UNIT-IV

Solar photovoltaic

Technologies

Pure silicon is derived from such silicon dioxides as quartzite gravel (the purest silica) or crushed quartz. The resulting pure silicon is then doped (treated with) with phosphorous and boron to produce an excess of electrons and a deficiency of electrons respectively to make a semiconductor capable of conducting electricity. The silicon disks are shiny and require an anti-reflective coating, usually titanium dioxide.

The basic component of a solar cell is pure silicon, which is not pure in its natural state.The solar module consists of the silicon semiconductor surrounded by protective material in a metal frame. The protective material consists of an encapsulant of transparent silicon rubber or butyryl plastic (commonly used in automobile windshields) bonded around the cells, which are then embedded in ethylene vinyl acetate. A polyester film (such as mylar or tedlar) makes up the backing. A glass cover is found on terrestrial arrays, a lightweight plastic cover on satellite arrays. The electronic parts are standard and consist mostly of copper. The frame is either steel or aluminum. Silicon is used as the cement to put it all together.

The Manufacturing Process

Purifying the silicon

- The silicon dioxide of either quartzite gravel or crushed quartz is placed into an electric arc furnace. A carbon arc is then applied to release the oxygen. The products are carbon dioxide and molten silicon. This simple process yields silicon with one percent impurity, useful in many industries but not the solar cell industry.
- The 99 percent pure silicon is purified even further using the floating zone technique. A rod of impure silicon is passed through a heated zone several times in the same direction. This procedure "drags" the impurities toward one end with each pass. At a specific point, the silicon is deemed pure, and the impure end is removed.

Making single crystal silicon

- Solar cells are made from silicon boules, polycrystalline structures that have the atomic structure of a single crystal. The most commonly used process for creating the boule is called the *Czochralski method.* In this process, a seed crystal of silicon is dipped into melted polycrystalline silicon. As the seed crystal is withdrawn and rotated, a cylindrical ingot or "boule" of silicon is formed. The ingot withdrawn is unusually pure, because impurities tend to remain in the liquid.

Making silicon wafers

- From the boule, silicon wafers are sliced one at a time using a circular saw whose inner diameter cuts into the rod, or many at once with a multiwire saw. (A diamond saw produces cuts that are as wide as the wafer—. 5 millimeter thick.) Only about one-half of the silicon is lost from the boule to the finished circular wafer—more if the wafer is then cut to be rectangular or hexagonal. Rectangular or hexagonal wafers are sometimes used in solar cells because they can be fitted together perfectly, thereby utilizing all available space on the front surface of the solar cell.
- The wafers are then polished to remove saw marks. (It has recently been found that rougher cells absorb light more effectively, therefore some manufacturers have chosen not to polish the wafer.)

Doping

- The traditional way of doping (adding impurities to) silicon wafers with boron and phosphorous is to introduce a small amount of boron during the Czochralski process in step #3 above. The wafers are then sealed back to back and placed in a furnace to be heated to slightly below the melting point of silicon (2,570 degrees Fahrenheit or 1,410 degrees Celsius) in the presence of phosphorous gas. The phosphorous atoms "burrow" into the silicon, which is more porous because it is close to becoming a liquid. The temperature and time given to the process is carefully controlled to ensure a uniform junction of proper depth.

  A more recent way of doping silicon with phosphorous is to use a small particle accelerator to shoot phosphorous ions into the ingot. By controlling the speed of the ions, it is possible to control their penetrating depth. This new process, however, has generally not been accepted by commercial manufacturers.

Placing electrical contacts

- Electrical contacts connect each solar cell to another and to the receiver of produced current. The contacts must be very thin (at least in the front) so as not to block sunlight to the cell. Metals such as palladium/silver, nickel, or copper are vacuum-evaporated through a photoresist, silkscreened, or merely deposited on the exposed portion of cells that have been partially covered with wax. All three methods involve a system in which the part of the cell on which a contact is not desired is protected, while the rest of the cell is exposed to the metal.

- After the contacts are in place, thin strips ("fingers") are placed between cells. The most commonly used strips are tin-coated copper.

The anti-reflective coating

- Because pure silicon is shiny, it can reflect up to 35 percent of the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is put on the silicon wafer. The most commonly used coatings are titanium dioxide and silicon oxide, though others are used. The material used for coating is either heated until its molecules boil off and travel to the silicon and condense, or the material undergoes sputtering. In this process, a high voltage knocks molecules off the material and deposits them onto the silicon at the opposite electrode. Yet another method is to allow the silicon itself to react with oxygen- or nitrogen-containing gases to form silicon dioxide or silicon nitride. Commercial solar cell manufacturers use silicon nitride.

Encapsulating the cell

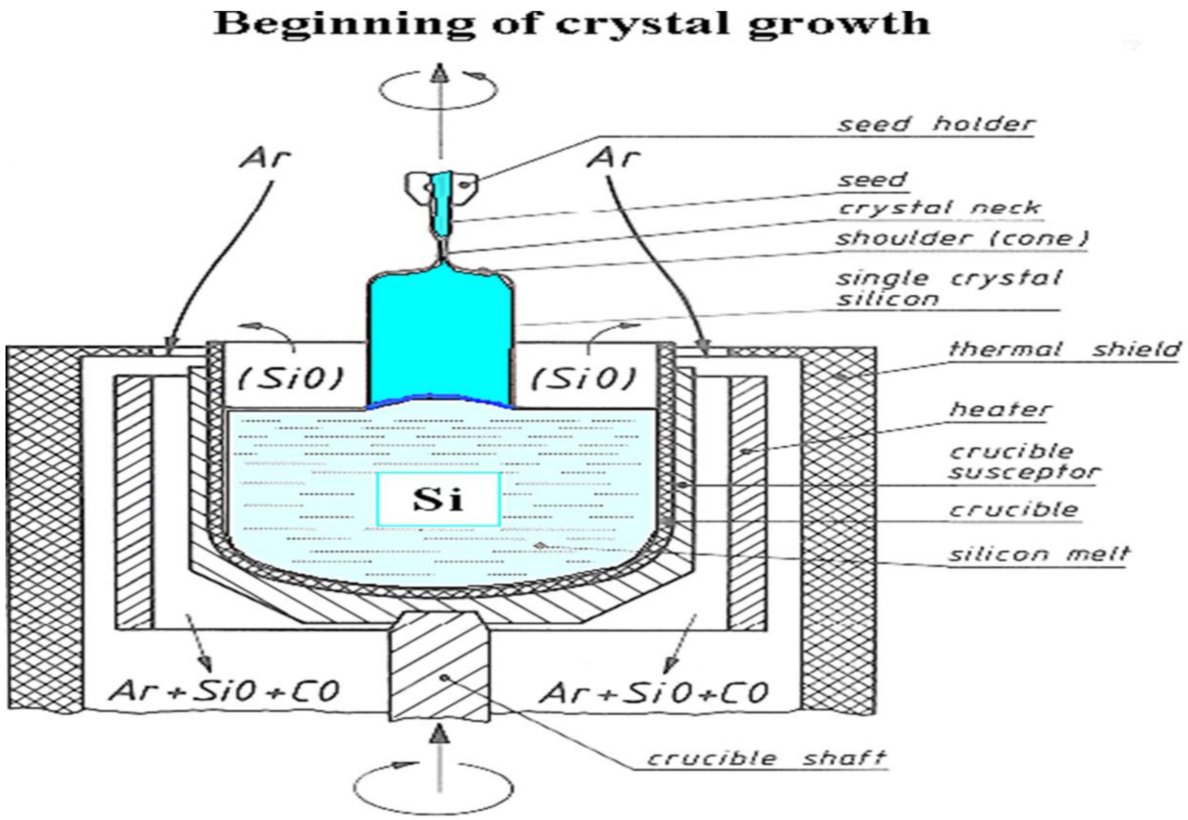
- The finished solar cells are then encapsulated; that is, sealed into silicon rubber or ethylene vinyl acetate. The encapsulated solar cells are then placed into an aluminium frame that has a mylar or tedlar backsheet and a glass or plastic cover.

Crystal Growth Techniques

- Bridgmann method
- Czochralski method
- Vernuil method
- Zone melting method
- Kyropoulos technique.
- Skull melting.

Czochralski method

- The Czochralski method or Czochralski process, is a method of crystal growth used to obtain single crystals of semiconductors (e.g. silicon, germanium and gallium arsenide), metals (e.g. palladium, platinum, silver, gold), salts and synthetic gemstones.
- It is also known as Pulling Technique
- This method is widely used for growing semi conducting material crystal. The shape of the crystal is free from the constraint due to the shape of the crucible.
- In this method the charge is melted and maintained at a temperature slightly above the melting point. The pulling rod is lowered to just touch the melt. Since the rod is at lower temperature of melt occurs at the point tip of the pulling rod. The crystal is pulled slowly.
- The rate of pulling upon various factors like thermal conductivity, latent heat of fusion of charge and rate of cooling of the pulling rod. The seed is rotated to keep the grow crystal uniform and cylindrical.
- A seed crystal is attached to a rod, which is rotated slowly.
- The seed crystal is dipped into a melt held at a temperature slightly above the melting point.
- A temperature gradient is set up by cooling the rod and slowly withdrawing it from the melt (the surrounding atmosphere is cooler than the melt)
- Decreasing the speed with which the crystal is pulled from the melt, increases the quality of the crystals (fewer defects) but decreases the growth rate.



