# Short-Course

# Solar PV System Installation and Maintenance

# NTQF Level II

# Learning Guide -02

| | |
|---|---|
| **Unit of Competence** | **Apply Principles of Photovoltaic system Operation** |
| **Module Title** | **Applying Principles of Photovoltaic system Operation** |
| **LG Code** | **EIS PIM2 M04 0120 LO2 LG-2** |
| **TTLM Code** | **EIS PIM2 TTLM 0120v1** |

## LO2: Explain the basics of photovoltaic (PV) technology

| Instruction Sheet | Learning Guide:-11 |
|---|---|

This learning guide is developed to provide you the necessary information regarding the following **content coverage** and topics

- Basic terms of PV technology
- Conversion of sunlight into electric current
- Different types of photovoltaic cells
- Identifying different PV configurations

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, **you will be able to:-**

- state and describe basic terms of PV technology
- Describe conversion of sunlight into electric current
- Describe different types of photovoltaic cells
- describe different PV configurations

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described below 3 to 6.
3. Read the information written in the information Sheet 1, Sheet 2, Sheet 3 and Sheet 4 in page 52, 62, 65 & 68respectively.
4. Accomplish the Self-check 1, Self-check 2, Self-check 3 and Self-check 4 in page 61, 64,67 & 74 respectively
5. If you earned a satisfactory evaluation from the Self-check proceed to Operation Sheet 1 in page 75.
6. Do the LAP test in page 76.

# LO2: Explain the basics of photovoltaic (PV) technology

| Information Sheet-1 | Basic terms of PV technology |
|---|---|

## 1 Basic terms of PV technology

### 1.1 What is Photovoltaic

The terms Photovoltaic and and photovoltaic technology are described below.

**Photovoltaic**

The term photo voltaic (PV) is drive from Greek word meaning:

- ✓ Photo... light and
- ✓ Voltaic ….. Electricity.

**Photovoltaic (PV) Technology**

is a process of generating electrical energy from the

Energy of solar radiation. The principle of conversion of solar energy into electrical

Energy is based on the effect called photovoltaic effect. The smallest part of the device that converts solar energy into electrical energy is called solar cell. Solar cells are in fact large area semiconductor diodes, which are made by combining silicon material with different impurities. The sand, a base material for semiconductor, is the most abundantly available raw material in the world. The ordinary sand ($SiO_2$) is the raw form of silicone.

The solar energy can be considered as a bunch of light particles called photons. At

Incidence of photon stream onto solar cell the electrons are released and become free. The newly freed electrons with higher energy level become source of electrical energy. Once these electrons pass through the load, they release the additional energy gained during collision and fall into their original atomic position ready for next cycle of electricity generation. This process of releasing free electrons (generation) and then falling into original atomic position (recombination) is a continuous process as long as there is the stream of photons (solar energy) falling onto the solar cell surface.

### 1.2 Definition of photovoltaic conversion

Photovoltaic cells, or solar cells, convert solar radiation into electricity using a process known as the “photovoltaic effect.” During this process, the materials in the solar cell produce electrons when exposed to the photons in sunlight.

Solar-powered photovoltaic (PV) panels convert the sun's rays into electricity by exciting electrons in silicon cells using the photons of light from the sun. This electricity can then be used to supply renewable energy to your home or business.

Photovoltaic energy is the conversion of sunlight into electricity. A photovoltaic cell, commonly called a solar cell or PV, is the technology used to convert solar energy directly into electrical power. A photovoltaic cell is a non-mechanical device usually made from silicon alloys.

The ultimate efficiency of a silicon photovoltaic cell in converting sunlight to electrical energy is around 20 per cent, and large areas of solar cells are needed to produce useful amounts of power.

When photons (light energy) strike the surface of the semiconducting material electrons are let loose. The delocalization of electron creates a flow of charge which produces electricity. Thus, it is the semiconductor present in a photovoltaic cell which is responsible for converting light to electricity

Simply put, a solar panel works by allowing photons, or particles of light, to knock electrons free from atoms, generating a flow of electricity. Solar panels actually comprise many, smaller units called photovoltaic cells. (Photovoltaic simply means they convert sunlight into electricity.)

Solar PV cells generate electricity by absorbing sunlight and using that light energy to create an electrical current. There are many photovoltaic cells within a single solar panel, and the current created by all of the cells together adds up to enough electricity to help power your home.

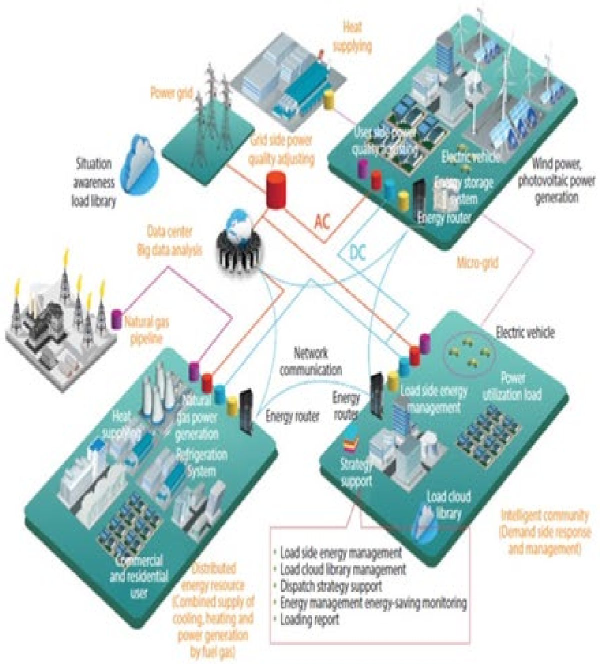
Solar photovoltaic are made with a number of parts, the most important of which are silicon cells. The manufacturing process involves cutting individual wafers of silicon that can be affixed onto a solar panel. Mono-crystalline silicon cells are more efficient than polycrystalline or amorphous solar cells.

Conversion of light energy in electrical energy is based on a phenomenon called photovoltaic effect. When semiconductor materials are exposed to light, the some of the photons of light ray are absorbed by the semiconductor crystal which causes a significant number of free electrons in the crystal.

Everybody know that the solar cells or the photovoltaic cells are the electrical devices that converts the energy of sunlight into the electricity by the photovoltaic effect which is the ability of matter to emit the electrons when a light is shone on it .

### 1.3 Main components of a solar photovoltaic system.

- Photovoltaic Array: this is the core of the system, composed of several solar modules which are in turn composed of solar cells.
- Battery Bank
- Charge Controller
- DC And Ac Disconnect
- Inverter
- Optional: Electric Meter



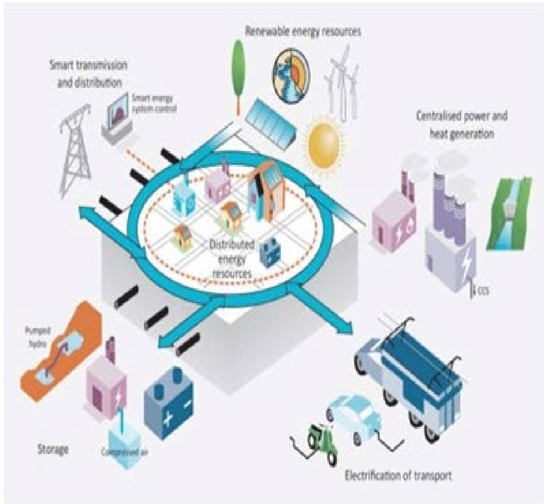




**Figure 39: Build up of a solar cell**

| Self-Check -1 | Written Test |
|---|---|

**Directions:** Answer all the questions listed below. Use the Answer sheet provided in the next page:

## I. Say true or false for the following questions below

1. The term photo voltaic (PV) is derived from England word

***Note:***

**Satisfactory rating - 1 points**

**Unsatisfactory - below 1 points**

You can ask you teacher for the copy of the correct answers.

