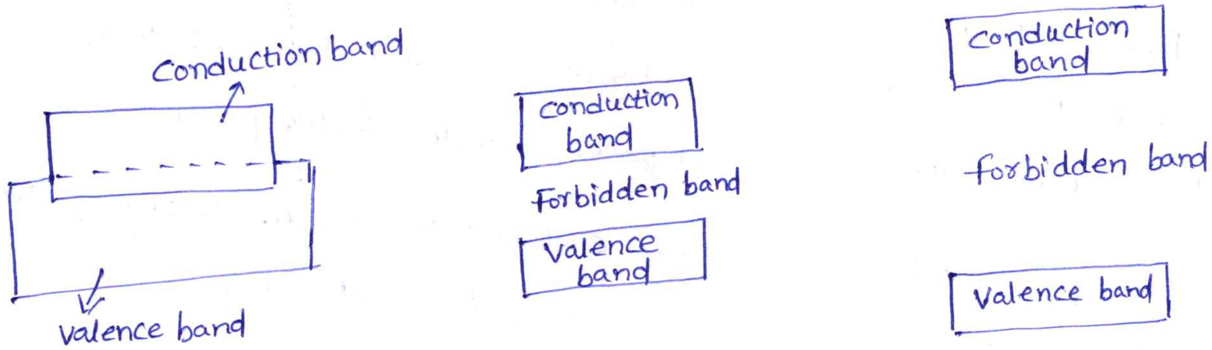
Unit-2

PV Energy systems

Introduction :-

→ **Photo Voltaic (PV) System :-** It is a method of generating Electrical power by converting solar radiation into directly Electricity with the help of semiconductors that exhibit photovoltaic effect.

→ **Conductor, semi-conductor and Insulator :**



fig(a): conductor fig (b): Semiconductor fig (c): Insulator.

→ No forbidden exists between the valence band & conduction band in a conductor.

→ forbidden band Exist ~~between~~ in semiconductor & insulator. The forbidden band is more in insulator when compared to Semiconductor.

→ **Semi conductor :** Semiconductors are the materials which have a conductivity between conductors and Insulators,

Types of semi conductor:

1) n-type semiconductor.
2) P-type semiconductor

→ PV effect in crystalline silicon basic principles :-

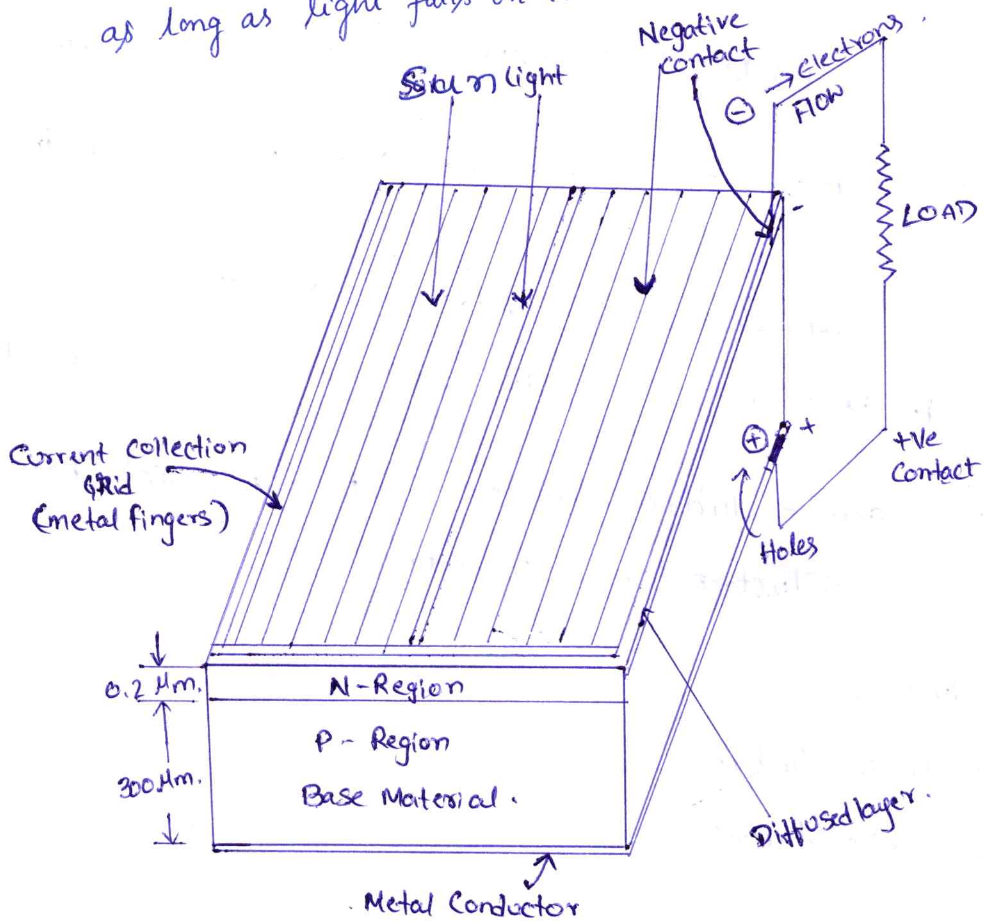
→ Photo voltaic effect is a process in which two dissimilar metals in close contact produce an electrical charge when struck by light.

