot move large volumes of water or pump from deep wells. Mechanical pumps powered by engines or electric motors are expensive, maintenance intensive, and use expensive fuel. Compared to many of the alternatives, PV systems are reliable and cost effective.

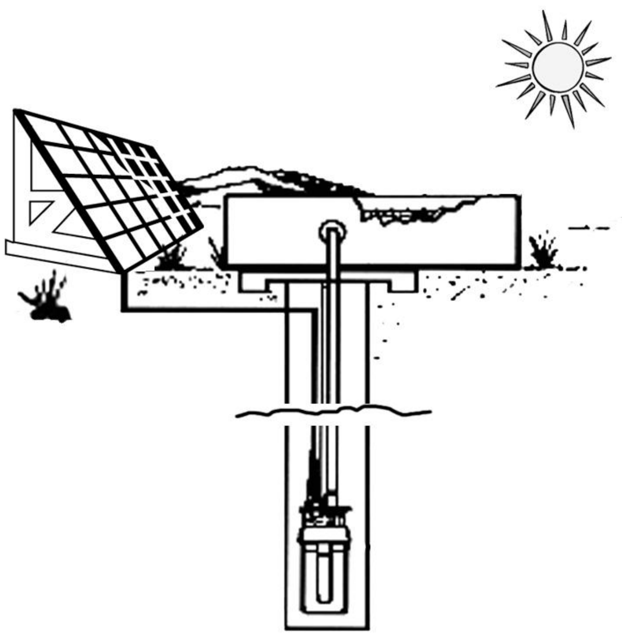


Figure 9.2: *Solar water pumping system*

9.2.1. Pump Terminology

When specifying water pumping system, you will need to be familiar with the following terms:

Static Head
It is the vertical distance from the water source to the point of free discharge.
Friction Head (FH)
The pressure the pump must provide to overcome the loss of energy due to friction as water moves through a pipe. The losses are more in case of smaller pipe diameter and fast flow. At low flow rates, friction losses are small compared to static head.
Flow
Flow is the rate of liquid volume capacity of the pump. Flow is measured as a unit volume per unit of time, such as gallons per minute (gpm) or litres per minute (Ipm).

9.2.2. Pump Types
Pumps can be divided into following major categories:

Centrifugal Pumps
Centrifugal Pump moves a liquid by the action of an impeller. The impeller draws the liquid to an intake at the impeller's centre and then discharges centrifugally at an outlet at the impeller's perimeter.

Submersible Pumps
Submersible pump has a series of centrifugal impellers or diaphragms and a motor in water tight housing. The entire assembly is submerged near the bottom of the well. These pumps can deliver water from great depths.

9.2.3. Storage and Delivery
Typically PV panels power the pumps directly. Controllers are used to monitor the photovoltaic system's output and run the pump only when there is sufficient sunlight to power the pump. As the sunlight's intensity increases and the photovoltaic system's output increases, the pump's performance increases proportionally.
Elevated tanks can provide water storage and delivery. Elevated tanks should he fitted with a float switch that turns the pump on or off according to a preset water level. Water from the tank is delivered to use points below the tank level by gravity pressure.

9.3. Hybrid System with Generators
Most residential PV systems cannot satisfy a home's advanced electrical needs.
A large part of the cost for PV stand-alone systems is due to the size of the array and batteries to support the entire load under worst-cast weather conditions. In some instances, some of the power requirement can be provided by another power source more economically.
A power generation system combining PV panels with another integrated power source is called a PV hybrid system. The most common auxiliary power source is a gas or diesel powered generator, called a PV-Diesel system. There are other types of hybrid systems, such as PV-wind systems.
The most common configuration for a PV-generator system is one in which both the PV array and the generator charge the same batteries as shown in Figure
9.3. The PV array is a slow speed battery charger, and the generator is used primarily as a high speed battery charger. Generators run more efficiently when operating close to their maximum

load, typically at 80 to 90 percent of their rated power. When generators are operating in this range, they can quickly charge batteries to nearly 70 percent state of charge. This allows the generator to operate for a short time at or near its most efficient operating point. As a result, generator maintenance and fuel costs are reduced and its lifetime is prolonged.

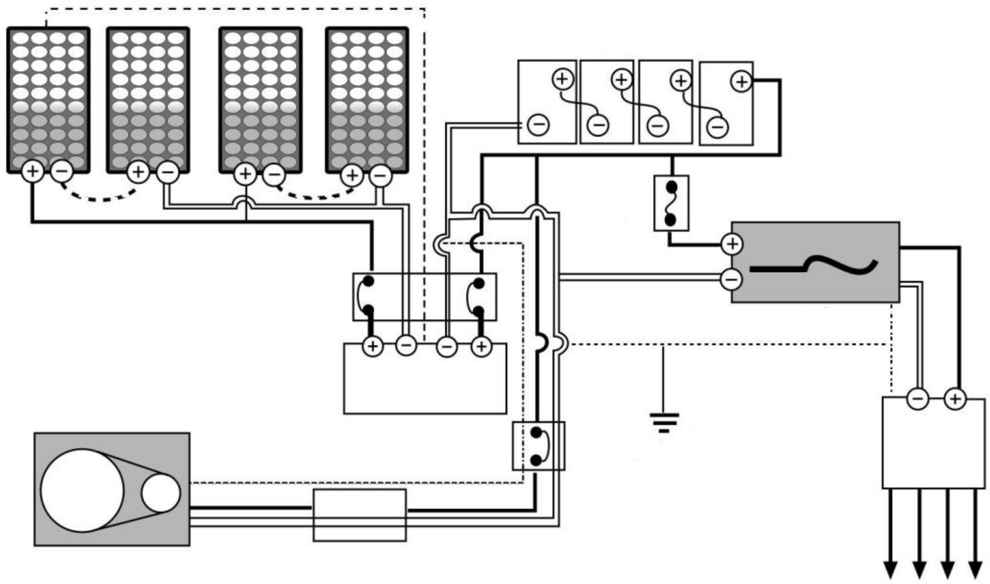


Figure 9.3: *Hybrid system with generator*

The photovoltaic array is designed to complement the generator by supplying the power to the load and completing the battery charging.

9.4. Other Applications

Photovoltaic systems are also used in wide range of applications such as:

- Refrigeration
- Fans
- Telecom Sector
- Navigation System
- Space Power System

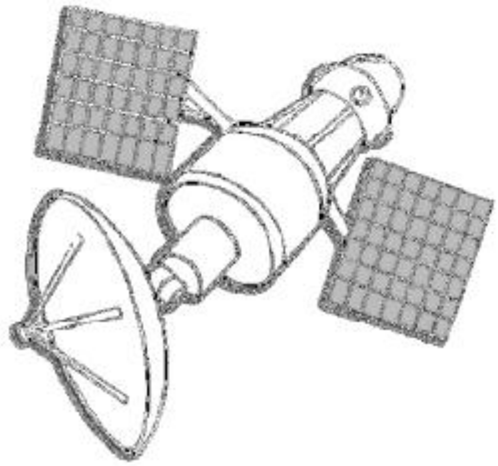


Figure 9.4: *Solar powered space station*

Key Points

1. A wide variety of attractive, economical lighting options are available in 12- volt and 24-volt DC and 120-volt and 220-volt AC types making photovoltaic powered lighting a feasible choice for many homeowners.
2. Efficiency is an important consideration when selecting the light, but it should not be the only criteria used.
3. Incandescent lamps are the most commonly used even though they have the poorest efficiency. The efficiency of l20-volt and 220-volt AC incandescent lamps generally increases as the lamp wattage increases. This is not necessarily true for 12-volt DC lamps.
4. Fluorescent lamps are the second most widely used light source and generally work in either AC or DC systems. Homeowners should remember to avoid using fluorescents in extremely cold environments because these lamps may have difficulty in starting.
5. LED Lamps produce more light per Watt than do incandescent bulbs; this feature is useful in battery powered devices.
6. When specifying water pumping system, you will need to be familiar with the terms used in water pumping system.
7. Controllers are available that allow the pump to be powered directly from a PV panel or array.
8. The most common configuration for a PV-generator hybrid system is one in which both the PV array and the generator charge the same batteries.

