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# The Factors Affecting the Performance of Solar Cell

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## ABSTRACT
Energy which comes from natural resources such as sunlight, wind, rain, geothermal heat etc. is called renewable energy. Renewable energy is very important because the non-renewable energy such as petrol, diesel, and fossil fuels are limited. Solar energy is the most easily available source of energy. Most important it is non-conventional source of energy because it is non-polluting, clean etc. The influences of temperature and irradiance variations on the different solar cell parameters are studied. It is useful to understand the effect of temperature and irradiance on the solar cell and module performance, in order to estimate their performance under various conditions. The efficiency of solar module is directly related with the solar parameter and therefore solar parameter changes and affects the efficiency of solar module.

## Keywords
Solar cell; temperature; open circuit voltage; short circuit current; irradiance; efficiency.

## 1. INTRODUCTION
The term photovoltaic refers to the phenomenon involving the conversion of sunlight into electrical energy via a solar cell. In Photovoltaic power generation there are two major problems which are less conversion efficiency of PV modules & amount of power generation depends on weather conditions. And also, the PV cell I-V characteristic be non-linear due to complex relationship between voltage and current and vary with change in temperature or insolation. There is single point on I-V or P-V characteristics curve knows as Maximum Power Point where PV system gives highest efficiency and produces highest output power.[2] The main source of the power loss is the failure to track MPP. So, Maximum Power Point Tracking is essential to operate PV system at MPP.

The most important parameters of the solar cell that describe the operating conditions are the irradiance and the temperature. Designer of solar cell asses their devices by evaluating the efficiency at standard test conditions (STC: illumination =1000 W/m2, temperature=25°C and AM1.5 reference spectrum)[14]. However, these conditions practically never occur during normal outdoor operation as they do not take into consideration the actual geographical and meteorological conditions at the installation site. In this paper, we discussed the temperature and irradiance variations effect on the parameters of the solar cells. This will be explained using crystalline silicon solar cells as an example, but the concept is also applicable to other types of solar cells.

## 2. PHOTOVOLTAIC ARRAY
Photovoltaic Arrays essentially consist of a number of internal silicon based photovoltaic cells combined in series and in parallel, depending on the voltage or current requirements. These cells are used to convert solar energy into electricity. This occurs when the photovoltaic cells are exposed to solar energy causing the cells electrons to drift which, in turn, produces an electric current. This current varies with the size of individual cells and the light intensity [2].

Photovoltaic cells, or solar cells as they are more commonly referred to, are available commercially in a number of different semiconductor materials. The most common materials are monocrystalline silicon, polycrystalline silicon, amorphous silicon and copper-indium selenide (CIS). These technologies consist of p-n junction diodes capable of generating electricity from light sources and usually have efficiencies of 6% - 20% in commercial use.

### 2.1 Equivalent Circuit of A PV Cell
The equivalent circuit of a PV cell is demonstrated below

in Figure 1.

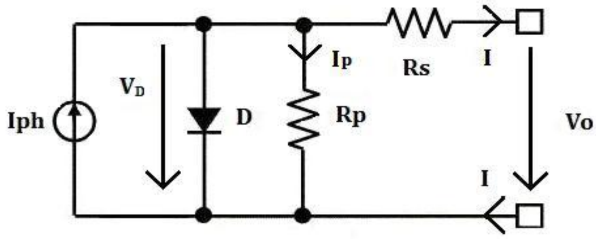


**Figure1. Equivalent circuit of a PV cell [7]**

Derived from Kirchhoff's first law (also referred to as Kirchhoff's current law), the output current is given by

$$I = I_{ph} - I_D - I_p$$

$$I = I_{ph} - I_{sat}.(\exp\frac{(q.(V_0 + I.R_s))}{(n.K.T_{cell}.N_s)} - 1) - \frac{V_0 + I.R_s}{R_p}$$

Where

**I** Output current

**Iph** Photo current

**Isat** Diode reverses saturation voltage

**Vo** Output Voltage

**Rs** Series resistance (Representing voltage loss on the way to external connectors)

**Rp** Parallel resistance (Representing leakage currents)

**k** Boltzmann's constant

**q** Charge on electron

**Ns** Number of cells in series

**N** Ideality factor

**Tcell** Solar panel temperature

The I-V characteristics of a typical solar cell are as shown in the Figure 2.

