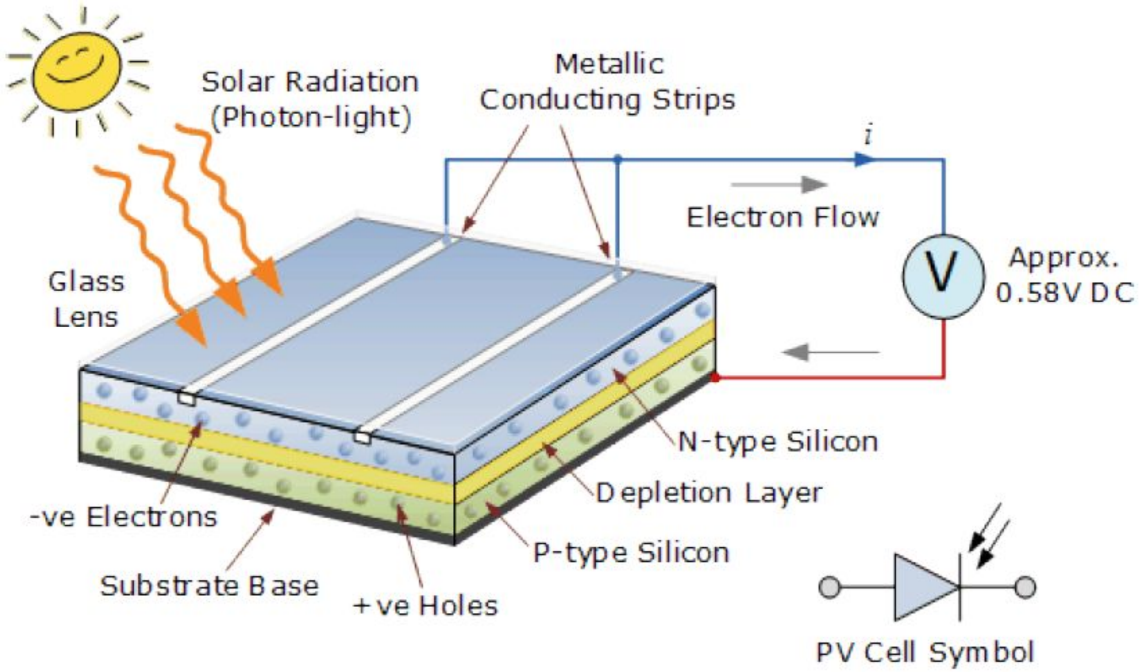
Solar cell

Solar cell is also called as photo galvanic cell or solar cell is the one which converts the solar energy (energy obtained from the sun) directly into electrical energy. The solar cells are based on the principles of photovoltaic effect.

- Solar cell (crystalline Silicon) consists of n-type semiconductor (emitter) layer and p-type semiconductor layer (base). The two layers are sandwiched and hence there is formation of p-n junction. The surface is coated with anti-reflection coating to avoid the loss of incident light energy due to reflection. When a solar panel exposed to sunlight , the light energies are absorbed by a semi conduction materials. Due to this absorbed energy, the electrons are liberated and produce the external DC current. The DC current is converted into 240-volt AC current using an inverter for different applications.