**Answer Sheet**

| Score = ____________ Rating: |
|---|

Name: ____________________________ Date: ________________

**Short answer question**

| Information Sheet-2 | Conversion of sunlight into electric current |
|---|---|

## 2 Conversion of sunlight into electricity

The following paragraph is adapted from (Hankins, 2010) chapter 1 and (DGS, 2008).

Photovoltaic (PV) effect is the conversion of sunlight energy into electricity. In a PV system, the PV cells exercise this effect. Semi-conducting materials in the PV cell are doped to form P-N structure as an internal electric field.

Photo voltaic directly convert solar energy into electricity. They work on the principle of the photovoltaic effect. When certain materials are exposed to light, they absorb photons and release free electrons. This phenomenon is called as the photoelectric effect.

### 2.1 The Sun

The sun is the Earth's nearest star and the source of virtually all the Earth's energy, producing 3.8 x1023 kW of power in huge nuclear fission reactions. Most of this power is lost in space, but the tiny fraction that does reach the Earth, 1.73 x 1016 kW, is thousands of times more than enough to provide all of humanity's energy needs.

The energy we derive from wood fuel, petroleum products, coal, hydroelectricity and even our food originates indirectly from the sun. Solar energy is captured and stored by plants. We use this energy when we burn firewood or eat food. The sun also powers rainfall cycles that fill rivers from which we extract hydroelectricity. Petroleum and coal are made up of the fossilized remains of plants and animals that collected energy from the sun thousands of years ago.

Energy can also be harvested from the sun directly for heating, drying, cooking, distilling, raising steam and generating electricity. Many types of equipment can be used to collect solar energy. These include flat plate solar- thermal panels and evacuated tubes, which harvest solar energy for heating water, and solar concentrators that focus the rays of the sun into high energy beams to produce heat for electricity generation (known as concentrated solar power or CSP).

Historically, collecting and harnessing solar power has not been as easy or convenient as it has been for other energy sources, for several reasons. First, energy from the sun is spread over a wide area in a relatively low energy form. Unlike petrol or coal, which are high-energy and can be easily transported, solar energy arrives in a scattered manner that is difficult to usefully trap, convert and store. In order to collect it, solar energy harnessing equipment must be utilized. Secondly, solar energy is not available at night or during overcast and cloudy weather, and the forms of energy derived from solar energy must be stored. This means additional equipment must often be used to store the energy; this accounts for a large portion of the costs of solar energy systems.

In the past, solar energy has often been overlooked because of the high price of the equipment used to harvest and store it. However, as the prices of other energy sources such as petroleum fuel, biomass and even coal-generated electricity rise – and as the environmental risks associated with other power sources are increasingly recognized – solar energy equipment is fast becoming economically attractive.

## 2.2 Converting Solar Energy

Solar energy is plentiful worldwide. Most people do not stop to think about how solar energy heats their homes or provides energy to grow crops. Sunshine has traditionally been used for drying all types of things: clothes, agricultural produce, cash crops and bricks – even in the production of salt from sea water.

To make use of solar energy, we must convert it into useful forms. Solar energy can be usefully transformed in three ways:

- solar energy to chemical energy;
- solar energy to heat energy;
- solar energy to electrical energy.

**Solar energy to chemical energy**

Green plants transform solar energy to chemical energy in sugar and cellulose by the process of photosynthesis (all biomass contains chemically stored solar energy). Unfortunately, we have not yet developed a way to directly transform solar energy into chemical energy. Photosynthesis remains a secret of plants!

**Solar energy to heat energy**

Solar heating devices transform solar energy into heat that is used for drying, water-heating, space-heating, cooking and distilling water. CSP plants convert water to steam that is used to generate electricity.

Solar thermal energy is most easily used in applications that require relatively small amounts of heat. The cheapest and simplest uses of solar energy (e.g. solar driers and water heaters) raise the temperature of air or water by 20–40°C (36–72°F). When more energy and higher temperatures are needed, solar energy must be concentrated, transported and/or stored, greatly increasing the cost and complexity of solar equipment needed.

**Solar energy to electrical energy**

Solar electric devices transform solar energy into electrical energy. This can be used to directly power electrical devices such as pumps and fans – or it can be stored in batteries to power lights, televisions, refrigerators and other appliances (these appliances are often used mainly at night when the sun has gone down).

## 2.3 The photoelectric effect

The photovoltaic or photoelectric effect was explored by the great scientist Albert Einstein. 1904 he described this phenomenon along with a paper on his theory of relativity. For his theoretical explanation of photo-electric effect, Albert Einstein was awarded a Nobel Prize in 1921.

The way in which solar cells work is shown below, taking crystalline silicon cells as an example. Highly pure silicon with a high crystal quality is needed to make solar cells. The silicon atoms form a stable crystal lattice. Each silicon atom has four bonding electrons (valence electrons) in its outer shell. To form a stable electron configuration, in each case in the crystal lattice two electrons of neighbouring atoms form an electron pair bond. By forming electron pair bonds with four neighbours, silicon achieves its stable noble gas configuration with eight outer electrons. An electron bond can be broken by the action of light or heat. The electron is then free to move and leaves a hole in the crystal lattice. This is known as intrinsic conductivity.

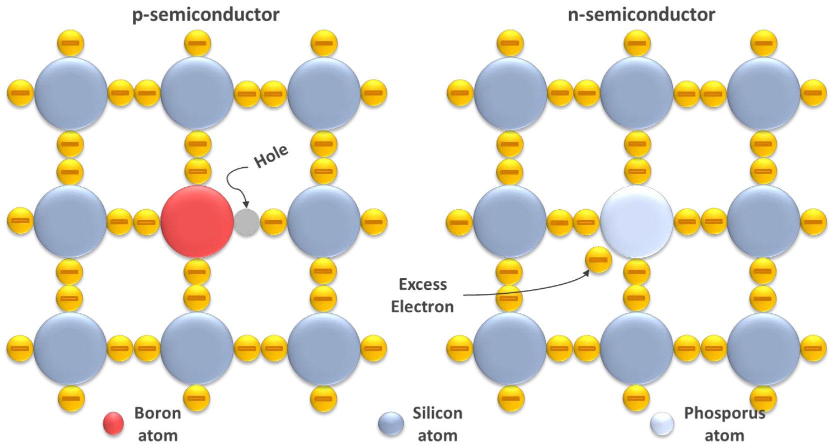



Figure 40: Crystalline structure of silicon and intrinsic conductivity

In the case of phosphorus doping (n-doped), there is a surplus electron for every phosphorus atom in the lattice. This electron can move freely in the crystal and hence transport an electric charge. With boron doping (p-doped), there is a hole (missing bonding electron) for every boron atom in the lattice. Electrons from neighbouring silicon atoms can fill this hole, creating a new hole somewhere else. The conduction method based on doping atoms is known as impurity conduction or extrinsic conduction. Considering the n- or p-doped material on its own, however, the free charges have no predetermined direction to their movement.

