# Low Efficiency of the Photovoltaic Cells: Causes and Impacts

Fazal Muhammad, Muhammad Waleed Raza, Surat Khan, Aziz Ahmed

**Abstract—** Solar cell converts visible light into Direct current (DC) electric power. The DC output of the solar cell depends on multiple factors that affect its efficiency i.e. solar irradiation falling over the cell, direct air around cell called local air temperature, cable thickness connected to solar panel, wave length of the photons falling, Ambient temperature, Shading effect, direct recombination of holes and electrons, Reflection of irradiation, Types of least efficient invertor, Batteries and charger controller used with solar cells panel. Any abnormality or deviation from reference level regarding these entire factors, limit the efficiency of the solar photovoltaic cells. This research paper presents the significant causes that affect efficiency of photovoltaic cells. Improving the said factors will increase the efficiency of the photovoltaic cells. Low efficiency reduces the output of solar cell and enhances the levelized cost respectively.

**Index Terms—** Amorphous silicon solar cell (a-Si), Efficiency of solar cell, Maximum power point tracker (MPPT), Monocrystalline solar cell (MCSC), Polycrystalline solar cell (PCSC), Standard Test Conditions (STC), Thin film solar cell.

## 1 INTRODUCTION

Most abundant and pollution free energy is solar energy. It utilizes sunlight to give heat, bright light and electricity to industrial and domestic users. With the disturbing decrease of conventional energy resources such as coal and petroleum it has become a requirement to take advantage of renewable energy resources that would provide the energy needs of the future adequately without degrading the environment through greenhouse gas release. The sun has immense energy potential, but due to a reduced amount of efficiency of the cells it is mainly a difficult task to extract electricity from it. Irradiance, wind speed and temperature of cell are the parameters on which complete performance of the solar cell depends. The parameters which are affected by the temperature are open circuit voltage, short circuit current and maximum power. But, open circuit voltage is affected mostly. The open circuit voltage changes very much with the temperature of the cell. It decreases with rise in temperature whereas short circuit current rises [1]. There are lots of different types of solar cells, crystalline silicon which includes both monocrystalline and polycrystalline and those made with thin film technology are the two most common types. The efficiency based solar cells are:

### 1.1 Monocrystalline Silicon Solar Cells

Single crystalline cells also known as Monocrystalline solar cells can be recognized easily by their distinctive look and coloring.



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They are made from a very pure type of silicon which makes them most unique. The material is most efficient when it is pure; it is pure when the alignment is regular. They are most efficient in their output so they are also most space efficient. This is understandable as fewer cells would be required to produce the electrical output of one unit.

### 1.2 Polycrystalline Silicon Solar Cells

Unlike monocrystalline cells Polycrystalline cells do not go through the process monocrystalline goes through. As an alternative, the silicon is emptied into a four-sided mold after being melted this gives the square shape to polycrystalline.

Characteristically, polycrystalline solar Photovoltaic system operates at efficiency of 13-16%. This is due to lower purity of the material. Because they are less efficient, these types of solar cells are also less space efficient so they require a lot of panels for small electrical power. Another disadvantage of these solar cells is that it tolerates less heat than monocrystalline, this means they are not as efficient in high temperatures and do not perform efficiently [2].

### 1.3 Thin Film Solar Cells

They are another type of solar cells. They exist in many types but their efficiencies lie from 7 to 13% [3]. Many experts say that their efficiencies will climb up to 16% in future models due to the research and advancement being [3]. They are made by coating numerous types of semi conducting materials with silicon. In some of the cases they are coated on top of each other to make a sequence of thin films. The production of these solar cells on a very large scale is easy when we compare them to monocrystalline and polycrystalline based modules. This decreases their price of production. One of the disadvantages of this technology is that they are not space efficient so they require a lot of space.

### 1.3.1 Amorphous Silicon Solar Cells (a-Si)

Thin film solar cells which are made up of amorphous silicon are utilized in smaller applications like handheld calculators, lights used while traveling and picnic camps used in far areas. Due to forming multiple layers of this material which is a new process the efficiency for these technologies have been recorded up to 8% [3].

### 1.3.2 Cadmium Telluride Solar Cells (CdTe)

The lone thin film material which has given competition to the crystalline in terms of cost is this type. It has efficiency in the range of 9-11% [3].

