UNIT -1
(NON-CONVENTIONAL ENERGY RESOURCES AND SOLAR CELLS)

ENERGY-

Energy is one of the major parts of the economic infrastructure, being the basic input needed to sustain economic growth. There exists a strong relationship between economic development and energy consumption. The more developed is a country; the higher is the per capita of energy consumption and vice-versa. Human civilization relies on different sources of energy.

The two major sources of energy can be classified under:

Conventional Sources- These sources of energy are also known as non-renewable sources of energy and are available in limited quantity. They find both commercial and industrial purposes. These can be considered to be one of the reasons for the cause of pollution. **Examples** include coal, oil and natural gas, Electricity.

Non-Conventional Sources- These non-conventional sources are also known as renewable sources of energy. They are mainly used for household purposes. These are not responsible for the cause of pollution. **Examples** include solar energy, bio energy, tidal energy, wind energy, energy from urban waste.

Merits of Non-Conventional Sources-

1. Available in nature free of cost.
2. They produce very little pollution
3. They are inexhaustible.

Demerits of Non-Conventional Sources-

1. Availability is uncertain because the energy flow depends on various natural phenomena beyond human control**.**
2. Initial investment cost is high
3. Plant size is small (kW range) so not suitable for main power plants

VARIOUS NON-CONVENTIONAL ENERGY RESOURCES-

1. SOLAR ENERGY -

- The energy from the sun in the form of radiations is the solar energy. Sun is a source of enormous energy. It is believed that with just 0.1 percent of the 75000 trillion KWH of solar energy that reaches the earth, the planet's energy requirements can be fulfilled.
- In India solar installed capacity was 36.9 GW as of 30 November 2020.
- World electricity generation by solar in 2018 is 2%.
- Bhadla Solar Park (2245 MW) is the largest solar park in the world as of March, 2020, and is spread over a total area of 5,700 hectares in Bhadla, Phalodi tehsil, Jodhpur district, Rajasthan, India. Rewa Ultra Mega Solar (750 MW) Madhya Pradesh etc.

Solar Energy can be utilized in three ways:-

A) Converting in to thermal energy
B) Converting it in to electricity
C) Photosynthesis

A) Thermal Energy (Heat Energy)-

- Thermal Energy from sun can be obtained by using a solar collector. A solar collector absorbs the solar radiation and converts it in to useful heat energy which is used to heat fluid such as water to convert it into steam which runs the turbine coupled to the generator.
- The material type and coating on a solar collector are used to maximize solar energy absorption. A common absorber coating is black enamel paint.
- A large numbers of applications of solar thermal energy particularly those where low grade thermal energy is required. These include solar cookers, solar water heating systems, solar air heating etc.

B) Solar or Photovoltaic Cells-

- A solar cell is as an electrical device that converts light energy into electrical energy through the photovoltaic effect. Its electrical characteristics – such as current, voltage, or resistance – vary when exposed to light.
- Individual solar cells can be combined to form modules commonly known as solar panels. The common single junction silicon solar cell can produce a maximum voltage of approximately 0.5 to 0.6 volts. By itself this isn't much but when combined into a large solar panel, considerable amounts of renewable energy can be generated.

Working Principle of Solar Cell

- A solar cell is basically a p-n junction diode. 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. Once, the newly created free electrons come to the n-type side, cannot further cross the junction because of barrier potential of the junction.
- Similarly, the newly created holes once come to the p-type side cannot further cross the junction became of same barrier potential of 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.

Advantages of Solar Cell

1. No pollution associated with it.
2. It must last for a long time.
3. No maintenance cost.

Disadvantages of Solar Cell

1. It has high cost of installation.
2. It has low efficiency.
3. During cloudy day, the energy cannot be produced and also at night we will not get solar energy.

Uses of Solar Generation Systems

1. It may be used to charge batteries.
2. Used in light meters.
3. It is used to power calculators and wrist watches.
4. It can be used in spacecraft to provide electrical energy.

C) Photosynthesis

Photosynthesis, a phenomenon of chemical conversion of carbon dioxide and water into carbohydrates in presence of sunlight and chlorophyll by the plants, is one of the nature's most efficient methods of conversion of solar energy into storable form. It has been proved both in algae and in higher plants that under optimal conditions and over short period of time and at relatively low intensity, up to 30 percent of the light absorbed is transformed into chemical energy.

Merits of Solar Energy

1. Solar power is a renewable resource. As long as the Sun exists, its energy will reach Earth.
2. Solar power generation releases no water or air pollution, because there is no combustion of fuels.
3. In sunny countries, solar power can be used in remote locations, like a wind turbine. This way isolated places can receive electricity, when there is no way to connect to the power lines from a plant.

Demerits of Solar Energy

Solar power is not always completely predictable because it depends on the amount of sunlight that reaches the earth at any given time. This makes a solar cell ineffectual during the night when sunlight does not reach the part of the Earth in which the cell is located and less effective when cloud cover scatters sunlight.