If n- and p-doped semiconductor layers are brought together, a p-n (positivenegative) junction is formed. At this junction, surplus electrons from the n-semiconductor diffuse into the p-semiconductor layer. This creates a region with few free charge carriers. This region is known as the space charge region.

Positively charged doping atoms remain in the n-region of the transition and negatively charged doping atoms remain in the p-region of the transition. An electrical field is created that is opposed to the movement of the charge carriers, with the result that diffusion does not continue indefinitely. In the case of phosphorus doping (n-doped), there is a surplus electron for every phosphorus atom in the lattice. This electron can move freely in the crystal and hence transport an electric charge. With boron doping (p-doped), there is a hole (missing bonding electron) for every boron atom in the lattice.

Electrons from neighbouring silicon atoms can fill this hole, creating a new hole somewhere else. The conduction method based on doping atoms is known as impurity conduction or extrinsic conduction. Considering the n- or p-doped material on its own, however, the free charges have no predetermined direction to their movement.

If n- and p-doped semiconductor layers are brought together, a p-n (positive-negative) junction is formed. At this junction, surplus electrons from the n-semiconductor diffuse into the p-semiconductor layer. This creates a region with few free charge carriers. This region is known as the space charge region.

Positively charged doping atoms remain in the n-region of the transition and negatively charged doping atoms remain in the p-region of the transition. An electrical field is created that is opposed to the movement of the charge carriers, with the result that diffusion does not continue indefinitely.

If the p-n-semiconductor (solar cell) is now exposed to light, photons are absorbed by the electrons. This input of energy breaks electron bonds. The released electrons are pulled through the electrical field into the n-region. The holes that are formed migrate in the opposite direction, into the p-region. This process, as a whole, is called the photovoltaic effect. The diffusion of charge carriers to the electrical contacts causes a voltage to be present at the solar cell. In an unloaded state, the open circuit voltage OCV arises at the solar cell. If the electrical circuit is closed, a current flows.

Some electrons do not reach the contacts and recombine instead. Recombination refers to the bonding of a free electron to an atom lacking an outer electron (hole). Diffusion length here is the average distance that an electron covers in the crystal lattice during its lifetime until it meets an atom with a missing electron and bonds with it. Here, free charge carriers are lost and can no longer contribute to generating electricity. The diffusion length depends upon the number of impurity atoms in the crystal and must be large enough so that a sufficient number of charge carriers reach the contacts. The diffusion length depends upon the material. With one crystal impurity atom (doping) to 10 billion silicon atoms, this distance is 0.5mm. This corresponds to roughly twice the cell thickness. In the space charge region, there is a high probability of successful charge separation (electrons and holes) without recombination. Outside of the space charge region, the probability of recombination increases with the distance from the space charge region.

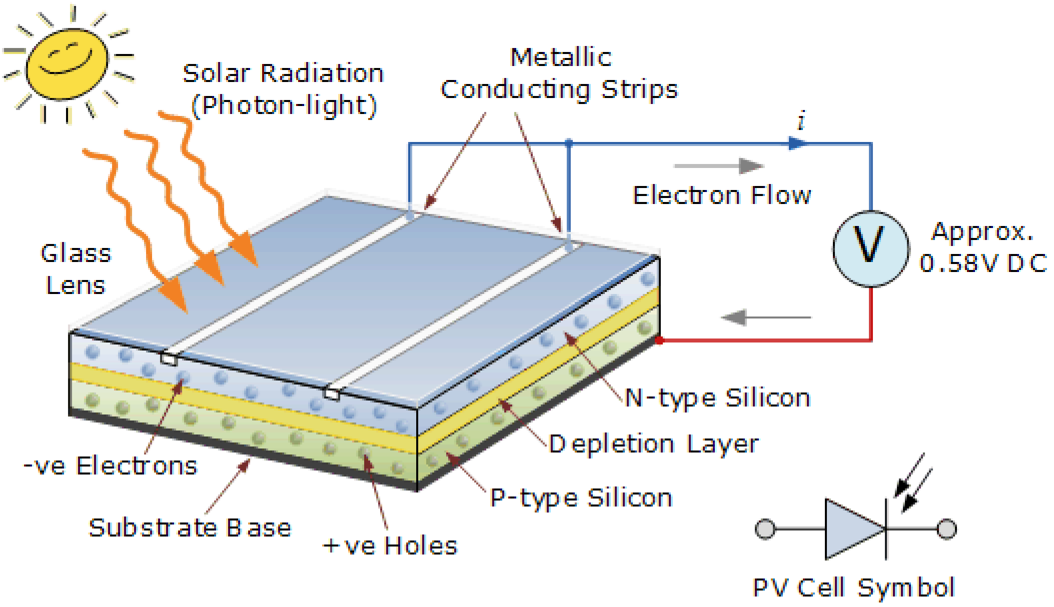



**Figure 41: Design and functioning of a crystalline silicon solar cell**

| Self-Check -2 | Written Test |
|---|---|

**Directions:** Answer all the questions listed below. Use the Answer sheet provided in the next page:

**Say true or false for the following questions below**

1. Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight indirectly into electricity
2. Photovoltaic cells, or solar cells, convert solar radiation into electricity using a process known as the photovoltaic effect.
3. Solar-powered photovoltaic (PV) panels convert the sun's rays into fuel energy by exciting electrons in silicon cells using the photons of light from the sun.
4. A photovoltaic cell is a mechanical device usually made from silicon alloys.
5. Photovoltaic Array is the core of the system, composed of several solar modules which are in turn composed of solar cells.

***Note:***

**Satisfactory rating - 5 points**

**Unsatisfactory - below 5 points**

You can ask you teacher for the copy of the correct answers.

**Answer Sheet**

| Score = ____________ |
|---|
| Rating: |

Name: ____________________________ Date: ________________

**Short answer question**

| Information Sheet-3 | Different types of photovoltaic cells |
|---|---|

# 3 Different types of photovoltaic cells

## 3.1 Definitions of photovoltaic cells:

A photovoltaic cell (PV cell) is a specialized semiconductor diode that converts visible light into direct current (DC). Some PV cells can also convert infrared (IR) or ultraviolet (UV) radiation into DC electricity. Large sets of PV cells can be connected together to form solar modules, arrays, or panels.

There are three types of PV cell technologies that dominate the world market: monocrystalline silicon, polycrystalline silicon, and thin film.

**For Further Reading**

- Photovoltaic cell.
- Solar panel.
- P-n junction.
- Semiconductor.
- Concentrated photovoltaic.

The Two Types of Solar Energy, Photovoltaic and Thermal. Photovoltaic technology directly converts sunlight into electricity. Solar thermal technology harnesses its heat. These different technologies both tap the Sun's energy, locally and in large-scale solar farms.

Solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 15-20%. SunPower produces the highest efficiency solar panels on the U.S. market today.

## 3.2 Photovoltaic cells:

Photovoltaic cells are based on a related phenomenon called the photovoltaic effect, and they convert light directly into electricity. Let’s look at how.

Most photovoltaic cells are made of silicon, an element that is at the heart of all modern electronics. Silicon is special because of the arrangement of its electrons—it has four out of the possible eight electrons in its outermost shell. This means that it makes perfect covalent bonds with four other silicon atoms, forming a lattice structure.