The PV array is a slow speed battery charger, and the generator is a high speed battery charger.

PRACTICAL WORK OF CHAPTER # 9

1. To show different types of lights.

i. Show different types of lights to the students, i.e. incandescent light, fluorescent light and LED light.

CHAPTER TEN

10. PHOTOVOLTAIC INSTALLATION

In this chapter, you will learn

- About the preparation for safe installation of PV systems
- Checklist of tools and materials required for initial visit and installation
- Installation of five different types of array mounting systems
- Guidelines for building battery enclosure and installation of a battery bank
- Guidelines for installation of controller.
- Installation of electrical boxes, wiring connections and switches used in PV systems.

10.1. Preparing for Installation

Designers or installers of remote photovoltaic systems encounter unique challenges in planning the logistics of transporting tools and materials to the system installation site. You should plan to bring all tools and materials, you can think of, to the remote site for installation. There may not be many electrical supply stores nearby, so proper planning is required. Since each remote site has unique installation characteristics, you should visit the site prior to the installation.

During this initial site visit, you should make a list of all tools and materials that may be required for the installation.

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During the planning visit of the site you should obtain detailed site-specific information needed to design and install the system in one trip. Topographic maps or detailed directions to the site location must be obtained prior to departure. The required personnel and safety gear will depend on the length of stay and conditions to be encountered.

You should bring paper and pencil to record all observations and measurements.

A 100-foot tape measure is adequate for most measuring tasks. An inclinometer is useful for leveling and quickly measuring sloped surfaces. A solar sitting device or Solar Pathfinder is very helpful for assessing site shading. The Solar

Pathfinder's compass doubles as an orienting compass if needed. A lightweight camera is also invaluable.

Initial site visits must be thorough enough to get accurate information needed to complete the design and plan the installation. Anything less will result in extra trips, added time, improper equipment choices and installation delays.

10.2. Tools and Materials

Checklists have been developed for an installation of a 12-V DC, stand-alone PV power system requiring a pole mount, battery storage, and controller. The lists assume the system will power incandescent and fluorescent lighting in a previously constructed shelter.

You should check certain installation tools to ensure they are in operational condition and have no missing parts prior to departure. Some tools are also more fragile than others. You should have a backup for these tools.

Many power tools that would be helpful during an installation are inappropriate for remote system installations. System installers often prefabricate items, especially metal components, prior to going into the field. Most power tools can be replaced with hand tools. A variety of DC power tools are available that can be powered on-site by rechargeable batteries or photovoltaic panels. You should charge all batteries before going into the field. These DC tools include:

- Lights
- Drills
- Circular Saws
- Flashlights
- Soldering Irons
- Jigsaws

Designers have developed a variety of methods to reduce weight and bulk to be carried. They replace heavier metal tools with lightweight wooden or alloy tools.

You should also eliminate single-use tools with multi-use tools where possible.

Before going into the field, you should verify that all components are operating properly, especially components with movable parts.

10.2.1. Basic Tools

- Pencil
- Volt-ohm-ampere meter with spare battery
- Sockets and wrench
- Drill bits
- Hand operated drill
- Screwdriver(s)
- Tape measure
- Hacksaw blade
- Knife
- Wire cutter
- Wire strippers
- Slip joint pliers
- Torpedo level
- First aid kit

10.2.2. Initial Site Visit Tools

- Maps
- Inclinometer
- Compass
- GPS
- Paper
- 100-foot tape measure
- solar sitting device
- Camera

10.2.3. Installation Tools

- Pencils

- Tape measure
- Rope
- String line
- C-clamps
- Hole saw
- Wood chisel
- Utility knife
- Drill bits
- Torque wrench
- Drill bit extender
- Volt-ohm-ampere meter
- Level
- Prick punch
- Slip joint
- Pliers
- Slotted screwdrivers
- Wire cutter
- Soldering iron
- Flashlight
- System operations literature
- Tool belt
- Drill
- Nut driver bits
- Paddle bits
- Brace and bit
- Socket set with extender
- File
- Adjustable wrench
- Hand saw
- Hack saw
- Hammer
- Combination square
- Wire stripper/crimpier
- Needle-nose pliers
- Black polyethylene
- Component product literature
- Plastic bags

10.3. Photovoltaic Array Installation

The major aspects of installing the PV array are choosing the most appropriate mounting systems and making proper installation. Once you have installed the array, you should verify that the array is functioning as expected by measuring the output and comparing this figure to the manufacturer's specifications.

10.3.1. Mounting System Considerations

The first step in completing a safe system installation is to carefully select the PV array's location. Electrical equipment should be protected from unnecessary environmental exposure and should be mounted in such a way that it facilitates convenient, regular system maintenance. The PV array should be located as near as possible to the load to minimize power loss from long wire runs.

PV modules are expensive, lightweight and compact, making them vulnerable to theft. So some sort of security arrangement should be made.

Photovoltaic module support structures should provide a simple, strong and durable mounting system. Most commercially available photovoltaic modules are manufactured with aluminium frames. These frames are strong, durable, corrosion resistant, and provide adequate support for the module to be mounted on a support structure.

Weather-resistant, corrosion-free materials (such as anodized aluminium, galvanized steel, and stainless steel) should he used when fabricating a photovoltaic array mounting system. The support structures need to be lightweight so they can be easily transported and installed.

Wooden racks have been successfully used in many mounting applications.

Wood, however, requires more maintenance over the life of the system, making other mounting system materials more desirable.

Throwing stones on the panel will damage it.

10.3.2. Bracket Mounting Systems

A simple bracket system can he used to mount a single solar module. Two galvanized steel angle brackets are bolted to a building's exterior walls or roof structure. A second pair of compatible brackets is attached to the end frames of the solar module. When the two sets of brackets are mated, they form a simple, durable, cost effective mounting system for a one module photovoltaic system.

Bracket systems can be constructed to pivot and tilt to seasonally optimize the photovoltaic system's performance.

10.3.3. Pole Mounting Systems

Arrays can also be mounted on a hardware system that bolts directly to a vertical pole placed permanently and securely in the ground. Generally, 2½ inch steel pipe works well for the base support. Pole mounting hardware can be bought or fabricated out of 19-gauge stainless steel. This popular mounting technique can be seasonally adjusted to optimise the system's performance.

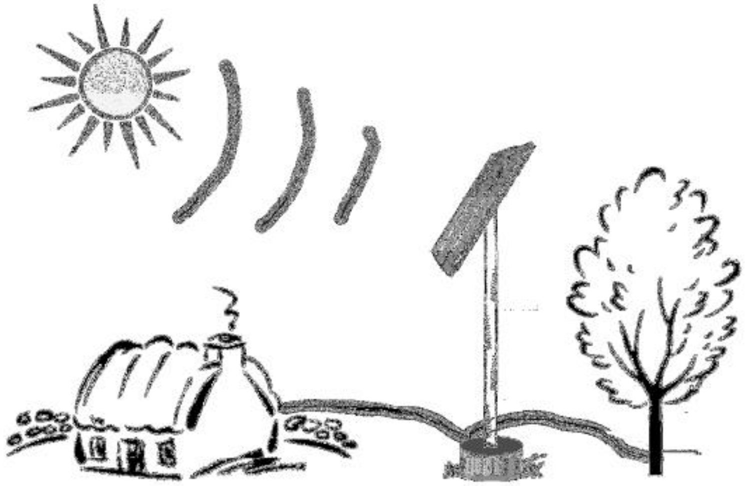


Figure 10.1: *Pole mounting system*

10.3.4. Ground Mounting Systems

A ground mounted array support structure uses a frame that is bolted directly to prepared footings.