### 1.3.3 Copper Indium Gallium Selenide Solar Cells

Copper Indium Gallium Selenide Solar Cells are the only type of thin film technology which has efficiency compared to crystalline technologies, i.e. 10-12% [3].

## 2 LITERATURE REVIEW

### 2.1 Effect of environment

While designing any solar PV system, energy efficiency factors must be carefully considered. Efficiencies of solar panels rest on many environmental factors which are:

#### 2.1.1 Temperature

The speed at which the electrons travel in an electrical circuit is affected by temperature. The increase in temperature increases the resistance. Similarly, decrease in temperature decreases resistance and hence the speed of electron flow is affected [4]. Solar cells are delicate to temperature like all other semiconductor devices. The band gap of a semiconductor material is reduced with an increase in temperature; most of the parameters of semiconductor material are affected by an increase in temperature. By increasing the temperature of the semiconductor material, the electrons in the material has their energy increased, to break the bond lower energy is needed. The reduction in the bond energy also reduces the band gap. Hence, temperature increase reduces the band gap.

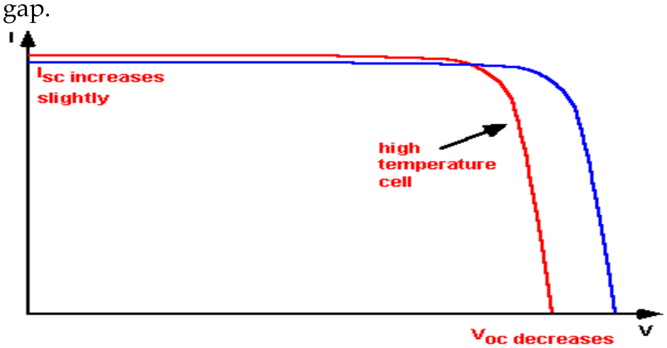


Figure 1 IV characteristic curve of solar cell with temperature [4]

Because of the temperature dependence of I0 the open-circuit voltage decreases with temperature. Power production efficiency of the solar panel drops when the panel reaches high temperatures. According to a field experiment conducted in the UK, an increase of 1oC showed a drop of 1.1% of maximum power after the panel reached 42oC. After reaching a temperature of 44oC the power production dropped gradually [5]. The temperature of the cell is the key parameter to determine quality of a solar cell.

TABLE 1 THE EFFICIENCY OF MC-SI SOLAR CELL WITH CELL TEMPERATURE AT DIFFERENT CONSTANT LIGHT [6]

| | Efficiency | | | |
|---|---|---|---|---|
| Temperature | At 515 W/m² | At 400 W/m² | At 280 W/m² | At 215 W/m² |
| 25 | 10.049 | 11.165 | 11.417 | 11.381 |
| 40 | 9.95 | 11.117 | 11.238 | 11.03 |
| 50 | 9.856 | 10.837 | 11.002 | 11.019 |
| 60 | 9.023 | 10.527 | 10.826 | 10.502 |

The table above shows how cell temperature affects the quality and performance of the mono crystalline solar cell. It can be seen that it has a significant impact on the said parameters. The cell temperature was varied from 25-60oC and the light intensities were constant at 215, 280, 400 and 515 W/m2.

TABLE 2 MCS AND AS SPECIFICATIONS AT STANDARD TEST CONDITIONS (STC) [7]

| STC condition measurements | Mono Crystalline Silicon | Amorphous Silicon |
|---|---|---|
| Output power (peak W) | 40 | 40 |
| Working voltage, VOP (V) | 17.2 | 44.8 |
| Working current, IOP (A) | 2.33 | 0.93 |
| Open Voltage, VOC (V) | 21.5 | 62.2 |
| Short circuit current, ISC (A) | 2.50 | 1.14 |
| Current temperature coefficient | +0.10% /◦C | +0.04% /◦C |
| Voltage temperature coefficient | -0.38% /◦C | -0.30% /◦C |
| Power temperature coefficient | -0.47% /◦C | -0.20% /◦C |

The main environmental parameter to decide the quality and performance of a solar cell is the temperature.