APPLICATION

- The most important application of the Czochralski Process may be the growth of large cylindrical ingots, or boules, of single crystal silicon used in the electronics industry to make semiconductor devices like integrated circuits. Other semiconductors, such as gallium arsenide can also be grown by this method.
- Monocrystalline silicon (mono-Si) grown by the *Czochralski method is often referred to as monocrystalline Czochralski silicon (Cz-Si).It is the basic material in the* production of integrated circuits used in computers, TVs, mobile phones and all types of electronic equipment and semiconductor devices. Monocrystalline silicon is also used in large quantities by the photovoltaic industry for the production of conventional mono- Si solar cells. The almost perfect crystal structure yields the highest light-to-electricity conversion efficiency for silicon.

Advantages

- This method is used to grow large single crystals. Thus it is used extensively in the semiconductor industry.
- There is no direct contact between the crucible walls and the crystal which helps to produce unstressed single crystal.

Disadvantages

- In general this method is not suitable for incongruently melting compounds and of course the need for a seed crystal of the same composition limits is used as tool for exploratory synthetic research.

Types of PV Cells

- Photovoltaic cells or PV cells can be manufactured in many different ways and from a variety of different materials.
- Despite this difference, they all perform the same task of harvesting solar energy and converting it to useful electricity.
- The most common material for commercial solar cell construction is Silicon (Si), but others include Gallium Arsenide (GaAs), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS).
- Solar cells can be constructed from brittle crystalline structures (Si, GaAs) or as flexible thin-film cells (Si, CdTe, CIGS).
- There are three types of PV cell technologies that dominate the world Crystalline silicon : monocrystalline silicon, polycrystalline silicon, and thin film.
- As the names suggest, monocrystalline PV cells are comprised of a uniform or single crystal lattice, whereas polycrystalline cells contain different or varied crystal structures.
- Higher efficiency PV technologies, including gallium arsenide and multi-junction cells, are less common due to their high cost, but are ideal for use in concentrated photovoltaic systems and space applications.
- Solar cells can also be classified by their number of layers or "p-n junctions".
- Most commercial PV cells are only single-junction, but multi-junction PV cells have also been developed which provide higher efficiencies at a greater cost
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Monocrystalline Silicon Cell

- The first commercially available solar cells were made from monocrystalline silicon, which is an extremely pure form of silicon.
- To produce these, a seed crystal is pulled out of a mass of molten silicon creating a cylindrical ingot with a single, continuous, crystal lattice structure.

- This crystal is then mechanically sawn into thin wafers, polished and doped to create the required p-n junction.
- Monocrystalline silicon, more often called single-crystal silicon, in short mono c-Si or mono-Si, is the base material for silicon-based discrete components and integrated circuits used in virtually all modern electronic equipment.
- Mono-Si also serves as a photovoltaic, light-absorbing material in the manufacture of solar cells.
- Mono-Si can be prepared as an intrinsic semiconductor that consists only of exceedingly pure silicon, or it can be doped by the addition of other elements such as boron or phosphorus to make p-type or n-type silicon.
- After an anti-reflective coating and the front and rear metal contacts are added, the cell is finally wired and packaged alongside many other cells into a full solar panel.
- Monocrystalline silicon cells are highly efficient, but their manufacturing process is slow and labour intensive, making them more expensive than their polycrystalline or thin film counterparts.
- Monocrystalline is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity.
- Due to its semiconducting properties, single-crystal silicon is perhaps the most important technological material of the last few decades—the "silicon era", because its availability at an affordable cost has been essential for the development of the electronic devices on which the present-day electronics and IT revolution is based.
- Monocrystalline silicon differs from other allotropic forms, such as non-crystalline amorphous silicon—used in thin-film solar cells—and polycrystalline silicon, which consists of small crystals known as crystallites.

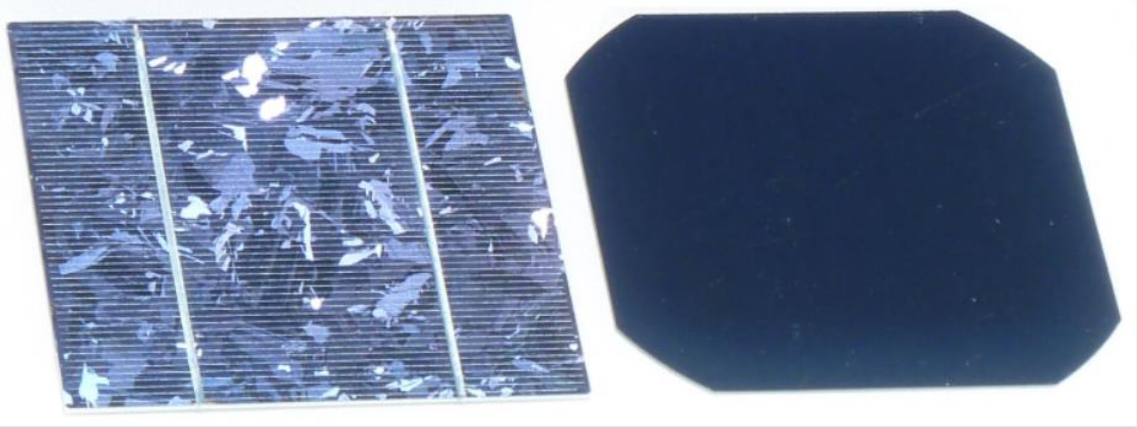


Figure 2. An image comparing a polycrystalline silicon cell (left) and a monocrystalline silicon cell (right).

AMORPHOUS

- Amorphous silicon (a-Si) is the non-crystalline form of silicon used for solar cells and thin-film transistors in LCDs.
- Used as semiconductor material for a-Si solar cells, or thin-film silicon solar cells, it is deposited in thin films onto a variety of flexible substrates, such as glass, metal and plastic.
- Amorphous silicon cells generally feature low efficiency, but are one of the most environmentally friendly photovoltaic technologies, since they do not use any toxic heavy metals such as cadmium or lead.
- Amorphous silicon (a-Si) which is produced by depositing thin layers of silicon on to a glass substrate.
- The result is a very thin and flexible cell which uses less than 1% of the silicon needed for a crystalline cell.
- Due to this reduction in raw material and a less energy intensive manufacturing process, amorphous silicon cells are much cheaper to produce.
- Their efficiency, however, is greatly reduced because the silicon atoms are much less ordered than in their crystalline forms leaving 'dangling bonds' that combine with other elements making them electrically inactive.

Amorphous Silicon Cells

- These cells also suffer from a 20% drop in efficiency within the first few months of operation before stabilizing, and are therefore sold with power ratings based on their degraded output.
- The efficiency of amorphous silicon solar cells has a theoretical limit of about 15% and realized efficiencies are now up around 6 or 7%.
- If efficiencies of 10% can be reached on large area thin film amorphous silicon cells on inexpensive substrates, then this would be the best approach to produce low cost electricity.

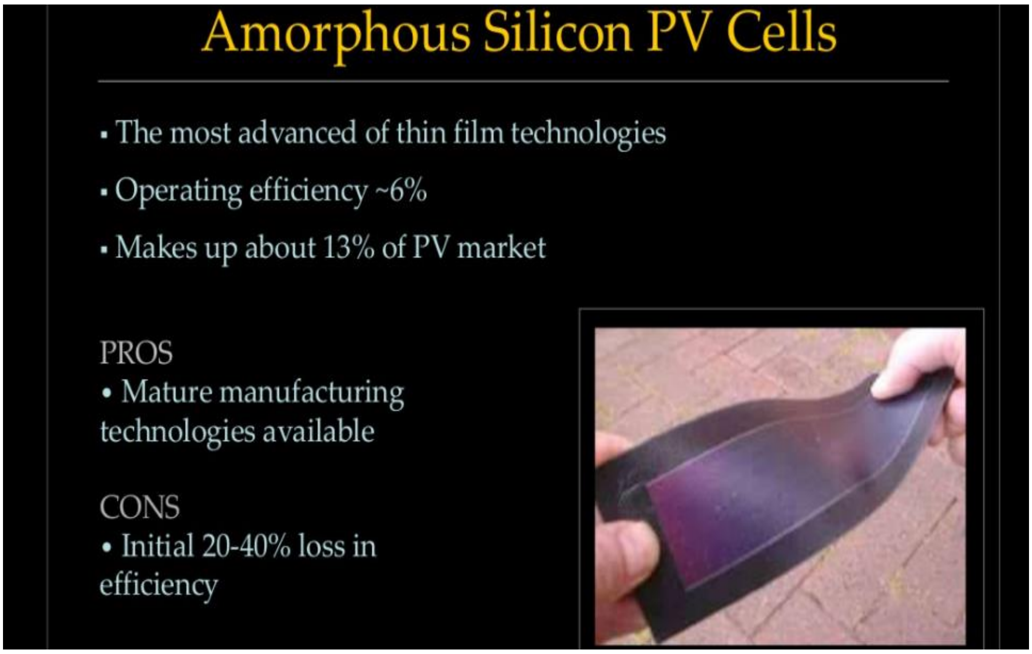
Amorphous silicon PV panels

- Amorphous silicon cells are made by depositing silicon in a thin homogenous layer onto a substrate rather than creating a rigid crystal structure.

