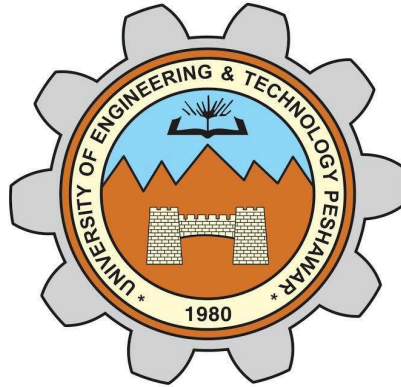


Experimental Study of Dust Deposition Impact on Power Output of Photovoltaic Module



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APPROVAL CERTIFICATE

This is to certify that the project titled “**Experimental Study of Dust Deposition Impact on Power Output of Photovoltaic Module**” has been conducted by the final year Electrical Engineering students at University of Engineering and Technology Peshawar.



This project dissertation is submitted for the partial fulfillment of the requirements for the Bachelor's Degree.

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With deep sense of reverence, we pay gratitude towards our parents and family members who always supported us morally and economically.

Abstract

In hope of a resilient, clean and green future, the world is moving towards renewable energy sources. More than 80% of all the new electricity capacity last year was renewable. In renewables, the electricity production from Photovoltaic solar modules has grown rapidly during the last five years and will grow more in the next decade. At the same time PV modules are under investigation in order to improve its reliability and efficiency with minimum possible cost. Till now while designing the modules the focus has been on irradiance and ambient temperature. Losses due to soiling are 1-7% globally and could be even more depending upon your geographical location and environmental conditions. Moreover, consumers are often misguided about cleaning their modules. With the help of our research work we came up with a solution about how to improve the reliability of a photovoltaic system. Our work consists of two outdoor experiments. Experiment 1 is conducted in Peshawar where one solar module is left in open environment to accumulate soil while the other one is being cleaned before taking every set of readings. This experiment reveals that output power of the uncleaned module decreases with each passing week and that with every 10 degrees increase in tilt of the panel, I_{sc} reduces by 7mA, drop in voltage is not significant which is 0.033V while power output reduces by 0.066W. Experiment 2 is to compare the soiling effect between Peshawar and Swat. Solar module is setup in Swat and left to natural environment to accumulate dust. This study reveals that dust density accumulated on the modules was different despite being left to open air for same time span. Due to different particulate matters as pollutants in the environments of the two regions, output power in Peshawar is about 18% less than that in Swat.

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List of Abbreviations

STC	Standard Testing Conditions
AM	Air Mass
PV	Photovoltaic
EVA	Ethyle Vinyl Acetate
TFSC	Thin Film Solar Cell
SQ	Shockley-Queisser
SHC	Solar Heating and Cooling
CSP	Concentrating Solar Power
PM	Particulate Matter
LDR	Light Dependant Resistor

Chapter 1 Introduction

In this chapter we will give a brief background about Photovoltaic which is the foundation to our proposed research topic.

1.1 Solar Cell

Solar cell is simply an electronic device which converts the light fallen onto it into Electricity. Source of light can be artificial or the sun's energy. The process with which it converts light into electricity is known as photovoltaic effect. Due to this phenomenon, it is also called Photovoltaic cell (PV Cell).

Majority of solar cells are fabricated with silicon (Si) which contributes to more than 90% of solar modules functional today. Single PV cell is normally 6 inches wide and 6 inches long. A single junction silicon solar cell produces 0.5-0.6V open circuit voltage (Voc) under standard test conditions (STC).

1.2 STC For PV Cell

STC is renowned term in industries. It is a PV output performance testing condition used by testing bodies. STC is a standard to indicate the performance of PV modules at cell temperature of 25°C , irradiance of 1000 W/m^2 and air mass of 1.5. It must be noted that 25 degrees Celsius is the temperature of PV cell not its surroundings.

Solar irradiance is the power per unit area received from the sun OR the rate at which solar energy falls onto the surface of solar cell.

Air mass (AM) is the shortest possible path length for sun light to go through the atmosphere and reach the surface of solar cell. When the sun is directly overhead the air mass is 1.