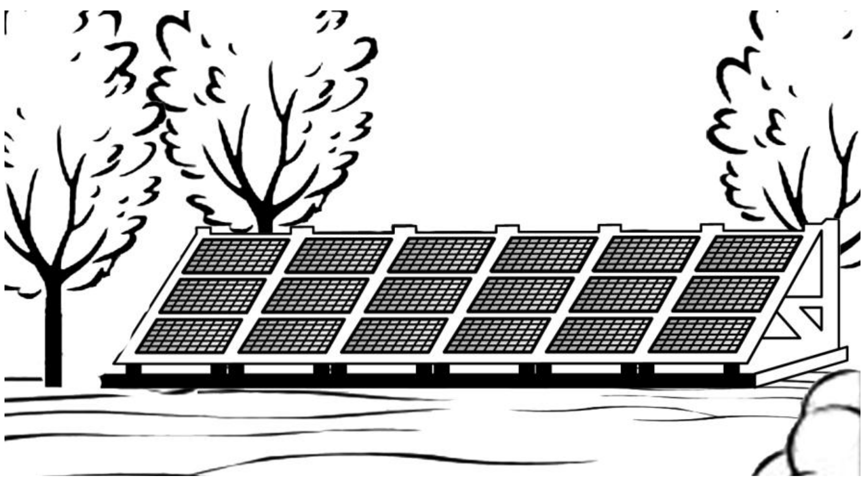


Figure 10.2: *Ground mounting system*

A mounting frame often consists of two parallel channel bars that form a simple rack. Cross supports are bolted to the frame to increase lateral structural support and to prevent wind damage. Nonadjustable, extruded aluminium legs bolt to the frame to hold the array at a predetermined tilt angle. Adjustable tilting support legs can also be fabricated to allow manual seasonal tilt adjustments.

Metal that is mounted directly to a concrete footing should be galvanized steel since the lime content in the concrete can corrode aluminium over time. In addition, nuts, bolts, and washers should be made of stainless steel to provide durable, corrosion resistant connections.

10.3.5. Tracking Mounting Systems

Solar photovoltaic array mounts that track the sun in its daily path across the sky are a cost-effective, alternate mounting system for some installations. Passive tracking units have no motors, controls, or gears and use the changing weight of a gaseous refrigerant within a sealed frame to track the sun. Sunlight activates the refrigerant, and the frame assembly moves by gravity or is driven by a piston.

They can also be seasonally adjusted to optimise altitude angle. Active trackers use motors powered by small, integrated photovoltaic panels to move the array.

Tracking mounts that follow the sun's azimuth but not its altitude are called single-axis trackers. Trackers that follow both the sun's azimuth and altitude are called dual-axis trackers. These sophisticated trackers are also commercially available, although they are not cost effective for small-scale residential systems.

Tracking mounts require firm foundations because of their weight and wind loading characteristics. Four to six inch outside diameter pipe is commonly set in reinforced concrete footings to insure long term, safe operation. The tracker stem is then placed over the pipe. The tracking unit needs to be mounted at an adequate height above ground level to allow unobstructed movement above snow or debris.

Tracking units generally enhance a system's annual performance by approximately 25% to 30% but can add a significant cost to a system. The economics of tracking mounts should be carefully evaluated in the initial design phase. Trackers offer different performance gains throughout the year, increasing system performance by 15 percent in the winter and by 40 percent in the summer. Systems requiring larger loads during the summer months are ideal candidates for tracking systems. Longer hours of effective insolation are available in the summer and increase the photovoltaic system's collection potential. In contrast, winter dominated loads are less likely to benefit significantly from trackers. Each system must be carefully evaluated to determine the economic viability of trackers versus fixed mounts.

10.4. Battery Installation

Installing a battery system starts with shipping. Remember that batteries are heavy and can easily leak. Consequently, some carriers will not ship liquid batteries. Even certain sealed batteries contain some liquid called reserve electrolyte that can spill. Upon arrival check the batteries for any damage that may have occurred during shipping.

You should protect batteries at all times, including during transport and while boost charging before departure for the site. A boost charge is needed if the batteries are not fully charged. When boost charging with an AC powered battery charger, make sure you do not exceed the charge termination voltage or charge at a faster rate than the manufacturer specifies. When charging batteries, keep them away from open flames and sparks and open the vent caps to allow explosive hydrogen gas to escape. Keep batteries away from children, unauthorized personnel, dust and oil. When transporting batteries, you should pack them to avoid spillage and short circuits. You should cover both battery terminals with an electrical insulator such as wood, tape or insulated connectors.

Building a Battery Enclosure

The battery bank must be safely located to prevent accidents, yet provide for periodic maintenance. Batteries are often housed in a ventilated battery box that is corrosion resistant and sometimes insulated. When building a battery enclosure, you should use the following guidelines:

- Protect batteries from items that can accidentally fall from above and cause a dangerous short circuit.
- Protect batteries from freezing temperatures by insulating the enclosure or locating the enclosure in a heated area.
- Build proper vents in the battery enclosure to provide free airflow and prevent the build-up of explosive hydrogen gas. The vents must be located high enough to properly vent hydrogen gas, which is lighter than air. Vents should be directed outdoors and screened to prevent insects and animals from blocking them. Note that with free airflow the battery temperature will be about the same as the average ambient air temperature.
- Build the enclosure, box, or compartment so that it can be locked, yet is easily accessible for maintenance. Size the access to the enclosure to allow for easy removal and replacement of batteries. When placed in the enclosure, the batteries or cells should have air space between them.
- Store the maintenance equipment and manufacturer's information in re-sealable plastic bag or container inside the enclosure.
- Build a strong level floor.
- Build the enclosure with material that will not be damaged by corrosion from the electrolyte. Use wood, plastic, or painted metal.

Installation Guidelines

When installing batteries, keep in mind the following installation guidelines:

- Use the connector bolt torque specified by the battery manufacturer.
- Adequately calculate the sizes of all battery wiring and fuses.
- Use #2 AWG or 25 mm2 battery interconnects cables for small systems.
- For wire entries, use connectors that protect the wire from tension and damage.
- Place fuses on the positive wires leaving the battery box.
- Use stainless steel nuts, bolts, and washers on battery terminals.
- Protect all battery terminals and terminal connections from corrosion by coating them with battery terminal coating, petroleum jelly, oxidation protection material, or high temperature grease.
- Provide a one-quarter inch space between batteries.

10.5. Controller and Inverter Installation

Photovoltaic charge controllers are intended for specific solar applications, and they should not be used for other system regulation unless specified by the manufacturer. You should read and follow the exact installation procedure specified in the manufacturer's instructions. When installing controllers and inverters, you should use the following guidelines:

- Protect control hardware from excess dust, dirt, overheating, and rough handling. Remember that electrical equipment is sensitive and requires careful handling. Some controllers require ventilation to prevent components from overheating. Use common sense in locating and mounting controller units; install all system components away from potential hazards, such as overhanging tree limbs, heat sources, snowdrift, and debris build-up areas.