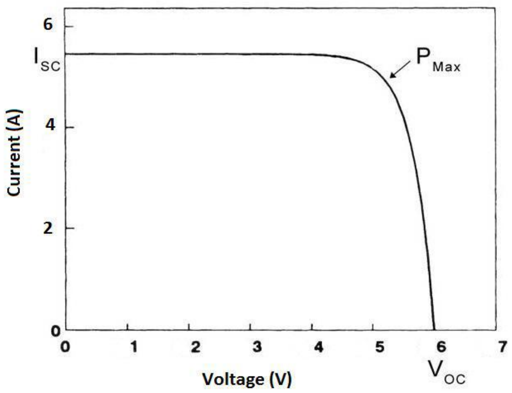


**Figure2. I-V characteristics of a solar panel [2]**

## 2.2 Parameters of Solar Cell

**Short Circuit Current (Isc):** The current is maximum when the two terminals are directly connected with each other and the voltage is zero. The current in this case is called 'short circuit' current. The short-circuit current is due to the generation and collection of light generated carriers.

**Open Circuit Voltage (Voc):** When the cell is not connected to any load there is no current flowing and the voltage across the PV cell reaches its maximum. This is called 'open circuit voltage'. When load is connected to the PV cell current flows through the circuit and the voltage goes down.

**Fill Factor (FF):** The FF is defined as the maximum power from actual solar cell to the maximum power from ideal solar cell. As time goes the PV curve degrades. It is essential to check quality of cell periodically. Quality of cell is determined by fill factor. For a good panel FF is between 0.7 to 0.8 while for bad panel it may be 0.4.

$$FF = \frac{Vmpp\ Impp}{Voc\ Isc}$$

**Efficiency (η):** Efficiency is defined as ratio of energy output from solar cell to input energy from sun.

$$\eta = \frac{Max\ cell\ power}{Incident\ light\ intensity} = \frac{Vm\ Im}{Pin} = \frac{Voc\ Isc\ FF}{Pin}$$

The efficiency is most commonly used parameter to compare the performance of one solar cell to another. Efficiency depend on solar spectrum, intensity of sunlight and the temperature of solar cell [7].

# 3. FACTORS AFFECTING ON PV CELL GENERATION

## 3.1 Effects of PV technology types

Many types of PV cells are available today. This section gives details on the types of the PV cells that are currently in the manufacturing, research and development stage.

**Monocrystalline silicon cells**: These cells are made from pure monocrystalline silicon. In these cells, the silicon has a single continuous crystal lattice structure with almost no defects or impurities. The main advantage of monocrystalline cells is their high efficiency, which is typically around 15%. The disadvantage of these cells is that a complicated manufacturing process is required to produce monocrystalline silicon, which results in slightly higher costs than those of other technologies [7]. Crystalline silicon cell technology is well established and the PV modules have long lifetimes (20 years or more).

**Multicrystalline silicon cells**: A less expensive material, Multicrystalline silicon, by passes the expensive and energy-intensive crystal growth process. Multicrystalline cells are produced using numerous grains of monocrystalline silicon. In the manufacturing process, molten Multicrystalline silicon is cast into ingots, which are subsequently cut into very thin wafers and assembled into complete cells. Multicrystalline cells are cheaper to produce than monocrystalline ones because of the simpler manufacturing process required. They are, however, slightly less efficient, with average efficiencies being around 12% [14, 7].

**Amorphous silicon cells**: Generally, the main difference between these cells and the previous ones mentioned above is that, instead of the crystalline structure, amorphous silicon cells are composed of silicon atoms in a thin homogenous layer. Additionally, amorphous silicon absorbs light more effectively than crystalline silicon, which leads to thinner cells, also known as a thin film PV technology. Thin film solar has approximately 15% market share; the other 85% is crystalline silicon [7]. The greatest advantage of these cells is that amorphous silicon can be deposited on a wide range of substrates, both rigid and flexible. Their disadvantage is the low efficiency, which is on the order of 6%.

**Other types of cells**: In addition to the above types, a number of other promising materials, such as CdTe and copper-indium selenide (CuInSe), are used today for PV cells. The main trends today concern the use of polymer and organic PV cells. The attraction of these technologies is that they potentially offer fast production at low cost in comparison to crystalline silicon technologies, yet they typically have lower efficiencies (around 4%), and despite the demonstration of operational lifetimes and dark stabilities under inert conditions for thousands of hours, they suffer from stability and degradation problems [14]. Each semiconducting material has its own properties which make it more or less suitable for use in a PV cell. One of these properties is the so-called band gap, which is the energy gap an electron must cross in order to be promoted from the valence band to the conduction band [7]. In the literature studies, it has been shown that silicon, with its bandgap of 1.12 eV, is not optimal. Materials with bandgaps nearer to 1.5 eV, such as GaAs and CdTe, have higher theoretical efficiencies.