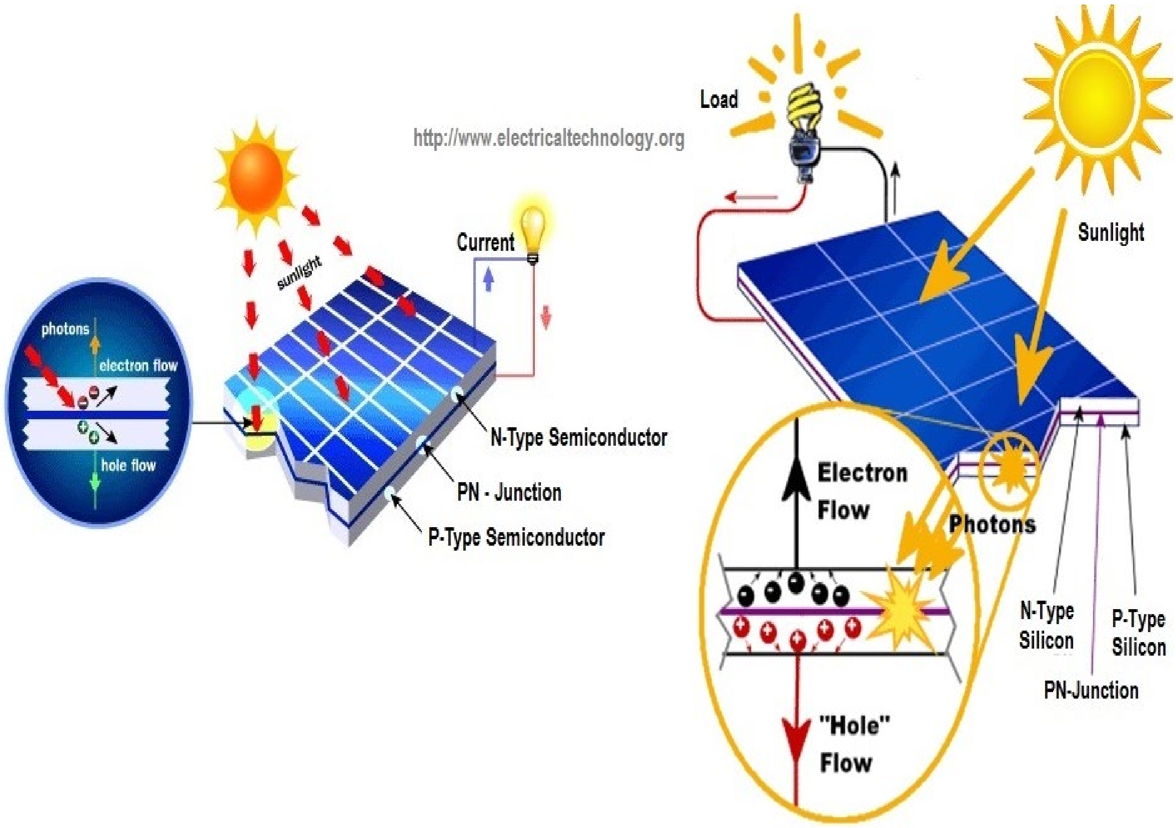



**Figure 42:-Basic operating Principle of solar Cell**

Crystalline silicon (c-Si) is the crystalline forms of silicon, either multicrystalline silicon (multi-Si) consisting of small crystals, or monocrystalline silicon (mono-Si), a continuous crystal. Crystalline silicon is the dominant semiconducting material used in photovoltaic technology for the production of solar cells.

Solar cells made of crystalline silicon are often called conventional, traditional, or first generation solar cells, as they were developed in the 1950s and remained the most common type up to the present time.

Solar cells made from c-Si are single-junction cells and are generally more efficient than their rival technologies, which are the second-generation thin film solar cells, the most important being CdTe, CIGS, and amorphous silicon (a-Si).

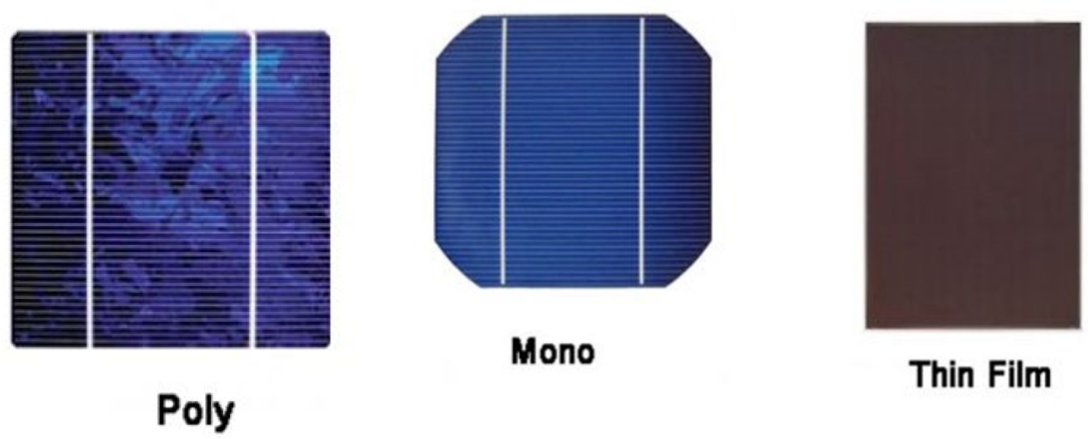



**Figure 43:- Types of PV cells**

### 3.3 Mono crystalline silicon PV Cells

These are made slicing cells from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, with cells typically converting around 23% of the sun's energy into electricity. The manufacturing process required to produce mono-crystalline silicon is complicated, resulting in slightly higher costs than other technologies.

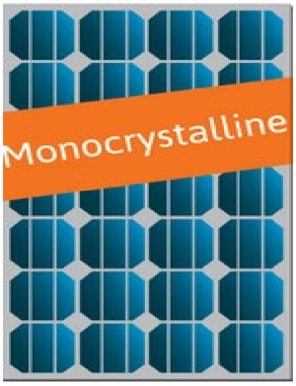



**Figure 44:-Mono-Crystalline cells**

### 3.4 Polycrystalline silicon PVCells

Also sometimes known as multi crystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and re-crystallized silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.