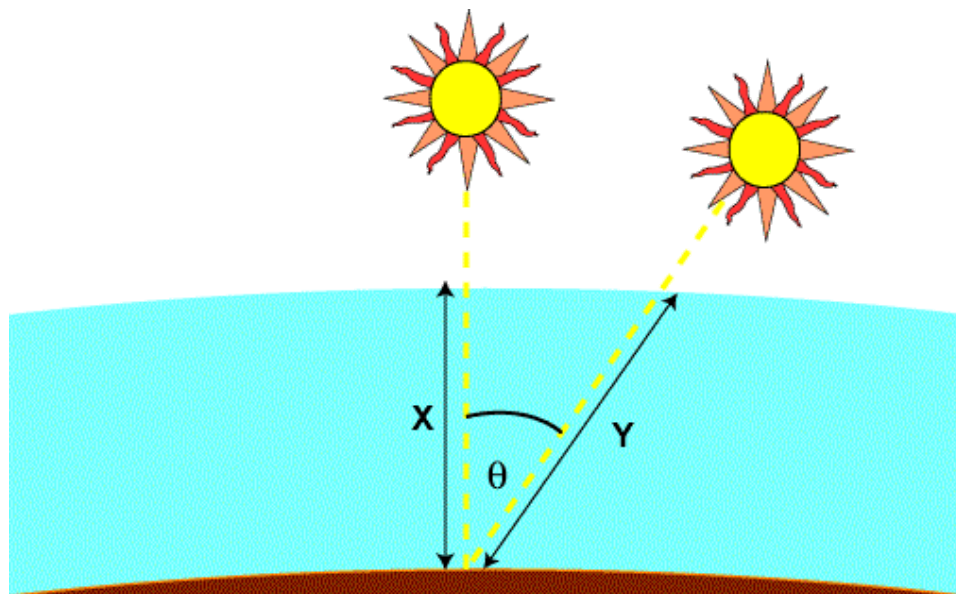


Figure 1-1: Air Mass^[8]

1.3 Difference Between Solar Module, Panel and Array

Before going further let's see how a solar module, panel and array differ from one another with the help of diagram.

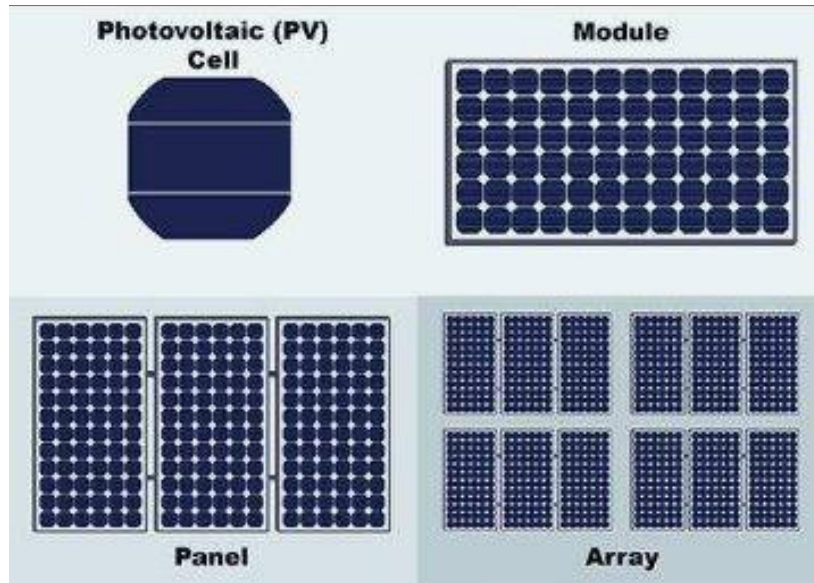


Figure 1-2: PV Module and Array^[2]

1.3.1 Solar Module

When number of solar cells are implemented together we call it a solar module.

1.3.2 Solar Panel

Number of modules connected together is known as a solar panel. The terms module and panel are often used interchangeably.

1.3.3 Solar Array

When number of panels are connected in series or parallel we call it a solar array. The series or parallel connections are made according to the demands and requirements of the consumer.

To understand how a solar cell works let us remind ourselves what a PN junction diode is.

1.4 PN Junction Diode

A PN Junction diode is a simple diode which conducts current in one direction only. It is made up of semiconductor materials such as silicon, germanium etc.