As mentioned above, a single-material PV cell can convert only about 15% of the available energy to useful electrical power. To improve this performance, multiple cells with different band gaps, which are more complex and therefore more expensive, can be used. These are called multi-junction PVs. Particularly; a triple-junction PV produced recently achieved a remarkable 40% efficiency. This PV consists of three layers of PV material placed one atop the other. Each of the three materials captures a separate portion of the solar spectrum and the objective is to capture as much of the solar spectrum as possible. These are much more expensive than other silicon PV cells, but their efficiency offsets their high cost, and in concentrating systems, a small area of these cells is required.

Another way to increase the effectiveness of PVs according to their technology is to concentrate sunlight on small, highly efficient PV cells using inexpensive reflective material, lenses, or mirrors. These are known as concentrating photovoltaic's (CPVs). Today, the technology takes up a very small portion of the solar industry; however, it is expected that the CPV industry will soon take up a larger share of the solar market as technology improves and cost comes down [14].

## 3.2 Effects of Ambient Conditions

There are various ambient conditions that affect the output of a PV power system. These factors should be taken into consideration so that the customer has realistic expectations of overall system output. Module temperature is a parameter that has great influence in the behavior of a PV system, as it modifies system efficiency and output energy. In addition to this, the atmospheric parameters such as irradiance level, ambient temperature, dirt/dust and the particular installing conditions have influence, too. Temperature effects are the result of a connatural characteristic of crystalline silicon cell-based modules. They tend to produce higher voltage as the temperature drops and, conversely, to lose voltage in high temperatures. Any PV module or system derating calculation must include adjustment for the temperature effect [6].

As temperature increases, the band gap of the semiconductor shrinks, and the open circuit voltage Voc decreases following the p–n junction voltage temperature dependency of seen in the diode factor q/kT. PV cells therefore have a negative temperature coefficient of Voc. Moreover, a lower output power results given the same photocurrent Iph because the charge carriers are liberated at a lower potential [7, 9]. As temperature increases, again the band gap of the intrinsic semiconductor shrinks meaning more incident energy is absorbed because a greater percentage of the incident light has enough energy to raise charge carriers from the valence band to the conduction band. A larger photocurrent results; therefore, Isc increases for a given insulation, and PV cells have a positive temperature coefficient of Isc. This effect would raise the theoretical maximum power by the relationship below,

$$\mathrm{Pmax} = \mathrm{ISC} \times \mathrm{VOC}$$

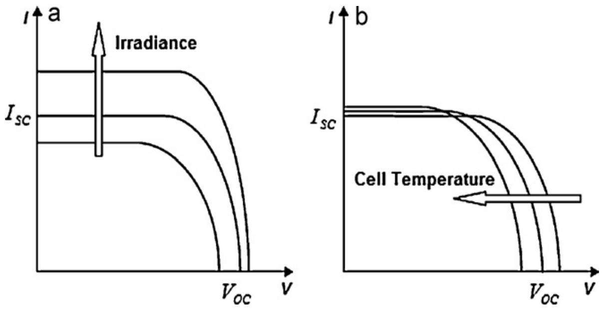


**Figure3. Effects of irradiation and cell temperature on PV cell characteristic (a) effect of increased irradiance and (b) effect of increased cell temperature [8].**

The influences of temperature and irradiance on the cell characteristics are shown in Fig. 3. As seen from Fig. 3(a), the open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly. The influence of the cell temperature on the cell characteristics is shown in Fig. 3(b). The main effect of the increase in cell temperature is on open circuit voltage, which decreases linearly with the cell temperature; thus the cell efficiency drops. As can be seen, the short circuit current increases slightly with the increase of the cell temperature [8]. The procedure to determine the normal operating cell temperature (NOCT) of a PV module included in the IEC standards is based on the fact that the difference between the module temperature Tm and the ambient temperature Tamb can be considered independent of the ambient temperature and linearly proportional to the irradiance at levels above 400W/m2. An example of application of NOCT determination is the calculation of module temperature from ambient temperature, available solar irradiance and NOCT following the known equation:

$$\mathrm{Tm} = \mathrm{Tamb} + (\mathrm{NOCT} - 20)\ \frac{\mathrm{E}}{800}$$

Where E the irradiance in W/m2.