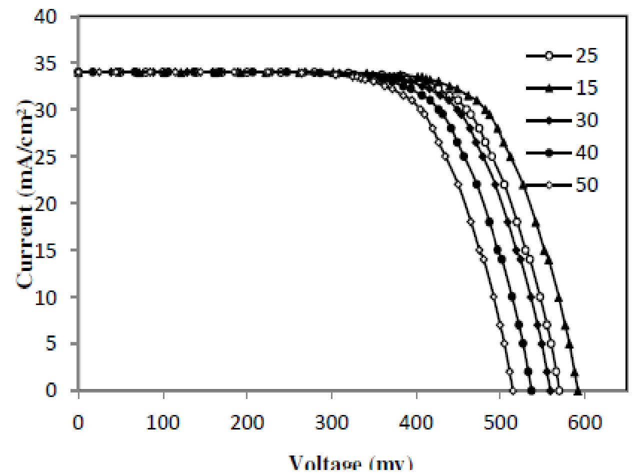


Figure 2 V-I characteristics of solar cell under different temperature [8]

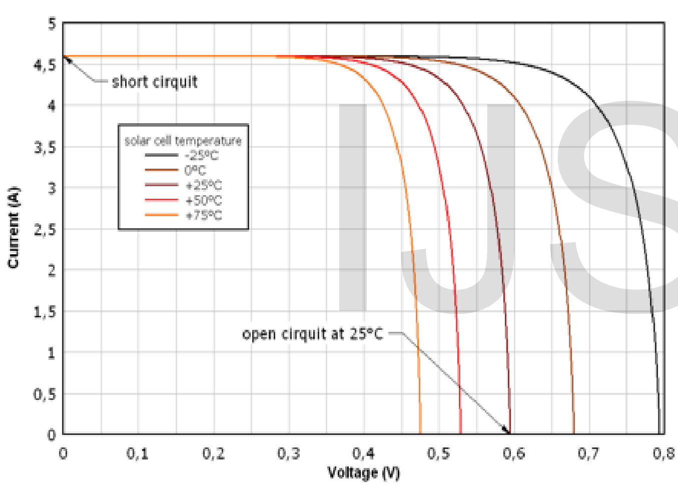


Figure 3 V-I characteristics of solar cell under different temperature [9]

### 2.1.2 Wind

The direct air around the panels is called the local air temperature. This can vary the voltage of the PV system. As solar cells are below glass they are insulated [7]. Consequently, they have temperatures more than the surroundings. In maximum cases, solar cells operate at temperatures about 25oC more than the immediate air around the panels [7]. The solar cell temperature reduces at higher wind speeds because the air temperature is also reduced [7]. As a result, wind gives a good impact on the solar cell efficiency because the temperature is reduced. But, wind can also affect the PV system physically. For instance, the wind can damage the solar system in case it is not installed properly. It can lose the electrical contact and will be displaced [7]. A 15-20oC cooling effect was stated for wind speeds of more than 10m/s at 1000W/m2 solar irradiance [10]. The wind cooling effect plays a central part for improved estimation of module temperature of PV system. The cell temperature will reduce as the air speed will rise [10].

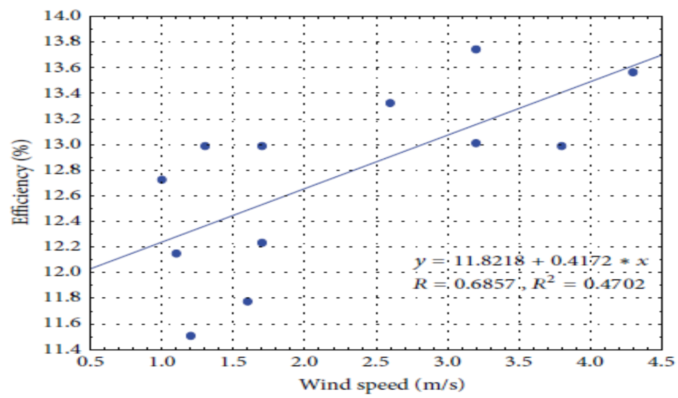


Figure 4 Average values of solar module efficiency and wind speed [11]

The African countries which are more desert are suitable for PV generation due to plenty of sunlight all year. But, the PV panel in these types of countries is greatly affected by the buildup of dust particles. In huge solar plants, more human power will be needed to clean the panels after sand storms in these regions. The dust buildup on the surface of the panel depends on different factors like PV panel tilt angle, adjustable or fixed panel and humidity. It is vital to know how frequently the panel will need cleaning and in the event cleaning the panel is not easy the panel will lose its performance [12]. Dust is the very small particles with less than 500μm diameter. When firm on external surface the microfibers of clothes, carpets and fabrics, small pollens, bacteria and fungi are also known as dust. Dust is accumulated due to several environmental and weather conditions [12].