→ when light strikes crystals such as silicon or germanium (p-n Junction) in which electrons are usually not free to move from n-region to p-region, due to the potential barrier.

→ The light provides the energy (emf) needed to free some electrons from the bound condition depending on absorption of solar energy.

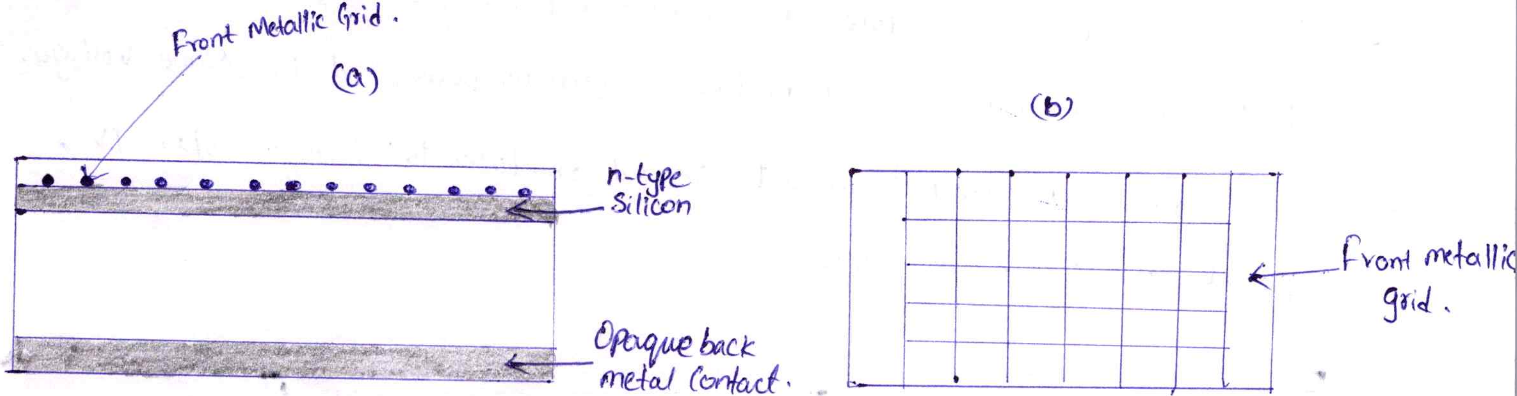
→ Free electrons cross the Junction between two dissimilar crystals and these electrons travel through an external circuit to return to their usual state and in this process create electric power.

→ The photo voltaic effect can continue to provide voltage & current as long as light falls on the Junction of two materials.



→ Solar Cell, Module, Panel and Array :-

→ Solar cell: consists of
(i) P-type silicon material layer
(ii) n-type silicon material layer
(iii) front metallic grid.
(iv) opaque back metal contact

