Daffodil International University
Dhaka, Bangladesh

# “Improving the Efficiency of Solar Photovoltaic Power System”

This thesis has been submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

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# A Thesis On

# “Improving the Efficiency of Solar Photovoltaic Power System”

A Thesis Presented to the Academic Faculty

By

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In Partial Fulfillment of the Requirement for the Degree of Bachelor of Science in Electrical and Electronic Engineering.

# APPROVAL

This Thesis titled "Improving the Efficiency of Solar Photovoltaic Power System" Submitted by **Md. Humayun kabir** to the Department of Electrical and Electronic Engineering, Daffodil International University, has been found as satisfactory and accepted for the partial fulfillment of the requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering.

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# DECLARATION

We hereby declare that this thesis is based on the result found by ourselves. The materials of work found by other researchers are mentioned by reference. This thesis is submitted to Daffodil International University for partial fulfillment of the requirement of the degree of B.Sc. in Electrical and Electronics Engineering. This thesis neither in whole nor in part has been previously submitted for any degree.

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# Abbreviation of some short terms

PV : Photovoltaic

OSC : Organic Solar Cell

Voc : Open Circuit Voltage

ISC : Short Circuit Voltage

FF : Fill Factor

HOMO : Highest Occupied Molecular Orbital

LUMO : Lowest Unoccupied Molecular Orbital

ITO : Indium Tin Oxide

STC : standard test conditions
NOCT : Nominal Operating Cell Temperature

MPPT : Maximum power point tracking

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# ABSTRACT

Organic photovoltaic has been developed for more than 30 years, however, within the last decade the research field gained considerable in momentum. The amount of solar energy lighting up Earth's land mass every year is nearly 3,000 times the total amount of annual human energy use. But to compete with energy from fossil fuels, photovoltaic devices must convert sunlight to electricity with a certain measure of efficiency. For polymer-based organic photovoltaic cells, which are far less expensive to manufacture than silicon-based solar cells, scientists have long believed that the key to high efficiencies rests in the purity of the polymer/organic cell's two domains -- acceptor and donor.

The basic principle of organic solar cells is to place layer(s) of organic electronic material between two metallic conductors of two different work functions. This difference of work function sets up an electric field within the organic layer(s) which when absorbs light, causes the excited electrons to be pushed towards positive electrode and holes towards negative electrode. This thesis has been based on an optimized two layer organic solar cell which aims to increase the photon absorption by increasing the interface area between donor and acceptor levels.

This report summarizes the latest advances in the interfacial layers for bi-layer OSCs (including bulk hetero-junction photovoltaic cells. Finally, a brief summary and some perspectives about the current challenges and opportunities have been presented about this interesting area of research.

Dedicated to

OUR PARENTS
TEACHERS
&
MY FRIENDS

With Love & Respect

# Chapter 1

# History of Solar Energy

## 1.1 Introduction

As part of any energy conversion technology, to maximize the amount of energy produced, one can either increase the number of converters or improve the converters ’own skills. If this technology could be made smaller, about half the space of solar panels would be needed for greater efficiency to produce the same amount of energy as today.

Although initial production is expensive, this test - and others like it - is important to show the upper limit of what is possible in solar technology. This set another person's example to make the cell more effective and create a market space.

Solar energy is already responsible for the amount produced worldwide and it is becoming perpetual. Therefore, it is important to continue to find ways to make solar energy more efficiently so that it can surpass fossil energy-based energy and become a source of green energy capable of surviving the damage it has done to our planet (and ours). That's it.

## 1.2 A History of Solar Cell

We will begin our discussion of PV technology with a summary of the history of solar energy. Already in the seventh century BC, people used split glasses in the light of the sun to concentrate and so on. Later the ancient Greeks and Romans used mirrors for the same purpose. In the eighteenth century, the Swiss physicist Horace-Benedict de Saussure created a heating mesh, a kind of tiny greenhouse. When exposed to direct solar radiation, the temperature in the innermost box can rise to a value of 108 ° C; These boxes could be considered the world’s first solar collector to boil water and be warm enough to cook.

In 1839, the French physicist Alexandre-Edmund Becquerel discovered the photovoltaic effect when he was just 19 years old. He observed this effect in an electrolytic cell consisting of two platinum electrodes placing an electronic signal.
In the 1860s and 1870s, French inventor Augustine Mouchot built the world's first solar-powered steam engine using the Parabolic Trot solar collector. Mouchot was inspired by his belief that coal resources were limited. At that time, coal was the source of energy for steam engines. However, as coal became cheaper, the French government decided that solar energy was too expensive and stopped funding Mouche's research.

In 1918, the Polish chemist Jan Kojokralaski discovered a method for enhancing the content of high-quality crystals. The development of C-C technology began in the second half of the 20th century.
In 1953, the American chemist Dan Trivich first made a theoretical calculation of the performance of solar cells for materials with different band gaps. The actual evolution of solar cells, as we know it today, began at Bell Laboratories in the United States.

In 1999, worldwide installed photovoltaic power exceeded 1 GWP. By renewing the public interest in solar energy since about 2000, environmental issues and economic issues have become more important in public discussion. Since 2000, the POV market has therefore transformed from a regional market to a global market, as discussed in Chapter 2, Germany has pursued a progressive feed-in tariff policy, leading to a larger national solar market and industry [19]. For 200 years, the Chinese government has been investing heavily in its PV industry. As a result, China has been an influential PV module manufacturer for several years. In 2012, global solar power surpassed the magic barrier of 100 gig watts [1 17]. Between 1999 and 2012, installed PV capacity increased by 100 factors. In other words, over the past 13 years, the average annual increase in installed PV capacity was about 40%.

## 1.3 Types of Solar Cell.

A solar cell is a solid-state electrical device that converts light energy into direct electricity through photovoltaic effects, which is a physical and chemical phenomenon. It is a form of photoelectric cell that is defined as a device whose electrical properties change when exposed to current, voltage, or resistance to light. Organic solar cells can be classified into two essential types.

Below are the different types of solar cells.

1. Amorphous Silicon Solar Cell (a-Si)
2. Biohybrid solar cells
3. Cadmium Telluride Solar Cell (CDT)
4. Centralized PV cells (CVP and HCVP)
5. Copper Indium Gallium Selenide Solar Cell (CI (G) S)
6. Crystal Silicon Solar Cell (C-C)
7. Float-zone silicone
8. Pigment Sensitive Solar Cell (DSSC)
9. Gallium arsenide germanium solar cell (GAI)
10. Hybrid solar cells
11. Luminescent Solar Concentrator Cell (LSC)
12. Micromorph (tandem cell using A-Si / μc-Si)
13. Monocrystalline Solar Cell (Mono-C)
14. Multi-Junction Solar Cell (MJ)
15. Nanocrystalline solar cells
16. Organic Solar Cell (OPV)
17. Perovskite solar cell
18. Photoelectrochemical Cell (PEC)
19. Plasmonic solar cells
20. Polycrystalline Solar Cell (Multi-C)
21. Quantum dot solar cells
22. Solid-state solar cell
23. Thin-film Solar Cell (TFSC)
24. Wafer solar cell, or wafer-based solar cell crystalline
25. Non-centralized different PV cells

### 1.3.1 Moncrystalline Solar Cell.

Monocrystalline silicon has been introduced for the high-performance photovoltaic (PDV) device. Since microelectronics applications are for a relatively small amount of structurally low power supply, then solar-grade silicon (Sag-C) is available for almost all cells. Nonetheless, silicon photovoltaic travel has benefited from the development of fast-CT systems for electronics levels.

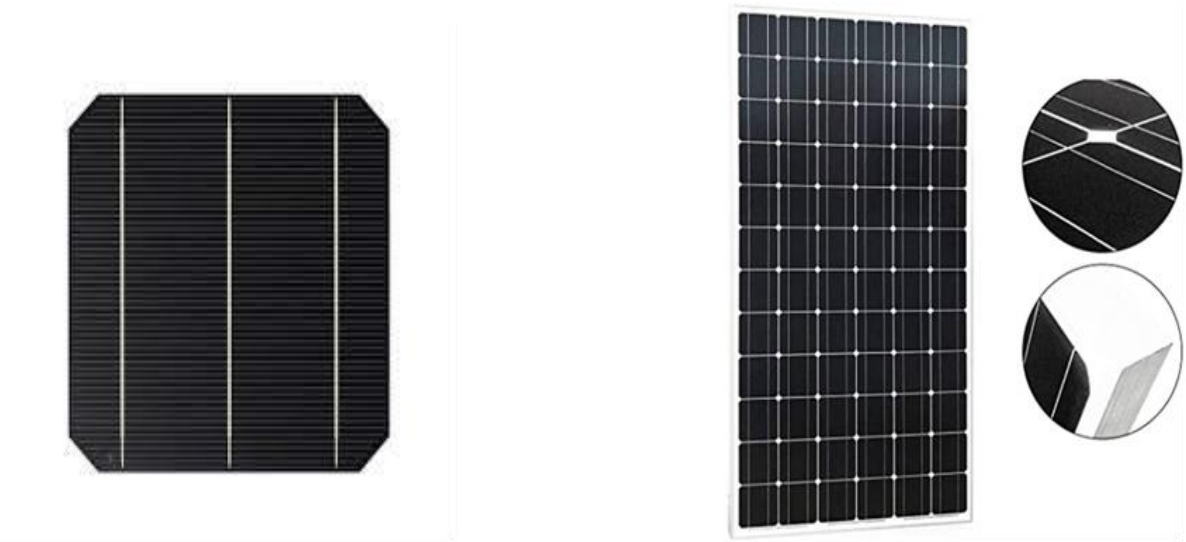


**Figure 1.1: Monocrystalline Solar Cell (Mono-C)**

With a recorded single-junction cell lab efficiency of 26.7%, monocrystalline silicon has the highest confirmed conversion efficiency out of all commercial PV technologies. Solar module efficiencies for mono-Si—which are always lower than those of their corresponding cells—finally crossed the 20% mark for in 2012 and hit 24.4% in 2016.[9] The high efficiency is largely attributable to the lack of recombination sites in the single crystal and better absorption of photons due to its black color, as compared to the characteristic blue hue of poly-silicon. Since they are more expensive than their polycrystalline counterparts, mono-Si cells are useful for applications where the main considerations are limitations on weight or available area, such as in spacecraft or satellites powered by solar energy, where efficiency can be further improved through combination with other technologies.

## 1.3.2 Polycrystalline solar cell (multi-Si)

Polycrystalline silicon, or multi-crystalline silicon, also called polysilicon or poly-C, is a high-purity, polycrystalline form of silicone used as a raw material in the solar photovoltaic and electronics industries.

Polysilicon metallurgy grade silicon is produced by a chemical refining process, called Siemens process. This process involves the distillation of volatile silicon compounds at high temperatures and their decomposition into silicon. An emerging, alternative process of purification uses a liquid bed furnace. The photovoltaic industry produces upgraded metallurgical-grade silicon (UMG-C) using metallurgy instead of chemical refining processes. When manufactured for the electronics industry, the unnecessary layers of polysilicon are less than a billion (ppb), while polycrystalline solar grade silicon (SOGI-C) is generally less pure. Headquartered in China, Germany, Japan, Korea, and several US companies, such as JCL-Poly, Walker Chemi, OCI, and Hemlock Semiconductor, Norway, the REC, in 2013, had about 230,000 tons worldwide.