- Cover the array with an opaque material when installing the controller. Also turn off all loads to protect the installer and equipment.
- Use correct wire size and proper terminal fasteners.
- Choose a controller with field adjustable set-points because each different battery type has slightly different voltage requirements.
- Use an enclosure or metal box made especially for electrical wiring.
  Controllers are mounted inside an enclosure to protect them from dust, moisture, sunlight, insects, tampering, and abuse. Also, other electrical wiring is often completed inside the enclosure. The cover of the enclosure protects people from shock and is a good place to mount electrical metering.
- Use some form of over-current protection and switching in or near the controller enclosure to protect the controller and provide a means of disconnection between the array and battery. Fusing or circuit breakers protect the controller from too much charging current and protect the wiring from too much current in the event of a short circuit. Too much current will overheat the wiring and may cause a fire if not protected with fusing or circuit breakers.
  Disconnect switching is used to open the circuit between the array, controller, and battery. Disconnect switching also turns off the load.
  This switching is necessary for servicing the system and in case of emergency.

Fuses are subject to corrosion from moisture and require that spare fuses be available. Circuit breakers are less likely to corrode and more convenient. In addition, breakers have more concealed wiring.

10.6. Photovoltaic System Wiring

When wiring a PV system, it is very important to use correct electrical boxes, wiring connections, and switches for each specific application.

10.6.1. Electrical Boxes

All wiring connections must be made within an accessible electrical box. The box must be securely fastened in place and have a removable cover. Electrical boxes can be either surface mounted or recessed into a wall, ceiling or floor.

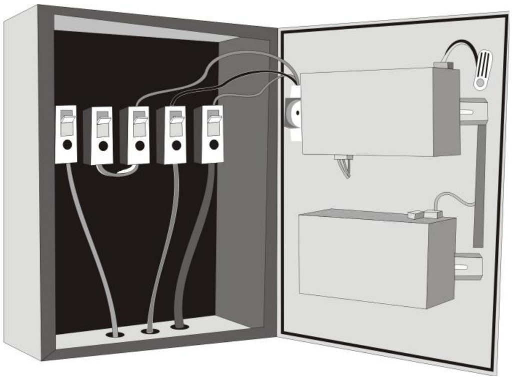


Figure 10.3: *Electrical box*

Electrical boxes that are exposed to weather must be weather resistant and have weather resistant connectors. Electrical boxes must be an adequate size for the number and size of wires contained within the box.
Boxes used for switches are often referred to as switch boxes. These boxes are rectangular in shape and use a cover plate. Electrical boxes used only for making wire connections are called a junction box. They are usually rectangular or octagonal in shape and covered with a blank cover plate, making them accessible when construction is complete.

10.6.2. Wiring Connections
Electrical connectors perform one of the following connecting functions:
Wire to Wire
Connections between wires are usually made with a wire nut, split bolt, reducer or crimped connector. Wire nuts are sized and colour-coded. Crimp-type connector must be crimped using a special tool recommended by the manufacturer and is best used with stranded wire.

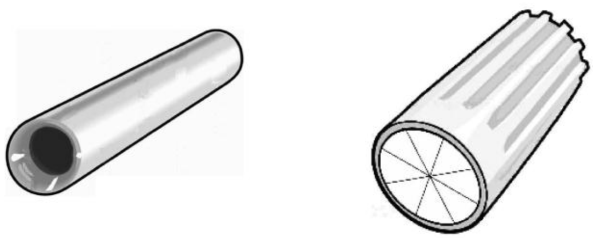


Figure 10.4: *Wire to wire connectors*

Wire to Terminal
Connections between a wire and terminal are usually made with a ring or spade type connector. These connectors are commonly used when connections are frequently removed and reconnected or where large wire would be difficult to connect.

Figure 10.5: *Wire to terminal connectors*

Wire, Cable, Cord, or Conduit to Electrical Box
Connections between electrical boxes and wires, cables, cords, or conduit must be secure enough to prevent wires from pulling loose. When exposed to weather, these connections must thread into the box and make a watertight seal. A "drip loop" should be used for outdoor wire

connections to electrical boxes to prevent water from running down a wire and into the box. Outdoor wire connections are made only from the underside of an electrical box.

Figure 10.6: *Wire to electrical box connectors*

10.6.3. Common Electrical Connectors

Following are the common electrical connectors used in PV system wiring:

Wire Nuts

Connectors used to connect two or more wires. Twist the wires together and screw wire nut on until tight.

Crimp Connectors

Connectors used to connect two wires. Both wires are inserted inside the crimp connector, one from each end, and then pressed with crimping tool.

Ring Terminals

Crimp-on connectors that maintain a connection even if the screw loosens.

Spade Terminals

Crimp-on connectors for use in non-vibrating applications. They allow for quick disconnection.

Screw Lugs

Bolt-on connectors used to connect large or multiple wires to one terminal.

Flag Terminals

Connectors used for securing wires where no electrical connection is made.

Cable Connectors or Romex Connectors

Connectors used for connecting non-metallic sheathed cable to a box.

Conduit Connectors

Connectors used for connecting conduit to a box for interior or dry applications.

Conduit Couplings

Connectors used for connecting lengths of conduit for interior or dry applications.

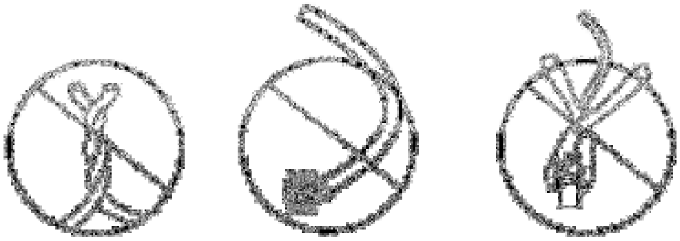


Figure 10.7: *Wrong connections*

10.6.4. Switches

Switches must be rated for a given voltage and for the amount and type of current that will flow through them. Type "T" switches are rated for DC use. Using

AC rated switches or "quiet switches" for DC systems will result in a shortened switch life because the contacts burn out from repeated electrical arcing. Under higher current conditions, the switch contacts may become permanently fused, the switch will not work then.

Disconnect switches are required for safe DC system operation. PV panels and batteries are voltage sources that need disconnect switches. Safety switches or circuit breakers are the most appropriate switches to use for disconnecting PV panels, batteries, and generators. A safety switch is fused, thus providing overcurrent protection between major PV system components. Circuit breaker used here functions as a switch on over-current protection.

Key Points

1. Initial site visits must be thorough enough to provide accurate information needed to design and plan the installation.
2. You should check all tools to ensure they are in operational condition and have no missing parts prior to departure along.
3. Photovoltaic module support structures should provide a simple, strong and durable mounting system.
4. You should protect batteries at all times, including during transport and while boost charging before departure for the site.
5. You should follow the guidelines for building the battery enclosure and installing the battery bank.
6. You should follow the guidelines for installing the controller.
7. All wiring connections must be made within an accessible electrical box. The box must be securely fastened in place and have a removable cover.
8. Wire to wire, wire to terminal and wire, cable, cord or conduit to electrical box must be made using standard connecters and procedure.
9. Disconnect switches are required for safe DC system operation. A safety switch or circuit breaker is the best option to use as a disconnect switch.

PRACTICAL WORK OF CHAPTER # 10

1. To perform an initial site survey.

i. Arrange a survey visit close to or just outside the training centre.

ii. Make different groups of students and ask them to perform surveys for different locations as follows:

a). Each group should suggest proper place for installing the solar panels.

b). They should find orientation with the help of compass.

c). They should suggest appropriate mounting system, i.e. ground mounting system, pole mounting system etc.

d). They should suggest proper place for battery and controller.

e). Depending upon the suggestions for placing each PV component, length of each wire should also be measured between components.

2. To show the tools and the materials used in PV system installation.
i. Show all tools and materials used in initial survey and installation of PV system.
ii. Make each student familiar with each tool so that he can use it confidently.

3. To install a pole mounting system.
i. Take a PV panel and pole mounting system.
ii. Fix the panel on the pole properly.
iii. Fix the pole with the prepared footings in the ground using nuts and bolts.
iv. Properly adjust tilt angle and orientation of the panel.