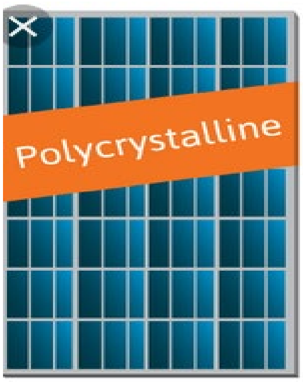



**Figure 45:-Poly Crystalline cells**

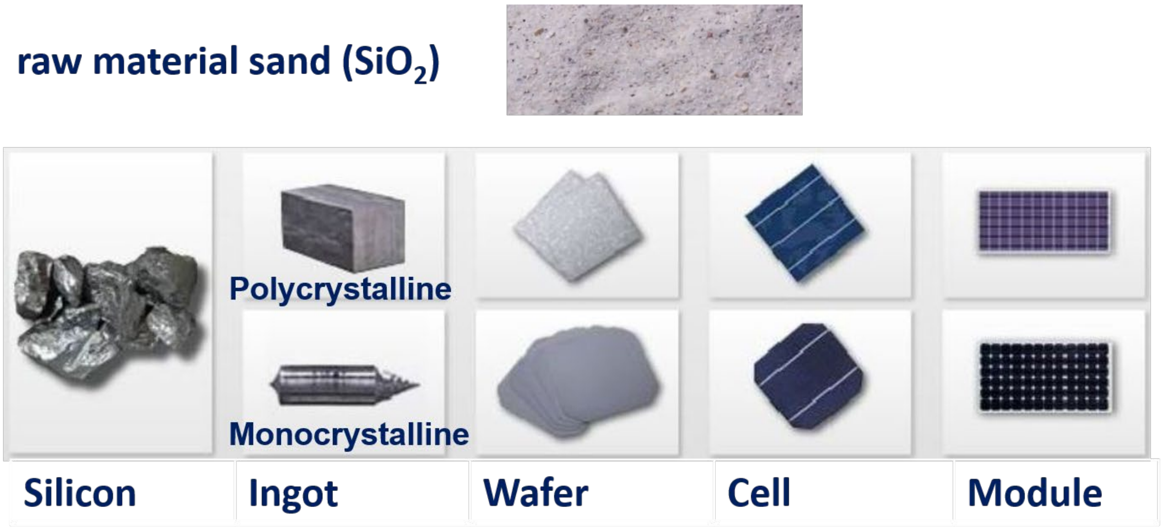



**Figure 46:-Steps of production of crystalline PV cells**

### 3.5 Thin-film PV cells

A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si).

| | |
|---|---|
|  |  |
| **Figure 47:-Thin film** | **Figure 48:-Amorphous** |

Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Amorphous silicon is an allotropic variant of silicon, and amorphous means "without shape" to describe its non-crystalline form.

| Self-Check -3 | Written Test |
|---|---|

**Directions:** Answer all the questions listed below. Use the Answer sheet provided in the next page:

**I. Choose the best answer for the following questions below**

1. All are components of photo voltaic cell except one
   A. Photovoltaic cell.
   B. Solar panel.
   C. P-n junction.
   D. Semiconductor.
   E. Concentrated photovoltaic.
   F. Voltmeter
2. Identify the one which is not types of photovoltaic cell
   A. mono crystalline silicon
   B. polycrystalline silicon
   C. Thin film.
   D. Tetra crystalline cupper

***Note:*** **Satisfactory rating – 1.5 points** **Unsatisfactory - below 1 point**

You can ask you teacher for the copy of the correct answers.

Score = ___________

Rating: ____________

**Answer Sheet**

Name: _________________________ Date: _______________

**Short answer question**

| Information Sheet-4 | Describing different PV configurations |
|---|---|

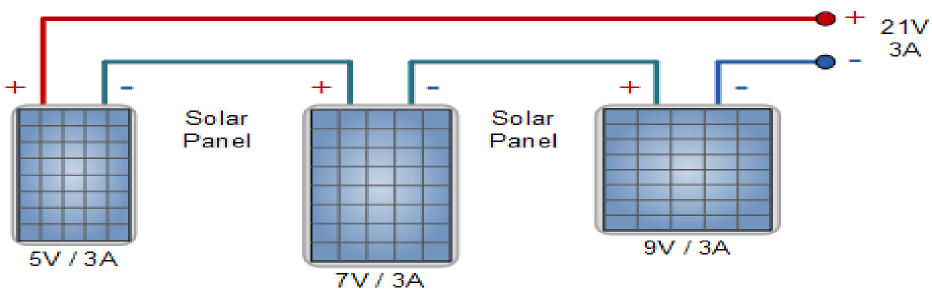
# 4 Identifying different PV configurations

## 4.1 PV connection

A bulk silicon PV module consists of multiple individual solar cells connected, nearly always in series, to increase the power and voltage above that from a single solar cell. There are two main types of connecting solar panels

### 4.1.1 In series

In series connection when two cells are connected, voltages are added while the current remains same. You connect solar panels in series when you want to get a higher voltage



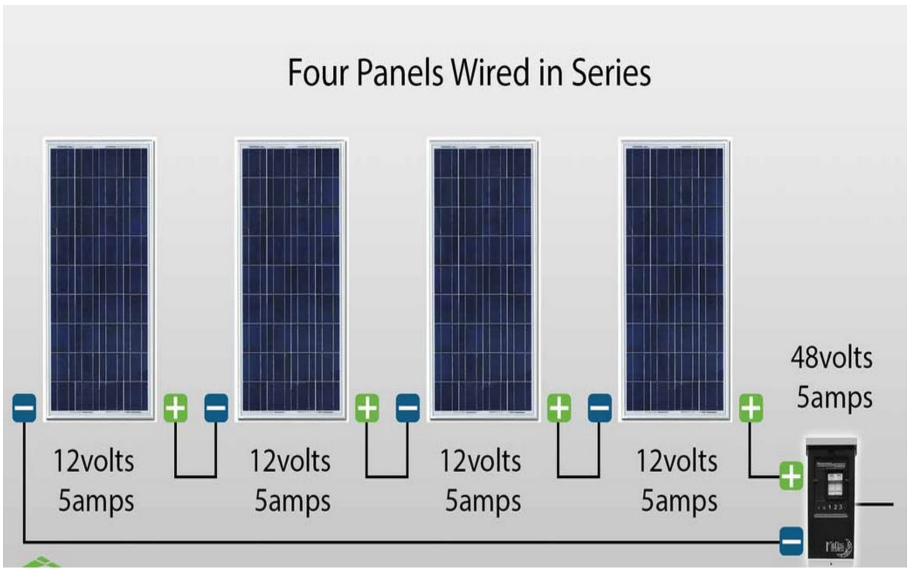




**Figure 49:-Series Connection**

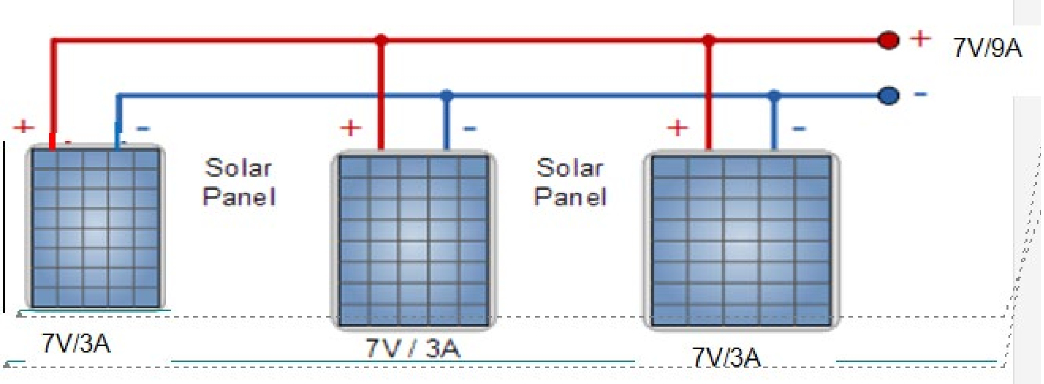
The following videos show about series, parallel & combination connections

- https://www.coursera.org/lecture/solar-cells/series-and-parallel-connections-XwXbe

### 4.1.2 Parallel connection:

In parallel connection voltage remains same and the amperage adds up. If you need to get higher current, you should connect your panels in parallel.

Strictly parallel connections are mostly utilized in smaller, more basic systems, and usually with PWM Controllers, although they are exceptions. Connecting your panels in parallel will increase the amps and keep the voltage the same. This is often used in 12V systems with multiple panels as wiring 12V panels in parallel allows you to keep your charging capabilities 12V.