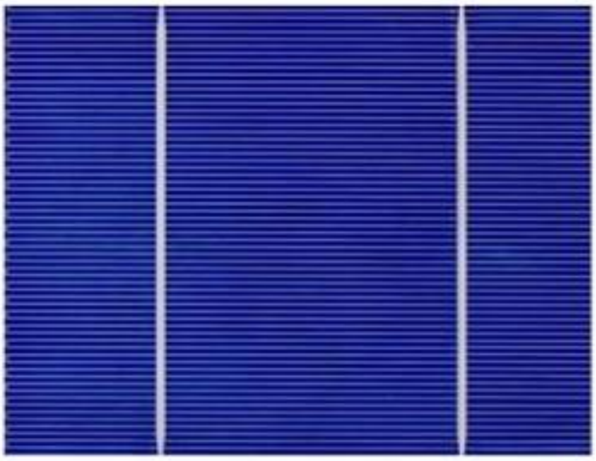


**Figure 1.2: Polycrystalline solar cell (multi-Si)**

Polysilicon feedstock - Large rods are usually cut into pieces of a certain size and packed in a clean chamber before shipment - are either thrown directly into multi-crystalline bricks or re-deposited in the re-installation process to raise single-crystal bottles. The products are then cut into thin silicon wafers and used for the production of solar cells, integrated circuits, and other semiconductor devices.

Polysilicon contains tiny crystals, also known as crystals, which give the material its ordinary metallic flake effect. Polysilicon and multi silicon are often used as synonyms multi-crystalline usually refer to crystals larger than one millimeter. Multicrystalline solar cells are the most common type of solar cell in the fast-growing PV market and consume most of the polysilicon produced worldwide. About 5 tons of polysilicon is required to produce 1 MW (MW) of conventional solar modules. [2] [citation needed] Polysilicon is different from monocrystalline silicon and amorphous silicon.

### 1.3.3 Thin-film solar cell

A thin-film solar cell is a second-generation solar cell that is made by depositing one or more thin layers, or thin-film (TF) of photovoltaic material on a substrate, such as glass, plastic, or metal. Thin-film solar cells are commercially used in several technologies, including cadmium telluride (CdTe), copper indium gallium diselenide (CIGS), and amorphous thin-film silicon (a-Si, TF-Si). Film thickness varies from a few nanometers (nm) to tens of micrometers (µm), much thinner than thin-film's rival technology, the conventional, first-generation crystalline silicon solar cell (c-Si) that uses wafers of up to 200 µm thick. This allows thin-film cells to be flexible, and lower in weight. It is used in building integrated photovoltaics and as semi-transparent, photovoltaic glazing material that can be laminated on windows. Other commercial applications use rigid thin-film solar panels (interleaved between two panes of glass) in some of the world's largest photovoltaic power stations.

**Figure 1.2: 23. Thin-film Solar Cell (TFSC)**

Thin-film technology has always been cheaper but less efficient than conventional c-Technology.

However, it has significantly improved over the years. The lab cell efficiency for CdTe and CIGS is now beyond 21 percent, outperforming multi-crystalline silicon, the dominant material currently used in most solar PV systems.[1]:23,24 Accelerated life testing of thin-film modules under laboratory conditions measured a somewhat faster degradation compared to conventional PV, while a lifetime of 20 years or more is generally expected. Despite these enhancements, market-share of thin-film never reached more than 20 percent in the last two decades and has been declining in recent years to about 9 percent of worldwide photovoltaic installations in 2013.[1]:18,19

Other thin-film technologies that are still in an early stage of ongoing research or with limited commercial availability are often classified as emerging or third-generation photovoltaic cells and include organic, and dye-sensitized, as well as quantum dot, copper zinc tin sulfide, nanocrystal, micro morph, and perovskite solar cells.

## 1.4 Evolution of Solar Cells:

**1st Generation Solar Cells (Crystalline silicon (c-Si) PV technology):** Photovoltaic effect was first recognized by the French physicist, Aleixandre-Edmond Becquerel in 1839, but the first modern solar cell with enough efficiency for power applications was not developed until 1954 at Bell Labs in New Jersey in 1954. While experimenting with semiconductors, Bell lab accidentally found that silicon doped 21 with certain impurities was very sensitive to light. This is the birth of 1st generation solar cell technology. It is Silicon-based technology and is the dominant technology in the commercial production of solar cells, accounting for more than 86% of the solar cell market. It is technically proven and reliable and has succeeded in achieving market penetration, primarily in off-grid remote areas and lately in grid-connected applications. There are, however, several inherent limitations to this 1st generation technology from the onset. Silicon wafers are very fragile and the process involved in manufacturing is difficult and labor-intensive, hence the high cost. There are two approaches to manufacturing crystalline silicon-based solar cells; single crystal and multi-crystalline cells. The Single crystal silicon wafers (c-Si) or the Mono-crystalline Solar Cells in which the crystal lattice of the entire sample is continuous and unbroken with no grain boundaries is still one of the most efficient photovoltaic solar cells to date. The process of production involves crystalline silicon rods being extracted from melted silicon and then sawed into thin plates. About half of the cost of production comes from wafering; A time-saving and expensive batch process so that the ingots are cut into thin wafers with a thickness of about 200 micrometers. If the wafers are too thin, the whole wafer will break down in the process, and because of this thickness requirement, a PV cell requires a significant amount of raw silicon, and it is lost in about half of the very low cost as wood. - Used cut from crystal ribbon; The process is less expensive than single crystal cells. The average value of single-crystal modules is about 93.97 per watt compared to peak-crystal modules [[6]. Although it is more expensive, mono-crystalline silicon 22 cells are generally more durable and efficient and produce more wattage per square foot than their polycrystalline cell feathers. Other advantages of crystalline silicon-based solar cells are their wide spectral absorption range and high carrier mobility. The efficiency of monocrystalline silicon solar cells is currently approximately 27%, while poly-crystal cells are approaching 20% [5]. For crystal-based solar cell efficiency milestones, please see Figure 1.12 below.

**2ND Generation Solar Cells:** Solar Cell Technology Solar Cells: Due to the high production costs of first-generation solar cells, 2nd generation solar cells, known as thin-film technology, are developing. The technology involves a thin layer of photo-active material (non-crystalline silicon) in the components of the low-cost substrate using a plasma-enhanced chemical vapor deposition (PECVD) process. Amorphous semiconductor material (A-C) is commonly used. An amorphous substance is separated from the crystal element in that the structural arrangement of the atom does not contain 23 long-range sequences. Although thin-film PV cells have a lower risk of rupture and are not at risk in most cases of other production problems prevalent in crystalline solar cells, their effectiveness is significantly lower. There are some concerns about the toxic inheritance of materials, both in production and at the end of life. Installing a shapeless solar cell as shown in Figure 1.13 below is more flexible, requires less support when installing roof panels, and has the advantage of fit panels in light materials such as backpacks, textiles, etc. 20%.

**3RD Generation Solar Cells:** Third-generation solar cells involve a variety of semiconductor technologies that are fundamentally different from previous semiconductor devices. It has been speculated that third-generation solar technology will achieve higher efficiency and lower cost than 1st or second-generation technology. Some of these technologies are nanocrystalline solar cells, photo-electrochemical cells, di-sensitive hybrid solar cells, and polymer solar cells. Nanocrystalline solar cell technology is based on granules of nanocrystalline or quantum dots, for example, lead selenide (PbSe) semiconductor and cadmium telluride (CdTe) semiconductor. Quantum dots have band-gaps that are protected across a wide range of energy by resizing quantum dots. This is in contrast to crystal materials where the band-gap is fixed based on material composition. This feature makes Quantum Dots effective for multi-junction solar cells, where 25 different band-gap elements are used to optimize efficiency by collecting selected parts of the solar spectrum. The added benefit of these cells is; Low-energy and high-medium processing technologies perform low material costs and even low-light conditions. The disadvantage is that the efficiency is still lower than that of silicon wafer-based solar cells and there is a risk of material degradation over time [5]. The efficiency of these national solar cells has reached about 11% [5]. For the best solar cell research skills of third-generation solar cells please see Figure 1.15 below.

**4 TH Generation Solar Cells and Future Trend:** The solar cells in this division combine third-generation technologies to create 4th generation solar cell technology. An example is the nanocrystalline / polymer solar cell, a composite photovoltaic cell technology that combines the components of solid 26 states and organic PV cells to form a hybrid-nanocrystalline oxide polymer composite cell. Although most of these technologies are still in the developing embryonic stage, it is predicted that these types of solar cells will significantly reduce the cost of solar installation. Another area where photovoltaic solar cell technology has achieved significant efficiency milestones is solid solar cell technology. An example is a multi-junction (III-Vs) solar cell that has recorded efficiency of over 41%. Figure 1.16 below shows the latest research on solar cell efficiency, courtesy of NRL (National Renewable Energy Laboratory), and Spectrolab.

# Chapter 2

# Photovoltaic Cell

## 2.1 Introduction

A photovoltaic (PV) cell is an energy-gathering technology that converts solar energy into an efficient energy emitter. A solar cell (also known as a photovoltaic cell or PV cell) is defined as an electrical device that converts light into electrical energy through photovoltaic effects. A solar cell is basically a p-n junction diode. A solar cell is a form of photoelectric cell, defined as a device whose electrical properties, such as current, voltage, or resistance, change when exposed to light.

Individual solar cells can combine modules commonly known as solar panels that ordinary single-junction silicon solar cells can produce a maximum open-circuit voltage of about 0.5 to 0.6 volts. By itself, it's not too much - but remember, these solar cells are tiny. Sufficient renewable energy can be created by assembling large solar panels. GH is a process that has a photovoltaic effect. There are different types of PV cells that all use semiconductors to communicate with photons to create electric currents from the sun.

## 2.2 Working Principle of Photovoltaic Cell

When the light reaches the P-N junction, the light photo can easily enter the junction with a very thin P-type layer. Light energy, in the form of photons, provides enough energy at the junction to form several electron-hole pairs. The event breaks the heat imbalance at the light junction. Free electrons in the reduction region can move rapidly towards the N-type of the junction.

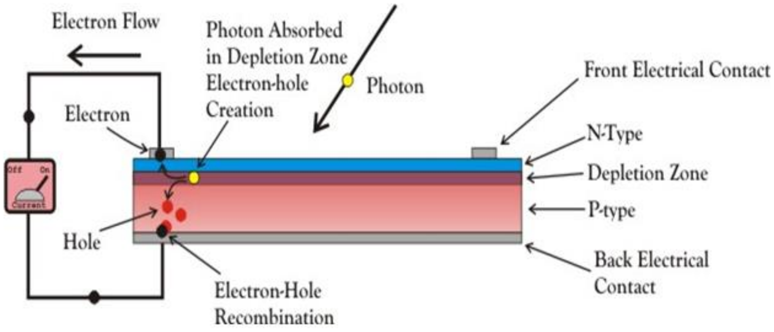


**Figure 2.1: Working Principle of Photovoltaic Cell.**

Similarly, the reduction holes can quickly come towards the P-type of the junction. Once, the newly formed free electrons come to the N-type, they cannot cross the junction further due to the possibility of junction obstruction.