If forward biased, diode ideally offers zero resistance and allows the current to flow while in reverse biased condition it offers infinite resistance and blocks the current flow.

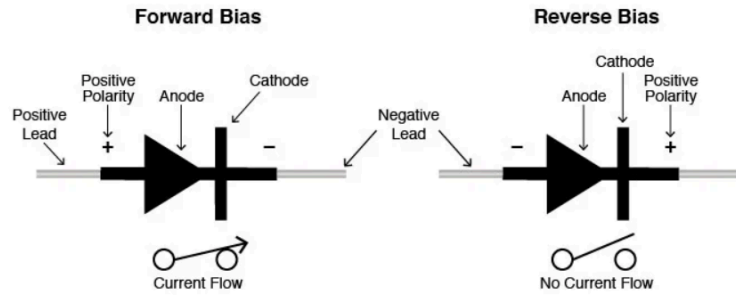


Figure 1-3: PN Junction Diode^[2]

1.5 Photovoltaic Effect

The generation of voltage in a material when light incidents upon it, is known as photovoltaic effect. This process occurs when two dissimilar materials (p and n type semiconductors) are illuminated by light.

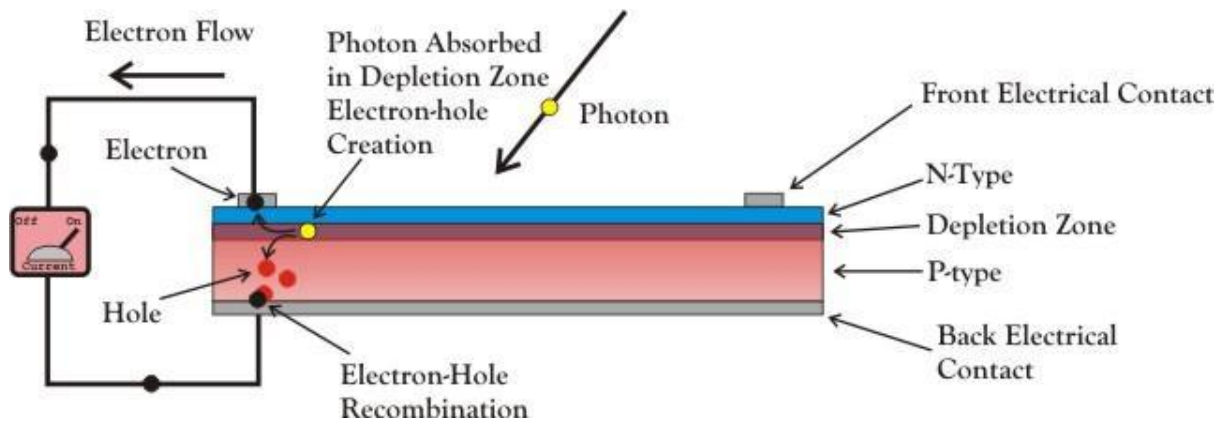


Figure 1-4: PV Effect^[2]

The N type semiconductor is made thin so that light can be passed through it easily. The electrons obtain excited state when it absorbs energy. The incident photon must have enough energy to overcome the potential barrier known as the PN junction and when we complete the circuit by connecting a wire from cathode to anode electrons will flow through the wire.

People often confuses Photovoltaic effect with photoelectric effect but these are two different terms. Photoelectric effect is the emission of electrons from the metal surface when exposed to light while in photovoltaic effect current is generated when light is illuminated upon the semiconductor materials. Moreover, PE effect occurs when the incident photons have enough energy to overcome the binding energy of electrons while in PV effect the energy provided by photons should be enough to overcome the potential barrier.

1.6 Reliability

1.6.1 Definition

“The quality of being trustworthy or of performing consistently well”. A PV module is said to be reliable if its efficiency is above 80% for 25 or more years.

1.7 General Reliability Issues

1.7.1 Corrosion

The moisture that enters the module through the laminated edges causes corrosion. The moisture retention in the housing of the module increases the electrical conductivity of the material. Indeed, the corrosion attacks the metallic connections of PV cells causing a loss of performance by increasing leakage currents. Corrosion also degrades the adhesion between cells and metallic frame. The moisture in the PV module is correlated with the rate of degradation [7], [9].

