
Program : **Diploma in Electrical and Electronics Engineering**

Course Code : **5033A**

Course Title: **Renewable Energy Power Plants**

Semester : **5**

Credits: **4**

Course Category: **Program Core**

Periods per week: **4 (L:3 T:1 P:0)**

Periods per semester: **60**

CO2	Explain electric power generation from solar energy and select number of solar panels for stand alone systems.		
M2.01	Illustrate various solar collectors	4	Understanding
M2.02	Classify concentrated solar power plants	4	Understanding
M2.03	Explain the operation of solar photovoltaic power plants	4	Understanding
M2.04	Identify various steps to determine the rating of solar PV systems	5	Applying
	Series Test – I	1	

Contents:

Solar energy -basic principle--advantages- disadvantages- applications.-definitions -solar radiation- solar irradiation- solar insolation.

Solar collectors-types-diagrams- concentrated(parabolic, trough,mirror strip and Fresnel lens)- non concentrated(Flat plate and evacuated tubes)

Concentrated Solar Power (CSP) plants- classifications-based on temperature- block diagrams- solar pond - Flat plate-Line focusing parabolic trough-parabolic dish - power tower

Solar cell- working principle (photovoltaic effect)- basic construction - definitions -cells-modules-panels-array- definition- megawatt peak(MWp)

V/I characteristics of pv module-definitions –maximum power point- fill factor-important factors considered for installing a solar panel -direction -tilt -shading - temperature-solar pv system-advantages- disadvantages-applications -basic concepts-Roof top - building integrated -Solar power satellite

Solar cell power plant- Classifications- block diagrams-Standalone-Grid connected Power converters in PV system- Buck converter - Boost converter Charge controller-block diagram-MPPT

Sizing of solar system-Selection of number of solar panels, battery and inverter for a given backup time-simple problems

SOLAR ENERGY

The sun has produced energy for billions of years. Solar energy is the sun's rays (solar radiation) that reach the earth. The sun may be regarded as an in-exhaustible source, of useful energy. Solar energy is the electro-magnetic energy or radiation emitted by the sun. Solar energy is unique source of energy and it can be exploited into useful form by different ways such as

1. By direct conversion into fuel by photosynthesis
2. By direct conversion into electricity by photovoltaic (PV)
3. By direct conversion into electricity through thermo-electric power system or solar thermal conversion system. In this system, the solar radiation is converted into heat energy which is further converted into mechanical energy and then into electrical energy. Solar collector is used to collect solar radiation.

SOLAR RADIATION RECEIVED ON EARTH'S SURFACE

The sun gives out 3.7×10^{26} watt of power into space, out of which the earth intercepted is equivalent to 1.7×10^{17} watt. The energy emitted by Sun within three minutes is equivalent to the world energy consumption during a year.

IRRADIANCE is a measure of solar power density in Watt/m^2 and is defined as power per unit area received from the Sun in the form of electromagnetic radiation

IRRADIATION is the measure of energy density of sunlight and it is measured in kwh/m^2 Insolation

REFLECTED RADIATION – Radiation from sun that has been completely reflected back to earth's atmosphere

- Total solar radiation that reaches the earth's surface.

SOLAR RADIATION MEASUREMENT

Solar radiation striking the earth's surface is composed of the following three modes

1. DIRECT OR BEAM RADIATION - The direct solar flux and reaches the earth's surface directly from the sun without getting absorbed or scattered called direct radiation or beam radiation. It is the radiation which produces a shadow when interrupted by an opaque object.

2. DIFFUSED RADIATION - The radiation received at the earth's surface from all parts of the sky's hemisphere is called diffuse radiation. This is the radiation that has been scattered by molecules and particles in the atmosphere but reaches the surface of the earth.