Types of Solar cell

- Based on the types of crystal used, soar cells can be classified as,

1. Mono crystalline silicon cells
2. Polycrystalline silicon cells
3. Amorphous silicon cells

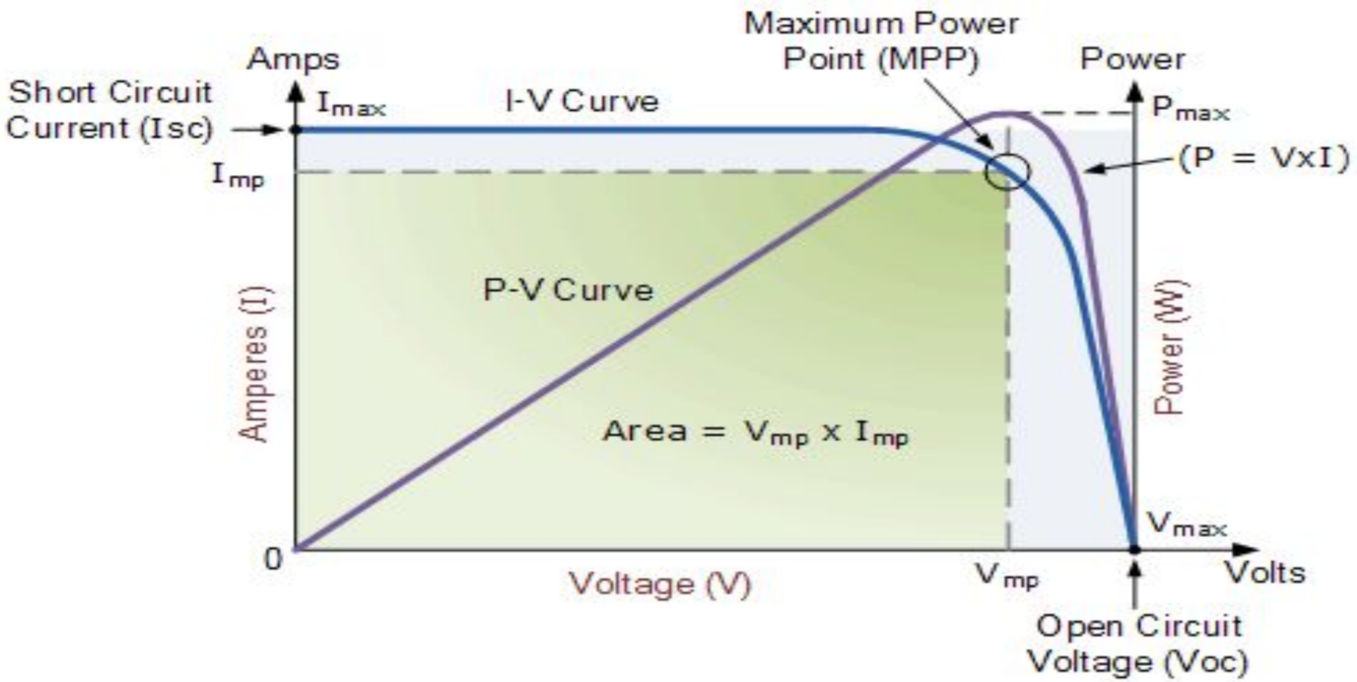
1. The **Mono crystalline** silicon cell is produced from pure silicon (single crystal). Since the Mono crystalline silicon is pure and defect free, the efficiency of cell will be higher.
2. In **Polycrystalline** solar cell, liquid silicon is used as raw material and polycrystalline silicon was obtained followed by solidification process. The materials contain various crystalline sizes. Hence, the efficiency of this type of cell is less than Mono crystalline cell.
3. **Amorphous** silicon was obtained by depositing silicon film on the substrate like glass plate. The layer thickness amounts to less than 1µm – the thickness of a human hair for comparison is 50-100 µm.

Comparison of Mono-Si, Poly-Si and Thin film Panels

Mono-Si Panels	Poly-Si Panels	Thin Film Panels
1. Most efficient with max. efficiency of 21%.	**1. Less efficient with efficiency of 16% (max.)**	**1. Least efficient with max. efficiency of 12%.**
2. Manufactured from single Si crystal.	2. Manufactured by fusing different crystals of Si.	2. Manufactured by depositing 1 or more layers of PV material on substrate.
3. Performance best at standard temperature.	3. Performance best at moderately high temperature.	3. Performance best at high temperatures.
4. Requires least area for a given power.	4. Requires less area for a given power.	4. Requires large area for a given power.
5. Large amount of Si hence, high embodied energy.	5. Large amount of Si hence, high Embodied energy.	4. Low amount of Si used hence, low embodied energy.
6. Performance degrades in low-sunlight conditions.	6. Performance degrades in low-sunlight conditions.	5. Performance less affected by low-sunlight conditions.
7. Cost/watt: 1.589 USD	7. 1.418 USD	7. 0.67 USD
8. Largest Manufacturer: Sunpower (USA)	8. Suntech (China)	8. First Solar (USA)