Similarly, once the newly constructed holes reach the P-type, this junction can no longer be crossed with the same barrier potential of the junction. As the density of electrons increases, on the one hand, the N-type side of the junction and the density of the P-type hole on the other, the P-N junction will behave like a small battery. A voltage known as cell mesh voltage is set up if we connect a small load across the junction. However, a small stream will flow through it.

## 2.3 Photovoltaic Effect

The photovoltaic effect is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. These solar cells are composed of two different types of semiconductors—a p-type and an n-type—that are joined together to create a p-n junction. By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side.

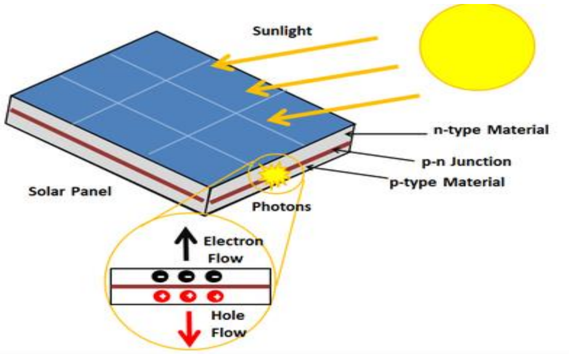


**Figure 2.2: Photovoltaic Effect**

This field is made up of light photons that carry negatively charged particles on one side and positively charged particles on the other, which are simply small bundles of electromagnetic radiation or energy. When the light of suitable wavelength appears in these cells, energy from the photon is transferred to an electron of the semiconductor material, causing it to move to a higher energy position known as the conduction band. In their excited state in the conductive band, these electrons are reluctant to pass through matter and it is this motion of the electrons that create the electric current in the cell.

## 2.4 Theory of I-V Characterization

A curve of the fourth character is a set of graphical curves used to define the functionality of components for electrical circuits, short or electrical devices, or for curves characterized only by current-voltage. As its name implies, the curves characterized by Ivy show the relationship between the current flowing through the electronic devices and the voltage used at its terminals.

The graph shows the running current voltage (I-V) characteristics of a typical silicon PV cell under normal conditions. The energy supplied by solar cells is the product of current and voltage (IXV). When the property is complete, make a point for the point, for all voltages from short circuit to open-circuit condition, the upper power curve is available for a given radiation level.

The solar cell is open-circuit, it is not connected to any load, the current will be its minimum (zero) and the voltage across the cell is the maximum, solar cells are known as open circuit voltage or vacuum. When the solar cell conducts briefly, it is the positive and negative lead that are connected to each other, the home voltage is the lowest (zero) but the current flowing outside the cell reaches the maximum in the solar cell short circuit.

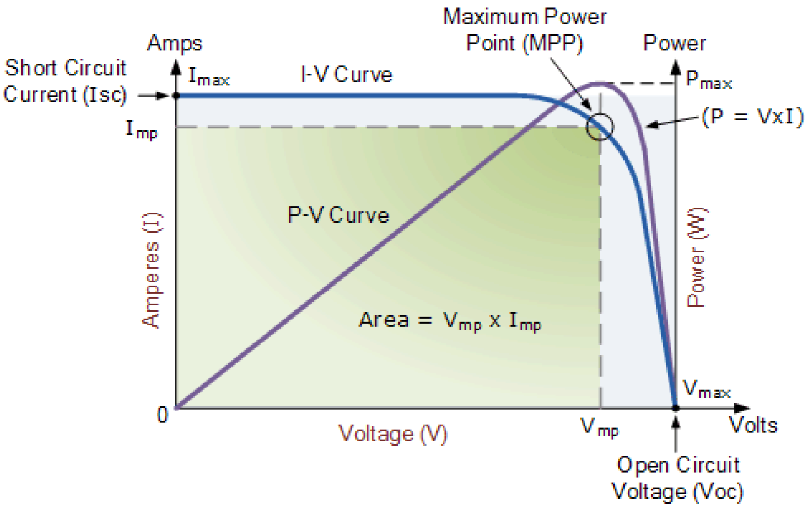


**Figure 2.3: Solar Cell I-V Characteristic Curve**

Solar cell IV properties then range from fully open circuit voltage (VOC) to zero current to curved short circuit current (ICC) to zero output voltage. The maximum voltage received from a house is in the open circuit and the maximum current is in the closed circuit. Of course, neither of these two conditions produces electrical energy, but solar cells must have a point to produce maximum electricity.

There is a special combination of current and voltage for which the power reaches its maximum value, impressions and VMP. The house then produces the most electrical energy and it appears at the top of the green rectangle it appears to be the "maximum power point" or MPP. Thus the ideal operation of a photovoltaic cell (or panel) is defined as the maximum power point.

The maximum power point (MPP) of a solar cell featuring Iv is located near a curve. Values related to VMP and EM can be inferred from open circuit voltage and short circuit current: VMP ≅ (0.8–0.90) VOC and Imp0 (0.85–0.95) SQ. Since the solar cell is dependent on both the output voltage and the current temperature, the actual output energy will vary with the change in ambient temperature.

### 2.4.1 I-V Characteristic Curve of a Diode

When the diode is biased, it is positive with respect to the cathode, a forward or positive current passes through the diode and the IV properties act as the upper right quadrant of the curve.

Starting from the zero intersection, the curve gradually becomes quadrilateral but continues and the voltage is extremely small

When the forward voltage exceeds the diodes the p-n junctions the internal barrier voltage which is about 0.7 volts for silicon, freezing occurs and the forward current increases rapidly due to a very slight increase in the linear curve output voltage. "Knee" points on the front bend.

When the diode is inversely biased, the ion matching cane is positive, the diode blocks the current by omitting a very small leakage current, and acts in the left quadrant below the IV-characteristic curve. The reverse voltage across the diode exceeds its breakdown voltage point until the diode continues to keep the current flowing through it, creating a lower bend of the reverse straight line due to sudden voltage loss control. This reverse breakdown voltage point is used to have a good effect on Zener diodes.

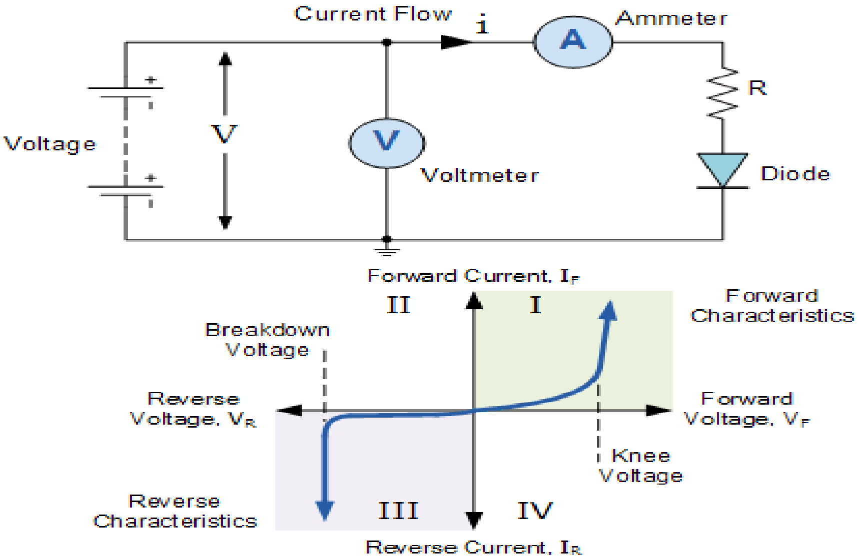


**Figure 2.4: I-V Characteristic Curve of a Diode.**

We then see that the IV-characteristic curves for silicon diodes are non-linear and very distinct from the linear fourth curves of the early resistors because their electrical properties are different. Curves of current-voltage properties can be used to conduct any electrical or electronic material, from resistors to amplifiers, to semiconductors, and to solar cells.

The current-voltage characteristics of electronic components tell us a lot about its effectiveness and the possible combinations of current and voltage can be a useful tool in determining the operating characteristics of a particular device or component and can help as a graphical aid to better understand visually.

### 2.4.2 Short Circuit Current Isc

The short circuit current flowing through the solar cell is when the voltage of the solar cell is zero (e.g., when the solar cell is in a small circle).

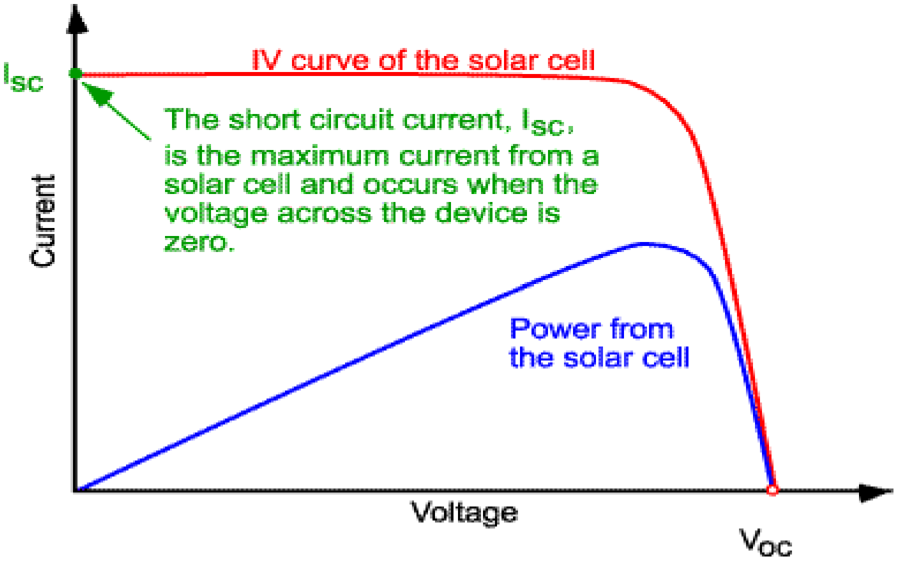


**Figure 2.5: IV curve of a solar cell showing the short-circuit current.**

The shorter the current ISC analyzes the shorter conditions when the resistance is low and the solution is reached when the voltage reaches 0.

Short circuit current ISC: It is the current flowing through the outer circuit.

When the electrodes of a solar cell are briefly performed. Short circuit current.

The event depends on the photon flux concentration and the event light spectrum.

Measure spectrum standardized standard solar cell parameters for AM1.5. For the ideal solar chamber, isk = ifton. And this

The maximum current distribution capacity of a solar cell in the case of a given illumination

The maximum ISCT level is obtained by spectral integration from level 1.10

Distributed from short wavelengths to maximum wavelengths where electronic-hole pairs can be made for a given semiconductor. The general relationship E (eV) = 1.24 /% wavelength and photon energy is 1.1eV and the gap between the silicon band is about 1.13 m Crystal silicon solar cells can deliver a maximum of 46 mA / cm2 under an AM 1.5 spectrum I (v = 0a) = Isaac.