2. WIND ENERGY-

Wind is emerging as one of the most potential source of alternate energy that will be helpful to a great extent in bridging the gap between the energy demand and supply. Wind has kinetic energy by virtue of the movement of large masses of air caused by differential heating of the atmosphere by the sun. This energy can be utilized for performing mechanical and electrical works**.**

Availability-

- As of 28 February 2021, the total installed wind power capacity in India was 38.789 GW, the fourth largest installed wind power capacity in the world. Wind power capacity is mainly spread across the Southern, Western and Northern regions.
- World electricity generation by wind in 2018 is 5%.
- Wind power plant in India are Muppandal Wind Farm (1500 MW) Kanyakumari, Jaisalmer Wind Park (1064 MW) Jaisalmer, etc.

How wind energy works?

Wind energy is used to run the wind turbine which drives a small generator. In order to obtain electrical energy from a wind turbine continuously, the generator is arranged to charge the batteries. These batteries supply energy when wind stop.

Type of wind turbine

a) Horizontal Axis Wind Turbine
b) Vertical Axis Wind Turbine

a) Horizontal Axis Wind Turbine-

- Main rotor shaft and electrical generator are kept at top of tower & must be pointed to wind.
- Turbine blades are made shift so they are not pushed into tower.
- Blade rotates at 10 rpm and at 22rpm.

Advantage – Tall tower base allow occurs to stronger winds in sites.
Disadvantage- Additional cost is transporting blades to height of tower.

b) Vertical Axis Wind Turbine-

- Main rotor shaft is vertical
- Turbine does not require to be pointed into wind to be effective when wind direction is variable.
- It is difficult to mount vertical turbine at height so they are mounted near base like roof tops but in that case they collect less power.

Advantage- Massive tower is not required.
Disadvantage- They located on ground so collected less power.

Merits of Wind Energy-

- Wind power produces no water or pollution that can contaminate the environment
- It can be beneficial for living permanently, or temporarily, in remote areas. It may be difficult to transport electricity through wires from a power plant to a faraway location and thus, wind towers can be set up at the remote setting.

Demerits of Wind Energy-

- Wind power is intermittent in many locations, because consistent wind is needed to ensure continuous power generation. When the wind speed decreases, the turbine lingers and less electricity is generated, thus the production at any time in these places in not fully predictable.

3. GEOTHERMAL ENERGY

- Geothermal energy is the energy produced by natural processes occurring within the earth. The major source of this energy (in the form of heat) is molten underground rock or magma. Geothermal energy is extracted for heating and power generation from natural steam, hot water or dry rocks in the Earth's crust. Water is pumped down through an injection well where it passes through joints in the hot rocks and then water rises to the surface through a recovery well. This water may be converted into steam through a heat exchanger. Dry steam may be passed through turbines to produce electricity.
- Approximately ten per cent of the earth surface provides access to heat inside the earth. The most potent sources are volcanoes and hot springs but there are other areas too from where heat can be generated under controlled conditions..
- The GSI (Geological Survey of India) has identified 350 geothermal energy locations in the country. The most promising of these is in Puga valley of Ladakh. There are seven geothermal provinces in India: the Himalayas, Sohana, West coast, Cambay, Son-Narmada-Tapi (SONATA), Godavari, and Mahanadi. The estimated potential for geothermal energy in India is about 10000 MW.
- The use of geothermal energy for space heating and greenhouse effect has been demonstrated.

Merits of Geothermal Energy-

- Geothermal energy does not produce air or water pollution if performed correctly.
- Geothermal power stations are relatively small and have a lesser impact on the environmental.

Demerits of Geothermal Energy-

- Geothermal Energy is only sufficient as source of power in certain areas of the world. These areas require the presence of hot rocks near the surface to warm the water. The depth of these rocks must be shallow enough that one can drill down to them, and the type of rock also plays a role as it must be easy to drill through.

4. MAGNETO HYDRODYNAMICS (MHD)

- The basic principle of MHD generation is the same as that of a conventional electrical generator i.e motion of a conductor through a magnetic field induces an emf in it.
- In MHD generation, electrical energy is directly generated from hot combustion gases produced by the combustion of the fuel without moving parts.
- The conventional electrical machines are basically electro-mechanical while an MHD generator is heat engine operating on a turbine cycle and transforming the internal energy of gas directly into electrical energy.
- In MHD generator, electrically conducting gas at a very high temperature is passed at high velocity through a strong magnetic field at right angles of direction of flow, thereby generating electrical energy. The electrical energy is then collected from stationary electrodes placed on the opposite sides of the channel. High temperature is required for ionization of the gas to have a good electrical conductivity. The conducting gas is obtained by burning a fuel and injecting a seeding material such as potassium carbonate in the products of combustion in order to increase the conductivity of the gas
- A small scale MHD power generator set up at Tiruchirapalli in Tamil Nadu.

Merits of MHD Generations

- It has high conversion efficiency about 50%
- More efficient heat utilization reduces amount of heat discharged to environments and so the mount of cooling water required is reduced.