3. REFLECTED RADIATION – Radiation from sun that has been completely reflected back to earth's atmosphere

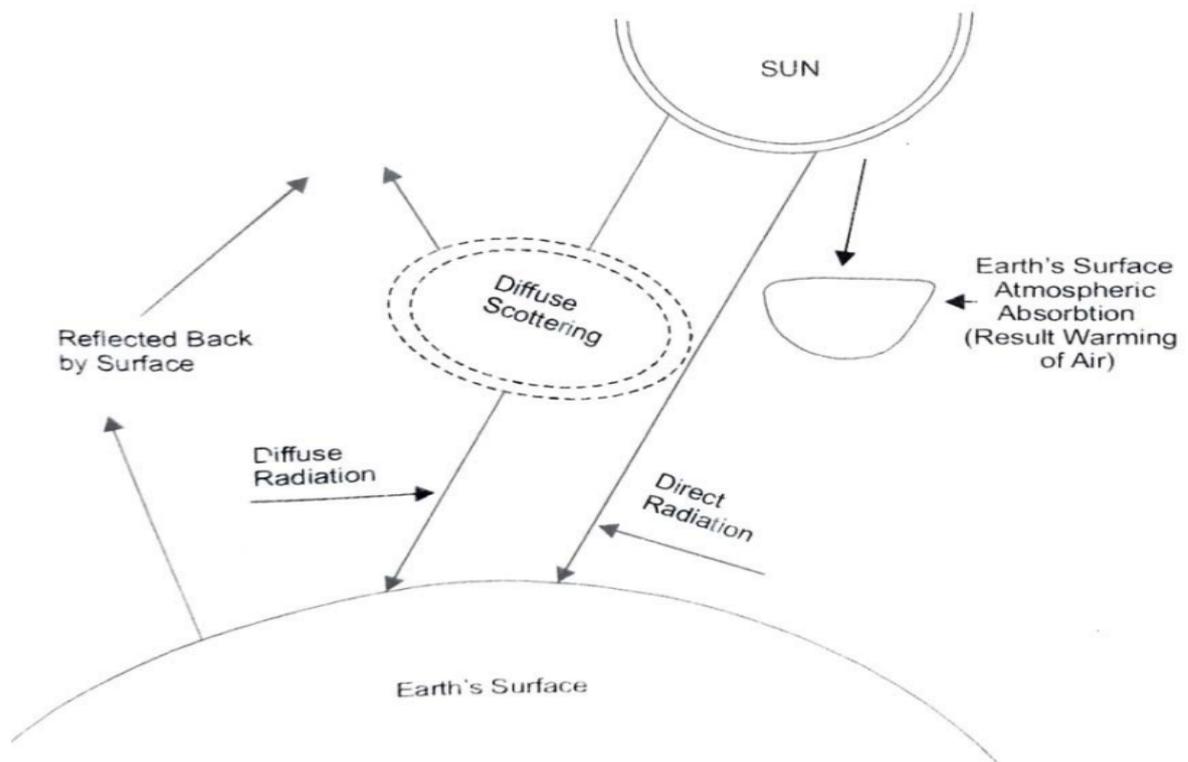


Fig. 2.3 SOLAR RADIATION

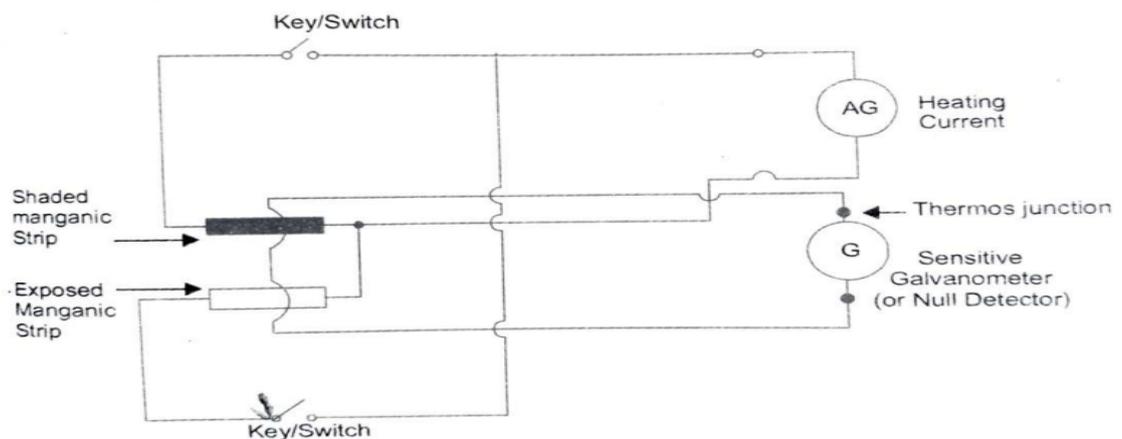
The total or global radiation received at any point on the earth's surface is the sum of the direct and diffuse radiation. This is referred to as the insulation at that point. The daily global solar radiation exposure is the total solar energy for a day. Typical values for daily global solar exposure range from 1 to 35 MJ/m (mega joule per square meter).

Solar radiation near the earth's surface can be measured by the following instruments.

1. Pyrheliometer – measure the direct solar radiation
2. Pyranometer - measures diffused solar radiation
3. Radiometer
4. Sun photometer
5. Ground radiometer
6. Microwave radiometer
7. Multifilter rotating shadow band radiometer(MFRSR)
8. Narrow field of view zenith radiometer (NFOV) etc.

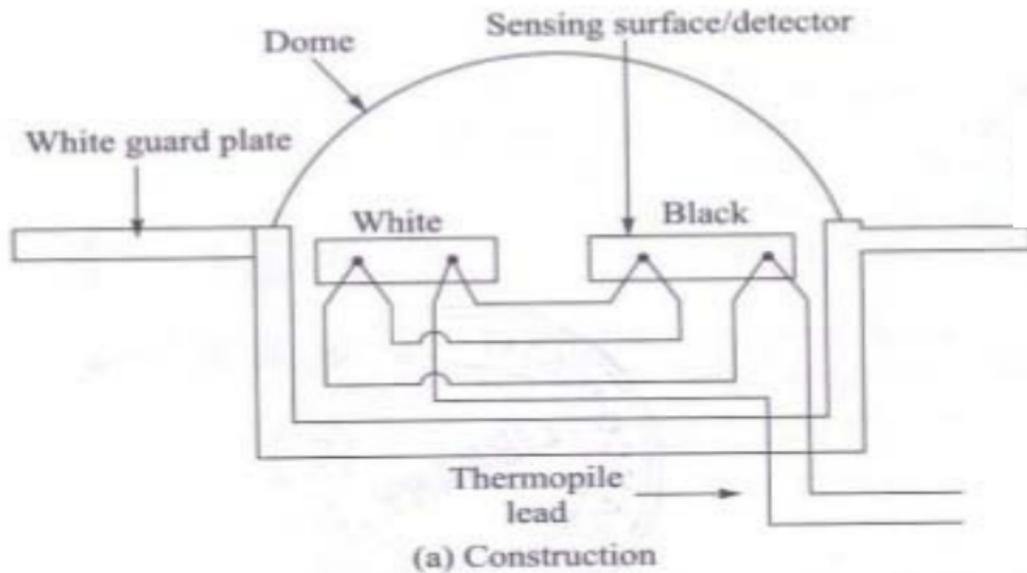
PYRHELIOMETER

Electric circuit of Angstrom Pyrheliometer is given. It mainly consists of two thin manganin strips, two keys, two ammeters or two galvanometers. One manganin strip is blackened shaded and the second manganin strip is exposed to solar radiation. The blackened shaded strip is heated electrically until it is at the same temperature as the second strip heated by solar radiation. Under steady state conditions i.e., both the strips are at the same



PYRANOMETER

In pyranometer, the sun's radiation is allowed to fall on black surface which forms the hot junction of a thermocouple. The cold junction of a thermocouple is located such that it does not receive the solar radiation. As a result, an emf proportional to the solar radiation is produced. This emf is recorded over a particular period of time and calibrated to measure the solar radiation



APPLICATIONS OF SOLAR ENERGY

The actual and proposed applications of solar energy may consider in three general categories.

1. **Direct thermal applications:** Direct utilization of heat from solar radiation.
2. **Solar electric applications:** Solar energy is converted in to electricity. (Solar thermal, high temperature electric conversion, photo voltaic method, thermo electric, wind energy and OTEC, etc.)
3. **Bio-mass and Biogas:** Organic matters derived directly or indirectly from plants which use solar energy to grow.

Based on above classification direct solar energy applications are:

1. Solar water heater (natural circulation).
2. Solar water heater (forced circulation).
3. Solar refrigeration (or cooling).
4. Solar space heating (active & passive).
5. Solar distillation
6. Solar dryer.
7. Solar cooker.
8. Solar furnace.
9. Solar pumping.
10. Solar green houses.
11. Solar production of hydrogen.
12. Solar energy (photovoltaic electric conversion).
13. Solar energy (thermal electric conversion) etc.