SKT occurs at the beginning of forward-trend clearing and is the most offensive motivation in the energy quadrant.

For an ideal chamber, it is the subject of the most significant currents that is the strong and active flow caused by photon excitation in the sun-controlled chamber.

ISC = IMX = IL Forward-Inclination Control Quadrant.
When comparing solar cells of the same material type, the most critical material parameter is the diffusion length and surface passivation. In a cell with perfectly passivated surface and uniform generation, the equation for the short-circuit current density can be approximated as:

$$JSC=qG(Ln+Lp)$$

Where G is the generation rate, and $L_n$ and $L_p$ are the electron and hole diffusion lengths respectively. Although this equation makes several assumptions which are not true for the conditions encountered in most solar cells, the above equation nevertheless indicates that the short-circuit current depends strongly on the generation rate and the diffusion length.

The short circuit current, $I_{SC}$, is the short circuit current density, $J_{SC}$, times the cell area:

$$ISC=JSCA$$

Silicon solar cells under an AM1.5 spectrum have a maximum possible current of 46 mA/cm$^2$. Laboratory devices have measured short-circuit currents of over 42 mA/cm$^2$, and commercial solar cell have short-circuit currents between about 28 mA/cm$^2$ and 35 mA/cm$^2$.

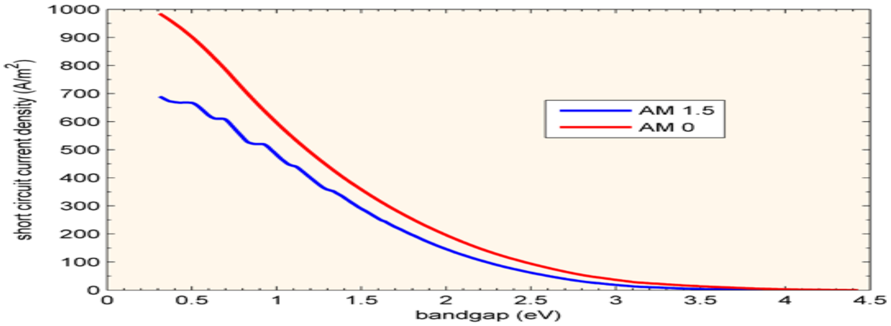


**Figure 2.6 Highest current is for the lowest band gap.**

In an ideal device every photon above the band gap gives one charge carrier in the external circuit so the highest current is for the lowest band gap.

### 2.4.3 Open-Circuit Voltage (Voc)

The open-circuit voltage, VOC, is the maximum voltage available from a solar cell, and this occurs at zero current(open circuit). The open-circuit voltage corresponds to the number of forward-bias on the solar cell due to the bias of the solar cell junction with the light-generated current. The open-circuit voltage is shown on the IV curve below.

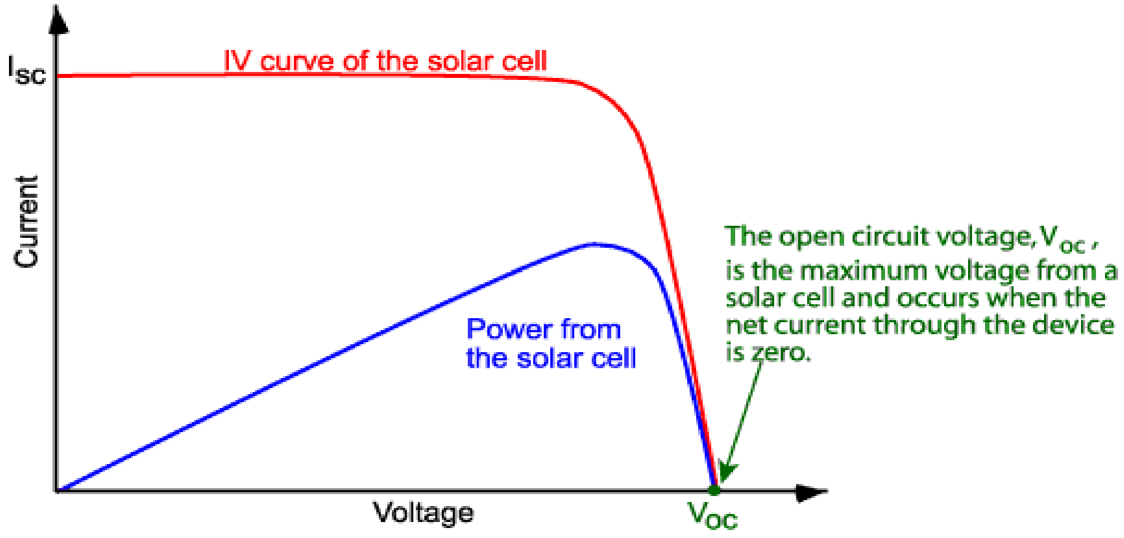


**Figure 2.7: IV curve of a solar cell showing the open-circuit voltage.**

An equation for $V_{oc}$ is found by setting the net current equal to zero in the solar cell equation to give:

$$V_{OC} = \frac{nkT}{q} \ln\left(\frac{I_L}{I_0} + 1\right)$$

A casual inspection of the above equation may indicate that the VOC goes up linearly with temperature. This is not the case, however, because primarily due to changes in internal carrier density, i0 increases rapidly with temperature The effects of i temperature are complex and change with cell technology.

The above equation shows that the saturation of unstable solar cells depends on current and light-generated flux. Although ISK usually has a short variant, the main effect is the saturation current, as it may vary in size. Saturation current, I0 depends on the rehabilitation of solar cells. The open-circuit voltage is then a measure of the amount of connection to the device. Silicon solar cells in high-quality single-crystal components have an open-circuit voltage of up to 764 mV under the sun and AM 1.5 condition 1.

Commercial devices of multi-crystalline silicon typically have an open-circuit voltage of about 600 mV.The $V_{OC}$ can also be determined from the carrier concentration 2

$$V_{OC} = \frac{kT}{q} \ln \left[ \frac{(N_A + \Delta n)\Delta n}{n_i^2} \right]$$

where kT/q is the thermal voltage, $N_A$ is the doping concentration, Δn is the excess carrier concentration and $n_i$ is the intrinsic carrier concentration. The determination of $V_{OC}$ from the carrier concentration is also termed Implied $V_{OC}$.

### 2.4.4 Current at *PMAX* (*IMP*), Voltage at *PMAX* (*VMP*)

The power made by the cell in Watts can be adequately decided along the I-V clear by the condition P = IV. At the ISC and VOC centers, the power will be zero and the most extraordinary impetus for power will occur between the two. The voltage and current at this most noteworthy power point are demonstrated as VMP and IMP independently.

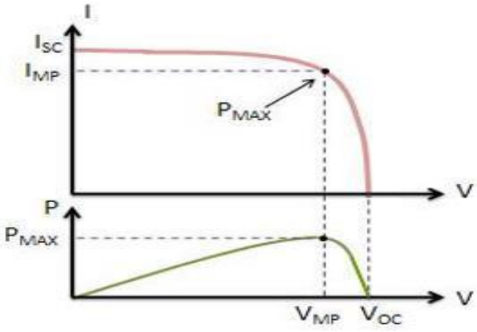


**Figure 2.8: Current, Voltage and Power Curves.**

### 2.4.5 Fill Factor

The fill factor is the ratio between the maximum power (Pmax = ImpVmp) generated by a solar cell and the product of Voc with Isc

$$FF = \frac{I_{MPP} \cdot V_{MPP}}{I_{SC} \cdot V_{OC}}$$

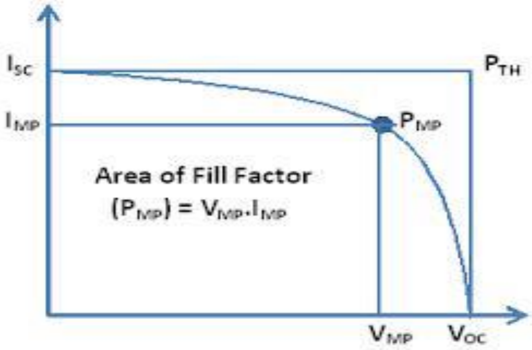


**Figure 2.9: The maximum power point (MPP) & I-V characteristic.**

The subscript “mpp” in Eq.denotes the maximum power point (MPP) of the solar cell, i.e. the point on the I-V characteristic of the solar cell, at which the solar cell has the maximal power output. To optimise the operation of PV systems, it is very important, to operate the solar cells (or PV modules) at the MPP. This is ensured with maximum power point tracking (MPPT),

$$\mathrm{FF}_{\mathrm{max}} = \frac{v_{\mathrm{OC}} - \ln(v_{\mathrm{OC}} + 0.72)}{v_{\mathrm{OC}} + 1}, \quad \text{with} \quad v_{\mathrm{OC}} = \frac{qV_{\mathrm{OC}}}{n_{\mathrm{ID}} k_{\mathrm{B}} T},$$

Assuming that the solar cell behaves as an ideal diode, the fill factor can be expressed as a function of open-circuit voltage Voc is a normalised voltage.

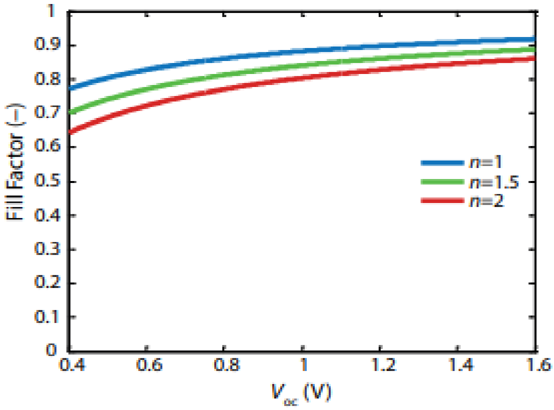


**Figure 2.10: The FF as a function of Voc for a solar cell with ideal diode behavior**.

Figure 2.10 is a good approximation of the ideal value of FF for voc > 10. The FF as a function of Voc is illustrated in Figure 2.10. This figure shows that FF does not change drastically with a change in Voc. For a solar cell with a particular absorber, large variations in Voc are not common. For example, at standard illumination conditions, the difference between the maximum open-circuit voltage measured for a silicon laboratory device and a typical commercial solar cell is about 120 mV, giving a maximal FF of 0.85 and 0.83, respectively. However, the variation in maximum FF can be significant for solar cells made from different materials. For example, a GaAs solar cell may have a FF approaching 0.89.

### 2.4.6 I-V Curves for Modules

For a module or cluster of PV cells, the state of the I-V bend does not change. Nonetheless, it is scaled dependent on the quantity of cells associated in arrangement and in parallel. At the point when n is the quantity of cells associated in arrangement and m is the quantity of cells associated in parallel and ISC and VOC are values for individual cells, the I-V bend appeared in Figure 2.11 is created.