Demerits of MHD Generations

- IT needs large magnets, leading to higher costs in implementing MHD generators.
- High operating temperatures in the range of 200°K to 2400°K will corrode the components sooner.

5. BIO ENERGY-

- Bio energy refers to electricity and gas that is generated from organic matter, known as biomass. This can be anything from plants and timber to agricultural and food waste – and even sewage. The term bio energy also covers transport fuels produced from organic matter.
- When biomass is used as an energy source, it's referred to as 'feedstock'. Feedstocks can be grown specifically for their energy content (an energy crop), or they can be made up of waste products from industries such as agriculture, food processing or timber production.
- Dry, combustible feedstocks such as wood pellets are burnt in boilers or furnaces. This in turn boils water and creates steam, which drives a turbine to generate electricity.
- Wet feedstocks, like food waste for example, are put into sealed tanks where they rot and produce methane gas (also called biogas). The gas can

be captured and burnt to generate electricity. Or it can be injected into the national gas grid and be used for cooking and heating.

- Bio energy is a very flexible energy source. It can be turned up and down quickly to meet demand, making it a great backup for weather-dependent renewable technologies such as wind and solar.
- Methan village in Sidhpur tehsil, Patan district of Gujarat saves 500 metric tons of fuel wood annually. They've been doing it for the last 15 years. This village is home to India's largest biogas plant, run by Silver Jubilee Biogas Producers and Distributors Cooperative Society Limited.
- India has a potential of about 18 GW of energy from Biomass.
- It is renewable, widely available, carbon-neutral and has the potential to provide significant employment in the rural areas. Biomass is also capable of providing firm energy. About 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.

Merits of bio energy-

- It can be used to burn organic waste products resulting from agriculture. This type recycling encourages the philosophy that nothing on this earth should be wasted.
- Biomass is abundant on earth and is generally renewable. In theory we will never run out of organic waste products as fuel, because we are continuously producing them.

Demerits of bio energy-

- Direct combustion without emissions filtering generally leads to air pollution similarly to that from fossil fuels.

6. OCEAN ENERGY

Energy from ocean or sea can be obtained in many ways. They are: **Ocean Thermal Energy Conversion.** India is having large potential of Ocean Thermal Energy Conversion (OTEC) which could of the order of about 50,000 MW. Some of the best sites in the world for OTEC are situated off the Indian mainland and near the islands Lakshadweep, Andaman and Nicobar.

The OTEC makes use of the difference in temperature between the surface of the sea and at a depth of 1000 m or more, to extract energy. This energy is used to drive turbines for generating electricity. In tropical countries like India the temperature gradient in the seas is as great as 25°C.

The main hurdles in OTEC technology is the cost factor, operational snags and the low operational efficiency of OTEC plants.

Wave Energy. The energy of waves, generated in their continual upward and downward motion, is harnessed to activate either a water operated or, preferably, air operated turbine to generate electricity. The wave energy potential of the 6000 km long Indian coast is estimated about 40,000 MW. Trade wind belts in Arabian Sea and Bay

of Bengal are the ideal places for trapping wave energy. Wave power is renewable and pollution free but very expensive (Re. 1 per unit).
India's first wave energy power plant of 150 KW (maximum) capacities based on. Oscillating Water Column (OWC) has been commissioned at Vzhinjam by IIT, Madras. The Department of Ocean Development has declared the plant at Vzhinjam as a national facility for wave energy and wave application studies. A Swedish organisation, Sea Power AB has developed technology for harnessing wave energy under floating wave power concept (FWPC). Harnessing wave energy on this principle is being explored in India and a 1 MW wave energy plant is being set up in the Andaman and Nicobar Islands.

Merits of Wave Power

- Potentially highly abundant for countries with large coastlines
- Potentially minimum effect on the environment.
- Wave power devices do not require large land masses

Demerits of Wave Power

- No viable large scale method of energy production exists.
- Limited to coastlines.
- Requires initial research, development and investment in infrastructure.
- Conversion devices are relatively complicated in construction.

Tidal Energy. The regular flow and ebb of tides, produced by the gravitational attraction of the sun and the moon are also useful for producing electricity, especially where the tidal range, *i.e.* the difference between the high and the low tide is large. If either a natural or artificial reservoir is available, power can be produced by moving the incoming and outgoing tides through turbines. The tidal power potential, in India is estimated to be about 8000 MW to 9000 MW. The potential sites identified are Gulf of Cambay (7,000 MW), Gulf of Kutch (1000 MW) and Sunderbans (100 MW). Asia's first tidal power point of 900 MW capacities is proposed to be set up at Kandla in the Gulf of Kutch.