ADVANTAGES OF SOLAR ENERGY

1. Solar energy is a renewable energy source and reduces carbon emissions

Solar energy is a renewable energy source, meaning you don't ever use it up. Solar energy is clean. It creates no carbon emissions or other heat-trapping "greenhouse" gases. It avoids the environmental damage associated with mining or drilling for fossil fuels.

2. Solar energy can reduce your home's electricity bill

A solar energy system for your home can reduce your reliance on the grid and help you save on your electricity bill. Some owners of residential solar energy systems may even have excess power that they can sell to the utility. Instead of paying a utility for electricity, homeowners get paid by the utility. You may not have to buy an entire solar energy system to cut your home's electricity bill.

3. Diverse Applications

Solar energy can be used for diverse purposes. You can generate electricity (photovoltaics) or heat (solar thermal). Solar energy can be used to produce electricity in areas without access to the energy grid, to distil water in regions with limited clean water supplies and to power satellites in space.

4. Low Maintenance Costs

Solar energy systems generally don't require a lot of maintenance. You only need to keep them relatively clean, so cleaning them a couple of times per year will do the job.

5. Technology Development

Technology in the solar power industry is constantly advancing and improvements will intensify in the future. Innovations in quantum physics and nanotechnology can potentially increase the effectiveness of solar panels and double, or even triple, the electrical input of the solar power systems.

DISADVANTAGES OF SOLAR ENERGY

1. Cost

The initial cost of purchasing a solar system is fairly high. This includes paying for solar panels, inverter, batteries, wiring, and the installation.

2. Weather-Dependent

Although solar energy can still be collected during cloudy and rainy days, the efficiency of the solar system drops. Solar panels are dependent on sunlight to effectively gather solar energy. Therefore, a few cloudy, rainy days can have a noticeable effect on the energy system. You should also take into account that solar energy cannot be collected during the night.

3. Solar Energy Storage Is Expensive

Solar energy has to be used right away, or it can be stored in large batteries. These batteries, used in off-the-grid solar systems, can be charged during the day so that the energy is used at night. This is a good solution for using solar energy all day long but it is also quite expensive.

4. Uses a Lot of Space

The more electricity you want to produce, the more solar panels you will need, as you want to collect as much sunlight as possible. Solar PV panels require a lot of space and some roofs are not big enough to fit the number of solar panels that you would like to have.

5. Associated with Pollution

Transportation and installation of solar systems have been associated with the emission of greenhouse gases. There are also some toxic materials and hazardous products used during the manufacturing process of solar photovoltaic systems, which can indirectly affect the environment.

TYPES OF SOLAR COLLECTORS

Solar collectors transform solar radiation into heat and transfer that heat to medium (water, air, or solar fluid etc.). The heart of a solar collector is the absorber, which is usually composed of several narrow metal strips. Their construction and working are very simple. Solar collectors are broadly classified into two main groups as given below:

1. Flat plate type solar collector and
2. Focussing type or concentrating type solar collector

1. FLAT PLATE COLLECTORS

Flat-plate collectors are commonly used in solar water- heating systems in residential, commercial and industrial projects. Flat-plate collectors are commonly used in solar water- heating systems in residential, commercial and industrial projects. The collector housing can be made of plastic, metal or wood, and the glass front cover must be sealed so that heat does not escape, and dirt, insects or humidity do not get into the collector itself. The collector housing is highly insulated at the back and sides, keeping heat losses low. Conduction is caused by air movements, while radiation is caused by exchange of heat by radiation between the absorber and the environment.

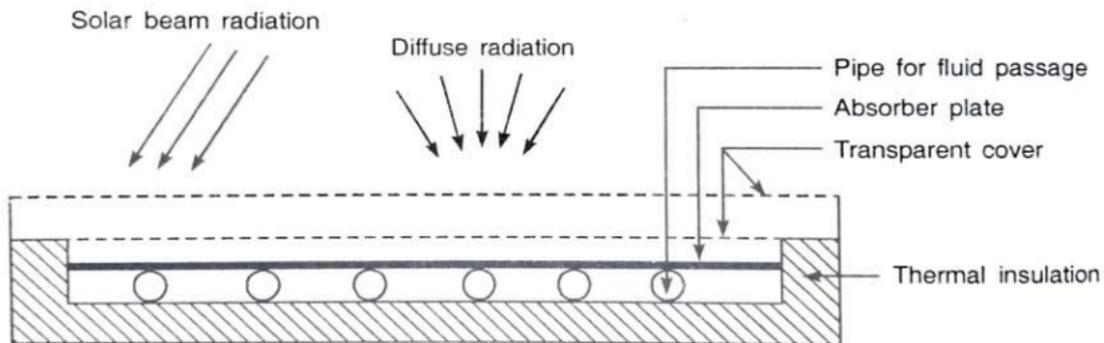


Figure 4.1 Schematic cross section of a flat-plate collector.

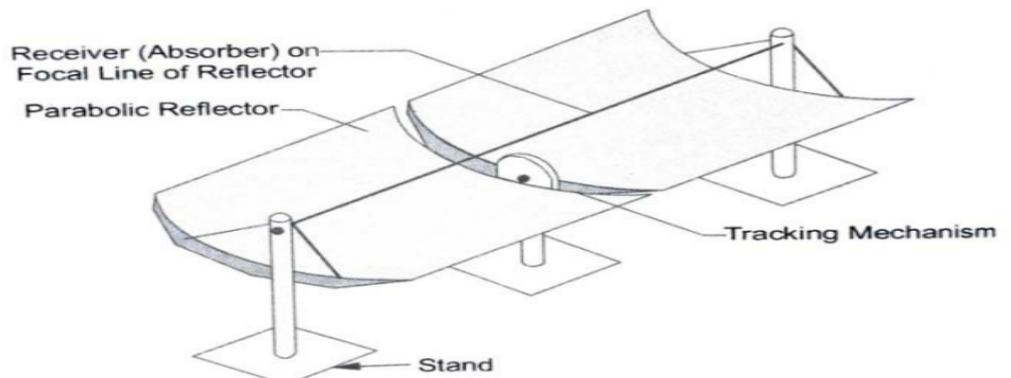
2. CONCENTRATING (OR FOCUSSING) TYPE SOLAR COLLECTORS:

When higher temperatures are required, concentrating solar collectors are used. Solar energy falling on a large reflective surface is reflected onto a smaller area before it is converted into heat. There are various types of concentrating solar systems; they are classified as below, according to the way they collect solar energy.