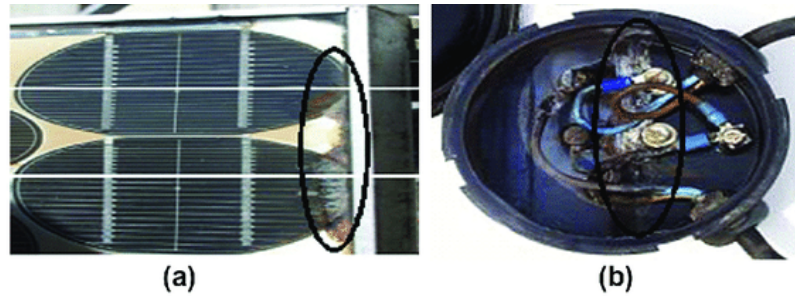


Figure 1-5 PV module affected by corrosion of the edge (a) and the junction box (b) ^[3]

1.7.1.1 Prevention from Corrosion

The only way to prevent moisture penetration is to properly seal the module by a high-quality Ethyl Vinyl Acetate (EVA).

1.7.2 Delamination

Adhesion loss called delamination occurs between the encapsulating polymer and the cells or between cells and the front glass. It represents a major problem because it causes two effects, the increase of the light reflection and of water penetration inside the module structure. Delamination is most severe when it occurs on the edges of the module because in addition to the degradation of power, it causes electrical risks for the module and the entire installation. Delamination is more frequent in hot and humid climates. It causes moisture penetration in the module and therefore causes various chemical and physical degradations such as metal corrosion of the module structure most frequently [7].



Figure 1-6: Delamination ^[3]

1.7.3 Discoloration

Discoloration usually results in a degradation of the encapsulate module, EVA (Ethylene Vinyl Acetate) or adhesive material between the glass and the PV cells. Module discoloration is a change in color of material which turns yellow and sometimes brown. It modifies transmittance of light reaching PV cells and therefore the power generated by the module is reduced. The main causes of EVA degradation are UV rays combined with water under temperatures higher than 50 C° [7].

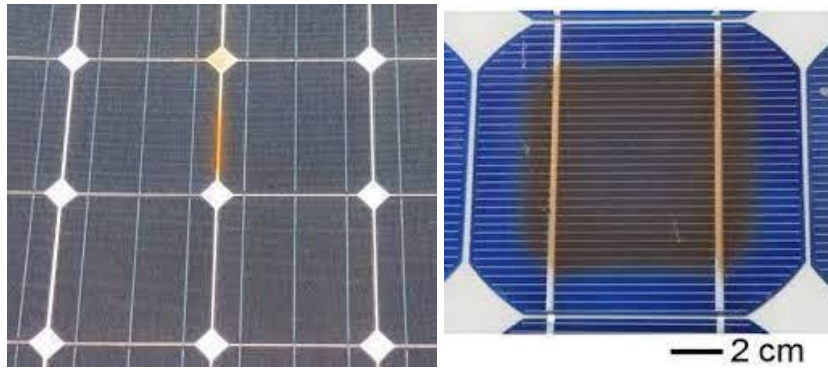


Figure 1-7: Discoloration^[3]

1.7.4 Glass Fracture / Cracks

Glass breakage is an important degradation factor of PV modules. They occur in most of the cases during installation, maintenance, and especially during the transportation of modules on their installation sites. The broken modules or with cracks may keep functioning correctly. However, the risk of an electrical shock and of a moisture infiltration increases. Breakages and cracks are usually followed by other degradation types such as corrosion, discoloration and delamination. In order to save silicon and reduce the manufacturing costs of PV cells, producers have varied the thickness and the surface of cells in recent years.



Figure 1-8: Glass Fracture^[3]

1.7.5 Bypass Diode Failure

When a bypass diode in a module fails, one of the three cell strings is normally switched off. The outcome is a one-third reduction in output.

1.7.5.1 Reason of Diode Bypass Failure

Under persistent, long-term overstress in forward bias, diode breakdown occurs due to thermal deterioration.