- As amorphous silicon absorbs light more effectively than crystalline silicon, the cells can be thinner - hence its alternative name of 'thin film' PV.
- Amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible, which makes it ideal for curved surfaces or bonding directly onto roofing materials.
- This technology is, however, less efficient than crystalline silicon, with typical efficiencies of around 6%, but it tends to be easier and cheaper to produce.

Advantages of Amorphous silicon

- Thin-film PV have efficiency of ~6% versus ~15% for single crystal Si cells. One way to improve the cell efficiency is to create a layered structure of several cells.
- The main advantage of the thin-film PV technology is that the amorphous silicon can be deposited on a variety of substrates, which can be made flexible and come in different shapes and therefore can be used in many applications.
- The amorphous silicon is also less prone to overheating, which usually decreases the solar cell performance.
- Amorphous silicon is most developed among the thin-film PV.



Amorphous Silicon PV Cells

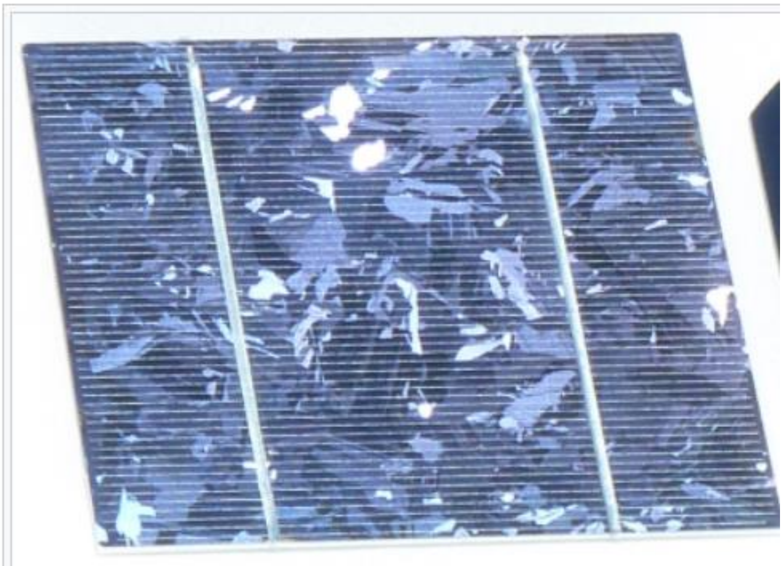
- The most advanced of thin film technologies
- Operating efficiency ~6%
- Makes up about 13% of PV market

PROS
- Mature manufacturing technologies available

CONS
- Initial 20-40% loss in efficiency

- **Polycrystalline silicon cell**

  Instead of a single uniform crystal structure, polycrystalline (or multicrystalline) cells contain many small grains of crystals shown in figure .

- 

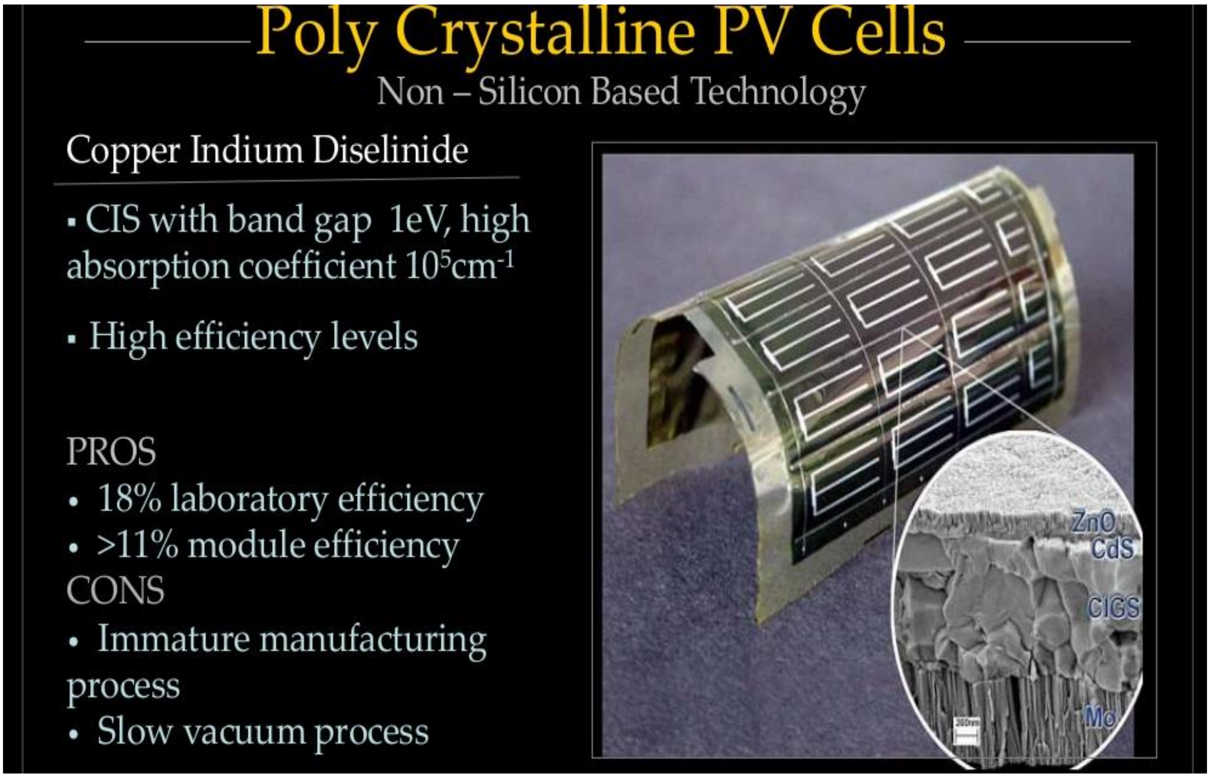
- Polycrystalline solar is made by pouring molten silicon into a cast.
- However, because of this construction method, the crystal structure will form imperfectly, creating boundaries where the crystal formation breaks.
- This gives the polycrystalline silicon its distinctive, grainy appearance, as the gemstone type pattern highlights the boundaries in the crystal.

- These impurities in the crystal makes polycrystalline modules less efficient and also cheaper than monocrystalline.
- 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%
- A cheaper but less efficient alternative, polycrystalline silicon PV cells dominate the world market, representing about 70% of global PV production in 2015.

Poly crystalline PV cells(Non-silicon based Technology)

- A number of other materials such as cadmium telluride (CdTe) and copper indium diselenide (CIS) are now being used for PV modules.

- The attraction of these technologies is that they can be manufactured by relatively inexpensive industrial processes, certainly in comparison to crystalline silicon technologies, yet they typically offer higher module efficiencies than amorphous silicon.
- Most offer a slightly lower efficiency: CIS is typically 10-13% efficient and CdTe around 8 or 9%.
- A disadvantage is the use of highly toxic metals such as Cadmium and the need for both carefully controlled manufacturing and end-of-life disposal; although a typical CdTe module contains only 0.1% Cadmium, which is reported to be lower than is found in a single AA-sized NiCad battery