### 2.1.3 Irradiance

The main source of energy for earth is the giant red burning star called sun. It radiates its energy from 150 million KM. After reaching the outer atmosphere the irradiance of this solar irradiation is about 1360 W/m2. Because of scattering, diffusion and absorption the solar radiation reaching the earth's surface changes its composition. This is a result of gases, vapors of water and clouds. Due to these effects direct, diffuse and global solar radiation can be distinguished at the surface. The solar rays that were travelling in straight line from the sun which were not dispersed are called direct. The solar radiation coming from all directions of hemisphere due to diffusion by the atmosphere and clouds is called the diffused. The global

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solar radiation is the addition of diffuse and direct solar radiation [13]. In the field of renewable energy superior quality solar radiation information is becoming very important [13].

PV system certainly shows a nonlinear I-V and P-V characteristic curve which vary with the irradiance and temperature of the cell. The most common I-V and P-V characteristic curves of solar cell are shown

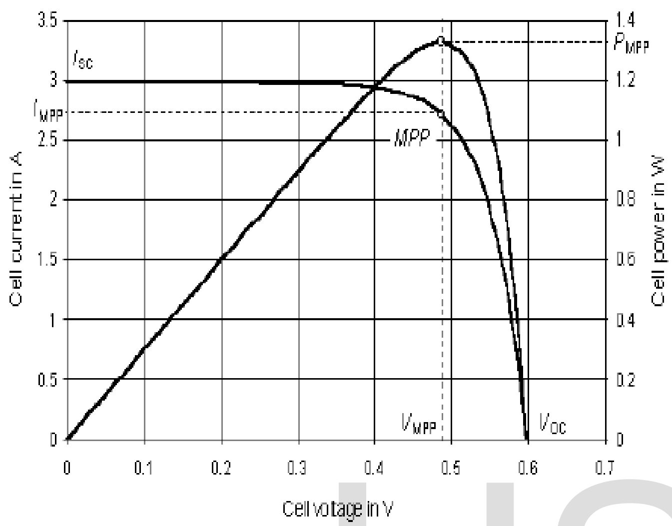


Figure 5 Typical Characteristics of solar cell [14]

As solar irradiance varies in a day likewise IV and PV characteristics also change with increasing irradiance. Open circuit voltage and short circuit current change and varies the maximum power point as a result.

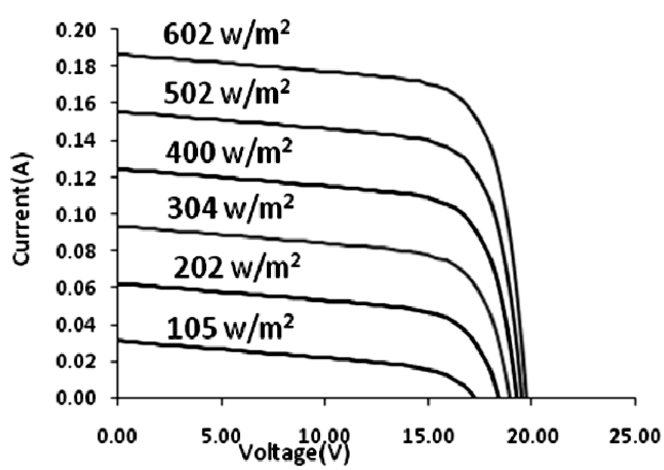


Figure 6 Shows the current versus voltage characteristics at six various irradiance levels [14]