1. Parabolic trough system
2. Parabolically shaped dish [concentrating type collector]
3. Heliostat central tower

1. PARABOLIC TROUGH SYSTEM : .

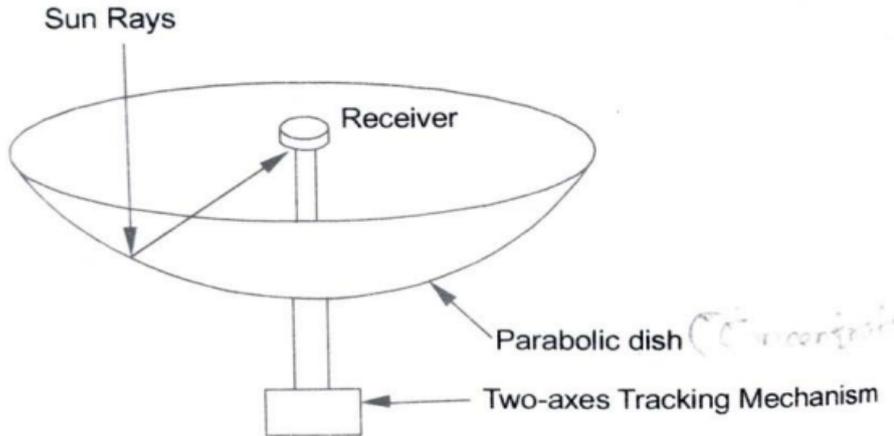
A parabolic trough concentrates incoming solar radiation onto a line running along the length or focal line of the Trough (reflector). A tube (receiver) carrying heat transfer fluid is placed along this line, absorbing concentrated solar radiation and heating the fluid inside. The trough must be tracked about one axis. Because the surface area of the receiver tube is small compared to the trough capture area (aperture), temperatures up to 400°C can be reached without major heat loss



(c) PARABOLIC-TROUGH COLLECTION

2. PARABOLICALLY SHAPED DISH

Parabolic system focuses solar energy at the focal point of a parabolically shaped dish at a temperature of about 800°C . Larger power plants will be assembled by connecting many dishes together



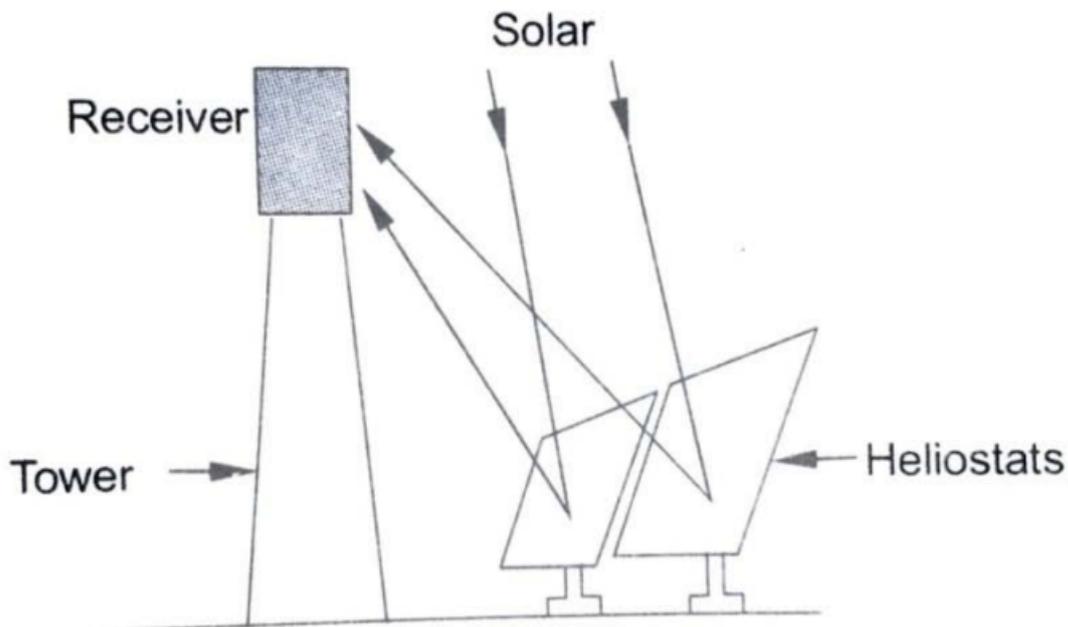
A schematic diagram of a typical concentrating collector is shown in Figure. The collector consists of a concentrator and a receiver.

Concentrator - It is a mirror reflector in the shape of a parabolic dish. It concentrates the incoming solar radiation to its central axis.

Receiver – It is an absorber tube located at the central axis of the parabolic dish. It carries a fluid to which the heat of radiation is transferred. A concentric glass cover around the absorber tube helps in reducing the convection and radiation losses to the surroundings. In order that the sun's rays should always be focussed on to the absorber tube, the concentrator has to be rotated. This movement is called tracking.

3. HELIOSTAT CENTRAL TOWER:

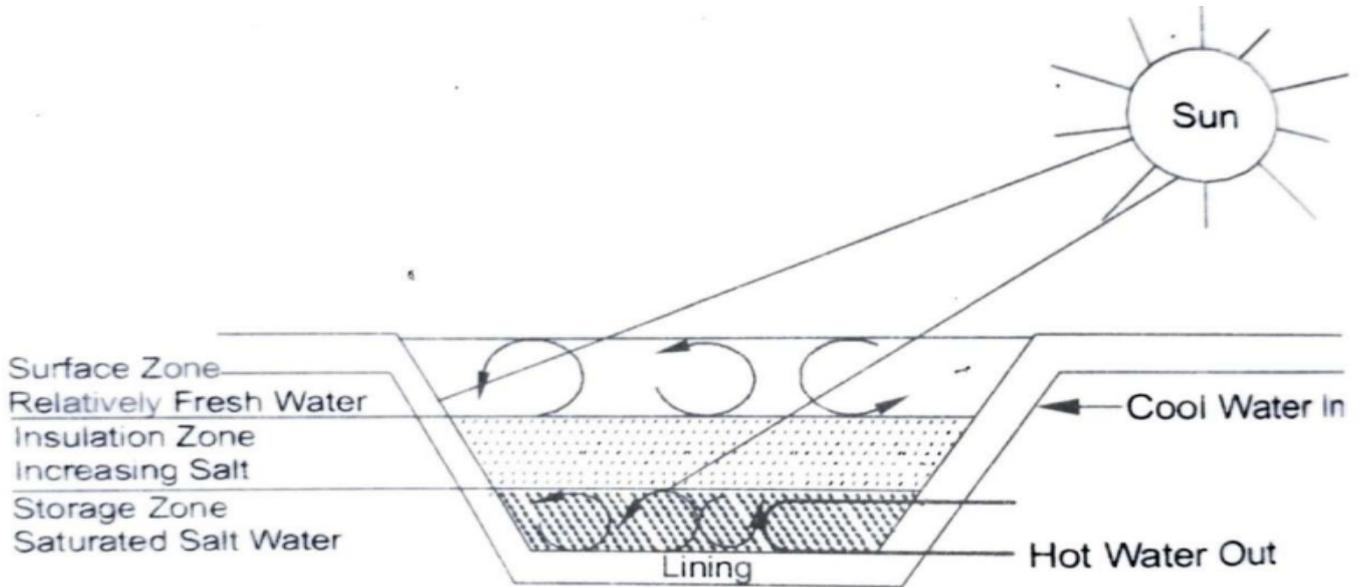
This system includes a field of heliostats that reflects the sunrays to a receiver located on top of a tower. energy is absorbed by molten salt working fluids and stored for up to several hours at 565°C in large tanks located at the base of the tower. They are suitable for large installation. A heliostat uses a field of dual axis sun trackers that direct solar energy to a large absorber located on tower. The mirrors concentrate sunlight onto a receiver on top of a high tower. A computer keeps the mirrors aligned so the reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000°C can be reached. High- pressure steam is generated by heating the working fluid to produce electricity.