4. To prepare a junction box.
i. Take a junction box and two DC circuit breakers (for two sets of panels).
ii. Take two positive wires (red) and connect them to each circuit breaker.
iii. Take two negative wires (black) and connect them on the terminal provided inside the junction box for the purpose.
iv. Short the positive wires at the exit side of the circuit breakers with a jumper wire and take one positive wire out of the junction box.
v. Take one negative wire from the negative terminal out of the junction box.
vi. Junction box is ready.

5. To show all commonly used electrical connectors.
i. Show all electrical connectors commonly used in a PV system.

6. To make a wire to wire connection using a crimp connector.
i. Take two wires and one crimp connector.
ii. Remove the insulation of the each wire equal to the half of the length of the crimp connector.
iii. Insert one wire from one side of the crimp connector and punch it using crimping tool with force.
iv. Now insert second wire from the other side of the crimp connector and punch it too.
v. Connection is ready.

7. To make a wire to battery terminal connection.
i. Take a wire and a ring terminal.
ii. Remove the insulation of the wire.
iii. Insert the wire inside the ring terminal and punch it using punching tool or crimping tool.
iv. Insert the ring terminal on the battery terminal and tighten it with a nut.
v. Connection is ready.

8. To install a battery or battery bank.
i. Take a battery or battery bank and wires with proper connectors.
ii. Connect the wires to terminals in proper configuration.
iii. Place the battery or battery bank inside the battery enclosure.
iv. Carefully perform the installation task by keeping all safety precautions in mind.

9. To install a controller.

i. Take a controller and wires.
ii. Cover the PV panel with opaque cloth or paper before installing the controller.
iii. Connect the wires properly to the terminals of the controller.
iv. Install the controller on a proper place carefully.

CHAPTER ELEVEN

11. MAINTENANCE AND TROUBLESHOOTING

In this chapter, you will learn

- materials and tools needed for maintenance.
- how to maintain PV arrays, batteries, controllers and wiring of PV systems.
- how to maintain lighting and water pumping systems.
- troubleshooting of common system faults.
- troubleshooting total system failure.
- troubleshooting if some appliances work but others do not.
- troubleshooting if the system works but runs out of power.
- safety precautions required for the troubleshooting of wiring problems using multi-meter.

11.1. Materials and Tools List

You should bring the following materials and tools on any maintenance trip:

- First aid kit
- Soldering iron and solder
- Torque wrench
- Paper
- Pencil
- Mild detergent
- Pieces of cloth
- Screwdrivers
- Hydrometers (2)
- Safety goggles, rubber gloves and rubber apron
- Baking soda (vinegar if you are working with alkaline batteries)
- Distilled water
- Volt-ohm-ampere meter (2)
- Adjustable power supply
- Anti-oxidizing compound
- Spare fuses, batteries, wire nuts, wire
- Wire strippers
- Lineman's pliers
- Manufacturer's literature and troubleshooting guides
- Personal equipment with pack

11.2. Maintaining Photovoltaic System Components

Although PV power systems require little maintenance compared to other power systems, you should periodically perform a few simple maintenance tasks.

11.2.1. Photovoltaic Array

- Check the panels for dust, if the system is in a dusty climate with little rain, the panels may need to be cleaned periodically. Clean the modules with water and mild soap. Avoid solvents or strong detergents.
- Check to see if there are any shade problems due to vegetation or a new building. If there are, make arrangements for removing the vegetation or moving the panels to a shade-free place.
- Check the panel mounting to make sure that it is strong and well attached. If it is broken or loose, repair it.
- Check that the glass of the panels is not broken. If it is, the panel will have to be replaced.
- The junction boxes should be checked periodically for weather protection, tightness of wires and water seals.

11.2.2. Batteries

Battery maintenance depends largely on battery type, though all batteries require periodic inspection to verify system operation.

Nickel-cadmium and Sealed Liquid Electrolyte (VRLA) Batteries

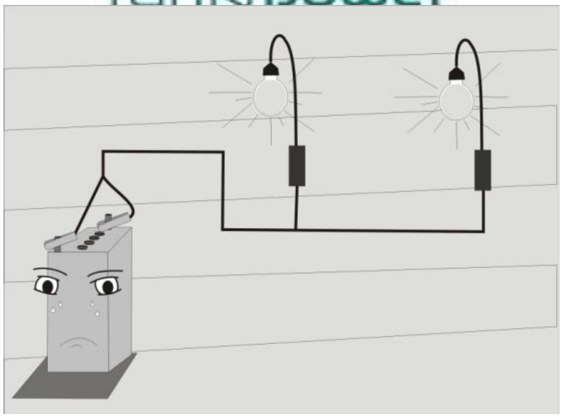
- Check connections for tightness and corrosion. Clean and tighten as needed.
- Cover connections with heavy grease. Do not get the grease on any part of the battery except the connections.
- Clean the battery with fresh water and a rag. The acid and the corrosion on the battery top should be washed off with the cloth moistened with baking soda or ammonia and water.

Vented Liquid Lead-Acid Batteries

- Clean the top of the battery. Check connections for tightness and corrosion. Clean and tighten as needed.
- Check each cell with a hydrometer and record the readings. When checking, take off one cap at a time. Do not remove all caps at once because that greatly increases the risk of dirt getting into the cells.

- The level of the electrolyte should always be 10 to 15 mm above the top of the plates. If any cells are low on water, add distilled water to obtain to the correct level. Never add more acid, only water. If distilled water is not available, carefully collected rainwater can be used. Remember that any salt, minerals or oil in the water will poison the battery and shorten its life, so be very careful about collection and storage of water for the battery.
- If any of the caps for the cells have been lost or broken, cover the fill holes loosely with plastic or glass until proper replacement caps are available. Never cover the holes with paper, cork, cloth or metal. Never leave the holes uncovered. Be careful that the temporary cover that you install does not plug the holes tightly because the cells must have air.
- Clean the battery with fresh water and a rag. The acid and the corrosion on the battery top should be washed off with the cloth moistened with baking soda or ammonia and water.

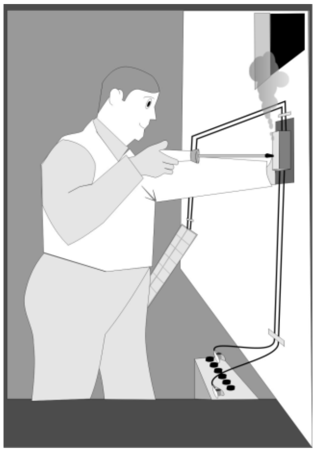
Do not put extra load on the battery; otherwise you will run out of power.



11.2.3. Controller

- Check that the controller is still firmly attached. If it is not, attach it correctly with screws.
- Keep the controller clean and do not break its seal.

Do not try to open the controller, you may damage it.



11.2.4. Wiring

- Check the wire covering (insulating sheath) for cracks or breaks. If the insulation is damaged, replace the wire. If the wire is outside the building, use wire with weather-resistant insulation.
- Check the attachment of the wire to the building to make sure that it is well fastened and does not rub against sharp edges when the wind blows.
- If someone has changed the wiring since the last check, make sure that it is the correct size, that it has suitable insulation and that it is fastened securely in its new place.
- If someone has added more wires to the PV system to operate additional appliances, advise the owner that this may seriously lower the reliability of the system. Advise increasing the panel and battery capacity to handle the increased load.
- Check the connections for corrosion and tightness.

11.3. Maintaining Appliances

To ensure that your PV power system operates efficiently, you need to wisely choose, operate, and maintain the appliances on the system.