1.7.6 Quick Connector Reliability

While there are extensive efforts to characterize the reliability of photovoltaic (PV) modules and the supporting power conversion systems, the degradation of connectors has received less attention. While the occasional open-circuit connector failure can be seen as a nuisance to owners and operators, hidden degradation in the form of increased contact resistance can potentially accumulate over a large number of connectors into a noticeable quantity of lost power output. These losses quickly add up over multiple connectors and strings. The degradation mechanism and losses could be further aggravated in systems with higher currents or warmer climates [8].

1.7.7 Clamping

A relatively often seen failure in the field is glass breakage of frameless PV modules caused by the clamps. Glass-glass modules are more sensitive to glass breakage. The excessively-tightened screws during the mounting phase or badly-positioned clamps can also cause the modules to break.



Figure 1-9: Left figure shows glass breakage caused by too tight screws and the right figure a PV module that broke due to poor clamp design^[3]

1.7.8 Quick Connector Failure

Solar modules are electrically connected to each other, fuse boxes, extension cables, combiner boxes, and the inverter using the fast connector. This component is critical for the system's safety and reliable power generation. However, in the PV world, there is virtually little literature on the reliability of fast connectors. In most cases problems caused by the quick connector are not considered a PV module failure. The use of non-exactly fitting quick connections of various types or incorrectly crimped quick connectors to connect PV modules to extension cables, the fuse box, combiner box, or the inverter at the installation site is a common cause of failure. A statistical review of fire sources in 75 PV systems, which caught fire, shows that the chance of the quick connector causing the fire (29%) is nearly as high as for the rest of the module (34%) or other parts of the PV system (37%) [8].

1.7.9 Lightning

A lightning strike damages a bypass diode, which is caused by an external source for which the module was not built. This effect, however, has been observed frequently and may result in later safety failures, but the PV module is not the source of the failure. Open circuit bypass diodes or a mechanically broken PV module directly hit by lightning are examples of induced faults created by a lightning strike. Both sorts of defects can result in hot spots and eventual breakdowns.

1.7.10 Degradation Causes of PV Modules

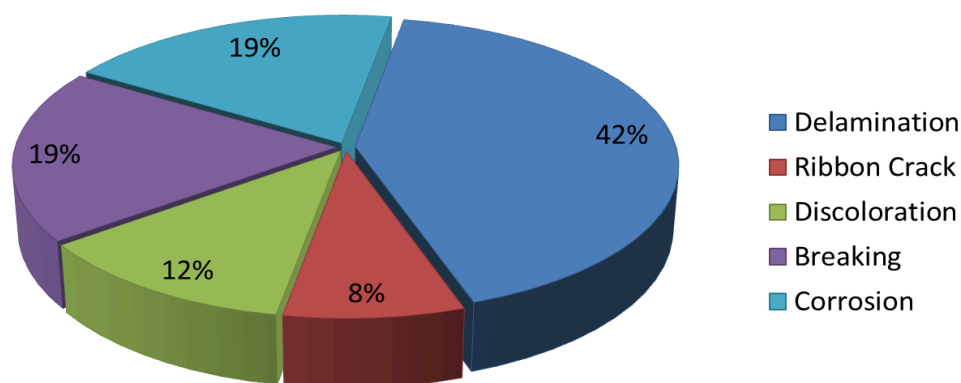


Figure 1-10: Representativeness of degradation modes (Changwon et al., 2012) ^[7]

1.8 Solar Cell Efficiency

It is the ratio of electrical power output to the solar power input. Electrical power of one solar panel / Area of that solar panel, gives us efficiency of PV cell. The efficiency of solar panel is limited by “Band gap energy”

$$\text{Efficiency} = P_{\text{out}}/P_{\text{in}} = P_{\text{out}}/\text{Area of solar panel}$$

1.8.1 Band Gap Energy

This energy represents the minimum energy required for an electron to excite up to a state in the conduction band where it can participate in conduction.

For solar cells this energy is provided by photons which are tiny packets of electromagnetic radiations from sunlight. If a photon strikes a cell and has less energy (since sunlight contains a wide spectrum of photons with different wavelengths and energy) than the band gap then the energy is absorbed as thermal energy which is useless in this case.