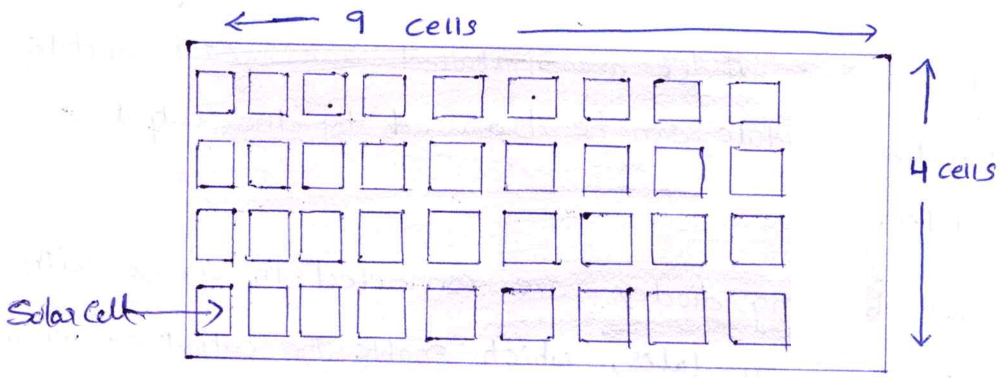


Construction of a solar cell (a) Side view of the Solar cell (b) Top view of the Solar cell.

→ Solar module :- A single solar cell cannot be used as such as it has (i) a very small output (ii) no protection against dust, moisture, mechanical impacts and atmospheric harsh conditions.

→ Suitable voltage and adequate power can be obtained by suitably interconnecting a no. of solar cells. The assembly of solar cells is called solar module.

→ A solar module has generally 32-36 solar cells connected in series to charge a 12V battery.



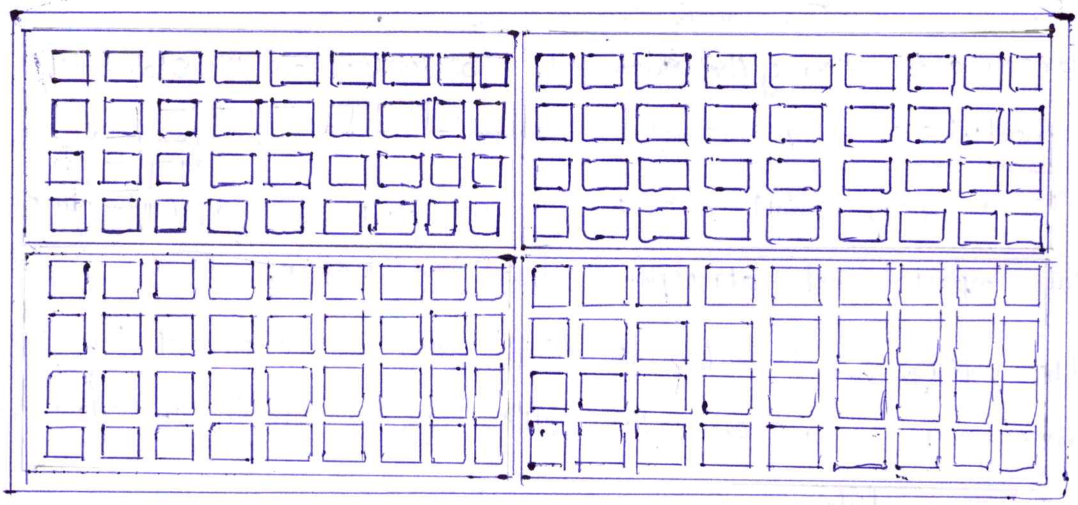
Solar PV module with 36 solar cells.

Solar PV Panel: Solar PV panel consists of a number of solar PV modules connected in series and parallel to obtain the power of desired Voltage and current.

→ when modules are connected in series, it is desirable that each module should produce maximum power at the same current.

→ when solar PV modules are connected in parallel, it is desirable that each module should produce maximum power at the same voltage.

→ A frame is used to mount several modules to form a solar PV panel as shown in fig.