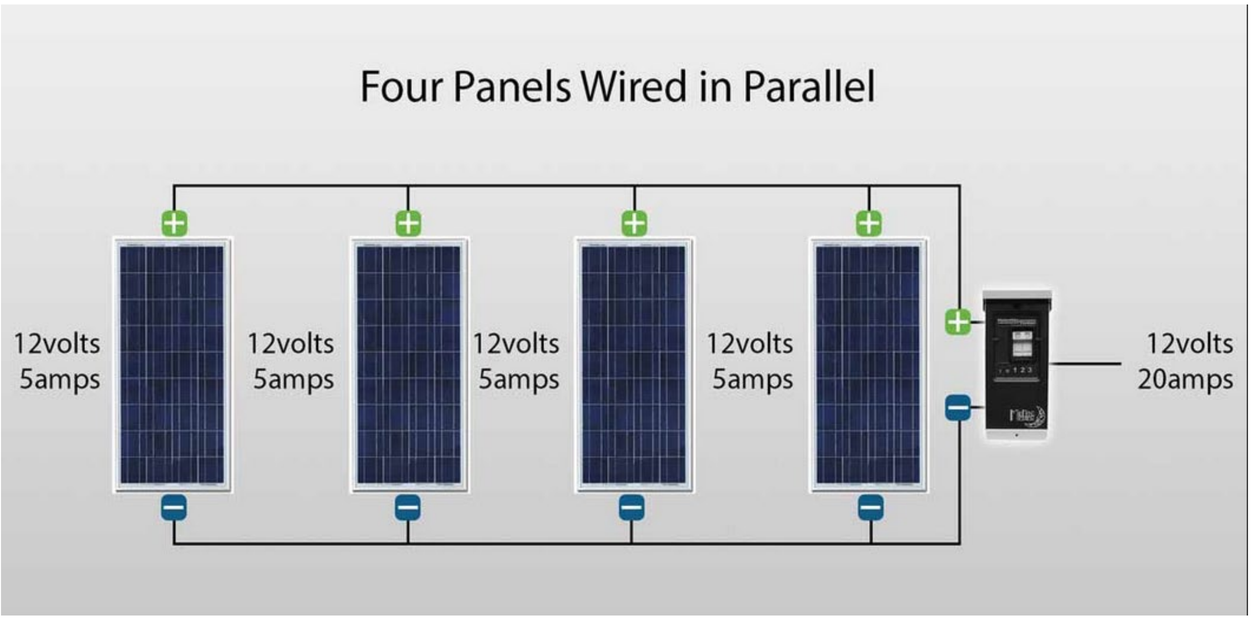




**Figure 50:-Parallel Connection**

- https://www.coursera.org/lecture/solar-cells/series-and-parallel-connections-XwXbe

### 4.1.3 Series parallel PV connection

When connecting multiple solar panels in a 12-48 volt off-grid system, you have a few options: parallel, series, or a combination of the two

Solar Panel arrays are usually limited by one factor, the charge controller. Charge controllers are only designed to accept a certain amount of amperage and voltage. Often times for larger systems, in order to stay within those parameters of amperage and voltage, we have to be creative and utilize a series parallel connection. For this connection, a string is created by 2 or more panels in series. Then, an equal string needs to be created and paralleled.

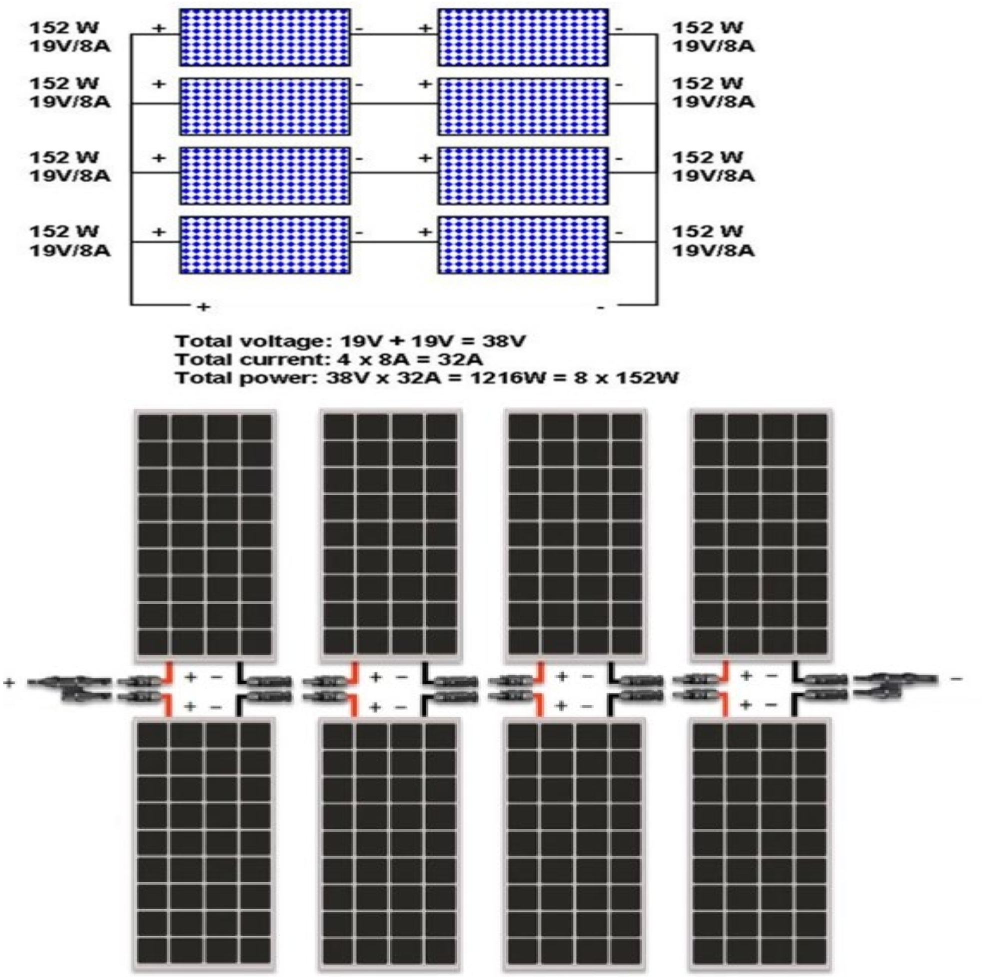



**Figure 51:-Series Parallel Connection**

Please also see the following video:

- https://www.youtube.com/watch?v=O8GgRIIB1Yc

## 4.2 Application of PV Power

Photovoltaic (PV) cells are one of the ways to harness solar energy. PV cells convert sunlight directly to electricity and can be influential in meeting the world's energy demand. PV systems are being used in a variety of applications.