Poly Crystalline PV Cells

Non – Silicon Based Technology

Copper Indium Diselinide

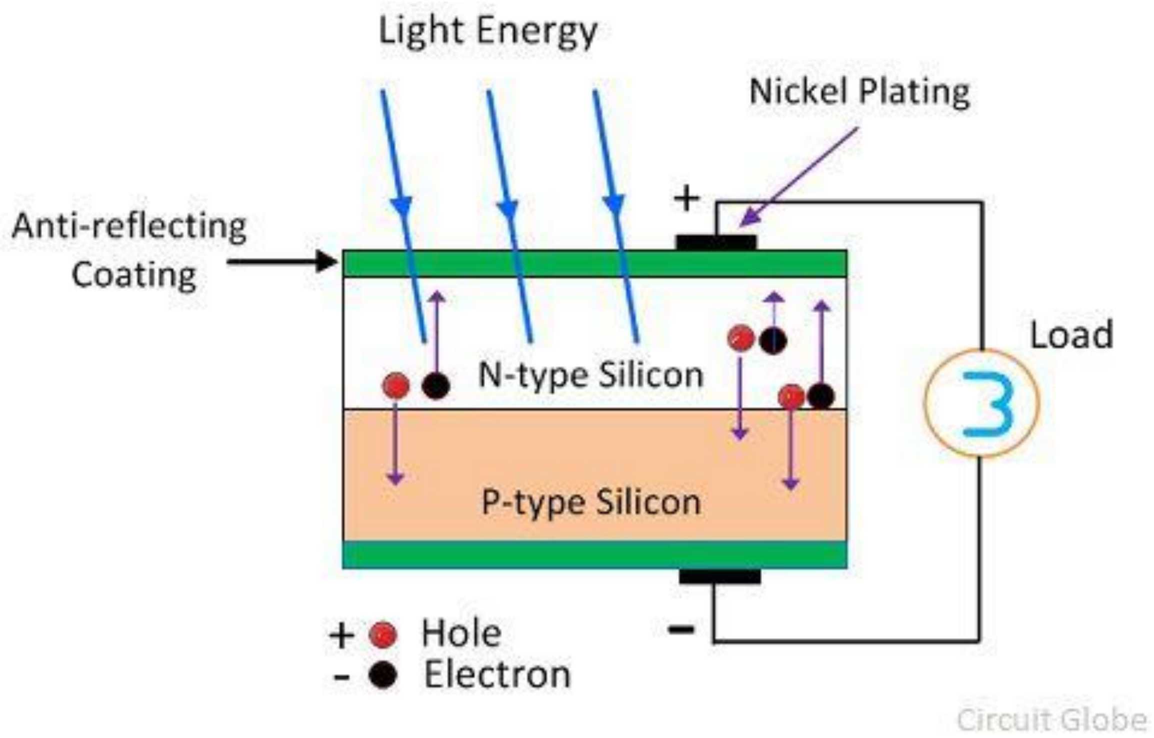
- CIS with band gap 1eV, high absorption coefficient $10^5 cm^{-1}$
- High efficiency levels

PROS
- 18% laboratory efficiency
- >11% module efficiency

CONS
- Immature manufacturing process
- Slow vacuum process

CONSTRUCTION OF PHOTOVOLTAIC CELL

The semiconductor materials like arsenide, indium, cadmium, silicon, selenium and gallium are used for making the PV cells. Mostly silicon and selenium are used for making the cell. Consider the figure below shows the constructions of the silicon photovoltaic cell. The upper surface of the cell is made of the thin layer of the p-type material so that the light can easily enter into the material. The metal rings are placed around p-type and n-type material which acts as their positive and negative output terminals respectively.



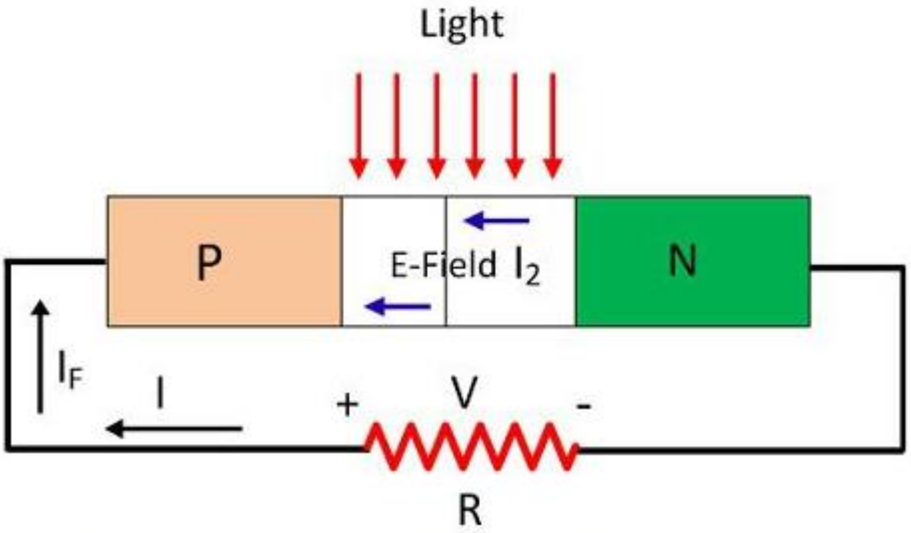
The output voltage and current obtained from the single unit of the cell is very less. **The magnitude of the output voltage is 0.6v, and that of the current is 28-35 mA.** The different combinations of cells are used for increasing the output efficiency. There are three possible ways of combining the PV cells.

WORKING OF PV CELL

The light incident on the semiconductor material may be pass or reflected through it. The PV cell is made of the semiconductor material which is neither a complete conductor nor an insulator. This property of semiconductor material makes it more efficient for converting the light energy into electric energy.

When the semiconductor material absorbs light, the electrons of the material starts emitting. This happens because the light consists small energise particles called photons. When the electrons absorb the photons, they become energised and starts moving into the material. Because of the effect of an electric field, the particles move only in the one direction and develops current. The semiconductor materials have the metallic electrodes through which the current goes out of it.

Consider the figure below shows the PV cell made of silicon and the resistive load is connected across it. The PV cell consists the P and N-type layer of semiconductor material. These layers are joined together to form the PN junction.



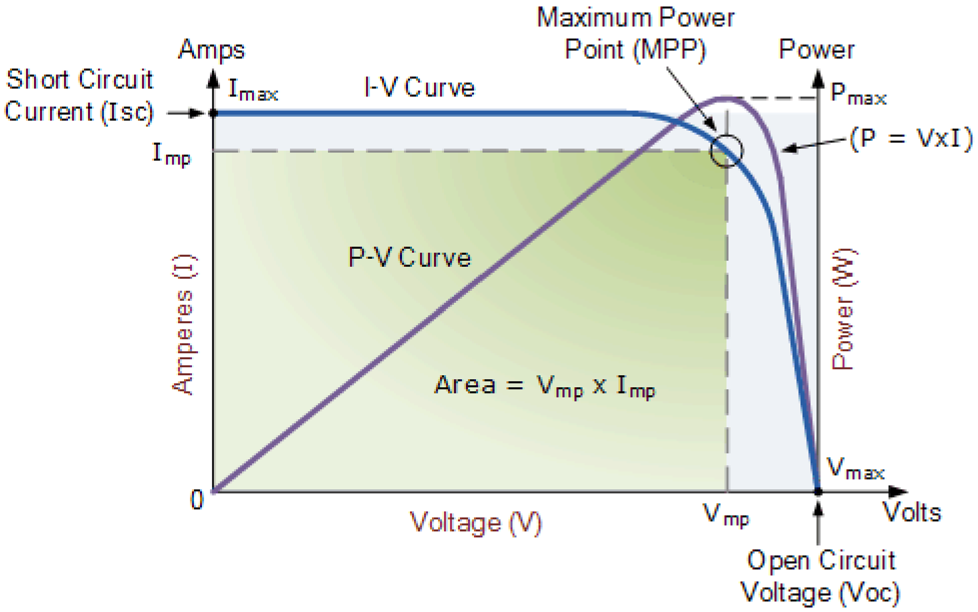
P-N Junction Solar Cell with Resistive Load

Solar Cell I-V Characteristic Curve

The main electrical characteristics of a PV cell or module are summarized in the relationship between the current and voltage produced on a typical solar cell I-V characteristics curve. The intensity of the solar radiation (insolation) that hits the cell controls the current (I), while the increases in the temperature of the solar cell reduces its voltage (V).

Solar cells produce direct current (DC) electricity and current times voltage equals power, so we can create solar cell I-V curves representing the current versus the voltage for a photovoltaic device.

Solar Cell I-V Characteristics Curves are basically a graphical representation of the operation of a solar cell or module summarising the relationship between the current and voltage at the existing conditions of irradiance and temperature. I-V curves provide the information required to configure a solar system so that it can operate as close to its optimal peak power point (MPP) as possible.



The above graph shows the current-voltage (I-V) characteristics of a typical silicon PV cell operating under normal conditions. The power delivered by a solar cell is the product of current and voltage (I x V). If the multiplication is done, point for point, for all voltages from short-circuit to open-circuit conditions, the power curve above is obtained for a given radiation level.

With the solar cell open-circuited, that is not connected to any load, the current will be at its minimum (zero) and the voltage across the cell is at its maximum, known as the solar cells **open circuit voltage**, or Voc. At the other extreme, when the solar cell is short circuited, that is the positive and negative leads connected together, the voltage across the cell is at its minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells **short circuit current**, or Isc.