Merits of Tidal Power

- Tidal power is free once the dam is built. This is because tidal power harnesses the natural power of tides and does not consume fuel. In addition the maintenance costs associated with running a tidal station are relatively inexpensive.
- Tides are very reliable because it is easy to predict when high and low tides will occur. The tide goes in and out twice a day usually at the predicted times. This make tides energy to maintain, and positive and negative spikes in energy can be managed.
- Tidal energy is renewable, because nothing is consumed in the rising of tides. Tidal power relies on the gravitational pull of the Moon and Sun, which pull the sea backwards and forwards, generating tides.

Demerits of Tidal Power

- Tidal power is not currently economically feasible, because the initial costs of building a dam are tremendous.
- The barrage construction can affect the transportation system in water. Boats may not be able to cross the barrage, and commercial ships, used for transport or fishery, need to find alternative routes or costly systems to go through the barrage.

Current Energy. Theoretically, the moving ocean current can be used to generate energy by allowing the water to pass through a series of turbines installed under water. But the energy density that can be harnessed is low; maintaining the turbines in position is a bigger problem.

Ocean Wind Energy. Winds in the coastal areas are relatively stronger and smoother than winds in the land area and can be harnessed as a source of energy. Several countries are producing energy from this source. Some of the problems associated with trade wind zone are icing and hurricane.

Salinity Gradient Energy. If a semi-permeable membrane is placed between two water bodies of different saline concentration then water with lower salinity begins to flow through the membrane towards higher salinity until both attain equal concentration. This is called *osmosis*. This movement in osmosis can generate an electric current. In Sweden a pilot study is being conducted to generate power of 2300 MW from salinity gradient energy.

Ocean Geothermal Energy. Theoretically, this method uses the temperature gradient as in OTEC but in the reverse way in that the temperature at the earth crust is low and higher at its deeper levels. But the method has not been practically applied.

Bio Conversion Energy. Sea weeds can also be converted into fuel and other energy products like methane, food and fertilizers.

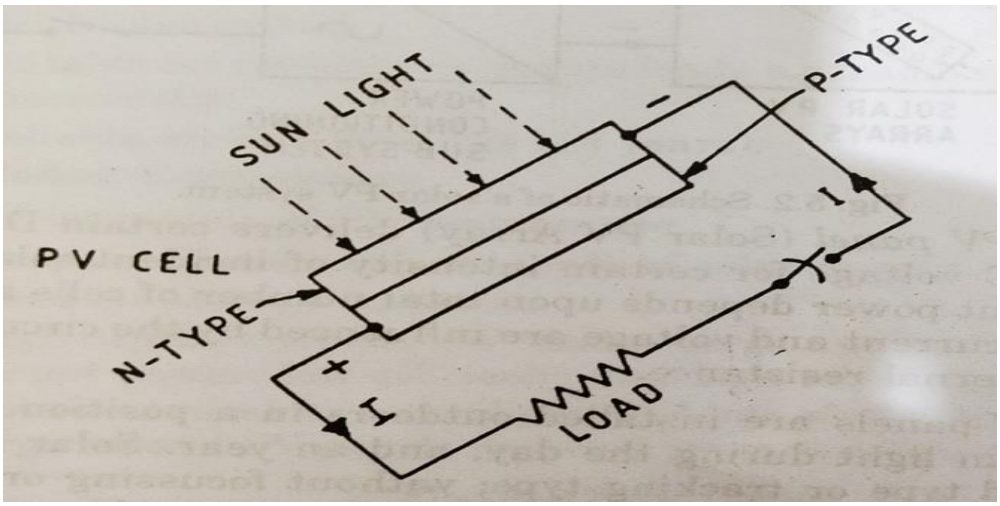
SOLAR CELL

- A **solar cell** (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light energy into electrical energy through the photovoltaic effect. A solar cell is basically a p-n junction diode. Solar cells are a form of photoelectric cell, defined as a device whose electrical characteristics – such as current, voltage, or resistance – vary when exposed to light. Individual solar cells can be combined to form modules commonly known as solar panels.
- A single cell has a rated voltage of about 0.5 V and rated power of about 0.3 W. Several Solar cells are connected in series to form a string. Several strings are connected in parallel to form a module. Several module are connected in series,

parallel, series-parallel configuration to form an array. The arrays installed on the structure to form a solar PV collector.

Principle of a Photo-Voltaic Cell

- The PV cell (Solar Cell) is a light sensitive, two terminal, semi conducting N-P junction made of semiconducting material such as silicon. A solar cell has two layers called N- Type and P-Type and two corresponding electrodes, negative and positive. N-Type material is obtained by doping silicon crystal with N-type impurity. P-Type material is obtained by doping silicon crystal with P-type impurity.