In this way, nearly $\frac{1}{4}$ of the total light that reaches the earth surface isn't sufficient to create electricity. For Silicon (which is the most abundant semiconductor used in solar cells) the band gap energy is 1.12 electron volts (eV). Photons having energy below than 1.12eV would not be able to knock out electrons as it will not be absorbed by the electron. Photons having energy greater than 1.12eV, the excess energy will be lost as heat.

Solar Energy from the Sun

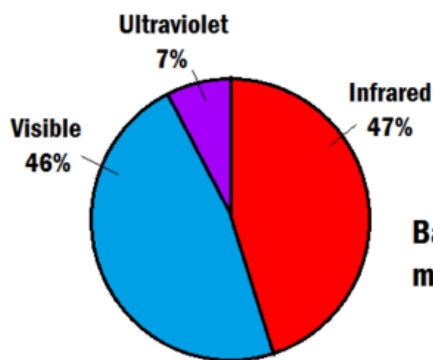


Figure 1-11: Band Gap Energy^[7]

1.9 Types of Solar Cells

1.9.1 Monocrystalline Solar Panels (Mono-Si)

Monocrystalline silicon solar panels are the purest type of solar panels. These solar panels are highly efficient due to their high purity silicon. The most recent ones have an efficiency rate of over 20%.

Monocrystalline panels have the highest power output in commercial Solar panels, take up the least amount of space, and last the longest of all the types of solar panels available. They are also the most expensive, of course. In addition, they tend to be less susceptible to high temperatures than polycrystalline panels.

In addition, the mono panel process of production is more wasteful than the alternative. Silicon wafers are sliced into squares and the edges scraped off to create the characteristic cell. Due to the fact that each cell is created from a single silicon piece, mono panels have a uniform black appearance.

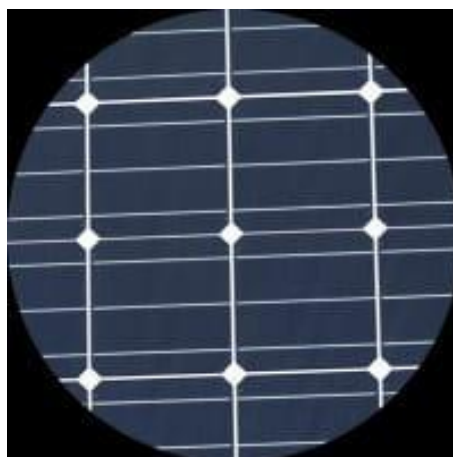


Figure 1-12: Monocrystalline-Silicon Solar Panel^[11]

1.9.1 Polycrystalline Solar Panels (Poly-Si)

Polycrystalline solar cell has less freedom to move electrons due to this its efficiency is less as compared to monocrystalline solar cell.

Unlike monocrystalline panels, they are manufactured by melting raw silicon, which is a faster and more cost-effective method of production.

This results in a reduced end price, but it also means lesser efficiency (about 15%), less space efficiency, and a shorter lifespan because they are more effected by hot temperatures. The differences between monocrystalline and polycrystalline solar panels, on the other hand are minor, and your decision will be based on your individual circumstances. The first alternative has a little higher space efficiency at a marginally higher cost, but the power outputs are essentially the same.

As a result of faults on the surface of solar cells, poly-solar panels are slightly less efficient than mono-solar panels. Their manufacturing cost is lower, which implies they are less expensive for the end-user to buy.

Solar panels with squares, non-cut angles and a blue speckled appearance can be easily identified.

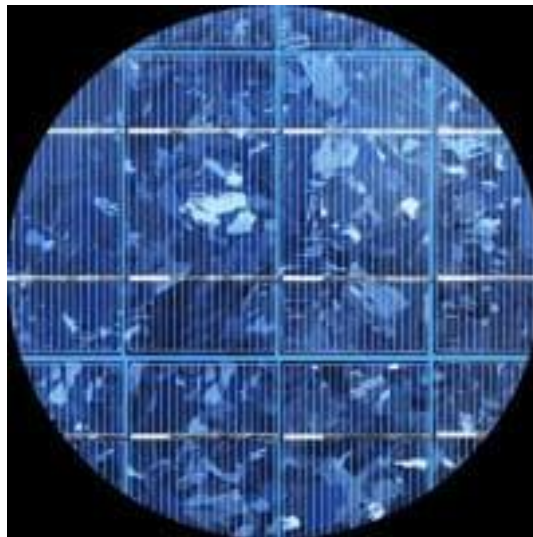


Figure 1-13: Polycrystalline-Silicone Solar Panel^[11]

1.9.3 Thin-Film Solar Cells (TFSC)

Solar panels made on thin-film are less efficient and have lower power capabilities than monocrystalline and polycrystalline solar cells. The efficiency of the Thin-Film system varies depending on the type of PV material used in the cells, however they typically have efficiencies of around 7% to 18%.