SOLAR POND

It has three zones with increasing salinity with depth.

1. Surface zone (0.3m - 0.5 m, salinity <5%)
2. Insulation zone (1m - 1.5m) in which salinity increases with depth.
3. Storage zone (lower convective zone) (1.5m - 2m, salinity 20%).



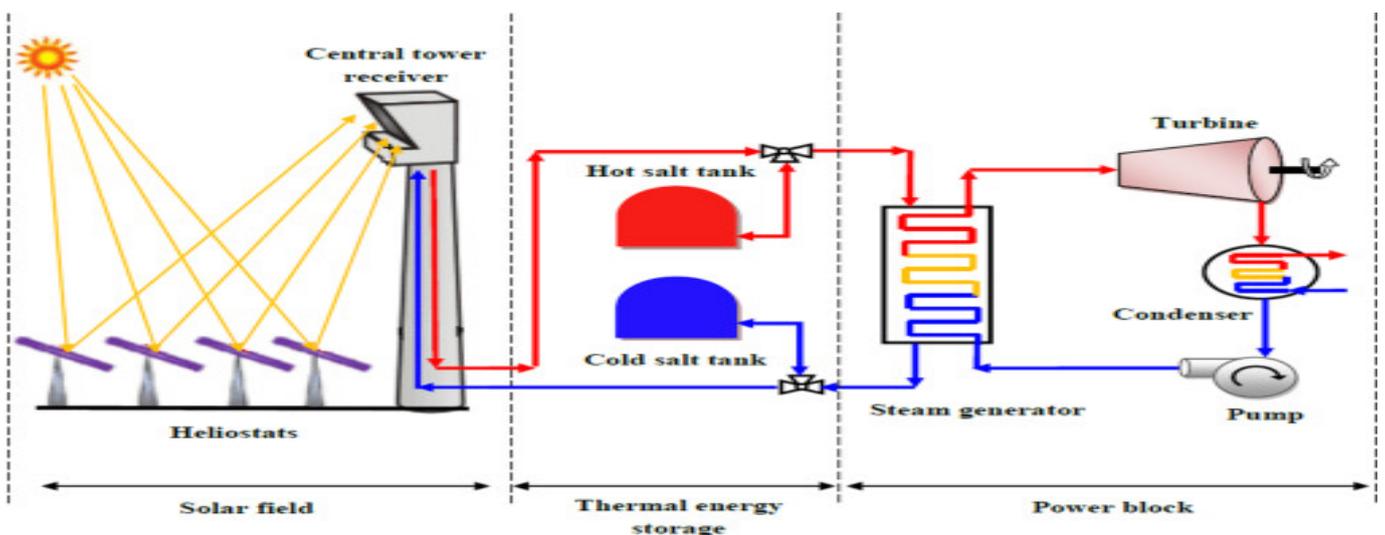
The surface zone has small thickness. The middle zone is much thicker. It mainly serves as an insulating layer and reduces heat loss in the upward direction. The lower or storage zone traps heat for long period and acts as thermal storage medium. As salty water near bottom heats up, it expands. However it cannot rise because it is denser. Consequently, the bottom zone traps heat and becomes very hot from 65 to 90°C while the surface remains at about 38°C.

CONCENTRATED SOLAR POWER (CSP) PLANTS-

Concentrated solar power (CSP) plants use mirrors to focus sunlight onto a receiver. The receiver collects the solar energy and transfers it to a heat-transfer fluid. The heat from the fluid can be used to power a turbine or engine to generate electricity.

The process of CSP plants generating electricity is as follows:

1. Mirrors reflect, concentrate, and focus sunlight onto a specific point.
2. The sunlight is converted into heat.
3. The heat is used to create steam.
4. The steam drives a turbine to generate electrical power.



Concentrated Solar Power (CSP) plants can be classified into several categories based on their technology and design. Here are the primary classifications:

- 1.Parabolic Trough Systems:**
- 2.Solar Power Towers:**
- 3.Dish/Stirling Systems:**
- 4.Fresnel Reflectors:**
- 5.Concentrated Solar Power with Thermal Storage:**
- 6.Hybrid CSP Systems:**