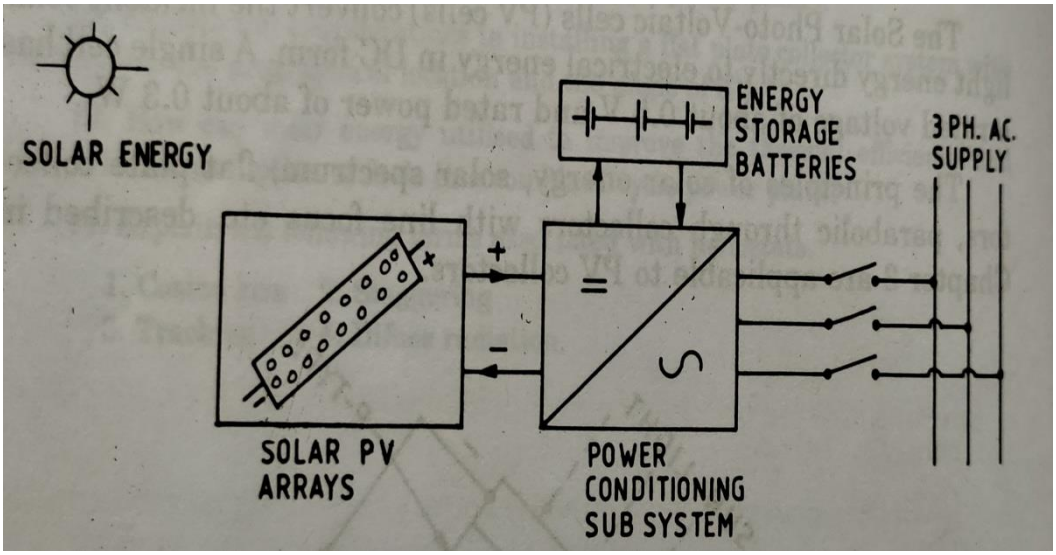


- The N-Type layer is thin and transparent. The P-Type layer is thick. When sun light strikes the N-type thin layer, some of the waves of light energy penetrate up to P-type layer. The energy from Photons in the light waves is imparted to the molecules and atoms in the N-P junction resulting in liberation of electrons-hole pairs. Electrons are released from N-type material and holes are created in P-Type material. Electrons are negative charges and holes are positive charges (lack of electrons).

- When external electric circuit is completed by connecting electrodes to the load , the electrons flow in the closed external circuit from N-type terminal (negative) to P-type terminal (Positive) Direction of current (by conversion) is from the positive terminal (P-Type) to negative terminal (N-Type) in the external circuit.

- Within the N-P junction ‘electron-hole’ pairs are continuously generated during the incidence of the sunlight. Energy from solar rays is captured by the solar cell and is converted directly to electrical energy. Thermal energy state is absent. Energy conversion is directly from Solar (wave) energy to electrical energy.

SOLAR PV SYSTEM



Schematic of a solar PV system

- A Solar PV panel (Solar PV Array) delivers certain DC current at certain dc voltage for certain intensity of incident solar energy.
- The DC output power depends upon total number of cells and power per cell. The current and voltage are influenced by the circuit connections and external resistance.
- Solar PV-panels are installed outdoors in a position to receive maximum sunlight during the day, and a year. Solar PV panels may be fixed type or tracking type; Flat plate fixed panels without focusing are commonly used as they are simple, cheap and maintenance free.
- The Solar PV panels deliver DC electrical power only during favorable conditions of sunlight. To obtain electrical power during cloudy weather or nights the energy storage batteries are necessary.
- During the favorable sun light hours and low load the storage batteries get changed. During nights and cloudy weather, the storage batteries supply the electrical energy to the load. It is generally uneconomical to install storage batteries for supplying the energy requirement or the load beyond a few hours.

Merits of Solar PV systems

- Use of clean, cheap, noiseless, safe, renewable solar energy to produce electrical energy at the location of utilization, conservation of non-renewable fuels.
- Suitable for remote loads away from main electrical network and at places where other fuels are scarce and costly. Cost of installation of long distribution lines, distribution substations etc. is eliminated.
- Suitable for portable or mobile loads e.g. radio sets, cars, buses, space-crafts.
- Reliable service, long life (15 years).
- Modest maintenance

Limitations of PV systems are

- Irregular, intermittent supply of solar energy.
- Need for storage batteries.
- High capital cost (Rs/kW) due to large number of PV cells, low output power, low efficiency and high technology involved.
- Not economical for central power plants of MW rating due to very large area of PV panels and very large storage battery system.
- Require storage batteries and or additional diesel generator sets for supplying power during night and during cloudy periods.
- Do not generate power during cloudy season. Not suitable during rainy season.
- Space for installing large PV-panels is not available in large cities, industrial cities, etc. except on roofs of buildings.
- Advanced PV-technology required for producing PV-cells
- Very low efficiency of PV-cells (10 to 14%)

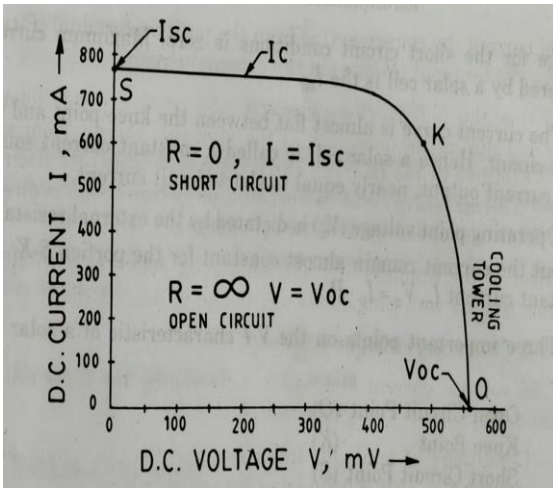
Solar PV System as power source is in use for a variety of application. These include,