11.3.1. Lighting

A systematic maintenance schedule allows the PV system user to keep lighting levels as high as possible without adding to the electric load. The following is a list of recommended design, maintenance, and operations procedures for lighting systems:

- Use a single incandescent lamp of higher wattage rather than two or more smaller lamps whose combined wattages equal the higher wattage lamp.
- Discontinue using multi-level lamps where possible. The efficiency of single wattage lamps is higher per watt than that of a multilevel lamp.
- Replace incandescent lamps with more energy conserving types of lighting, such as fluorescent in general purpose areas.
- When re-lamping, replace fluorescent lamps with more efficient, lower wattage lamps, such as a 34-watt lamp instead of a 40-watt lamp.
- Consider de-lamping where it is possible, for example in four-lamp fixtures disconnects two of the lamps.
- Lower fixtures to increase illumination levels on task areas. The increased illumination enables a reduction in the number of fixtures or the required lamp wattage.
- Regularly inspect and clean lamps and fixtures. Dust and dirt buildup can reduce unit effectiveness by as much as 20 percent.
- Replace outdated or damaged fixtures with modern, energy efficient types.
- Reduce outdoor lighting levels.
- Eliminate outdoor lighting where practical.
- Install a control device, such as a timer or photocell, to automatically turn off lights when not needed.
- Provide signs instructing occupants to turn off lights when leaving the room.
- Consolidate task areas to eliminate unnecessary illumination.
- Eliminate single switches that control all the fixtures in multiple workspaces.
- Utilize natural lighting whenever possible.
- Clean walls and ceilings. Paint or decorate walls with light colours to reflect light.
- Install light sensors and dimming equipment that automatically compensates for varying natural lighting conditions.

11.4. Troubleshooting Common System Faults

The best method for avoiding system failures is to initially install a high quality, properly designed system. Regular maintenance is the second line of defence against failures. The first step in troubleshooting photovoltaic power system problems is to save all of the manufacturers' product literature that comes with each component. This literature should be kept in a handy location that is protected from weather, chemicals and rats.

The most common system failures are usually the simplest to fix. You should check the system for fundamental problems first to save a great deal of time. The most common system failures are blown fuses, tripped breakers, or bad connections. The other common problem is a low or empty battery bank. The following general troubleshooting checklist for system operation can be completed visually, with the possible exception of the last two Items.

- Has the weather been cloudy for several days? If so, system may need recharging.
- Check the array for partial shading or dirt.
- Check all fuses and circuit breakers.
- Check system wiring for loose connections and/or corrosion.
- Check system wiring for proper polarity.
- Check system for proper system voltage and current.
- Check modules and batteries for proper series-parallel configuration.

11.5. Troubleshooting Total System Failure

If the system fails completely, the reason is usually a broken wire, poor connection or controller failure. There is a need to isolate the fault in the system.
First check the battery charge using a hydrometer or voltmeter.

11.5.1. Discharged Battery

If the battery is discharged and does not charge when the appliances are switched off for several days, then the fault lies between the battery and the panel.
Fuse or Circuit Breaker Problem
Make sure that all appliances are switched off. Check any fuse or circuit-breaker in the panel to battery circuit.
Action: Disconnect the loads at the controller. If the fuse is blown, replace it with the correct type and ampere capacity. If the circuit-breaker is tripped, turn it back on. See if the battery will charge. If the fuse or circuit breaker blows again or the battery will not charge, there is a problem with the wiring between the panel and battery or with the controller. Continue with this checklist. If the fuse or circuitbreaker does not blow, reconnect the load and turn the appliances on. If the fuse or circuit-breaker blows again, there is a short in the appliance wiring or in an appliance.
Faulty Panel or Panel Wiring
Disconnect the leads to the panel terminals of the charge controller. Check the voltage across the two wires from the panel when the sun is shining. If the voltage is less than 12 V, there is a problem with the panel or the panel wiring. If the voltage is 12 V or more, then measure the amperes from the panel. If the amperes are very low for the panel that is installed, the connections to the panel may be loose or corroded. Also the panel may be damaged.

Action: Disconnect all the panels and carefully check that each one is working properly (voltage and amperage). Replace panels that are not working well.
Clean all terminals and wires. Reconnect the panels, making sure that the correct wires are connected to the correct terminals. Also make sure that the panels are not shaded.

Battery Failure

Check all cells of the battery with a hydrometer. If one or more cells are very different from the other cells, there is a battery problem. A damaged cell will often have cloudy electrolyte or white scum on the electrolyte. If the cell readings are about the same but very low, or if you have a sealed battery, connect the panel directly to the battery for several sunny days to see if the battery will fully charge.
If it will charge, reconnect the battery to the system and check the operation of other parts of the system.

Action: If the battery shows damage or will not charge from the panel, replace the battery and check the panels, controller and wiring. Disconnect, clean and reconnect all connections. If the battery will charge directly from the panel, continue with the following checks.

Faulty Controller

Check the voltage at the battery connections and the panel connections on the controller when the sun is shining. If the voltage at the battery connection is less than 13.5 V and the voltage at the panel connection is more than 14 V, the controller has probably failed.

Action: Replace the controller.
Faulty Wiring between Controller and Battery
With the battery charged, turn on all the appliances. Measure the voltage at the battery terminals of the controller and the voltage directly on the terminals of the battery (not on the battery connections, but on the actual terminals of the battery itself). If the voltage is more than 0.5 V lower at the controller than at the battery terminals, there is a wiring problem.

Action: Disconnect all wires, remove connectors from battery terminals. Clean all connections and wires. Replace wires in connectors and terminals and tighten all connections. Make sure that the wire connecting the controller and the battery is the correct size for the current being carried.

11.5.2. Charged Battery

When the battery is charged but the appliances do not work, there is a wiring fault between the battery and the appliances.

Fuses or Circuit Breakers

Check all fuses and circuit-breakers. If they have opened the circuit, there is a short circuit in the wiring or appliances. Check all appliances and the wiring from the controller to the appliances.

Action: Fix shorted wiring or faulty appliances, replace fuses and reset circuitbreakers.
Wiring between Controller and Appliances
Turn on at least one appliance and check the voltage at the load connections on the discharge controller. If the load voltage is about equal to the battery voltage, the fault is in the wiring between the controller and the appliances.

Action: Clean all connections, replace all wires that are damaged or that are not the correct size for their length.
Faulty Switch
If there is one switch that controls all appliances, it may be the problem. Using a short wire, connect across the switch terminals. If the appliances work, then the switch is faulty.

Action: Replace the switch.
Controller Failure

Measure the voltage at the load terminals and at the battery terminals of the controller. If the load terminal voltage is zero or much lower than the battery terminal voltage, then the controller may not be working properly.

Action: Replace the controller.

11.6. Troubleshooting If Some Appliances Work but Others Do Not

This type of failure is rarely due to PV panel or battery failure. It may be caused by:

A Faulty Appliance Switch
Use a short wire and connect the switch terminals together. If the appliance works, the switch is faulty.

Action: Replace the switch.
Wrongly Connected Appliance
Check the connection at the appliance. Make sure that the + wire of the appliance is connected to the + wire of the controller.

Action: Connect the wires correctly.
Faulty Appliance
Check the battery voltage. If the battery voltage is low, there may be a controller problem. If the voltage is over 12 V, use a new wire of the correct size and connect the appliance directly to the battery. If the appliance does not work, it is probably faulty.

Action: Repair or replace the appliance.
Problem with Controller
Check the battery voltage. If it is below 11 V, the controller may be faulty.

Action: Replace the controller.

Wire Size
Measure the length of the wire run. Check to see if the wire is too thin for its length.

Action: Replace the wire with one of the correct size.

Wire Connections
Remove wires from all connections between the appliance and the controller.
Clean the wires and terminals. Put the wires back and tighten the connections.