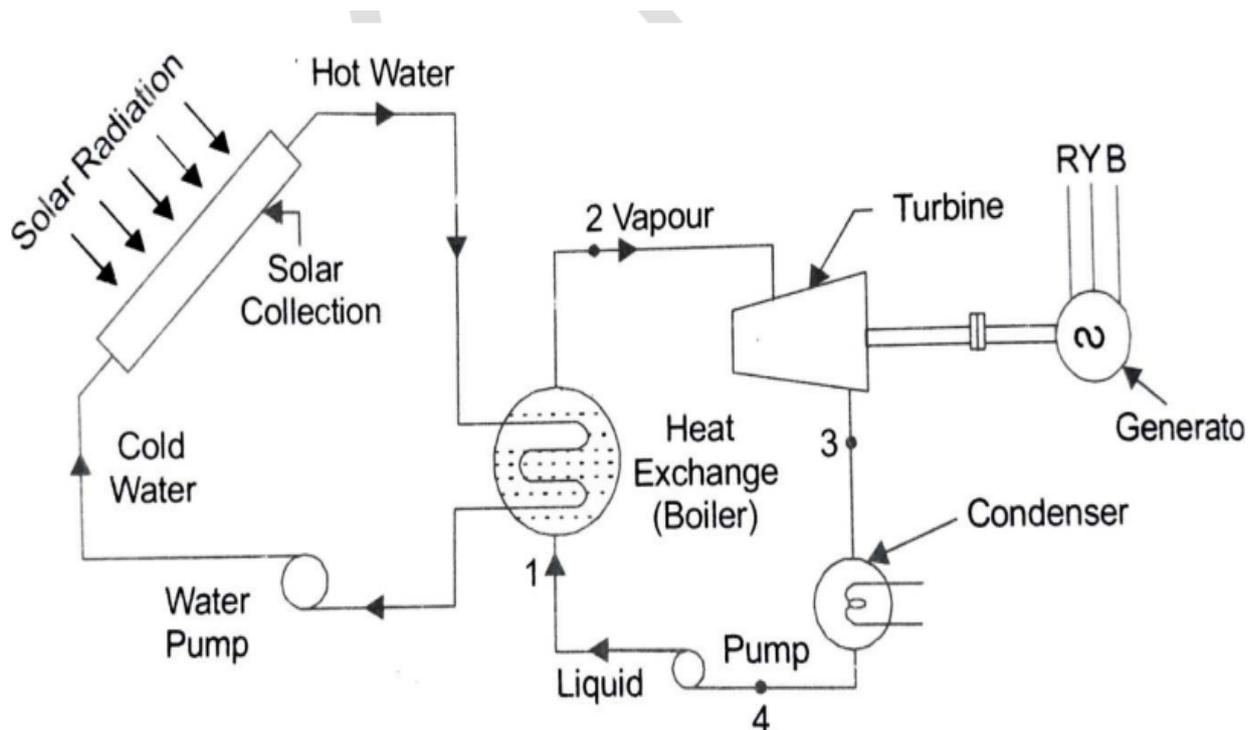
THERMAL ELECTRIC CONVERSION OF SOLAR ENERGY:

In solar power generation system the solar energy is first collected by collectors. This energy is used to heat the fluid and the energy in the fluid is utilised to generate steam in the heat exchanger. The steam generated is expanded in a prime mover to produce mechanical energy which can be converted into electrical energy in the generator. The power cycles employed in the solar power generation may be classified as

- (1) Low-temperature cycle (max. temperature is limited to 100'C).**
- (ii) Medium-temperature cycle (temperature ranges from 150 to 300 C).**
- (iii) High-temperature cycle (temperatures above 300°C**

LOW-TEMPERATURE PLANT WORKING ON RANKINE CYCLE:

The system has an array of flat-plate collectors to heat water and in the heat exchanger (Boiler), the heat of water is used for boiling butane. The high pressure butane vapour is expanded in a turbine to produce mechanical energy. The turbine coupled to generator converts mechanical energy to electrical energy (or turbine work may be used to run hydraulic pump which lifts the water from well for irrigation). The exhaust vapour from the turbine enters the condenser where it is condensed back to liquid. The liquid is then pumped through heat exchanger and the cycle is repeated



SOLAR PHOTOVOLTAIC SYSTEM

Photovoltaic power generation is a method of producing electricity using solar cells. A solar cell converts solar optical energy directly into electrical energy.

Photovoltaic cell (PV cell or solar cell) is a specialized semiconductor p-n junction diode that converts visible light into direct current (DC).

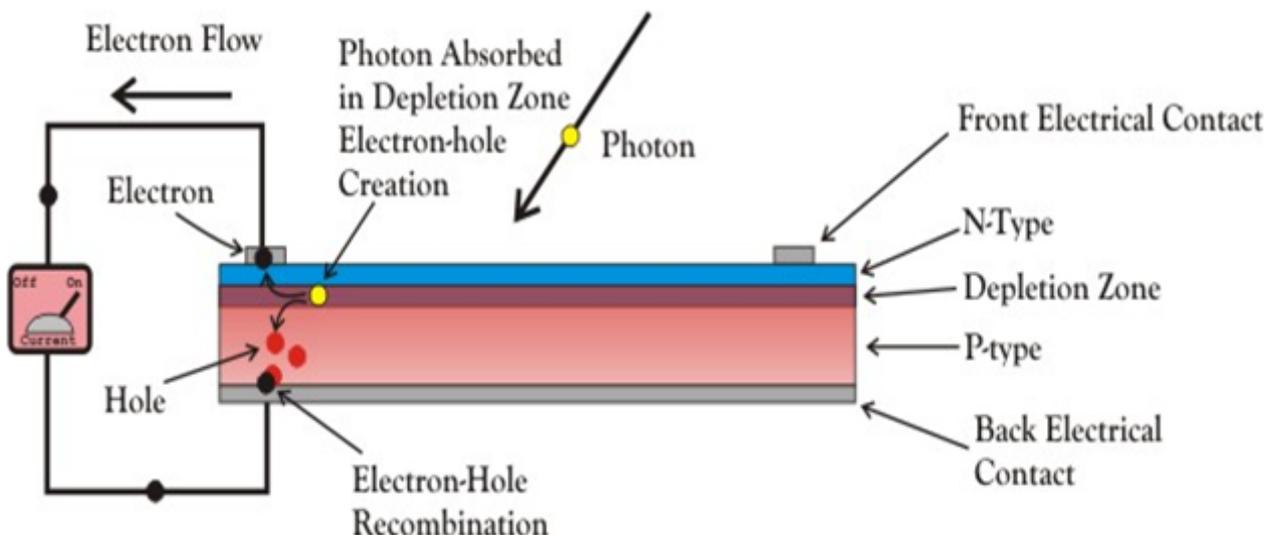
SEMICONDUCTOR MATERIALS FOR SOLAR CELLS

A few semiconductor materials such as silicon (Si), cadmium sulphide (CdS) and gallium arsenide (GaAs) can be used to fabricate solar cells. Semiconductors are divided into two categories intrinsic (pure) and extrinsic. An intrinsic semiconductor has negligible conductivity, which is of little use. To increase the conductivity of an intrinsic semiconductor, a controlled quantity of selected impurity atoms is added to it to obtain an extrinsic Semiconductor. The process of adding the impurity atoms is called doping

CONSTRUCTION OF SOLAR CELL

A solar cell is basically a junction diode, although its construction it is little bit different from conventional p-n junction diodes. A very thin layer of p-type semiconductor is grown on a relatively thicker n-type semiconductor. We then apply a few finer electrodes on the top of the p-type semiconductor layer.