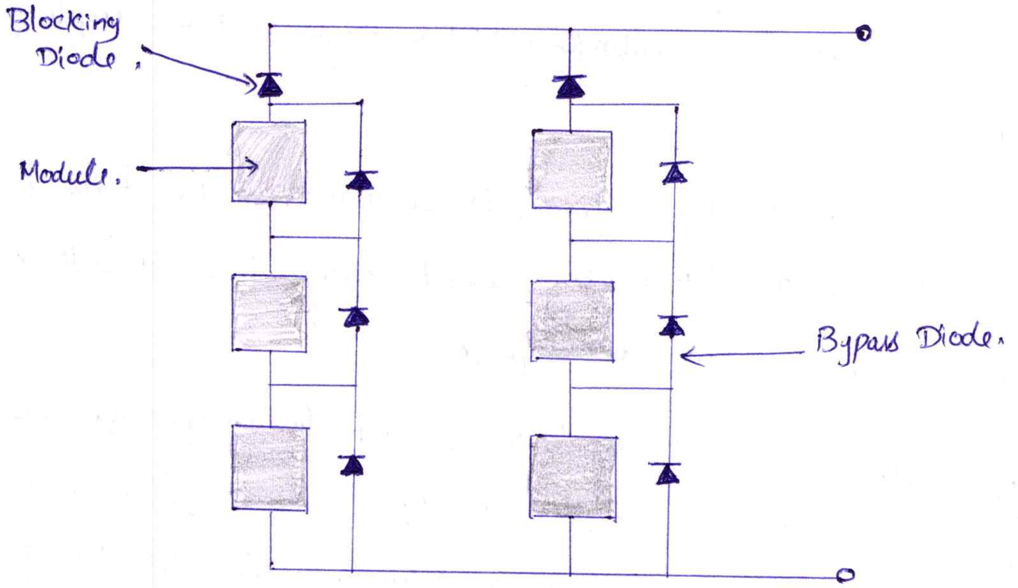


A Solar PV Panel of four modules.
Each moduel has 36 Solar cells.

→ In the panel, bypass diodes are installed across each module so that any defective module can be bypassed by the output of remaining modules.

→ The ~~bypass (or)~~ blocking diodes are connected in series with each series string of modules, which enable the output of remaining series strings should not be absorbed by the failed string.

A typical panel with the series and the parallel connections is shown in fig.



Solar PV array : A pv array consists of a number of solar panels which are installed in an array field.

→ The solar panels may be installed as stationary facing the sun or installed with some tracking mechanism.

Different types of PV Technologies: (or)

→ Materials used for Solar cells :- (or)

Different types of Solar cells :-

The solar cells depending on the type of material used can be classified as single crystal silicon cell, poly crystalline, Thin film such as amorphous silicon cell, cadmium sulphide - cadmium Telluride cell, copper indium diselenide cell and gallium arsenide cell.

I) Single crystal Silicon cell Technologies:

→ It is a silicon material, in which crystal lattice of the Entire sample is continuous and unbroken to the edges of the sample, with no grain

→ The single crystal p-type silicon is obtained in the form of a long cylindrical block. The block is sawed using diamond cutter to obtain a no. of silicon slices or wafers.

→ The p-type silicon wafers are then Exposed to phosphorous vapour in a furnace so that phosphorous can diffuse into silicon wafer for a short depth, thereby forming n-silicon region over the p-silicon bulk material.

→ The efficiency of single crystal silicon is about 22%.

Advantages:

i) Well established and Tested Technology

ii) Stable

iii) Relatively efficient

Disadvantages:

i) Uses a lot of expensive material

ii) Lots of waste in slicing wafers.

iii) costly to manufacture.

(2) Poly crystalline silicon cell Technology :

→ It is made up by poly crystalline having small crystals.

→ The poly crystalline silicon is directly melted, doped with phosphorous and manufactured in desired shape and size.

→ This helps in economy of materials and energy consumption for the production of cells.

Advantages :

i) well established and Tested Technology
ii) stable
iii) Relatively efficient
iv) Less expensive than single crystal silicon.
v) Square cells for more efficient spacing.

Dis advantages :

i) Uses a lot of expensive material
ii) lots of waste in slicing wafers
iii) fairly cost to manufacture.
iv) Slightly less efficient than single crystal Si.

(3) Thin film PV Technology :-

→ Thin film solar cells are made by depositing one or more thin layers or films of photovoltaic material onto a substrate such as glass, plastic or metal.

→ It uses less silicon to develop the cell allowing for the cheaper production costs.

→ Thin film solar cells are typically a few nanometers to a few microns. thick - much thinner than the wafers used in conventional crystalline silicon based solar cells.

→ Thin film solar cells are commercially used in several technologies including Amprphus silicon, cadmium sulphide - cadmium Telluride cells, copper indium diselenide, Gallium arsenide.

(i) Amorphous silicon (a-si) :

→ Amorphous silicon solar cells are the most well developed thin-film solar cell.

→ The structure usually has the p-i-n (or n-i-p) type of duality, where p-layer and n-layer are mainly used for establishing an internal electric field (i-layer) comprising amorphous silicon.

→ It is an alloy of silicon & carbon.