11.7. Troubleshooting If the System Works but Runs Out of Power
This is the most common problem with solar PV systems and can be caused by many things acting alone or in combination. This type of failure shows that there is not enough charge in the battery to operate the appliances as long as the user requires. This may be caused by:

Too Little Charge from Panels
The reason for this may be shading, damaged panels, wiring too thin or too long, dirty or loose connections, panels not facing in the right direction or dirt on the panels.

Action: Remove the cause of the shade or move the panels so they are no longer shaded and are facing in the right direction, clean and replace the panels if damaged, check the wiring on the panels.

Adding More or Larger Appliances
This takes more energy from the battery than the system was designed for and discharges the battery too quickly.

Action: Remove the extra appliances or add more panels and increase the battery capacity.
Longer Operation of Appliances than Originally Intended
This takes more energy from the battery than the system was designed for.

Action: User needs to reduce the operational time of appliances to the original level or add more panels and increase the battery capacity.
Incorrect Adjustment of Charge Controller for Battery Charging
This may prevent the battery from fully charging. You can check by asking the user to keep appliance use to a minimum for several sunny days so that the battery will fully charge. Come to the site in the late afternoon of the third or fourth sunny day while the sun is still shining. Check the voltage at the battery terminals and at the panel terminals of the controller. If the two voltages are about the same and they are both above 13 V for a 12 V system, or 26 V for a 24 V system, then the charge controller is probably working properly. If the panel voltage is several volts higher than the battery voltage, and the battery voltage is less than 12.8 V for a 12 V system or 25.6 V for a 24 V system, then the charge controller may be disconnecting the system too soon and not allowing the battery to fully charge.

Action: Replace the controller and send the old one for repair.
Incorrect Adjustment of Controller for Battery Discharging
This disconnects the appliances from the battery before the maximum charge has been taken from the battery. If the battery shows more than half fully charged voltage when the appliances go off, the discharge side of controller is probably out of adjustment.

Action: Replace the controller and send the old one for repair.

Weak Battery
This can be checked by a battery ampere-hour capacity test. The battery is likely to be the problem if one or more cells show readings very different from the others or if the battery is more than four years old. If the battery is less than four years old, its failure may have been caused by another problem in the system.
Whenever a battery less than four years old must be replaced, check the rest of the system very carefully. Make sure that the panels are not shaded part of the day and that the user is not trying to take more energy from the system than it was designed to deliver. All these things may have

seriously shortened the life of the old battery and if allowed to continue will ruin the new battery as well.

Action: Replace the battery but monitor the replacement carefully. If after the first month the system once again does not seem to be providing energy as long as expected, one or more of the other reasons for failure exists and must be corrected, otherwise the new battery will also rapidly weaken and fail.

11.8. Troubleshooting Wiring Problem using a Multimeter

The volt-ohm-milliamp (VOM) meter is essential for troubleshooting wiring problems. You should be familiar with this meter's proper operation to insure your personal safety and protect the meter and system equipment. The most useful tasks performed with a VOM meter include:

- Checking for continuity
- Measuring AC and DC voltage
- Measuring AC and DC current
- Checking the polarity of DC voltage

11.8.1. General Safety Precautions

These precautions are reminders of specific hazards that should be avoided when using a VOM meter. Always refer to the equipment manual and pay attention to the manufacturer's specific warnings and instructions.

- Always wear safety glasses when working with electrical circuitry.
- Do not work alone on electrical circuits. Make certain that someone capable of rendering medical aid is nearby.
- Do not handle the instrument, its test leads, or the circuitry while high voltage is being applied.
- Operate the VOM meter only if you are qualified to recognize shock hazards and trained in the safety precautions required to avoid possible injury.
- Turn off the power and discharge any capacitors in the circuit to be measured before connecting to or disconnecting from the circuit.
- Dry your hands, shoes, floor, and workbench before working with electricity.
- Do not change switch settings or test lead connections while the circuit is energized. This could result in damage to the instrument and possible personal injury.
- Locate all voltage sources and accessible current paths before making connections to circuitry.
- Check and double check switch positions and jack connections before applying power to the instrument.
- Make certain that the equipment you are working with is properly grounded and fuses are of the proper type and rating.
- Whenever measuring a current or voltage of unknown magnitude, begin measurements at the highest scale available. Proceed to a lower scale when you are satisfied that the value is within the limits of a lower scale.

Key Points

1. You should check whether you have all the materials and tools needed for maintenance before leaving on a maintenance trip.

2. The PV array needs very little maintenance. If PV system is in a dusty climate with little rain, the array may need to be cleaned periodically.
3. Nickel-cadmium and sealed liquid electrolyte batteries require the least amount of annual maintenance which includes the checking of terminal connections, casing, venting and wiring.
4. The deep cycle liquid electrolyte lead-acid batteries require the most maintenance because they have a higher amount of gassing than other batteries and require the addition of distilled water.
5. Controllers are maintenance free sealed devices and you should not break the seal of the controller in any case.
6. Wiring does not need huge maintenance, just the inspection of tight and corrosion free connections are enough.
7. Lighting levels can be kept as high as possible without adding to the electric load by performing recommended design, maintenance, and operations procedures for lighting systems.
8. Pump controller and pump does not need any maintenance.
9. You should check the system for fundamental problems first to save a great deal of time and cost. The most common system failures are blown fuses, tripped breakers and bad connections.
10. You should always follow the safety precautions to avoid specific hazards when using a VOM meter.

PRACTICAL WORK OF CHAPTER # 11

1. To perform maintenance tasks of a complete PV system.

i. Maintenance tasks for each component of a PV system are given in chapter 11. Perform these tasks for each component.
You can break the tasks in more than one part, if time is the constraint

2. To check for continuity of broken wires, short circuits, fuse or switch operation.

Checking for continuity indicates whether a circuit is open or closed, which is useful when checking for broken wires, short circuits, fuse, or switch operation. Checking for continuity involves circuit resistance. Short circuits have very low resistance. Closed circuits have some resistance depending upon circuit wire and loads. Open circuit exhibits infinite resistance. Use the following procedure for checking continuity:

i. Turn the power off and discharge all capacitors.
ii. Disconnect at least one conductor in the circuit.
iii. Choose the Rxl00 resistance scale or another resistance scale if more appropriate for your application.
iv. Plug the black test lead into the common (-) jack. Plug the red test lead into the positive (+) jack.
v. Connect the ends of the test leads together to short the VOM resistance circuit.
vi. Turn the zero ohms control until the needle indicates zero ohms.
vii. Disconnect the test leads. You are now ready to check for continuity.
viii. Connect one test lead to the disconnected point on the circuit you want to test and the other lead at the opposite end of the circuit.

Result: An open circuit has no continuity and will read infinite resistance. The needle will not move. A closed circuit has continuity and will read little or no resistance. The needle will move to extreme right hand side of the scale.

3. To measure the voltage of a circuit.

Measuring voltage is similar to measuring for continuity, with the exception that you are measuring the energy potential in the circuit: the voltage. The following steps are part of the procedure to measure the voltage in a circuit.

i. Review "General Safety Precautions" in Chapter # 11.

ii. Select the proper type of voltage being measured, AC or DC. To help measure DC voltage some meters have a DC positive (+) and DC negative (-) position. In DC positive (+) position, the meter will read correctly if the wiring is correct and the meter leads are correctly connected. If the meter leads are inadvertently placed on the wrong wires, the polarity may be corrected at the meter by switching to the DC negative (-) position.

iii. Set the range indicator to the appropriate scale. If the voltage scale is unknown, start at the highest scale and work your way down to prevent meter damage or personal injury.

iv. Plug the black test lead into common (-) jack. Plug the red test lead into the positive (+) jack.

v. Turn the power off and discharge any capacitors in the circuit.

vi. For DC circuits, connect the black test lead to the negative side of the circuit. Connect the red lead to the positive side.

vii. For AC circuits, connect the black test lead to the common or neutral side of the circuit. Connect the red lead to the hot side of the circuit.

viii. Turn the power on.

ix. Read the voltage on the proper scale. If the needle deflects or moves backwards, the polarity of the wiring or the meter may be reversed.