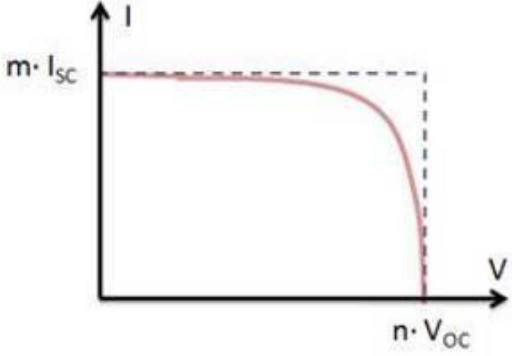


**Figure 2.11: I-V Curves for Modules**

# . Chapter 3

# Solar Panel Efficiency

## 3.1 Introduction

A PV module specification sheet usually contains a module efficiency standard. We know these numbers

Performance is an indication, but aren't they just mentioned? The efficiency of the PV module is only a second of a ratio: the presence of solar energy STC conditional panels (this is an unnecessary standard test condition of 1000 watts per square meter, a cell temperature of 25° C and an air mass) of 1.5, which determines the wavelength of light presence). Divided by the module of the power output. The PV module efficiency symbol is denoted by 'η' if a solar module can fully convert energy, which means 100% efficiency, power output equal to available energy. This is not possible because there are various causes of energy loss

.

A. Solar energy is reflected by the glass covering

B. Shades of metal conductors at the top of the cells for electrical collection generate current.

C. Not all solar energy is converted to electricity through the photovoltaic effect - some light wavelengths have excess energy and nothing is sufficient to generate electricity.

d. As it travels through the power cell and cell interconnection, it becomes electrically resistant as a result of heat resistance. The source of energy loss in solar panels. The efficiency of the module will always be less than the efficiency of the PV cell. The reason for the disadvantages of PV modules is the reflection of the light glass, the shadow of the houses from the connection bars, and the interconnection of the modules to increase the electrical resistance is not a solar cell. Determines strength. E sync (η) = Power output (as electricity) Power available (as solar radiation)

## 3.2 Efficiency of solar Panel

The ability to compare the performance of one solar cell with another is the most used parameter. Efficiency is defined as the ratio of energy from solar cells to input energy to solar output. In addition to reflecting the efficiency of the solar cell, the efficiency depends on the spectrum and intensity of sunlight and the temperature of the solar cell. Thus, the conditions under which efficiency is measured must be carefully controlled to compare the performance of one device with another. Terrestrial solar cells are measured under the AM1.5 condition and at a temperature of 25°C the solar cells are measured under the AM0 condition for space use. The latest top efficiency solar cell results are given in the solar cell efficiency results.

The efficiency of a solar cell is determined as the fraction of incident power which is converted to electricity and is defined as:

$$P_{max} = V_{OC} I_{SC} FF$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{in}}$$

Where:

$V_{oc}$ is the open-circuit voltage;

$I_{sc}$ is the short-circuit current;

$FF$ is the fill factor and

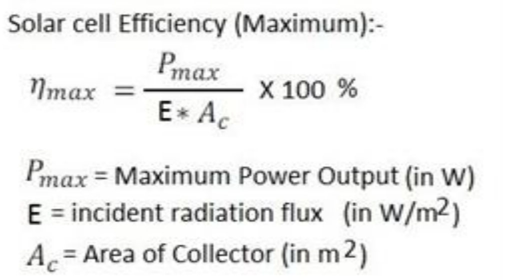
$\eta$ is the efficiency.

The input power for efficiency calculations is 1 kW/$m^2$ or 100 mW/$cm^2$. Thus the input power for a 100 × 100 $mm^2$ cell is 10 W and for a 156 × 156 $mm^2$ cell is 24.3 W

## 3.3 Maximum Efficiency of solar Panel

The efficiency of a solar panel is that the surface area of the solar panel is reduced to convert the usable electricity into sunlight. The higher the efficiency rating, the more sunlight your solar system can convert your home into electricity.

With the advancement of solar technology, the efficiency rating of the average solar cell continues to increase. At the same time, the price of the solar continues to decline. This means you can now get solar which is cheaper and more efficient than before!



Solar cell Efficiency (Maximum):-

$$\eta_{max} = \frac{P_{max}}{E * A_c} \text{ X } 100\ \%$$

$P_{max}$ = Maximum Power Output (in W)
E = incident radiation flux (in W/m$^2$)
$A_c$ = Area of Collector (in m$^2$)

According to the National Renewable Energy Laboratory (NRL), the efficiency of most solar panels sold in 2020 ranges from 15% to 20%. Some solar panels on the market have an efficiency of more than 20% - these are known as high efficiency solar panels.

## Solar panel efficiency rating of PV models by manufacturer

| **Solar Panel Manufacture** | **Mini. Efficiency** | **Max. Efficiency** | **Ave. Efficiency** |
|---|---|---|---|
| Sun Power | 16.50% | 22.80% | 20.72% |
| LG Solar | 18.40% | 22.00% | 20.04% |
| REC Group | 16.50% | 21.70% | 19.02% |
| CSUN | 19.88% | 21.17% | 20.53% |
| Solaria | 19.40% | 20.50% | 19.76% |
| Axitec | 18.96% | 20.45% | 19.78% |
| Panasonic | 19.10% | 20.30% | 19.66% |
| Trina Solar | 16.20% | 19.90% | 17.95% |
| JA Solar | 15.80% | 19.80% | 17.92% |
| Risen | 16.30% | 19.60% | 18.12% |

**3.1 Table: Solar panel efficiency rating of PV models by manufacturer**

Most solar panels are between 15% and 20% efficient, with outliers on either side of the range. High-quality solar panels can exceed 22% efficiency in some cases (and almost reach 23 %!), but the majority of photovoltaic panels available are not above 20% efficiency.

## 3.4 Measuring Efficiency of solar Panel

The most basic of solar cell characterization techniques is to measure cell efficiency. Standardized testing allows comparing devices produced with different technologies in different organizations and laboratories. Cell testing values:

1. Air mass 1.5 spectra (AM 1.5) for terrestrial cells and air mass 0 (AM 0) for space cells.
2. Intensity of 100 mW / cm2 (1 kW / m2, also known as one-sun of illumination).
3. Cell temperature 25 degrees (not 300 K).
4. Search for four points by removing the effect of resistance to probe/cell contact.

At the same time, it is difficult and expensive to create a system that meets all of the above criteria. Most research laboratories have general custom-built testers that are approximate only with the above conditions. The results of the "sitting at home" test are approximate. Periodically companies and research institutes will send the devices to a certified laboratory for verification with record efficiency. Such skills are published as "confirmed skills" with the name of the test center and the date of the test.

## 3.5 Output of a photovoltaic system

The global formula to estimate the electricity generated in output of a photovoltaic system is:

$$E = A * r * H * PR$$

**E** = Energy (kWh)

**A** = Total solar panel Area (m2)

**r** = solar panel yield or efficiency (%). r is the yield of the solar panel given by the ratio: electrical power (in kWp) of one solar panel divided by the area of one panel.

**H** = Annual average solar radiation on tilted panels (shadings not included). H is the annual average solar radiation on tilted panels.

**PR** = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75) PR (Performance Ratio) is a very important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses.

## 3.6 Type of Solar Panel Efficiency Losses

- DC to AC Conversion Losses 10 %
- Temperature losses 11%
- Dirt and Dust Losses 7%
- Module Mismatch losses 2%
- Wiring (Ohmic) losses 3%
- DC to AC Conversion losses 10%
- Transformation losses 2%
- Shadings 0 % to 80%!!! (Specific to each site)
- Losses at weak radiation 3% to 7%

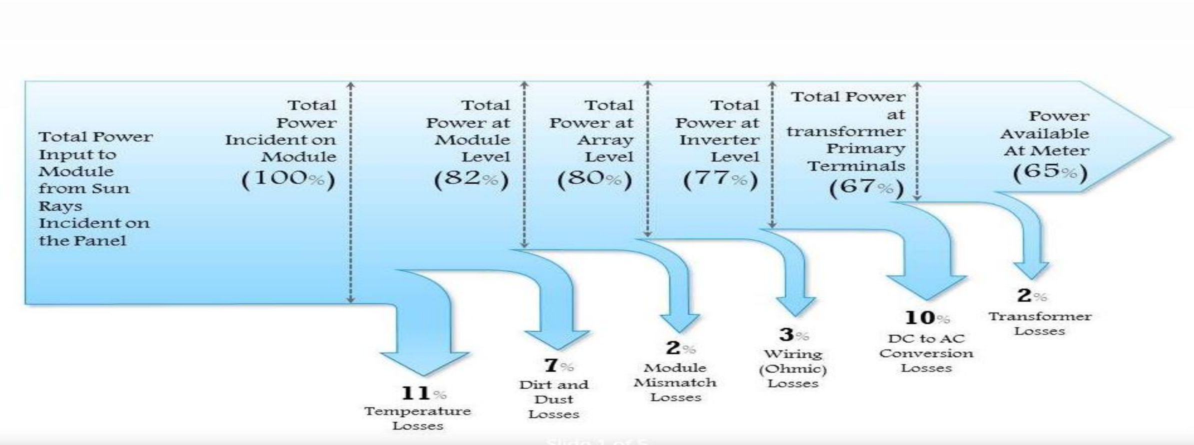


**Figure 3.1:** **PR value depends on the site, the technology, and sizing of the system**

### 3.6.1 PV Temperature Efficiency losses

Solar panels, also called photovoltaic panels, collect visible sunlight and convert it into energy to generate electricity. Since solar panels work directly with the sun, many wonder how the ambient air temperature plays a role in how solar panels operate.

For example, is the solar panel more efficient or less efficient if the ambient air is hot? Although the power and duration of sunlight are more important, temperature plays a big role in the efficiency of your solar panel. As the temperature of the module increases, so does the efficiency of our solar panels. Due to the temperature, we achieve 20% less efficiency.

### 3.6.2 Irradiation Efficiency loss

Damage due to low space, some discomfort between the two rows in the morning and evening will not be collected by solar cells which were earlier identified as “linear shading damage” due to deterioration of bulk C-based solar photovoltaic (PV) panels affects the efficiency of electronic components and is combined with a reduction in the yield of the PV system. Thus, careful planning of PV sizing and efficiency of PV panels is important to determine the amount of this underlying loss. In this work, the effects of different solar radiations on the efficiency of crystal C-based solar panels have been measured through a fancy mathematical framework, which is a model of performance degradation based on actual isolation and temperature profile. Outbreaks of these losses are mainly attributed to open-circuit voltage reduction and panel filling factors, which reduces conversion efficiency. An empirical relationship also emerges, which is related to the reduction of energy cut in the actual peak-sunlight of a region. The results show that this low radiation loss has a linear dependence on the approximate equivalent sunlight period (EPSH).

## 3.7 Current-Voltage (IV) Curve

The current-voltage (IV) curve shows the possible combinations of current and voltage outputs of a photovoltaic (PV) device. A PV device, such as a solar module, produces its maximum current when there is no resistance in the circuit, i.e. when there is a short circuit between its positive and negative terminals. This maximum current is known as short circuit current and is shorted. When the module has shorted the voltage of the circuit is zero.

Conversely, the maximum voltage if there is a break in the circuit. This is called the open-circuit voltage. The resistance under this condition is infinitely high and there is no current since the circuit is incomplete.