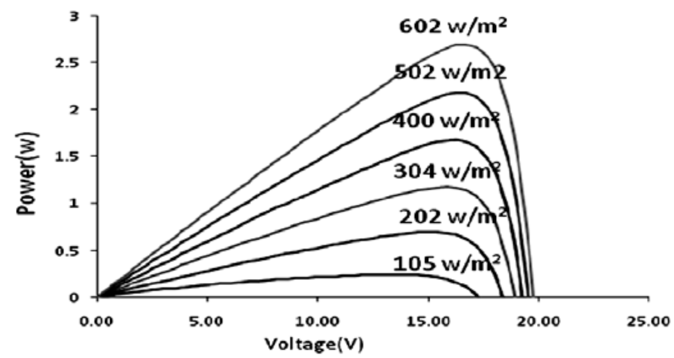


Figure 7 shows the power versus voltage characteristics at six different irradiance levels [14]

Maximum power is a key parameter in solar cells which is decidedly affected by solar radiation.

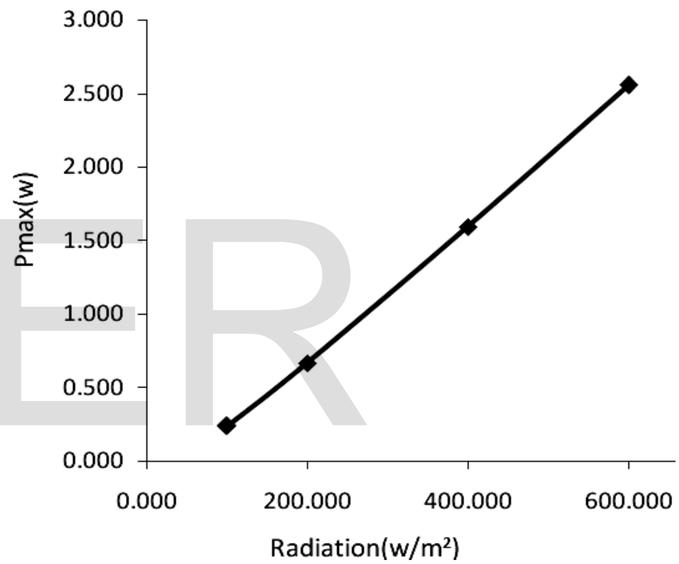


Figure 8 Radiation versus Pmax [14]

The efficiency is dependent on the intensity of light and temperature of cell.

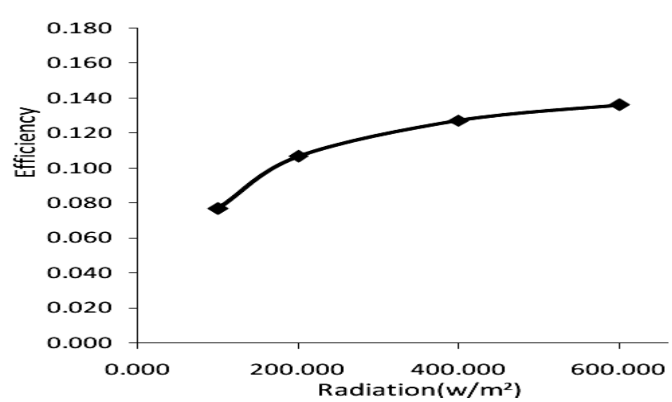


Figure 9 Shows the Radiation versus Efficiency characteristics [14]

Edge shadowing is a type of shadowing which occurs in PV systems due to dust buildup on the tilted PV module. The power is reduced very abruptly [14].

## 3 METHODOLOGY

We review in this section the major causes that affect the Solar cell efficiency.

### 3.1 Factors responsible for low Efficiency of the Photovoltaic cells

While designing a solar photovoltaic system, factors enhancing efficiency of the solar system must be carefully considered .if one have least efficient appliances one have to buy rather large photovoltaic system that would be exorbitant in price. If one use efficient appliances still one have to use efficient solar system. This need substantial knowledge of the different factors that potentially degrade your PV system.one should effort at planning stage to minimize the impact of those factors causes low efficiency. Some of the pre dominant considerations are as follows