For a less expensive solution, thin-film can be a good choice. In order to make thin-film solar panels, photovoltaic material (such as silicon, cadmium or copper) is deposited on a

substrate. These types of solar panels are less expensive than the alternatives because less material is required for their production.

In general, they are unsuitable for residential installations due to their large size. These panels also have the shortest warranties because they last less time than monocrystalline and polycrystalline panels. If you have a lot of space available, they can be an excellent alternative to choose from among the numerous varieties of solar panels.

Thin film technology is also responsible for flexible solar panels on recreational vehicles (RVs) and boats. Thin films can be put on plastic to generate flexible solar panels because they are (as their name implies) much thinner than a typical silicon wafer. For RVs and transportable use, these panels are particularly useful because they can be mounted on a non-flat surface.



Figure 1-14: Thin Film Solar Cells^[11]

1.9.4 Multi-junction Solar Cell

Multi-junction solar cell has multi layers of p-n junction and each p-n junction has different bandgap energy. So, it harnesses energy from different sections of solar spectrum by overcoming Shockley-Queisser (SQ) limit.

Multi-junction solar cells based on III-IV materials gallium arsenide (GaAs), aluminium indium phosphide (AlInP), gallium indium phosphide (GaInP), aluminium gallium indium phosphide (AlGaInP), gallium indium phosphide (GaInP), indium phosphide (InP).

Efficiency of multi-junction solar cell is up to 40% but to high cost they are not used for commercial purposes. However due to high efficiency they are suitable for Space applications

CHAPTER 2 LITERATURE REVIEW

Burning fossil fuels such as oil, natural gas and coal could meet more than 75% of the energy demands of today's world but these sources are likely to deplete within the next few decades. Moreover, they have some severe and life-threatening effects on human bodies. According to a report everyday 10,000 people die due to air pollution from fossil fuels [1].

It's crystal clear that the continued use of non-renewable sources has harmful impacts on our health and environment. Following are some of the ways in which non-renewable sources influence biodiversity.

2.1 Air Pollution

Air pollutants emitted due to fossil fuel combustion include nitrogen oxides, Sulphur dioxide, mercury and particulate matters. These air pollutants affect our environment and biodiversity. For example, when mercury is emitted into the air it either deposits on the ground or goes into the water where it affects marine life by mixing into their food chain. Apart from this, exposure to mercury can create neuro-behavioral effects in young children.

2.1.1 Green House Gas Emissions

Contributing to climate change is probably the most well-known impact of using non-renewable energy sources. It emits greenhouse gases such as carbon dioxide and methane in which coal is considered as the worst emitter of CO₂. Methane which is 34 times stronger than CO₂ in terms of its potential for heat trapping is being released in the process of drilling for extracting natural gas.

2.1.2 Waste Generation and Land Pollution

While generating energy from non-renewable sources, one can't ignore the environmental impacts which occur as a result of disposing wastes they generate, into the land. For example, in case of nuclear energy the disposal of wastes creates some critical issues due to its radioactive nature.

2.1.3 Acid Rain and Water Pollution

Acid rain is caused when Sulphur and other chemicals are introduced into the atmosphere from industrial processes. Acid rain weakens forest ecosystem as it is dangerous to trees. It also changes the acidity of water bodies which results in the disturbance of aquatic life.

So, keeping the above implications in mind it is need of the hour to explore Renewable sources of energy which are affordable, clean and sustainable. Renewable sources include wind, thermal, solar, hydropower, geothermal, bioenergy and currently they constitute nearly 25% of global energy demands.