Advantages :

i) very low material use

ii) potential for highly automated and very rapid production.

iii) potential for very low cost

Dis advantages :

i) low efficiency (4 to 8%)

ii) pronounced degradation in power output.

(ii) Cadmium sulphide - Cadmium Telluride Cells : (Cd-S)-(Cd-Te) :

→ These cells are also produced using thin film Technology.

In this film technology, The Semiconductor (Cadmium Telluride) is vapourised and its film is deposited on a thin layer of cadmium sulphide.

→ A barrier layer of copper sulphide is then deposited on top of the cdS - cd Te cell.

→ The Cell consists of n-type cd S and p-type Cd Te.

→ The cells require very less material.

→ The Cell has efficiency of 10%.

(III) Copper Indium diselenide :-

→ It is a thin film poly crystalline cell made from copper indium deselinide.

→ It has an efficiency of about 14%.

→ Its properties remains stable.

→ It has an easier manufacturing process.

(iv) Gallium arsenide:

→ The cell has thin film of n-type and p-type gallium arsenide (Ga As) grown on a suitable substrate.

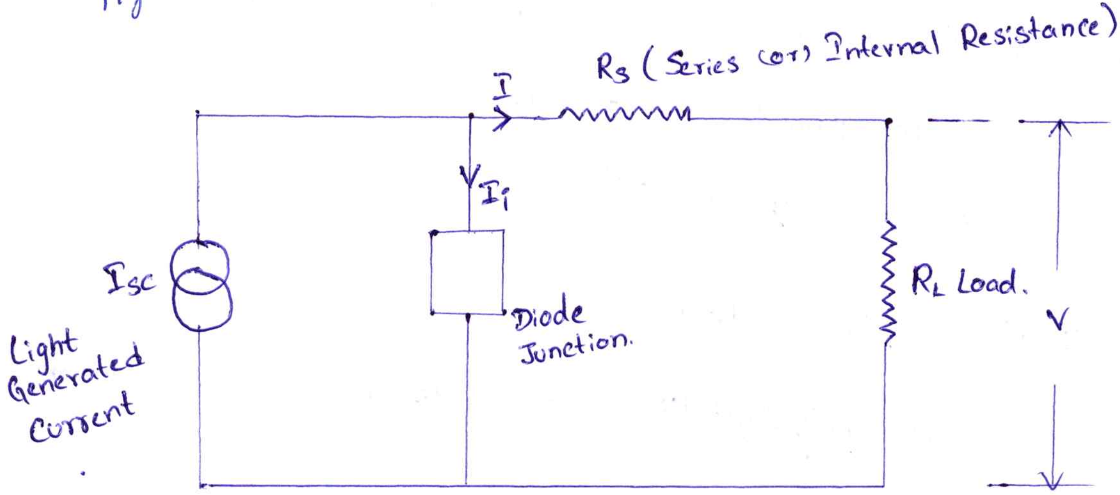
→ The efficiency of cell is about 20%, but it has high cost of production.

→ The cell has high performance in Extra-terrestrial applications.

→ Electrical characteristics of silicon PV cells (or).

Current- voltage characteristics of p-n Junction (or solar cell):-

The simplified equivalent circuit for solar cell is shown in fig.



→ A solar cell usually uses a p-n Junction and its current Voltage relationship is given by

$$I_i = I_o \left[\exp\left(\frac{Ve}{KT}\right) - 1 \right] \quad \text{--- (1)}$$

where I_o is saturation current also called dark current

V is Voltage across Junction

e is Electronic charge

K is Boltzman constant

T is absolute Temperature.

→ when light falls on the Junction, electron hole pairs are created at a constant rate providing an electrical current flow across the Junction.

The net current is the difference between the normal diode current and light generated current.