### 3.2 Cable Thickness

At the planning stage of the photovoltaic system the size and length of cable needs deep insight attention. Resistance of the cable per meter matters considerably. Our home appliances working on 220V that is considerably higher than usual PV system DC output voltages of 12V, 24V and 48V.In PV system this low voltage causes high current. This shows resistance losses in the wiring to see how this happens, let a cable has resistance about 0.012 Ohms/meter its cross section area is 1.5 squire mm and its length is 20 meter long wire will offer resistance 20 x 0.012 = 0.24 ohms. As per Ohm's law V = IxR, we calculate voltage drop as 2.4V.so at charge controller end 2.4V will be less than actual voltage produced by solar panel. If 10 Ampere current is flowing that is clearly unacceptable drop level. If we have 20 meter long cable having 6 squire mm cross sectional area and resistance .003 Ohm per meter. Total resistance for 20 meter length would be 0.06 Ohms. So far 10 Ampere the total voltage drop is 10×0.06 or 0.6V. .It is 2.5 % voltage drop for a 24V system that may be acceptable. In this scenario we have used thicker cable but it will increase the cost. High cable cost would affect the levelized cost .Conspicuously size and length of the cable is a matter of system installation and design.

### 3.3 Wavelength

Sun light that reaches to earth that consists on visible range, Ultraviolet and infrared light having different wave length. Light is composed of photons that have different energies and wave length. What visible light falls on the surface of the solar cell some of the photons absorbs and the remaining reflects. The absorbed electrons energy turns into heat, the remaining part separate electrons from their atomic bonds to generate the charge carriers. Head production limits the efficiency of the solar cell.

### 3.4 Temperature

The efficiency of the solar cell is temperature dependent. Solar cell has better efficiency in cold climate rather than hot climate. The solar panels are rated on 25˚C but the outer door situation is significantly being different for it. Each degree rise in temperature above then 25˚C the output of the amorphous cells will decrease by 0.25% and 0.4% to 0.5% for the crystalline cells respectively. In summer the temperature of the solar panel easily reach 70 to 72˚C.This increase the losses up to 25% compare to that temperature at which it is rated. This way 100Watt panel will generate 75 watt in the months of May and June when some time the temperature in hot climatic regions of the Pakistan that reach up to 50˚C. Solar panels are tested at1000W/m2 level of solar irradiance and 25˚C of temperature is called Standard Test Condition STD. But in the real outdoor environment temperature and irradiance level deviates from STC that affect the efficiency of the solar cell. High temperature than that of the rated temperature will limit to great extent the efficiency of the solar cell

### 3.5 Shading

Solar panels need be placed in a way that no shadows should come on them as shadows on even a minor portion of the solar panel can produce remarkably big effect on the power output of panel. In most cases the solar cells in a solar panel are all connected in series so the cells under shade upset the current flowing in the entire panel. In some situations it is not possible to avoid partial shading. Thus it must be well-thought-out before planning. If all the panels are connected in series and one of the panels is being affected by partial shading then the clear solution is to avoid connecting panels in series.

### 3.6 Recombination

When a negatively charged electron flows across the semiconductor material we say electric current flows. The negatively charged electron is called charge carrier. The other type of charge carrier is the hole which is formed because of lack of an electron within the semiconductor material and acts like a positive charge carrier. When electron and hole meet they might recombine and stop out their involvement to the electric current. One of the major factors that limit efficiency is direct recombination. In this the electrons generated from light are recombined with the holes and emit a photon which contraries the process from which electricity is generated in a solar cell. Indirect recombination is a process in which the electrons or holes meet an impurity this is caused by a flaw in the crystal structure, or interface, that makes it easier for the electrons and holes to recombine and release their energy as heat.

### 3.7 Charge Controller and Solar Cell's IV Characteristics

The current produced by a solar cell for a certain irradiance level is constant up to a particular voltage which depends upon the material used for manufacturing of solar cell and is 0.5V for silicon; above this voltage this current decreases rapidly. This is an internal trait of a solar cell. A solar panel that has a rated voltage of 12V usually has 36 cells connected in it. This produces a constant current up to 18V. If the voltage becomes more than 18V the current decreases quickly. So, the maximum power is produced at about 18V. The voltage of the panel is brought down to the battery voltage if it is connected to a simple charge controller. This brings about lower power from the panel. Consequently, when the battery voltage is at its peak i.e. fully charged the panel output power will be highest. Thus, a system is designed such as the voltage of battery remains at its peak voltage. The voltage of the battery decreases to a very low value in rainy days and clouded days this decreases the voltage of the panel and the output from it. To overcome this problem we use MPPT (Maximum Power Point Tracking) Charge Controller. Its primary task is to keep the voltage of the panel at its peak value and at the same time produce the voltage which is required by the battery. A simple charge controller ensures that the batteries are not harmed by overcharging. This is done by stopping the current when the battery voltage is maximum i.e. fully charged. MPPT prevents the battery from damage as well as improves the efficiency of the system.