These electrodes do not obstruct light to reach the thin p-type layer. Just below the p-type layer there is a p-n junction. We also provide a current collecting electrode at the bottom of the n-type layer. We encapsulate the entire assembly by thin glass to protect the solar cell from any mechanical shock.

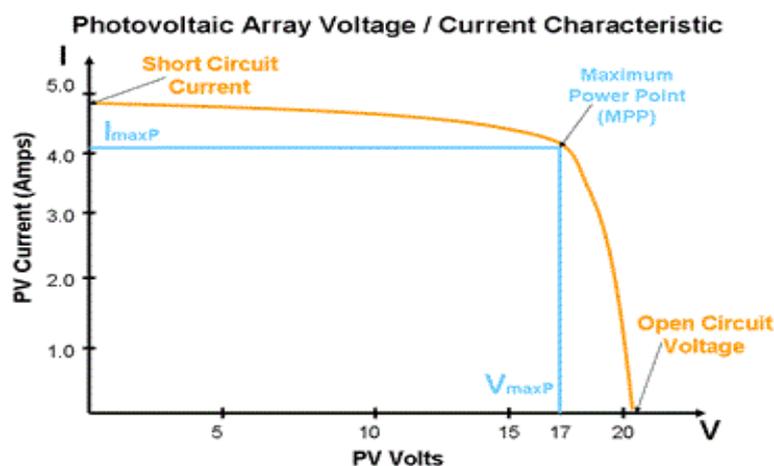


WORKING PRINCIPLE OF SOLAR CELL

When light reaches the p-n junction, the light photons can easily enter in the junction, through very thin p-type layer. The light energy, in the form of photons, supplies sufficient energy to the junction to create a number of electron-hole pairs. The incident light breaks the thermal equilibrium condition of the junction. The free electrons in the depletion region can quickly come to the n-type side of the junction. Similarly, the holes in the depletion can quickly come to the p-type side of the junction

The newly created free electrons come to the n-type side, cannot further cross the junction. Similarly, the newly created holes once come to the p-type side cannot further cross the junction. As the concentration of electrons becomes higher in one side, i.e. n-type side of the junction and concentration of holes becomes more in another side, i.e. the p-type side of the junction, the p-n junction will behave like a small battery cell. A voltage is set up which is known as photo voltage. If we connect a small load across the junction, there will be a tiny current flowing through it.

V-I CHARACTERISTICS OF A PHOTOVOLTAIC CELL



A solar cell is basically a p-n junction which generates emf when solar radiation falls on the p-n junction. Its I-V characteristic is shown here. (open circuit voltage) The generation of emf by a solar cell, when light falls on it, is due to following three basic processes :

- (i) Generation of e-h pairs due to incident light
- (ii) Separation of electrons and holes due to electric field of the depletion region. As a result electrons are swept to n-side and holes to p-side of junction.
- (iii) Collection of electrons reaching the n-side and holes reaching p-side by metal contacts provided at the two sides of solar cell.

MEGAWATT PEAK(MWP)

Megawatt peak (MWp) is a unit of measurement used to express the peak or maximum power output of a solar cell or a solar photovoltaic (PV) system. It represents the amount of electricity that a solar cell or system can generate under ideal or peak sunlight conditions.

MAXIMUM POWER POINT

The Maximum Power Point (MPP) is a crucial concept in the operation of solar photovoltaic (PV) systems. It refers to the specific operating point at which a solar panel or PV system generates the maximum amount of electrical power.

FILL FACTOR

The Fill Factor (FF) is a parameter used to evaluate the performance of solar panels or solar cells. It quantifies how effectively a solar device converts sunlight into electricity by considering the shape of the current-voltage (I-V) curve. The Fill Factor is calculated as the ratio of the maximum power output (P_{max}) of the solar panel to the product of its open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}):

$$\text{Fill Factor (FF)} = (P_{max}) / (V_{oc} * I_{sc})$$

IMPORTANT FACTORS CONSIDERED FOR INSTALLING A SOLAR PANEL

- 1.Solar Resource:** Assess the amount of sunlight your location receives throughout the year. A good solar resource is essential for optimal energy production
- 2.Roof Orientation and Tilt:** The orientation (azimuth) and tilt angle of the solar panels should be optimized to capture maximum sunlight throughout the year. South-facing roofs at an angle close to the latitude of the location often work well.
- 3.Shading:** Ensure that the solar panels are not shaded by nearby trees, buildings, or other obstructions. Even partial shading can significantly reduce system efficiency.
- 4.Local Regulations and Permits:** Understand and comply with local building codes, zoning regulations, and permitting requirements for solar installations. Secure any necessary permits.
- 5.System Size:** Calculate the appropriate size of your solar system based on your energy needs and available roof space. An energy audit can help with this.
- 6.Energy Storage:** Determine if you want to add energy storage (batteries) to your solar setup to store excess energy for use during cloudy days or at night.
- 7.Inverter Type:** Select the appropriate inverter technology (string inverters, micro-inverters, or power optimizers) based on your system design and shading conditions.

SOLAR POWER SATELLITE (SPS)

A Solar Power Satellite (SPS), also known as a Space Solar Power System (SSPS), is a theoretical concept for capturing solar energy in space and transmitting it to Earth for use as electricity.

Solar power satellites use giant mirrors to reflect solar rays onto smaller solar collectors. The radiation is then beamed to Earth as a microwave or laser beam. On Earth, antennas convert the microwaves back into electrical energy.

Solar power satellites have several advantages:

They can collect more energy because there is no reflection or absorption by the atmosphere.

They can generate continuous electricity, 24 hours a day, 99% of the year.

They do not cause pollution and do not require transmission lines or cables.

SOLAR CELL POWER PLANT

A solar power plant is a facility that converts sunlight into electricity. Solar power plants can be used to power homes and industries. The main benefit of a solar power plant is that it can minimize energy consumption.

Solar power plants are made up of various solar components, including solar panels, that absorb and convert sunlight into electricity. Solar power plants can use photovoltaics (PV) to convert sunlight directly into electricity. They can also use a variety of reflectors or lenses to concentrate solar energy onto a small receiver.

There are three main types of solar power plants: On-grid, Off-grid, Hybrid.

Solar power plants that are connected to the public electricity grid are called on-grid systems.