$$I = I_{SC} - I_i \quad \text{—— (2)}$$

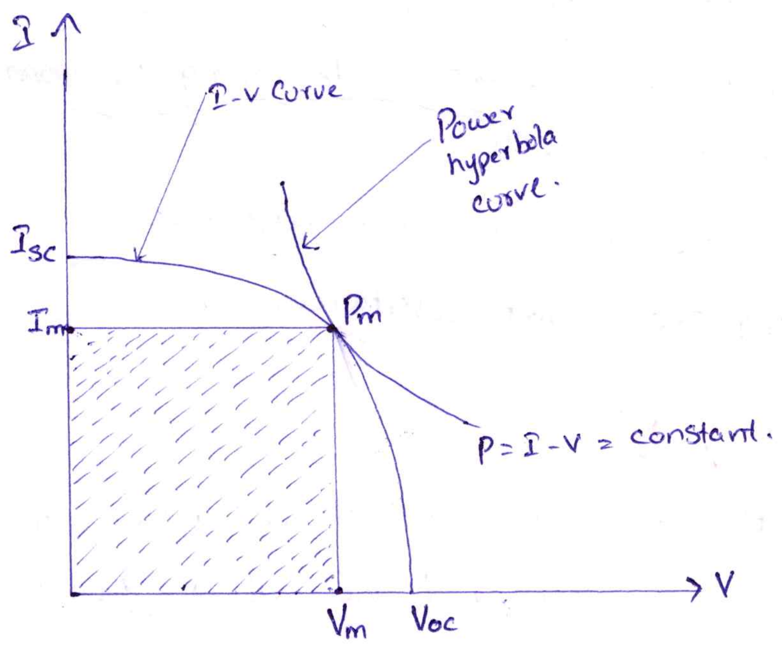
$$= I_{SC} - I_0 \left[\text{Exp}\left(\frac{Ve}{KT}\right) - 1 \right] \quad \text{—— (3)}$$

for Ideal cell, internal resistance $R_s = 0$, is assumed.
The corresponding I-V plot is shown in fig.
The open circuit voltage V_{oc} for the ideal cell is then given by

$$V_{oc} = \left(\frac{KT}{e}\right) \ln\left(\frac{I_{SC}}{I_0} + 1\right) \quad \text{—— (4)}$$

since, $I_{SC} >> I_0$, the Term 1 in the eq (4) can be neglected.
Then open circuit voltage is

$$V_{oc} = \frac{KT}{e} \ln \frac{I_{SC}}{I_0} \quad \text{—— (5)}$$



Current-Voltage characteristics of Solar Cell & maximum power point (P_m).

↳ maximum power :

The maximum power that can be derived from the device is given by

$$P_{max} = V_{mp} I_{mp}. \quad \text{———} \quad (6)$$

where V_{mp} and I_{mp} are the voltage and current at maximum power point as shown in fig(2).

↳ Fill factor (FF) :

→ fill factor (FF) of a solar cell is defined as the ratio of maximum power to the product of V_{oc} and I_{sc}.

→ FF indicates the quality of solar cell, that is how much power or area of the characteristic curve is being used.

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \quad \text{———} \quad (7)$$

The typical value of FF is in the range of 0.5 to 0.83.

The fill factor can be improved by the following ways :

(i) Increasing the photo current & decreasing the reverse saturation current of a solar cell.

(ii) minimizing the internal series resistance

(iii) maximizing the shunt resistance.

↳ Solar Efficiency (η) :-

It is the ratio of maximum solar cell power output $V_{mp} \times I_{mp}$ to the total solar Energy supplied to the cell. (or) total power density of sunlight.

$$\eta = \frac{V_{mp} \times I_{mp}}{P_{sun}} \quad \text{———} \quad (8)$$

we have, $FF = \frac{V_{mp}\ I_{mp}}{V_{oc}\ I_{sc}}$

$$V_{mp}\ I_{mp} = FF \times V_{oc}\ I_{sc}$$

$\therefore$ Efficiency can also be given by,

$$\eta = \frac{FF \times V_{oc} \times I_{sc}}{P_{sun}} \quad \text{——— (9)}$$

→ **Energy losses of solar cell: (or)**

Various factors that affects the performance of solar cell :-

The highest conversion efficiency of a solar cell is about 24 %.
There are many factors which lead to energy losses and limit the efficiency of solar cell. The factors are as follows:

1) Reflection losses : some of the incident radiation is lost due to reflection from the cell surface.

2) In complete absorption :
The Energy of photon related to its wavelength (λ) ~~is~~ given by,

$$E = \frac{h \times c}{\lambda}$$

where h = planc's constant
$= 3 \times 10^{-27}$ ergs.

c = velocity of light
$= 3 \times 10^{8}$ m/s.

$$\therefore E = \frac{1.24}{\lambda}.$$

The solar cell shoulb be ~~able~~ to made of a material, which can absorb the energy associated with the photons of solar radiation.

→ Photons having Energy (E) larger than band gap energy (1.1ev for si) will be absorbed in the cell materials.