4. To measure the current of circuit.

Measuring current is similar to measuring voltage, with the exception that you are measuring the energy passing through the circuit: the current. The following steps are part of the procedure to measure the voltage in a circuit.

i. Review "General Safety Precautions" in Chapter # 11.

ii. On the VOM meter, select the type of current being measured, AC or DC. DC positive (+) position will indicate proper polarity when red is connected to positive (+) side of the circuit and black is connected to negative (-) side of the circuit. Polarity may be reversed by switching to the DC negative (-) position.

iii. Set the range indicator to the appropriate scale. If the current scale is unknown, start at the highest scale and then move down as you get a better idea about the amount of current.

iv. Plug the black test lead into the common (-) jack. Plug the red test lead into the positive (+) jack.

v. Turn the power off and discharge all the capacitors in the circuit.

vi. Open the ground side of the circuit where the current is being measured.

vii. Connect the meter in series (the circuit must be broken then the meter inserted in line with the circuit).

viii. Turn power on and read the current on the proper scale.

Never connect the meter across a voltage source. Doing so can result in damage to your meter or the device being tested.

5. To check the circuit polarity

Polarity of a circuit refers only to DC circuits. AC circuits don't have polarity, because polarity in an AC circuit is reversed fifty times per second. When polarity in a DC circuit is reversed, DC motors will run backwards and often overheat. Some DC appliances simply will not work at all. Others will be destroyed by reverse polarity. In the following are the steps for measuring the current or voltage of a DC circuit.

i. Polarity is correct when the selector is on DC positive (+) position, the test leads are connected with red to the positive (+) side of the circuit and black to negative (-) side, and the needle reads a positive value on the meter scale.

ii. Polarity is reversed when the selector is on DC positive (+) position, the test leads are connected with red to the positive (+) side of the circuit and black to negative (-) side, and the needle deflects to below zero on the meter scale.

6. Troubleshooting

i. A large number of troubleshooting tasks for different situations are given in chapter 11. Depending upon the possibilities, students are encouraged to perform a few troubleshooting tasks.

CHAPTER TWELVE

12. SAFETY AND PHOTOVOLTAIC INSTALLATION

In this chapter, you will learn

- How to work safely on PV Systems
- Basic safety involved in major areas of PV system i.e. system current and voltage, wiring and disconnect requirements, grounding and PV system output.

12.1. Introduction

As with any activity, safety is the responsibility of everyone working with PV equipment, whether in design, installation, maintenance, or use of the systems.

The following items constitute good, safe practices for any type of job and reduce the potential for accidents and injuries. To work safely, you must have the following:

- Good work habits
- A clean and orderly work area
- Proper equipment and training in its use
- An awareness of potential hazards and how to avoid them
- Periodic reviews of safety procedures

PV devices generate electricity, and they should always be considered electrically "hot." Because they generate electricity any time light falls on them, even attempting to cover them, for example with a blanket, is not a safe practice, as light could still reach the PV or the covering could come off. Similarly, batteries are always "hot" and cannot be turned off.

When working with PV modules and systems, you need to be familiar with the basics of safety:

- You are your own best safety system – be alert, check everything, and work carefully.
- Never work on a PV system alone.
- Study and understand the system before you start to work on it.
- Review the safety, testing, and installation steps with everyone involved before starting work.
- Make sure that your tools and test equipment are in proper working order.
- Check your test equipment before going to the job site.
- Wear appropriate clothing, including a safety helmet, eye protection, and dry leather gloves. Also, remove all jewellery that might come in contact with electrical components.
- Measure everything electrical with a digital multi-meter. Measure the conductivity from exposed metal frames and junction boxes to ground. Measure voltage from all conductors (on the PV output circuit) to ground. Measure the operating voltage and current.
- Expect the unexpected. Do not assume that switches always work, that the actual configuration agrees with the electrical diagrams, that current is not flowing in the grounding circuit, etc.
- Working with any size PV system involves a number of potential hazards, both non-electrical and electrical. Consequently, safety must be foremost in the mind of anyone working on a PV system.

12.2. Basic Safety

Basic safety is to be considered in following major areas:

12.2.1. System Current and Voltage

When designing a PV system, one has to consider the following:

- The rated maximum voltage in any PV source circuit should be the open-circuit voltage.
- Voltages should be less than 40 V DC.
- Conductors and over-current devices should be able to carry at least 125 percent of the short-circuit current of the source circuit PV panel.
- PV source circuit, inverter system, and including charge controller and battery conductors should have over-current protection.
- A sign indicating PV system operating maximum voltage and the short-circuit current should be placed near the system disconnect point.

12.2.2. Wiring and Disconnect Requirements

You/One should be consistent with electrical wiring. There are certain conventions for the colour of conductors and specific requirements for disconnecting the power source, including the following:

- The grounded conductor must be white. The convention states that the first ungrounded conductor of a PV system must be red and the second ungrounded conductor must be black.
- Single-conductor cable is allowed for module connections only.

Sunlight- or ultra violet (UV)-resistant cable should be used if the cable is exposed.

- Any wiring junction boxes must be accessible.
- Means to disconnect and isolate all PV source circuits must be provided.
- Means to disconnect all ungrounded conductors from the inverter must be provided.
- If fuses are used, means to disconnect the power from both ends must be provided.
- Switches must be accessible and clearly labelled.

12.2.3. Grounding

The purpose of grounding any electrical system is to prevent unwanted currents from flowing through equipment or people and possibly causing equipment damage, personal injury, or death. Lightning, natural and man-made ground faults and line surges can cause high voltages in low voltage systems. Proper grounding, along with over-current protection, limits the possible damage that a ground fault can cause.

One should be familiar with the following and recognize the difference between the equipment grounding conductor and the grounded system conductor:

- One conductor of a PV system (>50 V) must be grounded, and the neutral wire of a centre-tapped, three-wire system must also be grounded. If these provisions are met, this is considered sufficient for the battery ground, if batteries are included in the system.
- A single ground point should be made. This provision will prevent the possibility of potentially dangerous ground fault current flowing between separate grounds. In some PV systems where the PV array is located far from the load, a separate ground can be used at each location. This will better protect the PV array from lightning surges. If multiple ground points are used, they must be bonded together with a grounding conductor.

- All exposed metal parts must be grounded (equipment ground).
- The equipment grounding conductor must be bare wire or green wire and be large enough to handle the highest current that could flow in the circuit.

12.2.4. Photovoltaic System Output

Before the PV array is connected to the load, battery, or inverter, there are certain requirements you need to address, including:

- If an inverter is used to interconnect the PV system to a utility, it must disconnect automatically if the utility power goes off. If the inverter is operating in a stand-alone hybrid system, it can supply power to the load continuously.
- The output of a single-phase inverter should not be connected to a three-phase service.
- The AC output from a PV system inverter must be grounded in accordance with the requirements for AC systems.
- A circuit breaker or fuse/switch mechanism must be included so that the PV system output can be disconnected.
- If batteries are used in a system, they must be guarded to prevent unauthorized access if the voltage is greater than 50 V DC.
  Otherwise, the voltage must remain below 50 V DC.
- If batteries are used in a system, charge controllers must be installed in the system.

Key Points

1. When working with PV systems, you need to be familiar with the basics of safety.
2. You should know that basic safety is involved in four major areas of PV systems: system current and voltage, wiring and disconnect requirements, grounding and PV system output.

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