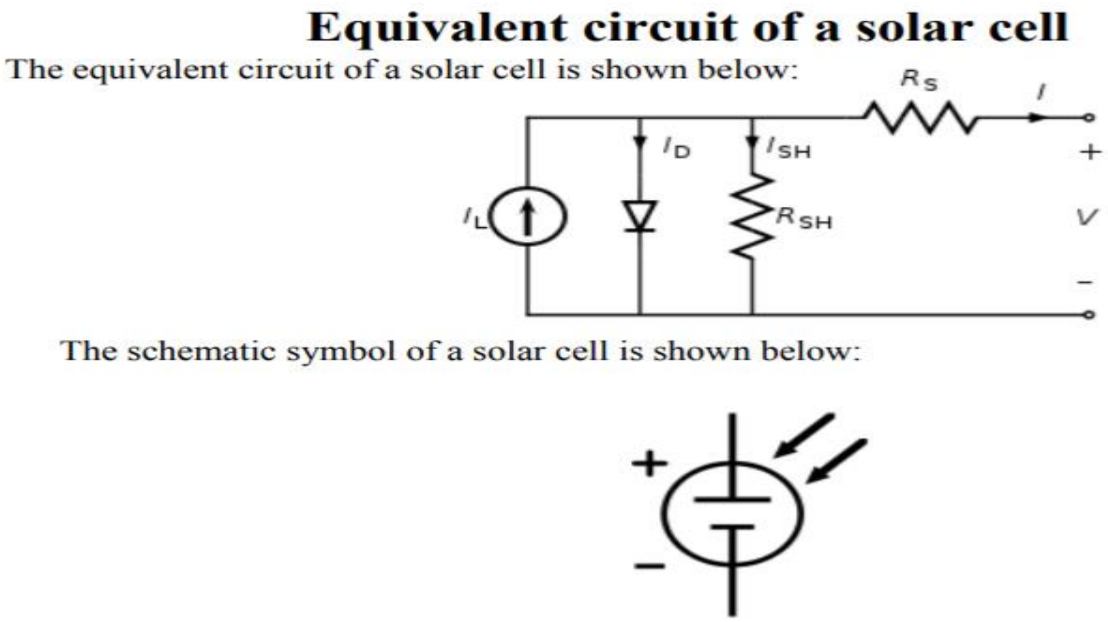
Then the span of the solar cell I-V characteristics curve ranges from the short circuit current (Isc) at zero output volts, to zero current at the full open circuit voltage (Voc). In other words, the maximum voltage available from a cell is at open circuit, and the maximum current at closed circuit. Of course, neither of these two conditions generates any electrical power, but there must be a point somewhere in between were the solar cell generates maximum power.

However, there is one particular combination of current and voltage for which the power reaches its maximum value, at Imp and Vmp. In other words, the point at which the cell generates maximum electrical power and this is shown at the top right area of the green rectangle. This is the “maximum power point” or **MPP**. Therefore the ideal operation of a photovoltaic cell (or panel) is defined to be at the maximum power point.

The maximum power point (MPP) of a solar cell is positioned near the bend in the I-V characteristics curve. The corresponding values of Vmp and Imp can be estimated from the open circuit voltage and the short circuit current: Vmp ≅ (0.8–0.90)Voc and Imp ≅ (0.85–0.95)Isc. Since solar cell output voltage and current both depend on temperature, the actual output power will vary with changes in ambient temperature.

Solar Array Parameters

- **V_{OC}** = open-circuit voltage: – This is the maximum voltage that the array provides when the terminals are not connected to any load (an open circuit condition). This value is much higher than Vmp which relates to the operation of the PV array which is fixed by the load. This value depends upon the number of PV panels connected together in series.
- **I_{SC}** = short-circuit current – The maximum current provided by the PV array when the output connectors are shorted together (a short circuit condition). This value is much higher than Imp which relates to the normal operating circuit current.
- **MPP** = maximum power point – This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where MPP = Imp x Vmp. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp).
- **FF** = fill factor – The fill factor is the relationship between the maximum power that the array can actually provide under normal operating conditions and the product of the open-circuit voltage multiplied by the short-circuit current, (V_{OC} x I_{SC}) This fill factor value gives an idea of the quality of the array and the closer the fill factor is to 1 (unity), the more power the array can provide. Typical values are between 0.7 and 0.8.
- **%eff** = percent efficiency – The efficiency of a photovoltaic array is the ratio between the maximum electrical power that the array can produce compared to the amount of solar irradiance hitting the array. The efficiency of a typical solar array is normally low at around 10-12%, depending on the type of cells (monocrystalline, polycrystalline, amorphous or thin film) being used.



Equivalent circuit of a solar cell

The equivalent circuit of a solar cell is shown below:

The schematic symbol of a solar cell is shown below:

- Electrical equivalent of solar cell is shown in fig.
- An ideal solar cell may be modeled by a current source in parallel with a diode; in practice no solar cell is ideal, so a shunt resistance and a series resistance component are added to the model.
- The schematic representation of a solar cell for use in circuit diagrams is shown in fig.

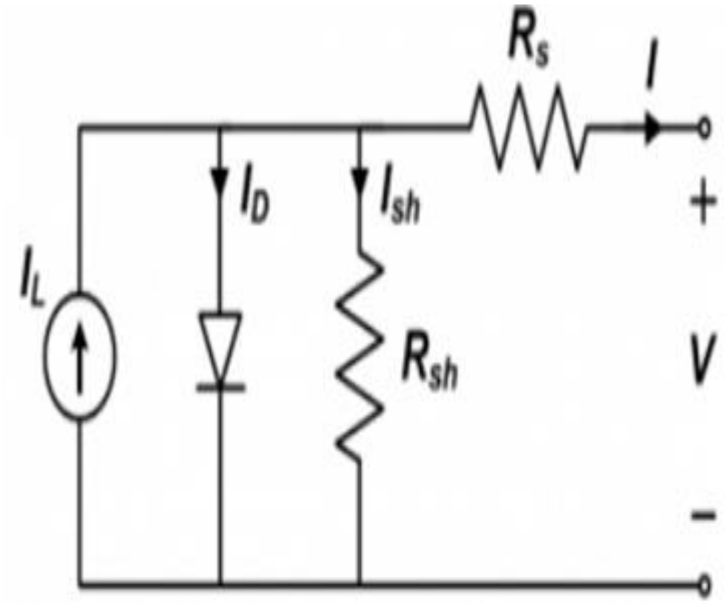
Characteristic equation

- From the equivalent circuit it is evident that the current produced by the solar cell is equal to

$$I = I_L - I_D - I_{SH}$$

where

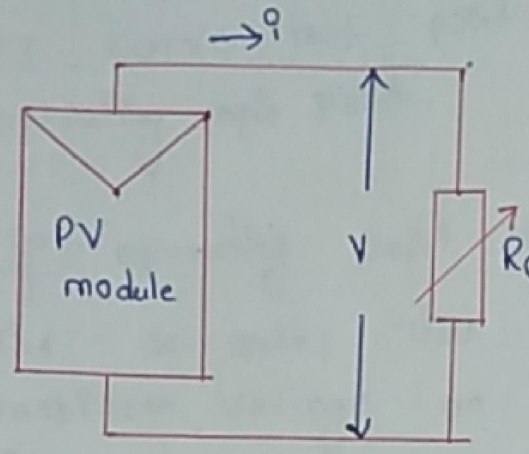
- I = output current (ampere)
- I_L = photogenerated current (ampere)
- I_D = diode current (ampere)
- I_{SH} = shunt current (ampere).


R_s
I
I_D
I_{sh}
I_L
R_{sh}
+
V
−

Maximum power point Tracking
(MPPT)

1. MPPT is maximum power point Tracking.
2. This Technique used commonly with wind Turbines and photovoltic (PV) solar system to get maximum power under all conditions.
3. the principle applies generally to sources with variable power.
4. MPPT efficiency depends on the amount of sunlight falling on the solar panels, Temperature of solar ~~pla~~ panels & the electrical characteristics of the load.
5. The efficiency of the system is optimized when the load characteristics changes to keep the power Transfer at highest efficiency.

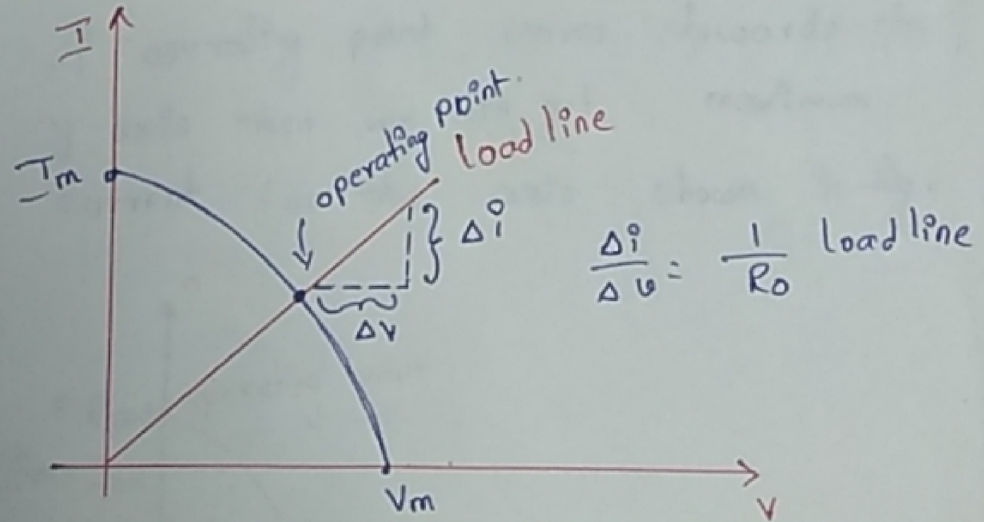
MPPT concept



1. Consider simple circuit. it have PV module connected to the simple R_o load. &

2. R_o is variable resistance & PV module resistance R_T Not Consider.

3. here we are appling O.C & S.C to the circuit to get maximum current and maximum voltage. i.e I_m & V_m.