→ photons having lower energy, are wasted in generation of Thermal energy. ~~The~~
The higher is the band gap of a material, the greater is the wastage.

3) Partial utilisation of photon Energy: Many photons in solar radiation generate Electron and hole pairs, which have more energy than that is needed for proper functioning of p-n Junction, That is making current flow through External circuit.
The excess energy is dissipated as heat.

4) Collection losses: The Electron hole pair carriers formed due to solar radiation must be collected so as to contribute to output current, instead of recombining to generate heat.
The collection efficiency is the ratio of actual short circuit current density to the short circuit current density at no recombination.

5) open circuit voltage: The open circuit voltage V_{oc} is always less than band gap energy, which lowers the potential difference at p-n Junction.

6) Curve factor: The maximum power output is always less than product of V_{oc} & I_{sc}. The characteristic curve does not have a rectangular shape.
→ Hence the area of characteristic curve is always less than product of V_{oc} & I_{sc}.

7) Series resistance losses : The voltage and current characteristic curves are flattened due to power loss resulting from series resistance.

→ The output power decreases as the area under the characteristic curve reduces.

8) Thickness of cell : Photons of high energy can pass through the cell material without absorption if thickness is inadequate.

→ **Maximising the performance of solar cell :-**

(or)

How can performance of solar cell can be maximised :

→ The performance of solar cell can be increased by taking the following steps :

(1) Maximising Voc and Isc : The efficiency of solar energy conversion depends upon Voc and Isc.

(2) Low series resistance : It will give high fill factor, that is more output power possible as the area of characteristic curve increases.

(3) High shunt resistance : shunt resistance can be increased by preventing any leakage occuring at the perimeter of the cell.

(4). optimum solar cell size : As the area of solar cell increases, the performance of cell reduces, due to difficult maintainance of homogenity of the material.

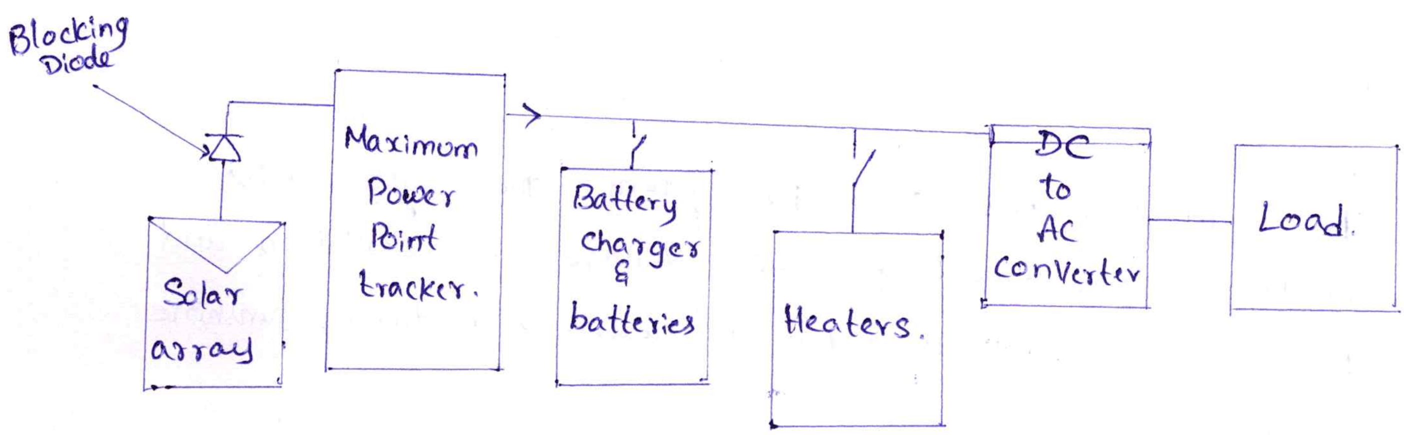
→ Stand alone PV system :- (or) PV systems for remote power :-

→ Solar PV power station is planned and located at load centre.

→ Its completely Electricity generation is meant to meet the electrical load of any remote area, village or installation.

→ Energy storage is essential to meet the requirement during non sunshine hours.

→ A typical stand alone solar PV system is shown in fig.