A PV cell's energy conversion efficiency (η), is the percentage of power converted (from absorbed light to electrical energy) and collected, when a PV cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, Pmax, divided by the input light irradiance (E, inW/m2) under standard test conditions and the surface area of the PV cell (AC in m2) [8]:

$$\eta = \frac{\mathrm{Pmax}}{\mathrm{EAc}}$$

The efficiencies in a PV module are decreased with increasing the module temperature Tm. The variation of a sample PV module [ efficiency _ with the module temperature Tm is given by the characteristic in Fig. 4.

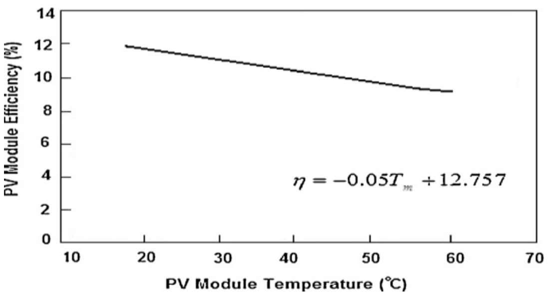


**Figure4. Relationship of the PV module efficiency (η) and PV module temperature (Tm) [8]**

An effective way of improving efficiency and reducing the rate of thermal degradation of a PV module is by reducing the operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. As an example, solar-water pumping system can be given. Such a system consists of a PV module cooled by water, a water pump, and a water storage tank. Cooling of the PV module is achieved by introducing water trickling configuration on the upper surface of the module. The results indicated that due to the heat loss by convection between cooling water and the PV module's upper surface, an increase of about 15% in system output is achieved at peak solar irradiation conditions. And also the results of such a system's indicated that an increase of 5% in delivered energy from the PV module can be achieved during dry and warm seasons.

Another important factor is dirt/dust. Dirt/dust can accumulate on the PV module surface, blocking some of the sunlight and reducing output. Although typical dirt/dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust build-up in the dry season. So the "100Wmodule" operating with some accumulated dirt/dust may operate on average at about 79W [8]:

- A manufacturer may rate a particular PV module output at 100W of power under standard test conditions, and call the product a "100W PV module." This module will often have a production tolerance of ±5% of the rating, which means that the module can produce 100W×0.95=95W.
- Output power of the PV module reduces as module temperature increases. When operating on a roof, a PV module will heat up substantially, reaching inner temperatures of 50–75 ◦C. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. So the "100-W module will typically operate at about 95W×0.89 = 85Wunder full sunlight conditions.
- A typical annual dust reduction factor to use is 93% or 0.93. A"100- Wmodule," may operate on average at about 85W×0.93=79W

## 4. CONCLUSION

Main topics for these factors that affecting the operation and efficiency of PV based electricity generation are PV cell technology, ambient conditions.

Many types of PV cells are available today such as monocrystalline, Multicrystalline, multi junction and concentrating. The main advantage of monocrystalline cells is their high efficiency, but the disadvantage of these cells is that a complicated process is required to produce monocrystalline silicon. Multicrystalline cells are cheaper to produce than monocrystalline types because of the simpler manufacturing process required. However, they are slightly less efficient. As mentioned above, a single-material PV cell has only about 15% efficiency. To improve this performance up to 40%, multi-junction cells with different band gaps can be used, but this technology is more complex and more expensive. However, another way to increase the efficiency is to concentrate sunlight on PV cells using inexpensive reflective material such as lenses, or mirrors.

There are various ambient conditions such as irradiance, temperature and dirt/dust that affect the output of a PV power system. The open circuit voltage increases logarithmically by increasing the solar radiation, whereas the short circuit current increases linearly and thus, the output power increases. However, the main effect of the increase in cell temperature is on open circuit voltage, which decreases with the cell temperature. The short circuit current increases slightly with the increase of the cell temperature, thus the cell efficiency drops. An effective way of improving efficiency of a PV module is by reducing the operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. Another important ambient factor is dirt/dust. Dirt/dust can accumulate on the PV module surface, blocking some of the sunlight and reducing efficiency.

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