ON-GRID SOLAR SYSTEM (GRID-TIED):

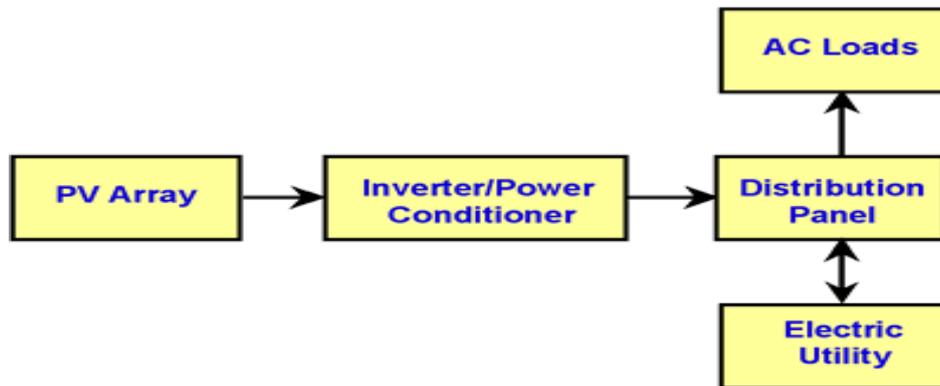
An on-grid solar system is connected to the public electrical grid.

Solar panels generate electricity, which is first used to power the electrical needs of the home or business. Excess electricity is fed back into the grid, often through a net metering arrangement, and the owner may receive credits or compensation for the surplus power.

On-grid systems rely on the grid as a backup during periods of low sunlight (e.g., at night) and draw electricity from the grid as needed.

Advantages: Potential cost savings, simplicity, and the ability to earn credits for excess power.

Disadvantages: No power during grid outages (unless a backup generator is added).



OFF-GRID SOLAR SYSTEM:

An off-grid solar system is not connected to the public electrical grid.

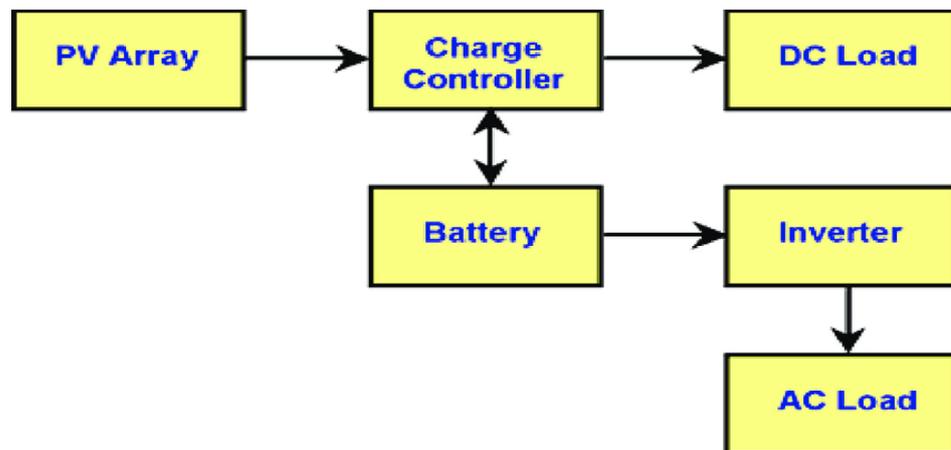
It typically includes solar panels, batteries, charge controllers, and inverters.

Solar panels generate electricity, which is stored in batteries for use when the sun is not shining.

The system provides power independently of the grid and is often used in remote areas or for backup power.

Advantages: Energy independence, suitable for remote locations, and backup power during grid outages.

Disadvantages: Higher initial costs due to the need for batteries, limited energy storage capacity, and occasional maintenance.



HYBRID SOLAR SYSTEM:

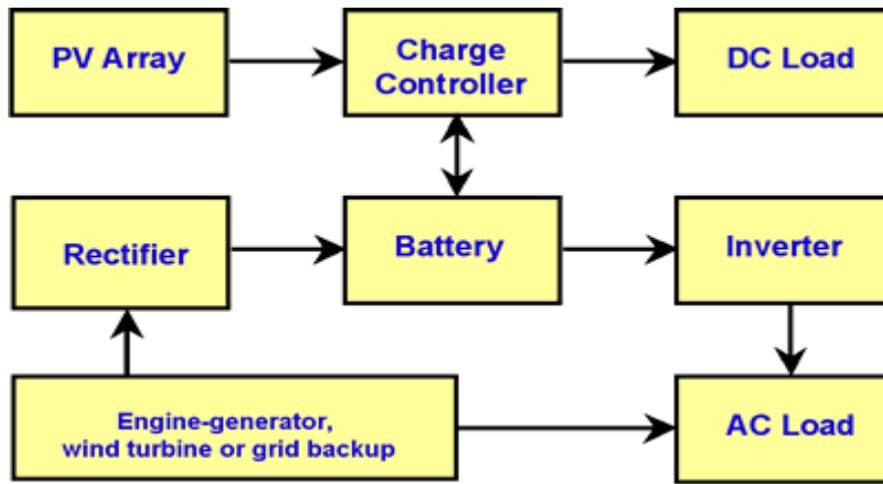
A hybrid solar system combines elements of both on-grid and off-grid systems.

It is connected to the grid but also incorporates energy storage (usually batteries) to store excess electricity generated by the solar panels. During periods of ample sunlight, excess power is stored in batteries. When the solar panels cannot meet the demand, electricity is drawn from both the grid and the batteries.

Hybrid systems can provide backup power during grid outages and optimize self-consumption.

Advantages: Combines the benefits of on-grid and off-grid systems, including energy independence and grid backup.

Disadvantages: Initial setup costs can be higher due to the inclusion of batteries, and maintenance may be required for the battery storage component.



POWER CONVERTERS IN PV SYSTEM

A PV system consists of a PV array connected to a DC-DC converter. The DC-DC converter regulates the output voltage of the photovoltaic cell. The three types of DC-DC converters that can be used in a PV system are: Buck, Boost, Buck-boost.

Buck converters are a type of switched-mode power supply. They convert high voltage DC to low voltage DC, which can extend battery life and reduce heat. The output voltage of a buck converter is always less than the input voltage.

Boost converters are sometimes called step-up converters. They convert a fluctuating solar panel voltage to a higher constant DC voltage. The output voltage of a boost converter is equal to or greater than the input voltage. However, the output current is lower than the source current.