### 3.8 Reflection

By decreasing the quantity of light reflected from the solar cell's outer surface we can increase the efficiency of the solar cell. The silicon solar cells that are not treated with antireflection coatings reflect about 30% of incident light. Antireflection coating and rough surface decrease the amount of reflected light. The appearance of highly efficient solar cell is dark blue or black.

### 3.9 Inverter Efficiency

If we want to supply an AC load from a solar panel inverter is needed. Inverters come in many ranges of efficiency as nothing in this world is 100% efficient. Typical solar inverters are available with efficiency of 80% to 90%.

Example: Su Kam's 1000 VA inverter is usually 85% efficient; their 2KW – 5KW products are more than 87% efficient. UTL's UTL Solar Hoodi Back Up (810VA – 3000VA) prototypes are available with 80% efficiency.

### 3.10 Battery Efficiency

Batteries are used to store charge. When backup is needed batteries are used. Most commonly used batteries are Lead acid batteries. The efficiency of the battery depends upon the design of the battery and the quality of its construction. Every battery discharges less than with what it was charged with. The energy with which a battery is charged Ein can be written as $E_{in} = I_C V_C \Delta T_C$ where $I_C$ is the constant charge current at voltage $V_C$ for time duration $\Delta T_C$. Similarly it is discharged at a constant current $I_D$, at a voltage $V_D$ during a time $\Delta T_D$. The supplied energy is $E_{out} = I_D V_D \Delta T_D$. Now we can write the efficiency of delivered energy as $E_{in}/E_{out} = I_C V_C \Delta T_C / I_D V_D \Delta T_D$. There are two types of efficiencies one is voltage efficiency ($V_D / V_C$) and the other is coulomb efficiency ($I_D \Delta T_D / I_C \Delta T_C$). The efficiency of lead acid battery is around 88% because it is charged at the voltage of 13.5 and discharged at 12V. In most cases the coulomb efficiency is around 92%. So, the net energy efficiency becomes 80%. Lead acid battery is 75% to 85% efficient with charging and discharging losses both inclusive. This energy which is lost is converted to heat which increases the temperature of the battery making it warm. This loss can be decreased by ensuring the low discharge rate. It will keep the batteries temperature low and will also maximize its life. In this estimation we did not include the losses that occur in the battery charger's electronic circuit and account for almost 60% to 80%. So, the overall efficiency of batteries is much lower than we have estimated.

## 4 Impacts of the Low Efficiency of Solar Cells

The following are the impacts due to low efficiency of the solar cell

### 4.1 Effect on the availability of power supply

Solar panel operation is related to sunlight. The sunlight shines and provides both heat and light. In very hot climatic regions where temperatures due to this sunlight reach more than 50 C the solar panels stop working because their efficiency is decreased so much that they cannot supply the load demand. This affects the availability of the power supply to consumers.

### 4.2 Exorbitant Prices

The prices of solar panel are very high. Due to their low efficiency more panels are used for power generation and they take more space. For small power generation the land prices are high and more panels are used because of low efficiency.

## 5 CONCLUSION

Solar energy requires no need of fuel it directly converts ultraviolet light to DC electric power. The DC output power depends upon the efficiency of the solar cells that constitute solar panel to extract power. Efficiency is the main factor to assess the worth of the solar cell. Some of the dominant factors that to great extent affect the solar cell efficiency i.e. Low solar radiation falling over the solar cell, clear sky and threshold frequency of visible light, Increase of the Ambient temperature, shading effect of the solar panel, thickness of the wire increases the current weightage, Reflection of the solar irradiance from the solar cell surface, least efficiency of the inventor and batteries used with solar cells. All the said factors are accountable to decrease the efficiencies of solar cell. Low efficiency has some depraved impacts like low power generation, and exorbitant level of prices of solar cell. If the above mentioned causes are to overcome solar cells will be rendered most efficient and substantial source to generate power.

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