- Street Lightning
- Community TV Centres
- On-site power supply
- Microwave repeater station
- Navigational Aids
- Telemetry Systems
- Space station power supply
- Off shore oil-rings

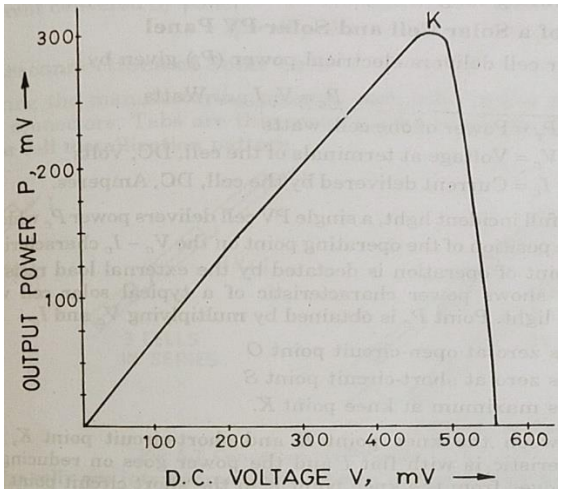
Photovoltaic power systems have emerged as the chosen renewable technology for Rural Areas

V-I Characteristic of a Solar Cell

- The voltage, current and power delivered by the solar cell are influenced by:
    - Conditions of sunlight, intensity, wavelength, angle of incidence etc. Visible band gives maximum power.
    - Conditions of the junction, temperature, termination, etc.
    - External resistance (R)
- Hence the ratings of a solar cell are specified for particular reference conditions and with the help of V-I Characteristics. The V and I are direct voltage and direct current measured in the PV cell circuit during full sunlight.



(a)



(b)

Fig 2 V-I Characteristics of a type commercially available solar cell.
(a) K corresponds to knee point and (b) Efficiency curve of a solar PV Cell

- When external resistance R is very high (Mega-Ohms) the condition is called Open Circuit. The Open circuit voltage Voc of a solar cell is about 0.5 V D.C. It is the maximum voltage across a PV cell. Open circuit current is zero. External resistance 'R' is very high in Mega-ohm range or infinity.

- If external resistance R is reduced gradually and the readings of terminal voltage V and load current I are taken, we get the V-I characteristic of the PV Cell.

- As external resistance is reduced from high value to low value, the terminal voltage of the cell falls and current increases. A Steep characteristic 'OX' is obtained.

- At knee point 'K' the characteristic undergoes a smooth change and becomes flat for the portion K-S. When the external resistance is completely shorted, the short circuit Isc is obtained. The terminal voltage for the short circuit condition is zero. Maximum current delivered by a solar cell is the Isc

- The current curve is almost flat between the knee point and the short circuit. Hence solar cell is called a constant current source with current output, nearly equal to short—circuit current.

- Operating point voltage (V_c) is dictated by the external resistance (R) but they remain almost constant for the portion S-K. For constant current Ic,

$$\mathbf{V_c = I_c . R}$$

Three important points on the V-I characteristic of a solar cell are:

- Open Circuit Point (O)
- Knee Point (K)
- Short circuit Point (S)

Operating range is the flat current portion KS.

Power of a Solar Cell and Solar PV Panel

- Solar cell delivers electrical power (P) given by

$$P_c = V_c I_c \quad \text{Watts}$$

where P= Power of one cell, watts
V_c = Voltage at terminals of the cell, DC, Volts
I_c= Current delivered by the cell, DC, Amperes.

- For full incident light, a single PV cell delivers power P_c which varies with the position of the operating point on the V_c -I_c, characteristic. The exact point of operation is dectated by the external load resistance R. Point P_c is obtained by multiplying Vc and I_c

P_c is zero at open-circuit point O
P_c is zero at short-circuit point S
P_c is maximum at knee point K.

- Between the knee point K and short-circuit point K, the V-I characteristic is with flat I and the power goes on reducing as the point moves from the knee point K to the short circuit point S.

- It is preferable to operate a PV cell with maximum possible light and at knee point K for obtaining maximum power and therefore maximum efficiency.