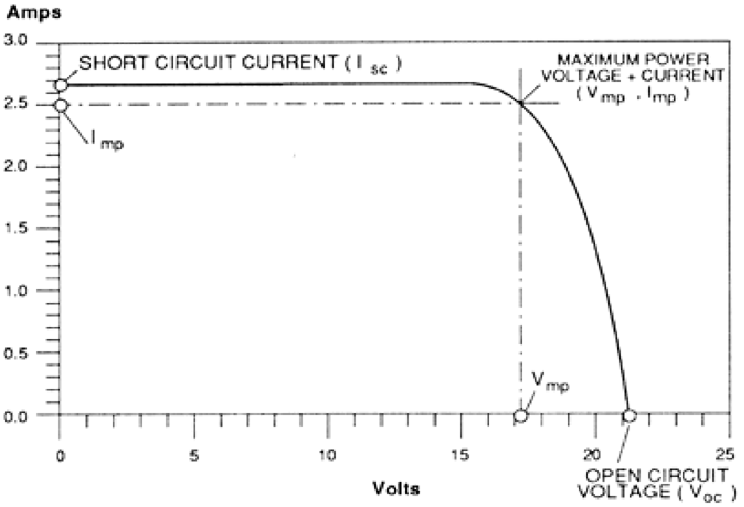


Figure 3.2: Current-voltage (IV) curve

These two extreme load resistances and the full range of conditions between them are illustrated in the IV curve. The current expressed in ampoules, the volts above the (vertical) y-axis, the volts above the (horizontal) x-axis.

The energy received from a photovoltaic device at any time along a bend is only expressed in current and voltage products and watts at that time. At the short circuit current point, the power output is zero, since the voltage is zero. At the open-circuit voltage point, the power output is also zero, but the current factor is zero.

The curved knee has a point where the maximum power output is located. Our example is this maximum power point of the curve where the voltage is 17 volts and the current is 2.5 MP so the maximum power of 1 volt is multiplied by 2.5 volts or 42.5 watts.

The curved IV device of a PV device is assumed to be subject to standard conditions of sunlight and the temperature of the device assuming that there is no shadow on the device. On clear days, standard sunlight is calculated as 1000 watts of solar energy per square meter (1000 W / m2 or 1 kW / m2). It is also sometimes called the sun or the top sun. Less than one sun will proportionally reduce the current output of the PV device. For example, if only one and a half suns (500 W / m2) are available, the amount of output current is cut in half.

# Chapter 4

# Solar Panel Efficiency

## 4.1 Introduction

To improve the efficiency of solar photovoltaic devices, three types of corrosion reduction are required: optical, electrical, and thermal. However, further reduction in optical and electrical losses in modern photovoltaic devices is becoming increasingly costly. Thus, there is a growing interest in heat dissipation. These are combined with a decrease in electrical power output and a skin-related increase in conduction at temperatures up to 25 C. Our proposed general method is suitable for each photovoltaic technology for research to reduce heat loss.

## 4.2 Temperature Co-Efficient

A temperature coefficient describes the relative change of a physical property that is associated with a given change in temperature.

Where is defined:

R0 = R (T0)

And α is independent of T.

Integrating the temperature coefficient differential law:

$$R(T) = R_0(1 + \alpha(T - T_0))$$

Applying the Taylor series approximation at the first order, in the proximity of T0, leads to:

For a property *R* that changes *when the temperature changes by* dT, *the temperature coefficient α is defined by the following equation:*

$$\frac{dR}{R} = \alpha\, dT$$

Here α has the dimension of an inverse temperature and can be expressed e.g. in 1/K or $K^{-1}$.

If the temperature coefficient itself does not vary too much with temperature and ,
a linear approximation will be useful in estimating the value *R* of a property at a temperature *T*, given its value $R_0$ at a reference temperature $T_0$:

$$R(T) = R(T_0)(1 + \alpha\Delta T),$$

Where $\Delta T$ is the difference between *T* and $T_0$.

The problem is when the temperature of the panel is more than about 25 degrees Celsius, the power outputs of the solar panel start to decrease.
Because of this, if you look at the specification label of the solar panel, most manufacturers cite the solar power output at a panel temperature of 25 degrees.
So does this mean that if it is outside 25 degrees Celsius and has a clear blue sky, your panels will perform their rated output?
Because, if the external air temperature is 25 degrees centigrade, baking dark solar panels on your roof will move closer to 50 degrees centigrade.
So if the panel manufacturer quotes the output of electricity at a temperature of 25 degrees C solar panel, how much solar energy would you lose at a temperature of 25 degrees C?
For this, to work we need to know the "maximum energy temperature coefficient" of the solar panel which should be on the blueprint sheet of the solar panel.

When the temperature coefficient is minus 0.5 percent that means the capability is reduced by 0.5 percent for every degree above 25 degrees Celsius (or 33.7 degrees above 33.7 degrees Fahrenheit).
So at a cooler 25 degrees centigrade where the panel is cooking at 50 degrees centigrade, you will lose 12.5% of your solar power.
For example:
0.5% x (50 ° C-25 ° C) = 0.5% x 25 ° C = 12.5%
And the day the mercury breaks down to 40 degrees Celsius you can lose about 20% of your solar energy.
That is why you can often find that the solar panels on your roof produce less solar energy than usual on the warmest days.

## 4.3 Temperature Measurement

As described, the electrical yield depends on the turbulence but is directly affected by the temperature. The most interesting temperature of the module is actually one of the p-n junctions. ISC (short circuit current) can be considered almost as distinct in T (due to subtraction values for temperature coefficient) and only as a function in G (not for thin-film modules, which differ in the case of poor light behavior)). This increases with higher temperatures, which can be explained by the increased absorption resulting in a reduction in the bandgap. VOC (Open Circuit Voltage) is more sensitive to temperature and reduction as well as efficiency η and fill factor FF:

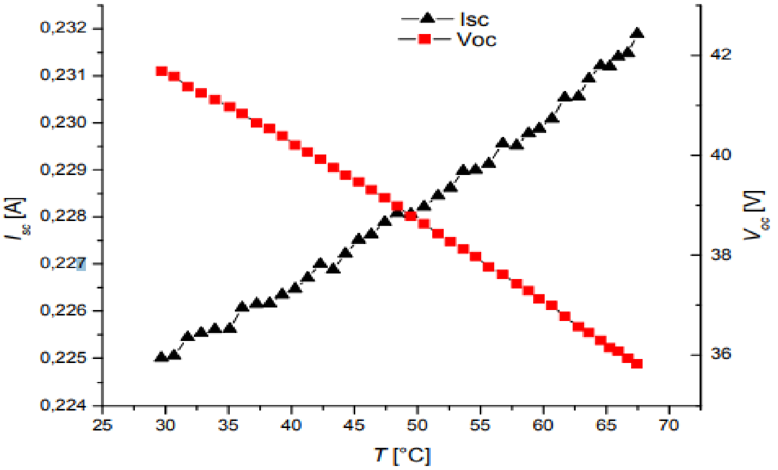


**Figure 4.1: I-V characteristics.**

Short circuit current ISC (black) and open circuit voltage VOC (red) as a function of module temperature T. Measurements have been carried out to extrapolate the temperature coefficients for voltage and current.

To determine the junction temperature according to IEC 60904-5 it is necessary to have the temperature coefficient β for the voltage and to have weak light measurements.

$$T_2 = T_1 + \beta^{-1}\left(V_{OC2} - V_{OC1} + D\frac{1}{ns}\ln\left(\frac{G_1}{G_2}\right)\right)$$

In that expression D is the thermal voltage and has to be measured in two additional weak light tests; ns is the number of cells in series. To improve accuracy temperature measurements and

NOCT determination have to be carried out precisely due to the negative temperature coefficients for PV power generation. However, we found significant deviations for different practices of temperature measurement and resolution. The following article compares six different methods for determining the operating temperature of a PV module:

1. Determining the junction temperature through the open-circuit voltage of the cell.
2. Cell temperature measurement using cell connected Pt100 foil-sensor, layered inside the module
3. Surface measurement via the attached PT-100 sensor (with and without thermal conductive paste).
4. Measure the surface by PT-100 sensors attached to different thicknesses of layers of fixation tape to prevent cooling from the sensor range.
6. Additionally we found that unqualified ambient temperature measurement can lead to deviations of ±2 K even using accurate temperature sensors.

## 4.4 Modula Temperature

A PV module is typically rated at 25 degrees C below 1 kW / m2. However, when working in the case they are usually operated at high temperatures and at slightly lower excitation conditions to determine the power output of a solar cell, it is important to determine the expected operating temperature of the PV module. Nominal Operating Cell Temperature (NOCT) .

A module is defined as the temperature obtained by an open circuit cell as listed below:

1. Illumination on the surface of the room = 800 W / m2
2. Air temperature = 20. He
3. Wind speed = 1 m / s
4. Mounting = open back.

The equation of solar radiation and the temperature difference between the module and the air show that both conductivity and conductor loss are linear with the solar impulse relevant to particular wind speed if the thermal resistance and heat transfer coefficient are not strongly separated by temperature. Shown below for the best case, worst case, and average PV modules. For optimal cooling, the module includes an aluminum wing at the back that reduces heat resistance and increases the surface area for flow.

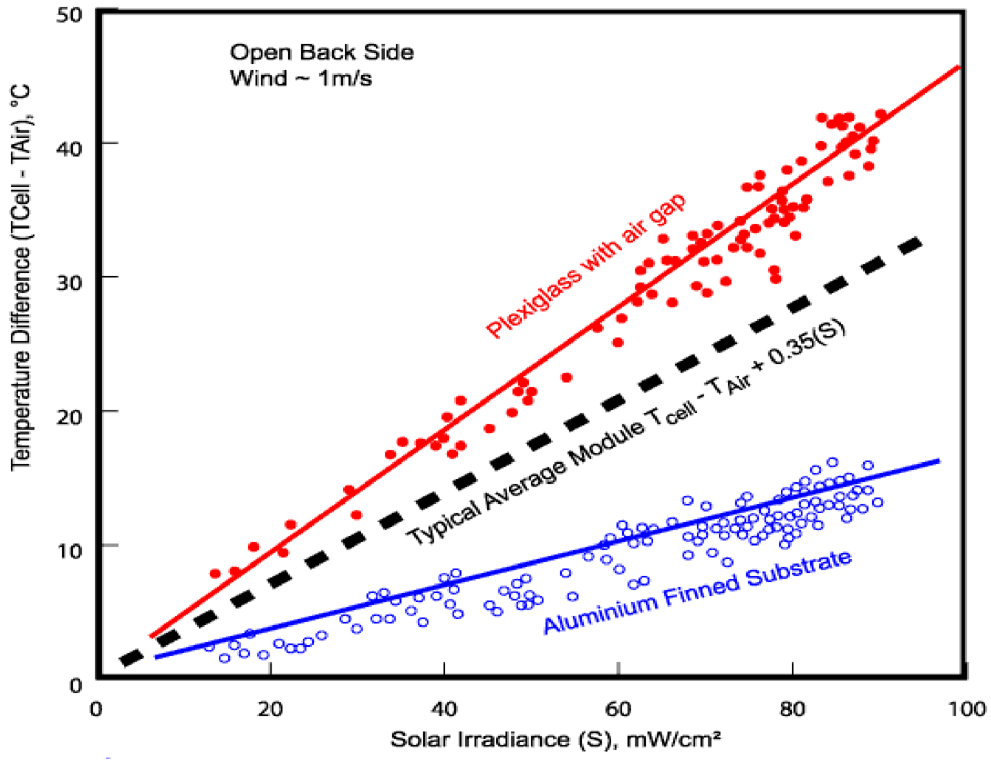


*Figure 4.2: Temperature increases, above ambient levels, with increasing solar irradiance for different module types*

The best module operated at a NOCT of 33°C, the worst at 58°C and the typical module at 48°C respectively. An approximate expression for calculating the cell temperature is given by

$$T_{Cell} = T_{Air} + \frac{NOCT - 20}{80} S$$

Where:

S = insolation in mW/cm$^2$. Module temperature will be lower than this when wind velocity is high, but higher under still conditions.