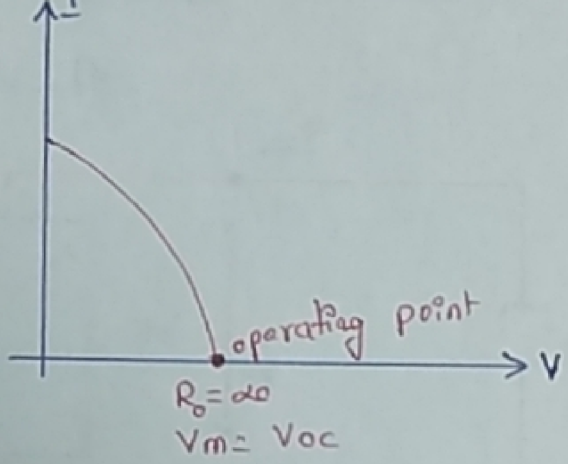
$$\frac{\Delta i}{\Delta v} = \frac{1}{R_o}$$ load line

4. from the circuit we will measure voltage and current. we consider V on X-axis and current on Y axis

5. Now we consider Load line passing through origion. i.e $\frac{1}{R_o} = \frac{\Delta i}{\Delta v}$

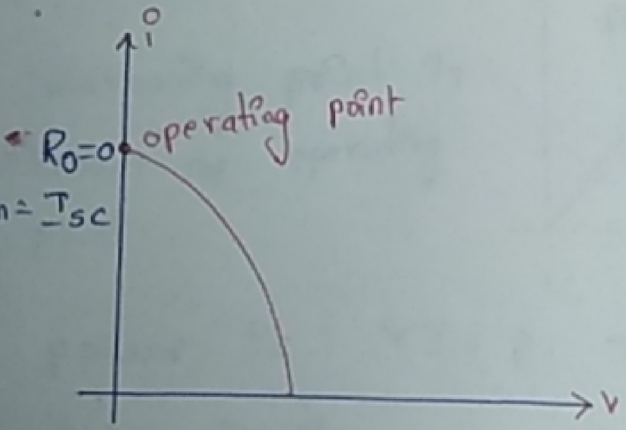
6. load line interse make interesting to the VI, curve that point is know as operating opin point.

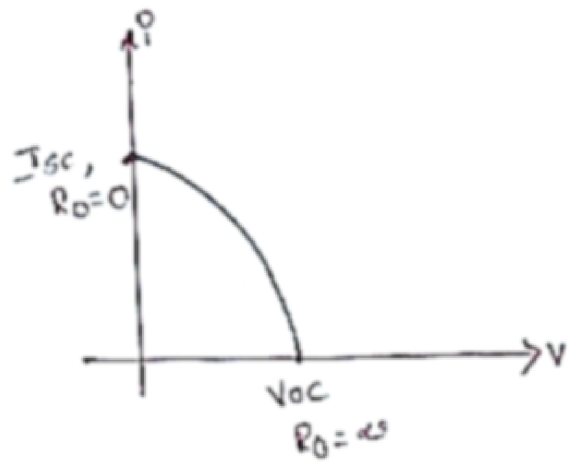
7. if operating point moves toward to The x- axies then we will get maximum voltage on the axis shown in fig.



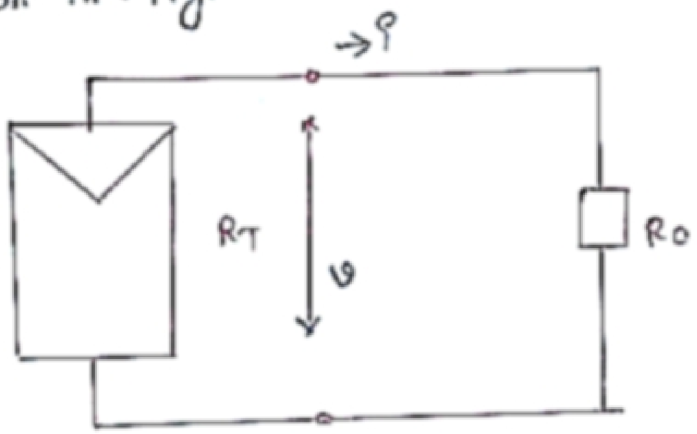
8. if operating point moves towards to y axis then we will get maximum current on the axis shown in fig.

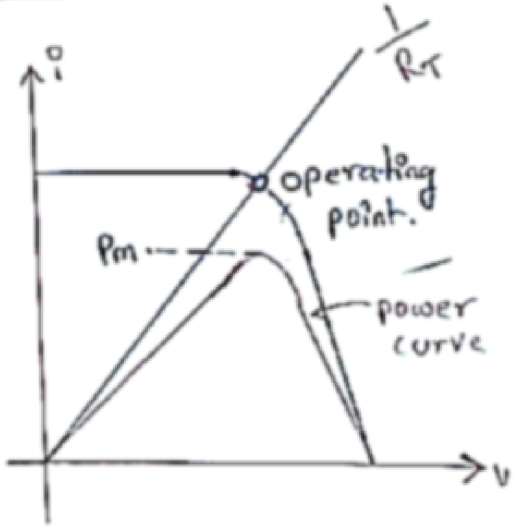
9.





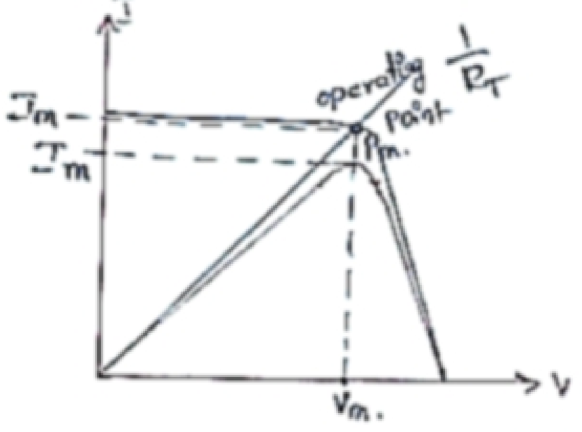
Now consider pv module resistance R_T shown in fig.



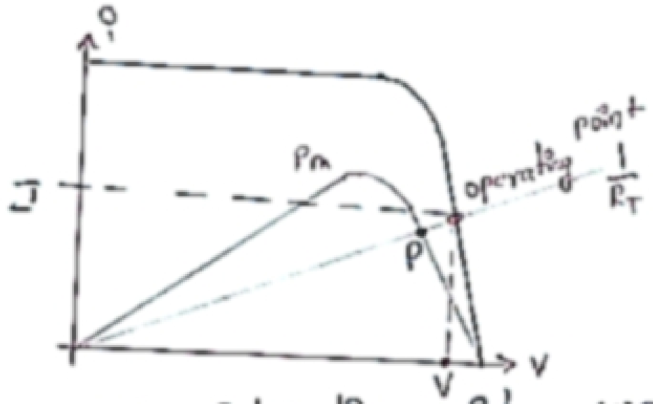


1. R_T is pv module resistance
2. Intersecting point is known as operating point.
3. power is $VI = P$. This power curve shown in fig.
4. the maximum power at power curve is Pm.

By using Pm point on the power curve we will get , Im & Vm shown in fig.



if the load line is shifted or moving towards to the X axis then maximum power is vario.