Power of a Solar Panel, Array and Module

Let, n= Number of solar cells in a module
m = Number of modules in an array or a panel
P_c= Power per solar cell, watts

Power per module = n P_c
Power per array or panel = m x n x P_c

$$P_p \; m \times n \times P_c \qquad W$$

For full light, solar panel will deliver power Pc. With power (P) and external resistance (R), the voltage and current can be calculated DC voltage of the PV panel (V_p), current delivered by the PV panel (I_p) and the external DC load (R) are correlated by the basic equations of the ohms law.

$$P_p = V^2/R = I^2_p R = V_p I_p$$

Power of a solar Panel = P_p Watts

$$P_p = m \times n P_c$$

Voltage across panel $Vp = P_p / I_p$

Current delivered by panel $I_p = \sqrt{P_p/R}$

Interconnection of Solar Cells

During the manufacturing process, each solar cell is tabbed to provide connectors. Tabs are thin metal pieces which are bonded to the solar cell metallization pattern.

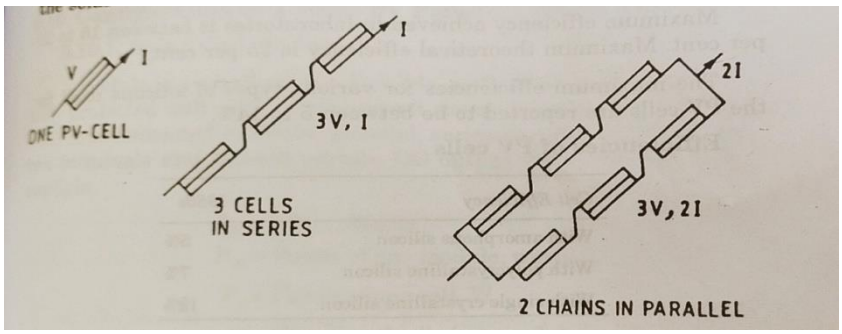


Fig 3 Connections of PV-cells

Solar cells are interconnected as shown in Fig. by any of the following soldering techniques.

1. Pulse/Parallel gap
2. Soldering iron
3. Infra-red heating
4. Induction heating
5. Laser
6. Vapour phase reflow

Cell strings are connected in series, parallel as shown in Figure 3 to form a module.

Efficiency of a Solar Cell

- Most of the manufacturers give the efficiency values of the solar cells on the basis of the following definition:

Efficiency of a solar cell = Incident radiation (W)/Power delivered (W)

- For specified conditions of temperature, Irradiance solar spectra.

Typical standard test conditions for efficiency measurement are:

Irradiance 1000 W/m or 800 W/m
Cell temperature 25°C to 45°C

Maximum efficiency occurs at:

Full solar radiation on the PV cell
Knee point on V-I curve

- Maximum efficiency of a particular solar cell depends on the materials, design parameters, manufacturing process, test conditions etc. and the efficiency range of commercially available solar cells is 12 to 15 per cent.
- Maximum efficiency achieved in laboratories is between 15 to 20 per cent. Maximum theoretical efficiency is 25 per cent.
- The maximum efficiencies for various types of silicon used for the PV cells are reported to be between 5 to 14T%.

Solar Cell Materials

- PV cells which have only silicon as the base for PN junction are called "Homojunction' PV cells.
- PV cells which have two base materials (e.g. Cadmium Sulphide Copper) are called hetero junction PV cell.
- Homojunction celle with silicon base are most successful and have following three types.
    - Amorphous silicon
    - Polycrystalline silicon
    - Single crystal silicon

Amorphous Silicon means non-crystalline silicon. Such material is used in film process. Pure silicon without crystals is used. There is no alignment of crystals. Crystals are scattered in random fashion. Amorphous silicon solar cells are least efficient but easy to manufacture. Efficiency of amorphous cells does not exceed 5 per cent.

Polycrystalline Silicon cell has many crystals in a single silicon. The polycrystalline material has inter-grain boundaries within a cell. The electrons are inhibited at these boundaries resulting in its reduction in efficiency below single-crystal silicon cells.

Efficiency of polycrystalline solar cells is around 7 per cent. Manufacturing process of polycrystalline silicon cells is less complex and less costly than that of single crystal silicon process.

Due to lesser complexity, lesser cost, higher production speed, polycrystalline silicon cells are commercially competing with single crystal silicon cells.

Single Crystal silicon cells with uniform crystal structure

Crystals have highly ordered atomic and molecular structure. The process of converting poly-crystalline silicon to the single crystal silicon is called 'crystal growing. The electrical characteristics of a PV cell are determined by the growth process.

Physical characteristics of single crystal water are

- Orientation of the crystal
- Thickness, diameter
- Flatness, taper, bow

Single crystal silicon cell has high efficiency (upto 159%) and is more complex and costly to produce.