## 4.5 Temperature Effect at Solar Output.

Free electrons and some electron-containing substances are held tightly by the nucleus of the atom. As the inequality increases many more packets hit the panel and this energy is absorbed by atoms and electrons and collides with each other emitting more electrons from the atoms and thus increasing the temperature. An increase in temperature increases the resistance to current flow. Efficiency also depends on temperature. Output efficiency decreases at higher temperatures of the solar panel than at lower temperatures [10]. According to estimates for each degree, the efficiency of the PV module decreases by 0.5 as the temperature increases.

Percent. PV modules are usually produced at 25o

C (77oF) and can be driven above 20oC.

Like all other semiconductor devices, solar cells are sensitive to temperature. The increase in temperature reduces the bandgap of the semiconductor, which in turn affects the parameters of most semiconductor components. A semiconductor band with increasing temperature is seen as an increase in electrical energy as a gap-reducing element. It takes less energy to break the bond. In the bond model of semiconductor band spacing, the decrease in bond strength also reduces the band spacing. Thus increasing the temperature reduces the band break.

In a solar cell, the parameters that are most affected by the increase in temperature are the open-circuit voltage. The effect of rising temperature is shown in the figure below.

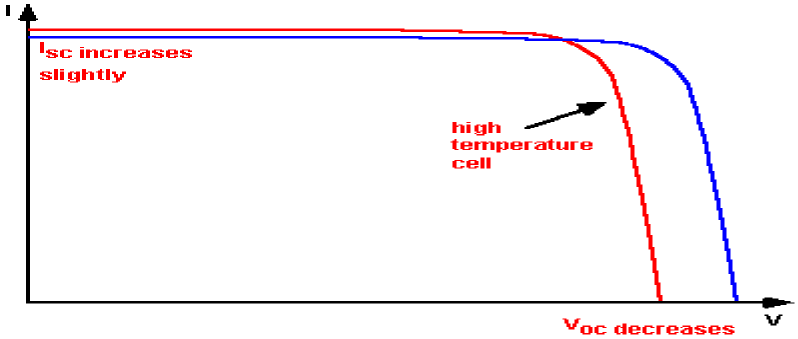


***Figure 4.3: The effect of temperature on the IV characteristics of a solar cell.***

The open-circuit voltage decreases with temperature because of the temperature dependence of $I_0$. The equation for $I_0$ from one side of a *p-n* junction is given by;

$$I_0 = qA\frac{Dn_i^2}{LN_D}$$

where:

q is the electronic charge given in the constants page;

A is the area;

D is the diffusivity of the minority carrier given for silicon as a function of doping in the Silicon Material Parameters page;

L is the minority carrier diffusion length;

$N_D$ is the doping; and

$n_i$ is the intrinsic carrier concentration given for silicon in the Silicon Material Parameters page**.**

In the above equation, many parameters have some temperature dependence but the most significant effect is due to the density of the interconnected carrier, NI. The density of the internal carrier depends on the bandgap strength (lower bandgaps give higher internal carrier density) and on the strength of the conductors (higher temperature gives higher internal carrier density). The equation for internal carrier density;

$$n_i^2 = 4\left(\frac{2\pi kT}{h^2}\right)^3 (m_e^* m_h^*)^{3/2} \exp\left(-\frac{E_{G0}}{kT}\right) = BT^3 \exp\left(-\frac{E_{G0}}{kT}\right)$$

Where:

T is the temperature;

h and k are constants given in the constants page;

$m_e$ and $m_h$ are the effective masses of electrons and holes respectively;

$E_{GO}$ is the band gap linearly extrapolated to absolute zero; and

B is a constant which is essentially independent of temperature.

Substituting these equations back into the expression for $I_0$, and assuming that the temperature dependencies of the other parameters can be neglected, gives;

$$I_0 = qA\frac{D}{LN_D} BT^3 \exp\left(-\frac{E_{G0}}{kT}\right) \approx B'T^{\gamma} \exp\left(-\frac{E_{G0}}{kT}\right)$$

Where

B' is a temperature independent constant

A = constant,

γ= is used instead of the number 3 to incorporate the possible temperature dependencies of the other material parameters. For silicon solar cells near room temperature,

$I_0$ =approximately doubles for every 10 °C increase in temperature.

The impact of $I_0$ on the open-circuit voltage can be calculated by substituting the equation for $I_0$ into the equation for $V_{oc}$ as shown below;

$$V_{OC} = \frac{kT}{q}\ln\left(\frac{I_{SC}}{I_0}\right) = \frac{kT}{q}[\ln I_{SC} - \ln I_0] = \frac{kT}{q}\ln I_{SC} - \frac{kT}{q}\ln\left[B'T^{\gamma}\, exp\left(-\frac{qV_{G0}}{kT}\right)\right]$$
$$= \frac{kT}{q}\left(\ln I_{SC} - \ln B' - \gamma \ln T + \frac{qV_{G0}}{kT}\right)$$

Where

$E_{G0} = qV_{G0}$. Assuming that $dV_{oc}/dT$ does not depend on $dI_{sc}/dT$, $dV_{oc}/dT$ can be found as;

$$\frac{dV_{OC}}{dT} = \frac{V_{OC} - V_{G0}}{T} - \gamma\frac{k}{q}$$

The above equation shows that the temperature sensitivity of a solar cell depends on the open circuit voltage of the solar cell, with higher voltage solar cells being less affected by temperature. For silicon, $E_{G0}$ is 1.2, and using γ as 3 gives a reduction in the open-circuit voltage of about 2.2 mV/°C;

$$\frac{dV_{OC}}{dT} = -\frac{V_{G0} - V_{OC} + \gamma\frac{kT}{q}}{T} \approx -2.2mV\ per\ {}^{o}C\ for\ Si$$

The short-circuit current, $I_{sc}$, increases slightly with temperature, since the band gap energy, $E_G$, decreases and more photons have enough energy to create e-h pairs. However, this is a small effect and the temperature dependence of the short-circuit current from a silicon solar cell is;

$$\frac{1}{I_{SC}}\frac{dI_{SC}}{dT} \approx 0.0006\, per\ \ {}^{o}C\ for\ Si$$

or 0.06% per °C for silicon.

The temperature dependency FF for silicon is approximated by the following equation;

$$\frac{1}{FF}\frac{dFF}{dT} \approx \left(\frac{1}{V_{OC}}\frac{dV_{OC}}{dT} - \frac{1}{T}\right) \approx -0.0015\, per\ \ {}^{o}C\ for\ Si$$

The effect of temperature on the maximum power output, $P_m$, is;

$$P_{Mvar} = \frac{1}{P_M}\frac{dP_M}{dT} = \frac{1}{V_{OC}}\frac{dV_{OC}}{dT} + \frac{1}{FF}\frac{dFF}{dT} + \frac{1}{I_{SC}}\frac{dI_{SC}}{dT}$$

$$\frac{1}{P_M}\frac{dP_M}{dT} \approx -(0.004\ to\ 0.005) per\ \ {}^{o}C\ for\ Si$$

Or 0.4% to 0.5% per °C for silicon.

Most semiconductor modeling is done at 300 K because it is close to room temperature and convenient numbers. Solar cells, however, are typically measured at 25° C (298.15 K) about 2°C. In most cases the difference is negligible (only 4 mV of the void) and both are referred to as room temperature.

## 4.6 Ambient Temperature

Ambient temperature is the air temperature of any object or environment where equipment is stored. Adjective envelope means "related to the surrounding environment". Also sometimes referred to as normal temperature or baseline temperature, this value is important for system design and thermal analysis.

In a computing context, maintaining the right ambient temperature is crucial to maintaining the proper functioning and longevity of the computer.

In general, a safe range is between 60 to 75 degrees Fahrenheit or 15 and 25 degrees Celsius, although the cooler edge of this range is better. Temperatures above this limit make it difficult to keep a computer's cooling system at a safe operating temperature.

| Month | Ambient temperature (%) | Efficiency (%) |
|---|---|---|
| January 2013 | 21.2 | 11.50 |
| February 2013 | 22.4 | 11.77 |
| March 2013 | 35 | 13.56 |
| April 2013 | 35.8 | 13.74 |
| May 2012 | 33.9 | 13.32 |
| June 2012 | 32.5 | 13.01 |
| July 2012 | 32.4 | 12.98 |
| August 2012 | 32.4 | 12.98 |
| September 2012 | 32.4 | 12.98 |
| October 2012 | 31.2 | 12.72 |
| November 2012 | 28.6 | 12.14 |
| December 2012 | 24.1 | 12.23 |

**Table 4.1: Variation of efficiency with ambient temperature for the period from May 2012 to April 2013.**

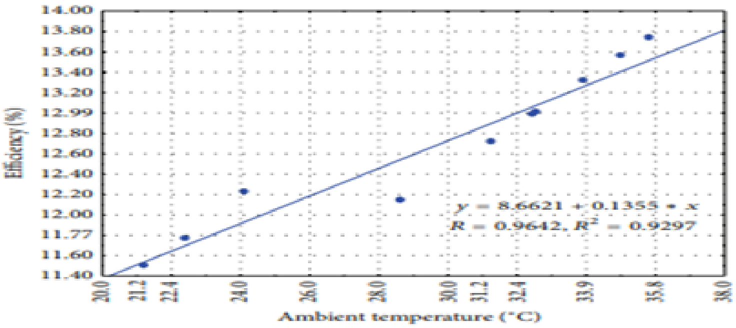


**Figure 4.4: Monthly average values of solar module efficiency and ambient temperature for the year 2012-2013.**

### 4.5.1 Measuring Ambient Temperature

The circumference of a room or component is measured using a thermometer or sensor. To ensure that the text is the most accurate, the measuring device must be shaded, in the middle of the room, and with good ventilation that allows air to flow freely.

When measuring the ambient temperature of the interior of the house, it is important to observe the temperature values above the length of the day to determine the maximum ambient temperature and the minimum. When determining the ambient temperature of the outdoor environment, the average of the historical temperature may be acknowledged.

One thing that is important to note is that some factors can sense the ambient temperature but not the temperature reading. Some of the factors involved in reading include moisture, air cooling, and insulation.

### 4.5.2 Importance of ambient temperature

Environmental temperature measurement is an important element in maximizing the longevity of the device, preventing errors, and avoiding damage. Some of the applications for knowing the ambient temperature of an item include:

The internal cooling system of a device verifies that it is adequately functioning as a laptop fan.