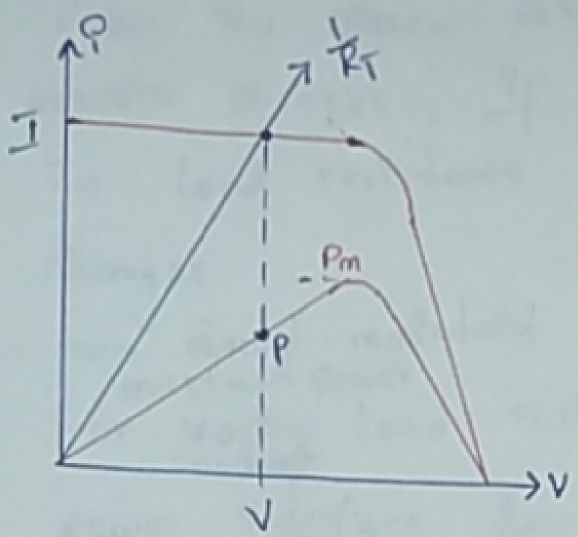


at intersecting point we will get voltage and current i.e V & I

Now the power is VI = P.

thus P is less than to Pm.

if the load line is shifted or moving towards to Y axis then maximum power is varies.



at intersecting point we will get voltage and current i.e V & I

power $P = VI$

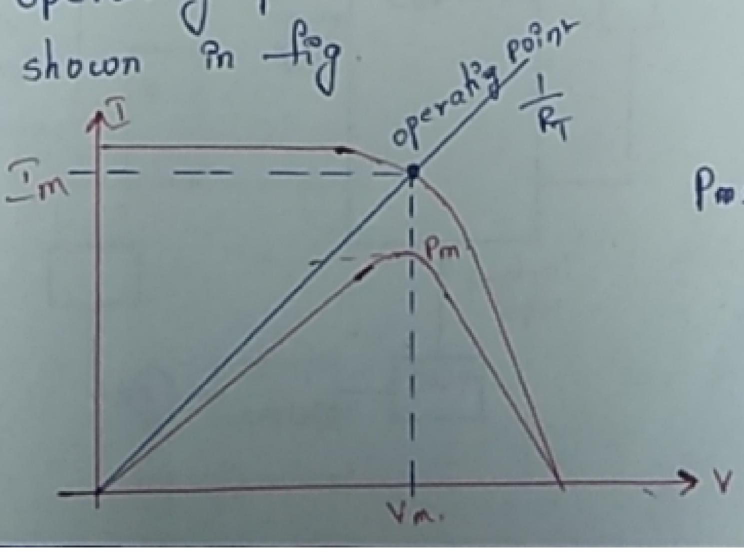
This power P is lessthan to Pm.

$P < P_m$.

In above two cases the power from the panel is less if the load line is moving towards x axis and y axis i.e O.C & S.C.

we will get maximum power from the pv module at load line intersecting at Pm point.

operating point is equal to Pm point shown in fig.



$P_m = V_m I_m$.

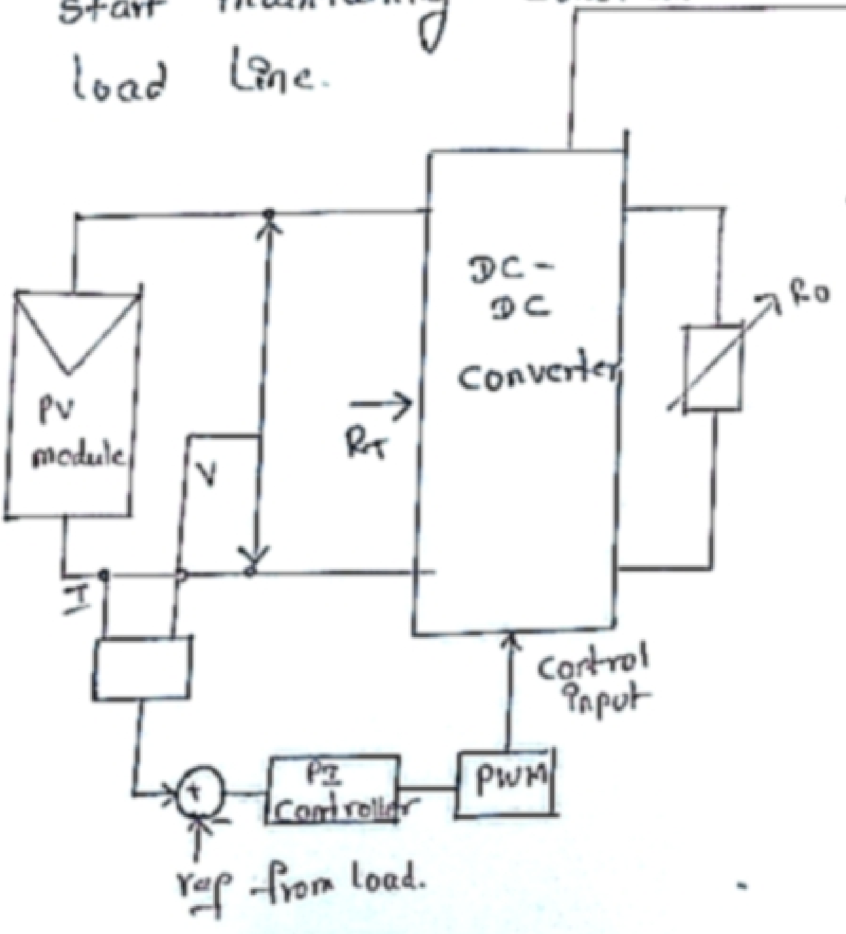
From this ~~discus·~~ ~~discuss·~~ discussion we ~~absexbe~~ observe, if the load line changes i.e load resistance change then power changes.

→ we should maintaint constant R_T for getting maximum power

For ~~varying~~ constant load resistance we are using power interface. here power interface is dc to dc converter

it require some control input.

if load resistance is R_o changes the control input give the signal to the power interface. this power interface start maintaining constant R_T i.e load line.



Non isolated
- Boost (step up)
- Buck (step-down)
- Buck-boost

isolated
- fly back
- forword
- push pull
- Half bridge
- full bridge
- ⋮

perturb and observe MPPT Algorithm

1. the concept behind the perturb and observe method is to modify the operating voltage or current of photovoltaic panel until you obtain maximum power from it.

2. for example.

if increasing the voltage to a cell, increasing the power output of a cell.

The operating voltage the system increases the operating voltage until the power output begins to decrease. once this happens, the voltage is decrease to get back to the maximum power output this process continues until the maximum power point is reached.

3. the algorithm starts by setting the computed maximum power PMAX to initial value (zero). Next the actual PV voltage and current are measured at specific intervals and compute the power Pact.

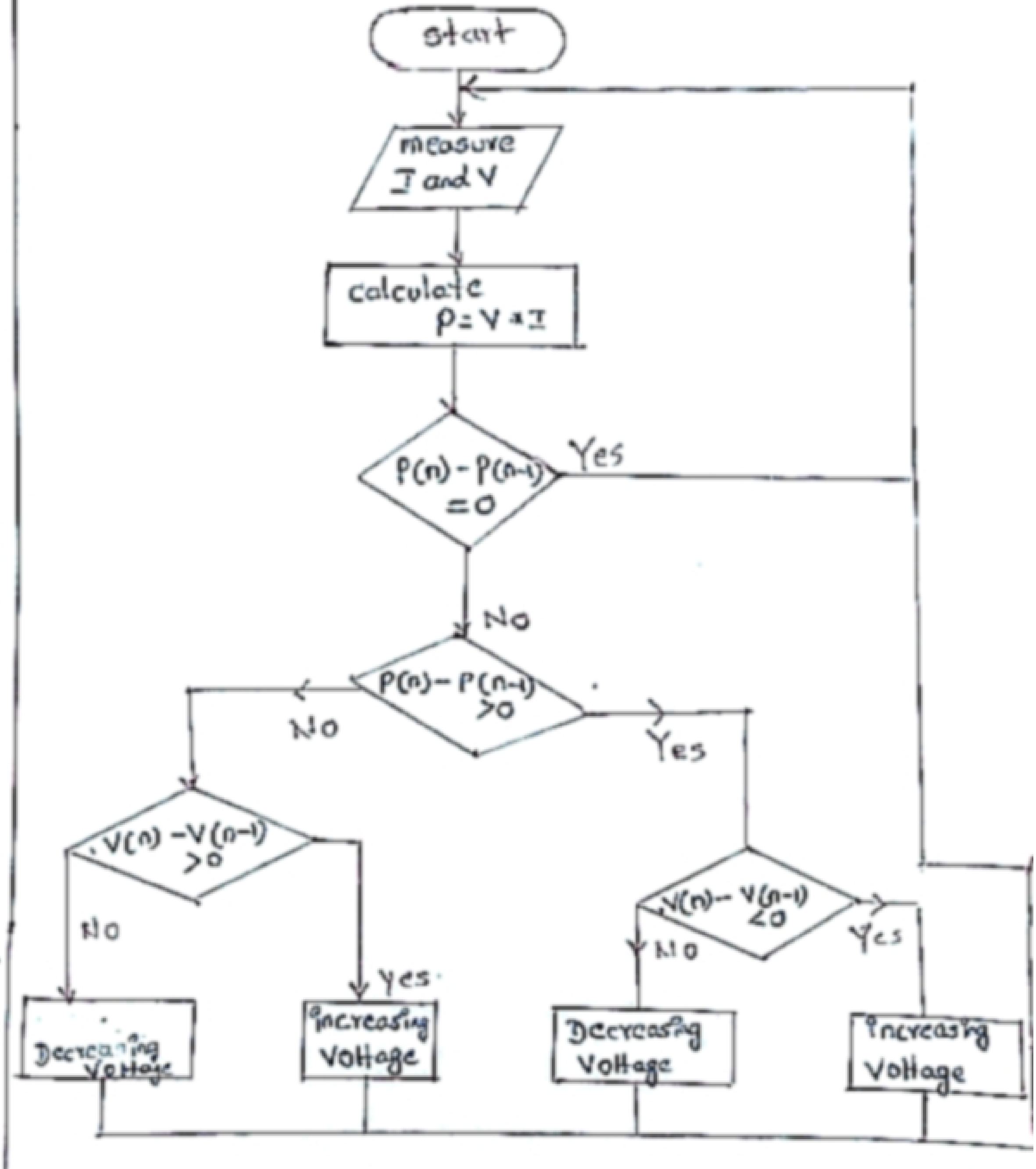
Pmax & Pact compared, if Pact > Pmax then Pmax = Pact.

i.e Pmax set a value of Pact.