**Table 6: Application of PV power**

| No. | Application | Description | Symbol |
|---|---|---|---|
| 1 | **Mobile Banking** | **Mobile banking** refers to the use of a smartphone or other cellular device to perform online **banking** tasks. Remote access is possible using power from PV systems. |   |
| 2 | **Residential Homes** | Homes in rural and Urban areas use PV systems to power electrical appliance |  |
| 3 | **Holiday Properties** | Remote holiday properties employ PV power systems |  |
| 4 | **Telecom** | The telecommunication sector uses PV systems to power Remote antennas and masts |  |
| 5 | **Street Sale Light** | Movable street sell carts use PV panels.<br>Street lights may also be powered from PV systems directly installed on the street light poles. |  |

| No. | Application | Description | Symbol |
|---|---|---|---|
| 6 | **Health** | In health centres PV systems are used to power refrigerators to preserve medicine and vaccination |  |
| 7 | **Cell Phone Charging** | The average solar-powered charger takes between 6 and 10 hours to charge an electronic device, such as a cell phone. |  |
| 8 | **Water pumping** | Solar water pumping employs PV systems to power motor driven pumps | |

**Advantages of the PV technology:**

- Environmental friendly it does not produce the greenhouse gases CFC
- It is limitless supply and in abundance
- Because of the sun solar energy founds every where
- Economic viability for future
- Low maintenance & operating cost
- Solar PVs do not produce noise when in operation
- Does not have mechanical moving parts that can fail or break.
- No fuel/running cost
- The technology is save & reliable
- Energy independence from the national grid
- Independence of import from foreign nation (save of currency)

**Disadvantages of Solar Energy**

- Cost. The initial cost of purchasing a solar system is fairly high
- Weather Dependent. Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system drops
- Solar Energy Storage Is Expensive
- Uses a Lot of Space

Needs to be recycled at the end of lifetime, especially battery waste needs to be collected to not harm the environment

## 4.3 Define PV configurations

Solar modules can be used for many different application. Depending on the purpose different system configurations are being used. Solar modules can be used in very simple systems with only a few components (e.g. solar lamps or pico systems) or can be combined in more complex systems to supply more power (e.g. Solar Home Systems). Solar energy can even be used on a utility scale to produce power for the public grid.

In the following paragraphs some system configurations or types of PV systems are introduced.

### 4.3.1 Solar lamps

A **solar lamp** also known as solar light or solar lantern, is a lighting system composed of an LED lamp, solar panels, battery, charge controller and there may also be an inverter. The lamp operates on electricity from batteries, charged through the use of solar photovoltaic panel.

Solar-powered household lighting can replace other light sources like candles or kerosene lamps. Solar lamps have a lower operating cost than kerosene lamps because renewable energy from the sun is free, unlike fuel. In addition, solar lamps produce no indoor air pollution unlike kerosene lamps. However, solar lamps generally have a higher initial cost, and are weather dependent.

**Figure 52:-solar lamp**

**Figure 53: solar Lantern**

### 4.3.2 Pico solar systems

We have all seen large photovoltaic solar panels on top of roofs or in array fields generating many kilowatts of free electricity. But there is another form of solar energy that has started to emerge called Pico solar or Pico pv, that uses small compact and light weight solar photovoltaic panels to generate just a few watts of power in a wide range of small and portable applications.

Pico Solar Systems are becoming more common place with us using Pico solar cells in our daily lives without even knowing it. Pico solar systems are much smaller and cheaper than traditional solar systems but have the potential to provide useful amounts of electrical power to charge the increasing number of low power gadgets such as calculators, toys, cameras, mp3 players, cell phones, tablets, and other portable electronic devices etc., as well as a variety of chargers all use Pico solar cells to charge batteries

**Figure 54:-Pico Light**

A typical Pico solar system generates relatively small and safe amounts of electricity of about 5 volts, affectionately called “Pico power”, which means that the amount of electricity generated by a Pico Solar Charger is low but can still be incredibly useful for people travelling or without access to a mains powered charger. Pico solar systems come in a range of shapes and sizes, with a typical system being made up of the following components:

- A Pico PV solar module usually less than 20 watts-peak to capture the sun’s light to generate the electricity.
- Rechargeable dry-cell battery or batteries of less than 12 volts to store the solar power for use when needed.

The following videos show about the use of Pico PV solar

- **https://www.youtube.com/watch?v=WTzV8kahpNU**
- **https://www.youtube.com/watch?v=Sc8bX4sNje0**
- **https://www.youtube.com/watch?v=W6gKoLrHuAU**

### 4.3.3 DC coupled Solar Home System (DC only):-

A simple 12 volt DC system provides lighting for small houses. Low wattage (<150W) solar panels are connected to a simple charge controller which charges the battery. The lamps and other 12 volt DC appliances are connected to the charge controller as shown in below figure. There is only DC power available and the amount is limited to the battery capacity and the PV production. Available appliances are limited for 12 volt DC power, because wire resistance limits power to a few hundred watts. This system is not connected to AC power lines and is considered to be “off the grid”.

If 2, 3 or 4 batteries are connected in series the system can also be a 24V, 36V or 46V system. The number of PV modules should also be increased to be able to charge the batteries.

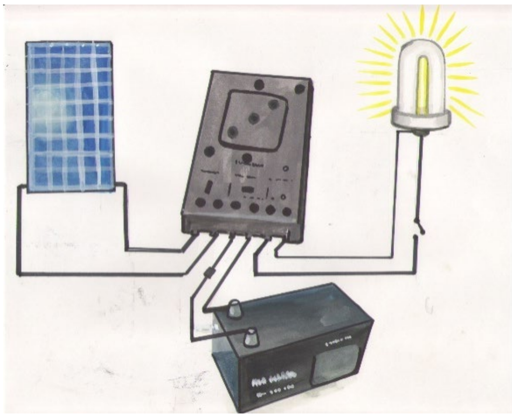


**Figure 55:-**DC-coupled Solar Home System (DC only)

**Solar Home Systems:** Like in the DC only Solar Home System, PV modules are connected to a charge controller which charges the battery and provides a DC power outlet. Additionally, there is an inverter connected to the battery which converts the DC power into AC. Conventional AC appliances like AC fridges or TVs can be connected to the inverter -under the condition that the consumption of the appliances matches the size of the PV system!

These systems typically have PV generators in the range of 100W – 5000W.

If a public grid is available. DC coupled solar home systems can also be connected to the grid. To connect them, an inverter charger is needed instead of the simple inverter. It must be able to connected to the grid and create an island grid in case of power failure. This type of system is often used when the available grid is rather unstable.

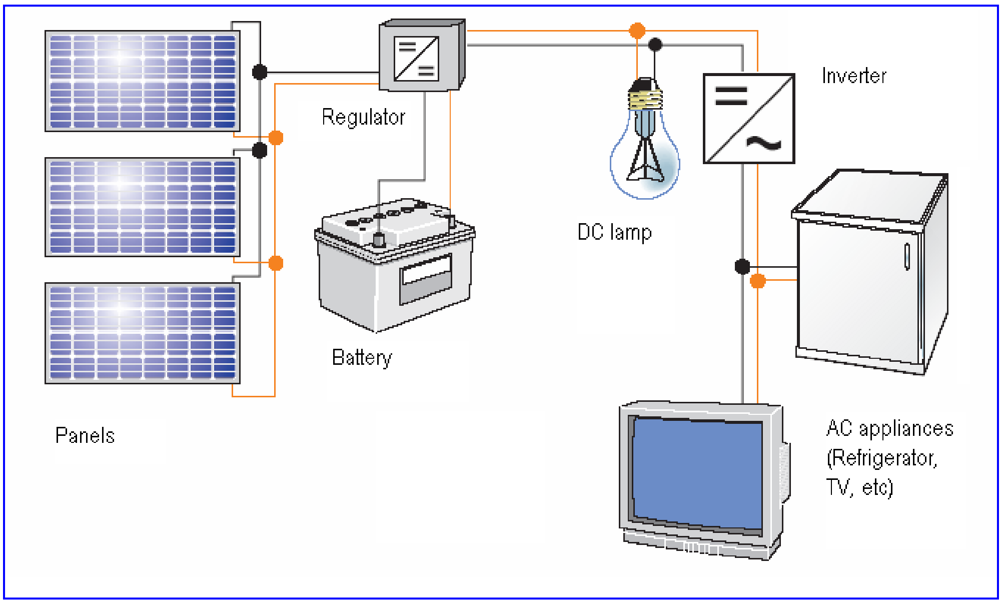



**Figure 56:-Solar Home System (with AC outlet)**

### 4.3.4 Grid connected **PV** Systems

The solar modules are connected to a grid-tied inverter which converts the DC solar electricity directly to 220V AC. This system is connected to AC power lines (i.e., connected to the grid) as shown in Figure 54.