Ensures that ingredients such as food or chemicals are stored safely.

Determining the energy efficiency of a heating or cooling system.

Analyzes components to ensure maximum and minimum temperatures do not affect efficiency or usability.

To control the ambient temperature within acceptable limits.

Limit the wastage or flow of electricity at a safe price.

Solar Power Plant - Roof, Captive Solar Support Ambient temperature refers only to the ambient temperature and will be equal to the ambient temperature of the indoor room. Ambient temperatures are typically 1 degree C (and 1 and) 9 degrees F with an average of 20 degrees C (686 degrees F). Solar PV panels produce less energy in very hot summers because heat reduces their efficiency (reduces voltage).

# Chapter 5

# Enhancing the Efficiency of Solar Panel Using Cooling System

## 5.1 Introduction

The global power crisis, global warming, and deteriorating environment and energy sources are currently facing problems; Alternative energy sources are required for power generation

Without the use of fossil fuels, water, and air. Fossil fuel hydride will decline over the next few decades. Power plants depend on annual rainfall and wind dependence on climate change. Like energy, water, and wind, the sun is one of the earth's life-supporting systems.

The solar energy that provides heat and light to fill the renewable annual world and provides a wide range of clean energy The energy from the sun can be bound by about 1.8 1011 megawatts of earth which is larger than the current

Consumer rates in all commercial worlds are a source of energy. So solar energy can supply all current and future energy needs of the world on an ongoing basis. It promises to be one of the unconventional energy sources of the large technology used for this.

The use of solar energy is photovoltaic solar technology. A panel of photovoltaic solar technology is used to integrate many solar cells. A solar cell is a semiconductor device that converts directly

Electrical energy from sunlight is energy in the photovoltaic process. Photovoltaic cells (solar cells) convert only a small fraction (less than)

20%) Fuel equilibrium in electrical energy is converted to room heat. An important parameter that affects the power output

The temperature of the PV module or operating system decreases the electrical efficiency of the growing temperature of the cell. Cooling cans

Cooling retains PV cells so standard flat electric generation panel PV modules are made from increased temperatures where irreversible damage occurs. It was found that the efficiency and output power of the PV module is inversely proportional to its temperature.

## 5.2 PROBLEM STATEMENT

Excess heat has significantly reduced the overall efficiency of solar panels. Due to the heat, the efficiency of the panel can be reduced from 5% to 20%. Linear panels are installed to deal with this problem by increasing the temperature and decreasing the voltage output so that the excess heat does not remain so cold. We will reduce the temperature of the panel here and increase the efficiency from 5% to 20%.

## 5.3 OBJECTIVE AND SCOPE

The goal of this project is to improve the efficiency of solar panels using Apple Cooling. If the opportunity is this project, it will help. For higher panels, the panel reduces corrosion and longevity. At the same time, keep the panel clean and free from dirt. Damage to dirt and dust can be reduced by 7%.

## 5.4 METHODOLOGY

I used a commercial polycrystalline panel. The 5-day average price is taken from 11.00 am to 2 pm. Sunny Portal software has been used to know the temperature of the panel and a temperature gun has been used for cross checking. Sunny Portal is an electronic inverter register portal and connected to active SMA Smart. SMA cluster controllers have been used to view the output data. In addition to the multimeter, the flash test has been used on the Quick Sun 810.

## 5.5 Experimental setup – 1

Experimental Setup-1 the temperature of a mini-grid temperature sensor part has been reduced. Here all the information about the temperature has been collected on the Sunny portal.

### 5.5.1 Without any cooling system

| SL No. | Time | Temperature(c) |
|---|---|---|
| 1 | 11:00am | 52.2 |
| 2 | 11:30pm | 60 |
| 3 | 12:00pm | 62.3 |
| 4 | 12:30pm | 64.1 |
| 5 | 1:00pm | 64.78 |
| 6 | 1:30pm | 64.7 |
| 7 | 2:00pm | 63.5 |

**Table 5.1: without any cooling system.**

### 5.5.2 Free flow front water cooling system

**Figure 5.1: with cooling system**

| SL No. | Time | Temperature(c) |
|---|---|---|
| 1 | 11:00am | 34.1 |
| 2 | 11:30am | 35.1 |
| 3 | 12:00pm | 34.4 |
| 4 | 12:30pm | 36.0 |
| 5 | 1:00pm | 37.6 |
| 6 | 1:30pm | 38.4 |
| 7 | 2:00pm | 39.8 |

**Table 5.2: with cooling system**

| SL No. | Time | Power(w) With free front flow cooling | Power(w) Without free front flow cooling | Average temperature |
|---|---|---|---|---|
|  | 11:30am | 34.1 | 52.2 | 18.1 |
| 2 | 12:00pm | 35.1 | 60 | 24.9 |
| 3 | 12:30pm | 34.4 | 62.3 | 27.9 |
| 4 | 1:00pm | 36.0 | 64.1 | 28.1 |
| 5 | 1:30pm | 37.6 | 64.78 | 27.18 |
| 6 | 2:00pm | 38.4 | 64.7 | 26.7 |
| 7 | 11:30am | 39.8 | 63.5 | 24.5 |

**Table 5.3: A comparison between the two systems shows that it is possible to reduce the average temperature by 25.5 degrees using the cooling system.**

## 5.6 Experimental setup – 2

Experimental Setup-2 a 30 watt solar DC system has been taken to reduce the temperature and output data. Here we have compared the outputs of the two, here clamp meter, battery, multimeter have been used.

### 5.6.1 Without any cooling system

Figure 5.2: without any cooling system

| SL No. | Time | Voltage(V) | Current(A) | Power(w) |
|---|---|---|---|---|
| 1 | 11:30am | 17.5 | 1.52 | 25.9 |
| 2 | 12:00pm | 17.26 | 1.44 | 24.38 |
| 3 | 12:30pm | 16.92 | 1.43 | 24.36 |
| 4 | 1:00pm | 16.7 | 1.43 | 23.88 |
| 5 | 1:30pm | 16.62 | 1.42 | 23.61 |
| 6 | 2:00pm | 16.41 | 1.43 | 23.47 |
| 7 | 2:30pm | 16.39 | 1.42 | 23.53 |

Table 5.4: without any cooling system

Figure 5.3: With free front flow cooling

| SL No. | Time | Voltage(V) | Current(A) | Power(w) |
|---|---|---|---|---|
| 1 | 11:30am | 17.9 | 1.52 | 27.21 |
| 2 | 12:00pm | 18.03 | 1.53 | 27.6 |
| 3 | 12:30pm | 18.16 | 1.55 | 28.15 |
| 4 | 1:00pm | 18.23 | 1.56 | 28.44 |
| 5 | 1:30pm | 17.79 | 1.52 | 27.04 |
| 6 | 2:00pm | 17.61 | 1.48 | 26.96 |
| 7 | 2:30pm | 18.09 | 1.51 | 27.75 |

Table 5.5: with cooling system

| SL No. | Time | Power(w) With free front flow cooling | Power(w) Without free front flow cooling | Percentage in Power(w) |
|---|---|---|---|---|
| 1 | 11:00am | 27.21 | 25.9 | 5.05 |
| 2 | 11:30am | 27.6 | 24.38 | 11.02 |
| 3 | 12:00pm | 28.15 | 24.36 | 15.55 |
| 4 | 12:30pm | 28.44 | 23.88 | 19.05 |
| 5 | 1:00pm | 27.04 | 23.61 | 14.52 |
| 6 | 1:30pm | 26.96 | 23.47 | 14.87 |
| 7 | 2:00pm | 27.75 | 23.96 | 17.63 |

**Table 5.6: Percentage increase in power**

A comparison between the two shows that there is an average increase in power of about 14.15%.

## 5.7 Cost and Economic

**Economic Calculation:** The rating power usually mentioned on the label of the module is measured at 25°C and with any temperature increase above 25°C you have to consider a loss of 1% for every 2°C increase.

In the process of reducing the temperature with water, I was able to reduce the temperature by an average of 25.5°C.

If temperature coefficient = 0.5

**Then,**

Decrease by 25.5 degrees centigrade = 25.5 * 0.5 = 12.75%

If we calculate with a 100 kW solar project.

1. Solar project = 100 kW
2. Total Solar Panel = 1,00,000/320=313 pcs Panels.
3. Panel size = 1956 * 992 mm (2m*1m approx)
4. Daily sunshine hours = 5 days
5. Electricity bill = BD. 7.50 / kWh.
6. Lifetime of solar project = 25 years

Solar power generation will be = 5 * 100 = 500 kWh/day.

Loss of efficiency due to daily temperature = 500 * 12.75% = 63.75 kWh.

Loss of efficiency per month = 63.75 * 30 = 1912.5 kWh.

The total efficiency of the project will be lost in 25 years = 1912.5 * (12 * 25) = 5,63,650 kWh.

Total money loss in 25 years will be = 5,63,650 * 7.5 Taka
= 43,03,125 Taka

Therefore, it is possible to save BD. 43,03,125 in 25 years by reducing the temperature by 25.5 degrees Celsius.

**Cost Calculation:** The following are the costs for installation a water system.

| SL. | Name | Quantity | Taka |
|---|---|---|---|
| 1. | PVC Pipe (1/2) " | 320 meters | 11,520 |
| 2. | PVC Pipe (2) " | 320 meters | 56,000 |
| 3. | Sanitary Pipe 2 " | 320 meters | 20,160 |
| 4. | PVC Ball Valve (1/2) " | 30 pitch | 1,280 |
| 5. | Water Pump | 1hp | 3000 |
| 6. | Water Tank | 1000 litar | 8,500 |
| 7. | Other Expenses | | 10,000 |

Table 5.7: Costs for installation a water system.

Total installation Costs for a water system = 1,12,060 Taka.
(Lifetime of solar project = 25 years)

# Chapter 6
# Conclusions

I conducted two experiments using the cooling system. I just collected the temperature from Experiment-1. Temperatures have been collected in two ways, one using a cooling system and the other without a cooling system. Using the cooling system I was able to reduce the temperature by 25.5°C and multiplying by the temperature coefficient (0.5) shows that it is possible to save 12.85% output. If it is an economic calculation with a 100kW solar project then it is possible to save 5,63,650 kW (approximately) of electricity in the project lifetime with a market capitalization of BD. 43,03,125 (four million three hundred three thousand one hundred twenty-five) (approximately).

The total cost for installation of cooling system in 100 kW solar project will be 1,12,060 Taka (approximately).

Experiment-2 is set up on a 30 watt solar panel. Along with this a multimeter for voltage and a camp meter for amperes have been used as loads. Output has been collected from now on. This calculation shows 14.15%. It is possible to increase the output.

However, it needs to be recharged a lot because you have to use water to reduce the temperature for an average of 5 hours. Whether there is any manufacturing obligation. Because if I pour water on the panel with more than 300 watts / m radiation then the warranty of the panel may be canceled as it is a manufacturing condition.

However, with the introduction of this system, not only the temperature loss can be reduced but also the dust loss can be reduced by 7% and also the panel cleaning cost can be reduced.
Because the biggest challenge of a solar project is to clean the solar panel.

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