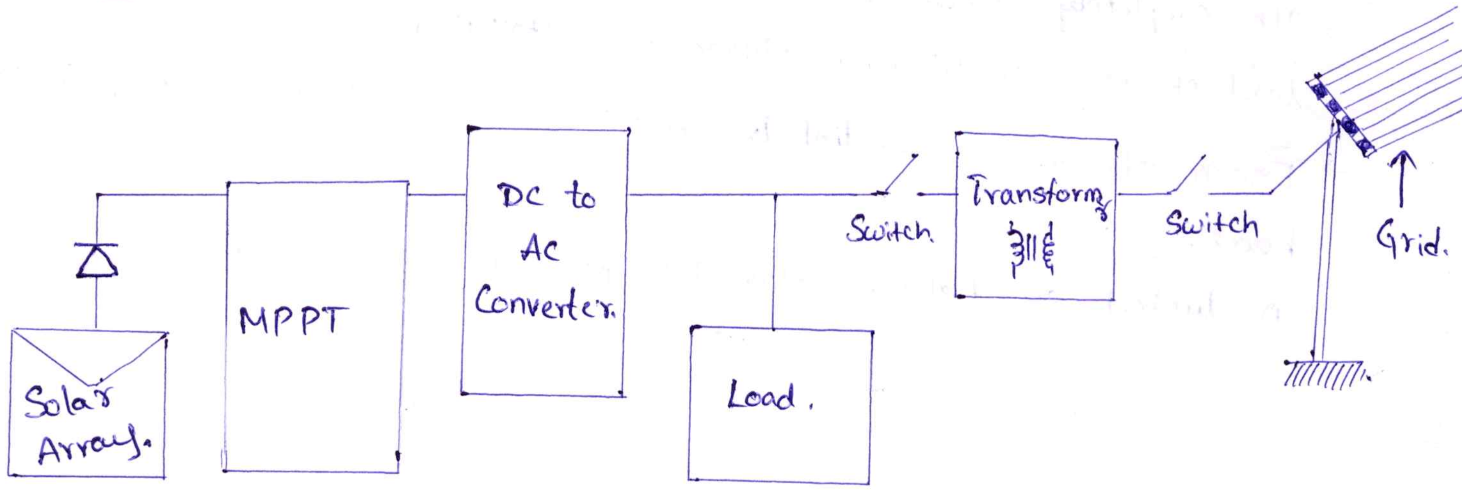
→ The Maximum Power point Tracker (MPPT) senses the voltage and current outputs from the solar array and then suitably adjusts the operating point to obtain maximum power output from the solar array as possible from the climatic conditions.

→ The solar electric output in direct current is converted into alternating current and it is fed into the load.

→ The excess power is preferably stored by charging battery and otherwise excess is dumped in the electric heaters.

→ when the sun radiation is unavailable, the batteries supply the electricity through the converter.

→ **Grid connected PV Systems :-**



Grid Interactive Solar PV System.

In grid connected solar PV system, the system first meets the requirement of house, village or installation and then all excess power is fed to an electric grid during sunshine hours.

Electric Energy is either sold or bought from local Electric utility depending on the local Energy load patterns and solar resource variation during the day.

This operation mode requires an inverter to convert DC currents to AC currents.

This grid connected PV system arrangement helps in preventing any dumping of electricity as required in the stand alone solar PV systems.

→ ~~The solar~~ Another advantage with this system is that during the absence of insufficient sunshine, the supply of electricity is maintained from the electric grid, thereby eliminating any need of battery.

Advantages of grid connected PV systems :

1) Smaller PV arrays can supply the same load reliably.
less balance of system components are needed.

2) Eliminates the need for energy storage and the costs associated to substituting and recycling batteries for individual clients.

3) Efficient use of available energy.

→ Advantages and Disadvantages of PV system :-

Advantages :

1) It directly converts solar energy to electric power without any use of moving parts.
2) It is more reliable, durable and maintenance free
3) It works without any noise
4) It is non polluting
5) It has long lifespan
6) It can be located near the load point and requires no distribution system.

Disadvantages :

1) It has high cost of installation
2) It has low efficiency
3) It requires a large area for installation to produce sufficient power.
4) Its output is intermittent, thereby requiring some means to store energy to use during non sunshine hours.

→ Applications of PV system :-

1) Solar street lighting system
2) Home lighting system
3) water pumping system
4) Solar Vehicles
5) Railway signalling equipment
6) Battery charging
7) Radio beacons for ship navigation at ports
8) Weather monitoring etc.