The customer can use the solar electricity during daytime. Depending on the legal situation, excess electricity can be sold to the power company during the day. During the night the client buys power from the power company.

In this setup no batteries are used which reduces the costs of the systems but on the other hand, there will not be any power when there is a power failure in the grid. This kind of PV system cannot operate without the grid and switches off during power failure.

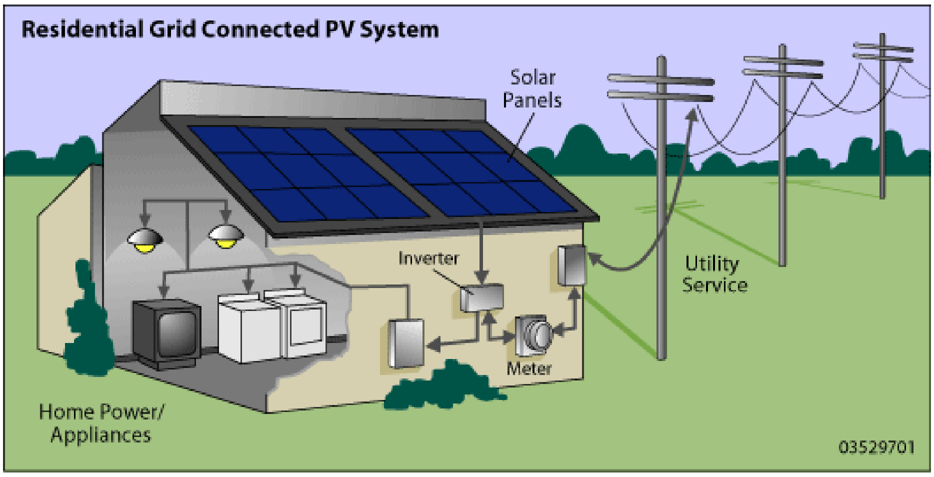



**Figure 57:-Grid-connected Solar System (source: www.mathworks.com)**

It is possible to use a PV system as backup system or uninterrupted power supply system (UPS). Then batteries and a control unit for the batteries, an inverter-charger are added to the system. The inverter charger not only charges the batteries but can also supply an island grid which enables the system to supply power during power failures of the public grid. This system configuration is called AC-coupled backup system. The major parts of a DC-coupled Solar Home System

- PV modules (which together form a PV array) with racking.
- A battery-based inverter
- A combiner box (for systems with more than 2 strings)
- A charge controller.
- A battery bank.
- DC over current protection.
- AC disconnects (for stationary SHS).

Fortunately, most of the tools needed for a PV install are commonly used and easily found.

**Table 7: Basic Tools Needed for Installation**

| No | Tool | No | Tool |
|---|---|---|---|
| 1 | Angle finder | 14 | Wire strippers |
| 2 | Torpedo level | 15 | Crimpers |
| 3 | Fish tape | 16 | Needle-nose pliers |
| 4 | Chalk line | 17 | Lineman's pliers |
| 5 | Cordless drill (14.4V or greater), multiple catteries | 18 | Slip-joint pliers |
| 6 | Uni bit and multiple drill bits (wood, metal, masonry) | 19 | Small cable cutters |
| 7 | Hole saw | 20 | Large cable cutters |
| 8 | Hole punch | 21 | AC/DC multimeter |
| 9 | Torque wrench with deep sockets | 22 | Hacksaw |
| 10 | Nut drivers (most common PV sizes are 7/16”, ½”, 9/16”) | 23 | Wire strippers |
| 11 | Tape measure | 24 | Caulking gun |
| 12 | Blanket, cardboard or black plastic to keep modules from going “live” during installation | 25 | Fuse Pullers |
| 13 | Heavy duty extension cords | 26 | Screwdriver (flat and Philips) |

| Self-Check -4 | Written Test |
|---|---|

**Directions:** Answer all the questions listed below. Use the Answer sheet provided in the next page:

**Say true or false for the following questions below**

1. **In urban Home System** a simple 12 volt DC system provides lighting.
2. **In Log Cabin System** larger panels providing 200- 400 volts are connected
3. **In country Home System** panels providing 24- 96 volts are connected
4. Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels.
5. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems.

***Note:***

**Satisfactory rating - 5 points**

**Unsatisfactory - below 5 points**

You can ask you teacher for the copy of the correct answers.

**Answer Sheet**

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

**Short answer questions**

| Operation Sheet 1 | Identify PV Components |
|---|---|

**Operation Title: Procedure to identify PV components**

**Given the PV system components**

Step-1Plan and prepare work place

Step-2Use appropriate tools and Instruments

Step-3Identify and record models of the given PV components

Step- 4. Identify the capacity/ratings of each component (in terms of power, voltage, current ratings etc.)

Step-5.For the given PV module identify the type of solar cells used (Monocrystalline, polycrystalline, thin film)

Step-6.For the given charge controller identify the connections for the PV module, Battery and Load

| LAP Test | Practical Demonstration |
|---|---|

Name: ________________________________ Date: _________________

Time started: __________________________ Time finished: _________________

**Instructions:** Given necessary materials, tools and measuring instruments you are required to perform the following tasks within 1 hour.

**Task 1.Describe each components of Photovoltaic (PV) system**

## List of Reference Materials

1. KhamphoneNanthavong, *Promotion of the Efficient Use of Renewable Energies in Developing Countries: Photovoltaic,* DGS REEPRO, 2008.
2. ChristofBuam, *Solar Photovoltaic: Basic in Solar Photovoltaic Systems,* 2nd edition, Don Bosco, Addis Ababa, 2008.
3. SNV, *Solar PV Training and Refferal Manual,* Developed by SNV for the Rural Solar Market Development, 2015.
4. SNV, *Solar PV Standardized Training Manual,* Developed by SNV for the Rural Solar Market Development, 2015.
5. David Tan and AngKianSeng, *Handbook for Solar Photovoltaic (PV) Systems,* Energy Market Authority and Building and Construction Authority, 2019.
6. Mark Hankins, *Stand-Alone Solar Electric Systems: the Earthscan Expert Handbookfor Planning, Design and Installation,*Earthscan, 2010.
7. Jan Kai Dobelmann and Antje Klauss-Vorreiter, *Promotion of the Efficient Use ofRenewable Energies in Developing Countries, Level 2 Technician Training Manual,* DGS REEPRO, 2009.

8. CLEAN (Clean Energy Access Network), *Installation, Operation and Maintenance of Solar PV Microgrid Systems: A hand book for trainers,* GSES Indian Sustainable Energy, 2016.
9. https://www.youtube.com/watch?v=WTzV8kahpNU
10. https://www.youtube.com/watch?v=Sc8bX4sNje0
11. https://www.youtube.com/watch?v=W6gKoLrHuAU
12. https://www.coursera.org/lecture/solar-cells/series-and-parallel-connections-XwXbe
    https://www.youtube.com/watch?v=O8GgRIIB1Yc