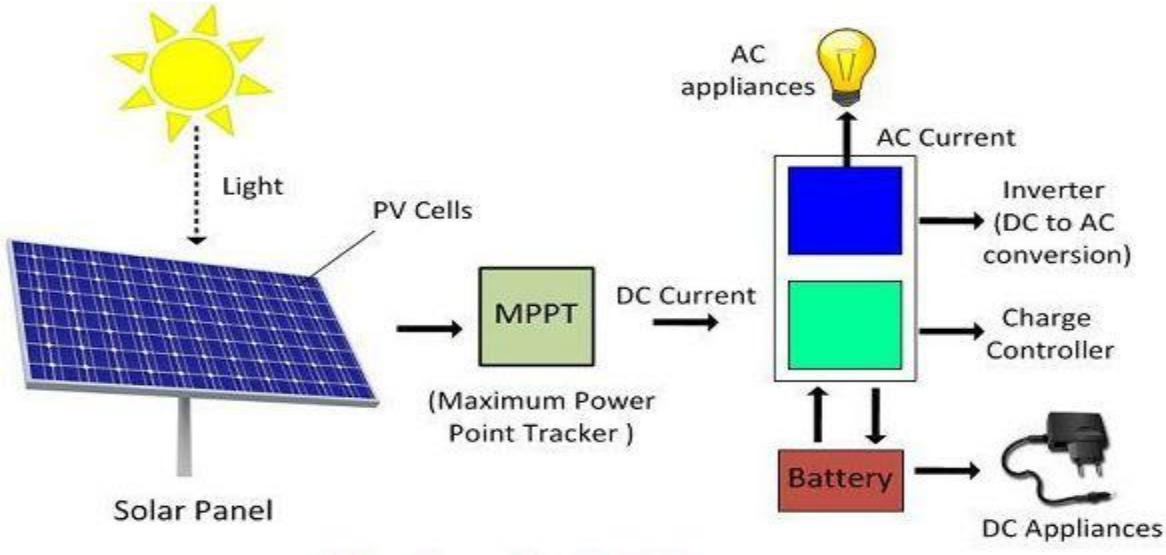
PN Junction - Any of the types of silicon (homo-crystalline, Polycrystalline, amorphous) are treated with a thin layer of any of the following intermediate compounds to obtain a PN junction.

- Cadmium-territide
- Cadmium-Sulphide
- Gallium-arsenide
- Indium-phosphate
- Cadmium-Selenide
- Zinc-Sulphide
- Gallium-antimonide

In a homo junction silicon cell, base material is all silicon. A large area called P type material is doped with acceptor material. A very thin layer of N type material is doped with donor atoms. A very thin barrier is created between N type and P type layers. The barrier resists movement of electrons from N type to P type through the junction.

Characteristics of a PV cells are influenced by the intermediate materials and the parameters of the cell Gallium- Arsenide gives open circuit voltage of 0.8 to 0.9 V.

Solar Power Plant



Maximum power point tracker, inverter, charge controller and battery are the name of the apparatus used for converting the radiation into an electrical voltage.

Maximum Power Point Tracker – It's a special kind of digital tracker that follows the location of the sun. The efficiency of the PV cell depends on the intensity of sunlight fall on it**.** The power of the sun varies with the time because of the movement of the earth. So for absorbing the maximum light, the panel needs to be moved along with the sun. Thereby the maximum power point tracker is used with the solar panel.

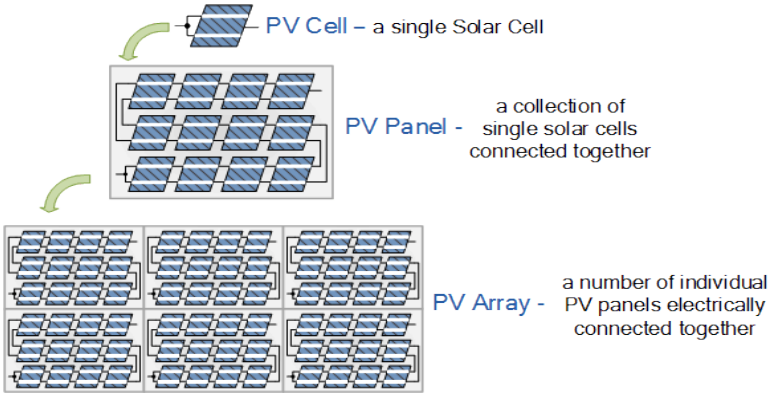
Charge Controller – The charge controller regulates the voltage drawn from the panel. It also protects the battery from the overcharging or overvoltage.

Inverter – The inverter converts the direct current into the alternating current and vice versa. The conversion is essential because some of the appliances require ac supply for their work.

Solar Cell Array

- If photovoltaic solar panels are made up of individual photovoltaic cells connected together, then the **Solar Photovoltaic Array**, also known simply as a **Solar Array** is a system made up of a group of solar panels connected together. A photovoltaic array is therefore multiple solar panels electrically wired together to form a much larger PV installation (PV system) called an array, and in general the larger the total surface area of the array, the more solar electricity it will produce.
- A complete photovoltaic system uses a photovoltaic array as the main source for the generation of the electrical power supply. The amount of solar power produced by a single photovoltaic panel or module is not enough for general use. Most manufactures produce standard PV panels with an output voltage of 12V or 24V. By connecting many single PV panels in series (for a higher voltage

requirement) and in parallel (for a higher current requirement) the PV array will produce the desired power output.



A Photovoltaic Solar Array