PV cell characteristics

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.**

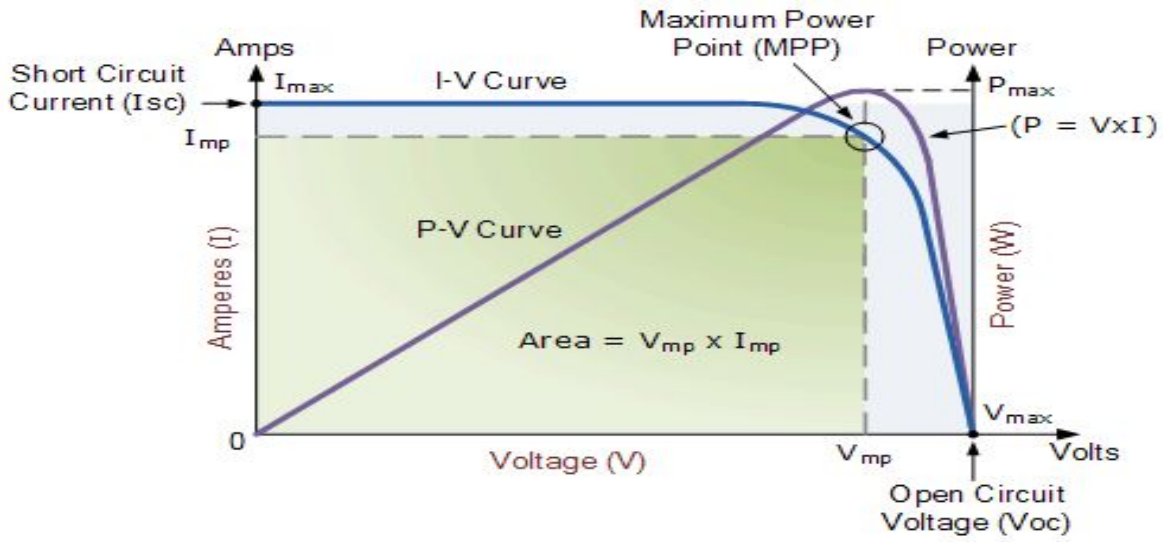


<u>**Solar Cell I-V Characteristic Curve**</u>

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.**

Then the span of the solar cell I-V characteristics curve ranges from **the short circuit current (I_{sc})** at zero output volts, to zero current at the full **open circuit voltage (V_{oc}).** 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 I_{mp} and V_{mp}. 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 $\mathbf{V_{mp}}$ and $\mathbf{I_{mp}}$ can be estimated from the open circuit voltage and the short circuit current:

$\mathbf{V_{mp}} \cong (0.8 - 0.90)\ \mathbf{V_{oc}}$ and $\mathbf{I_{mp}} \cong (0.85 - 0.95)\ \mathbf{I_{sc}}$. 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 $\mathbf{V_{mp}}$ 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 $\mathbf{I_{mp}}$ 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 **$MPP = I_{mp} \times V_{mp}$**. The maximum power point of a photovoltaic array is measured in **Watts (W) or peak Watts (W_p).**

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, **($V_{OC} \times I_{SC}$)** 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 (mono-crystalline, polycrystalline, amorphous or thin film) being used.

Maximum power point tracking methods

Maximum power point tracking (**MPPT)** or sometimes just **power point tracking** (**PPT**) is a technique used commonly in photovoltaic (PV) solar systems to maximize power extraction under all conditions.

Classifications of MPPT are

- Perturb and observe
- Incremental conductance
- Current sweep
- Constant voltage
- Temperature Method

Let us see the first two types in detail

Perturb and observe

In this method the **controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases**.

This is called the perturb and observe method and is most common, although this method can result in oscillations of power output.

It is referred to as a ***hill climbing*** method, because it **depends on the rise of the curve of power against voltage below the maximum power point**, and the fall above that point.

Perturb and observe is the **most commonly used MPPT method** due to its ease of implementation.

Perturb and observe method may result in top-level efficiency, provided that a proper predictive and adaptive hill climbing strategy is adopted.

Incremental conductance

In the incremental conductance method, the controller **measures incremental changes in PV array current and voltage to predict the effect of a voltage change**.

This method requires more computation in the controller, but can track changing conditions more rapidly than the perturb and observe method (P&O). Like the P&O algorithm, it can **produce oscillations in power output.**

This method utilizes the incremental conductance (dI/dV) of the photovoltaic array to compute the sign of the change in power with respect to voltage (dP/dV).

The incremental conductance method computes the maximum power point by comparison of the incremental conductance (I_Δ / V_Δ) to the array conductance (I / V). When these two are the same ($I / V = I_\Delta / V_\Delta$), the output voltage is the MPP voltage... The **controller maintains this voltage until the irradiation changes and the process is repeated.**

Current sweep

The current sweep method uses a sweep waveform for the PV array current such that the I-V characteristic of the PV array is obtained and updated at fixed time intervals. The maximum power point voltage can then be computed from the characteristic curve at the same intervals.

Constant voltage

The term "constant voltage" in MPP tracking is used to describe different techniques by different authors, one in which the output voltage is regulated to a constant value under all conditions and one in which the output voltage is regulated based on a constant ratio to the measured open circuit voltage (V_{OC}).

Temperature Method

This method of MPPT estimates the MPP voltage $\mathbf{V_{mpp}}$ by measuring the temperature of the solar module and comparing it against a reference.