At every instant the Pact is calculated and compare to Pmax continuously executed. hence finally we reached to Pmax.

→ For maximum power transfer across the load the impedance should be equal to load impedance.

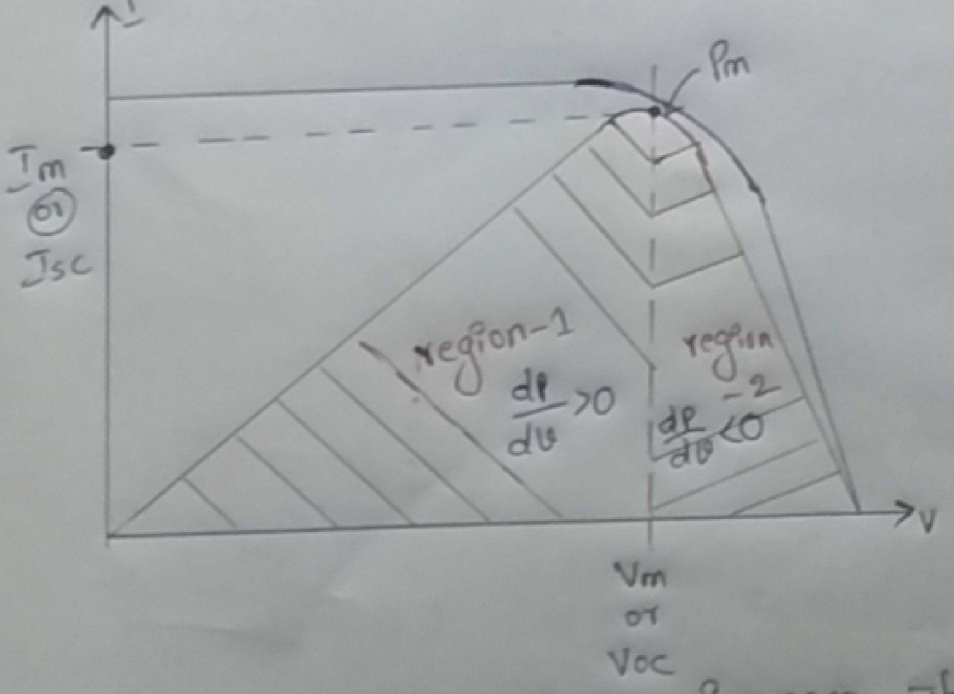
→ Based on mechanism, a duty cycle of gate pulses are varied. so output power varied.



Incremental conduction method.

In the incremental conduction method, the controller measures the incremental change in pv array current & voltage to predict the effect of a voltage change.

This method require more computation in controller, because it can track changing conditions more rapidly.



In region 1, if voltages increase then power is increases so $\frac{dP}{dV} > 0$ i.e positive

In region 2, if voltage increases then power is decreases so $\frac{dP}{dV} < 0$ i.e -ve.

At Pm point $\frac{dp}{dv} = 0$

How to get $\frac{dp}{dv}$

we will get $\frac{dp}{dv}$ from conduction equation.

Conductio

conductance $G = \frac{I}{V}$

$$\frac{dp}{dV} = \frac{d}{dV}(IV)$$

$$= I\frac{dV}{dV} + V\frac{dI}{dV}$$

$$= I + V\frac{dI}{dV}$$

Assome $\frac{dI}{dV} = \frac{\Delta I}{\Delta V}$ incremental conductance

$$\frac{dp}{dV} \approx I + V\frac{\Delta I}{\Delta V}$$ (incremental conductance)

from the VI curve, current is constant upto operating point but voltage is increased so

$$\underbrace{I - V\frac{I}{V}}_{\text{Instantaneous conductance}} = 0$$

Comparing conductance to Incremental conductance

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V} \Rightarrow \frac{dP}{dV} \approx I + V\frac{\Delta I}{\Delta V}$$

$$> I - V\frac{I}{V} = 0$$

$$\frac{dP}{dV} > 0$$

1. when the voltage is smaller than the maximum power point $\frac{dP}{dV} > 0$

so $\frac{dI}{dV} > -\frac{I}{V}$ (or) $\frac{\Delta I}{\Delta V} > -\frac{I}{V}$

2. when the voltage is bigger than maximum power point $\frac{dP}{dV} < 0$ (or)

$$\frac{dI}{dV} = \frac{\Delta I}{\Delta V} < -\frac{I}{V}$$

- The incremental conductance method is based on the observation that at the maximum power point $\frac{dP}{dV} = 0$.

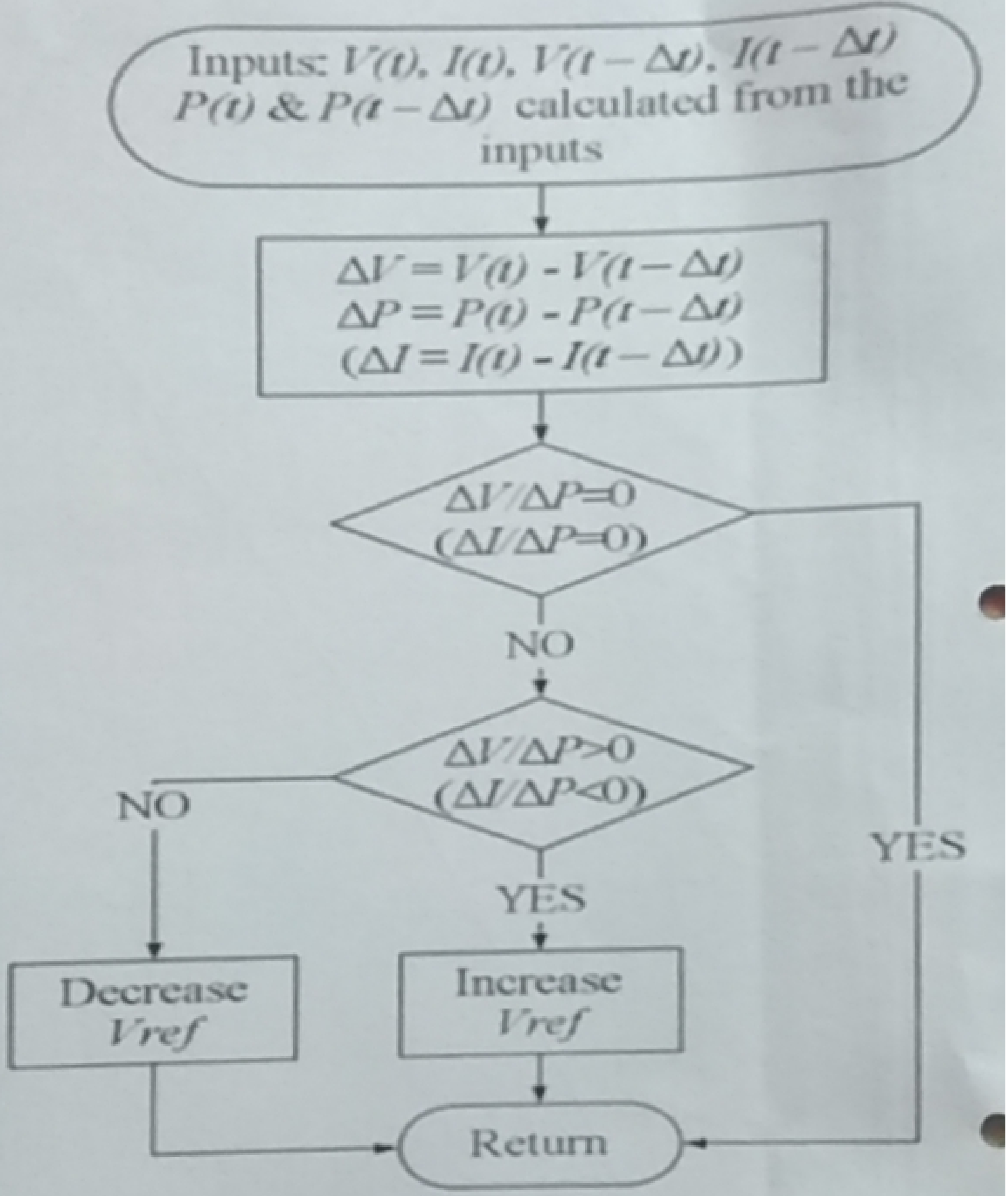


Figure 2 **- Incremental Conductance algorithm.**