2.2 Solar Energy

The energy we receive from sun in the form of electromagnetic radiations is known as solar energy. There are 3 ways to harness solar energy.

2.2.1 Solar Heating and Cooling (SHC)

Through this technology we harness heat from sun to provide heating and cooling, hot water, pool heating and space heating for residential, commercial and industrial applications.

2.2.2 Concentrating Solar Power (CSP)

CSP plants concentrate sun's energy with the help of mirrors to run traditional steam turbines and engines to generate power. The energy concentrated in a CSP plant can be stored and used to generate electricity even at night.

2.2.3 Photovoltaics (PV)

PV devices use sunlight to generate electricity through an electronic process that occurs naturally in semiconductors. PV devices can be used to run small electronic devices like calculators up to providing sufficient power for residential, commercial and large industrial purposes.

2.3 Advantages of Solar based PV Electricity

Shifting to PV based energy has numerous advantages over other forms of energy. Down below we will discuss few of them.

2.3.1 Economically Viable

Installing solar panels will help you reduce your monthly electricity bill as you are generating your own power with the help of sun.

2.3.2 Sustainable

Solar energy is the most abundant form of energy on earth. 173,000 terawatts of solar energy strike the Earth continuously which is 10,000 times the world's total energy use. So, we could use solar energy for billions of years and it won't mitigate.

2.3.3 Low Maintenance

Once you invest in solar panels it will work properly for many years to come. Most of the solar panels these days come with a reliability of 25 years which means after 25 years its efficiency will degrade a bit.

Despite being economically viable, less capital intensive, low maintenance and easy to install, it faces some shortcomings like dependence upon weather, low conversion efficiency and only day time availability. Maximum solar conversion efficiency is around 33.7% which is the theoretical limit of silicon p-n junction also known as Shockley-Queisser limit but still most commercial solar cells manage an efficiency of 13-20%. However, this efficiency of solar panels drops down a little more due to wrong orientation and elevation of the panels and not cleaning it regularly.

Before going into their details and proposed solution according to the research conducted by our team, let's discuss some terminologies first.

2.4 Open Circuit Voltage (V_{oc}) and Short Circuit Current (I_{sc})

Open Circuit Voltage (V_{oc})

Open circuit voltage is the maximum voltage available from a solar cell when there is no load connected to the system. Since there is no load connected to the solar panel, no current would be produced.

V_{oc} is the maximum voltage that can be produced under STC. V_{oc} is a very important number because it tells us how many solar panels can we wire into our inverter in series.

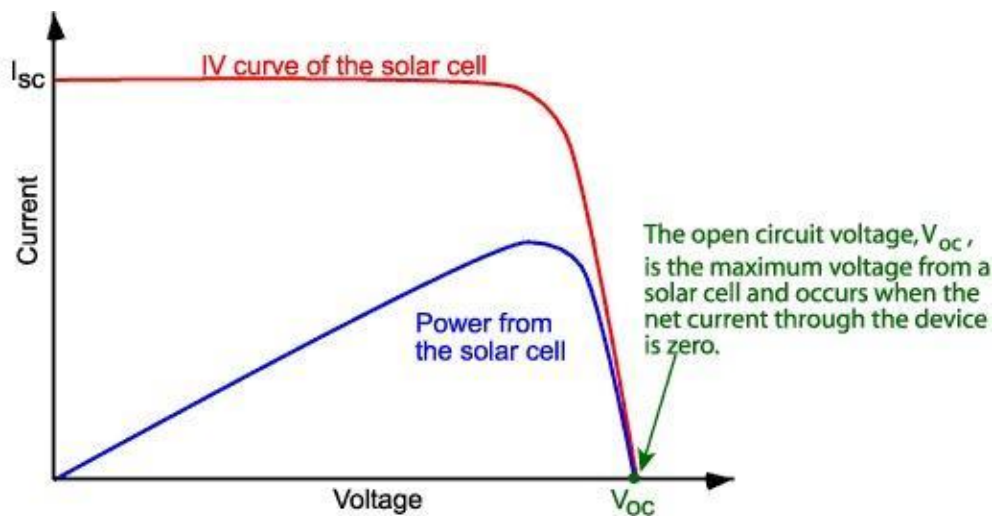


Figure 2-1: Open Circuit Voltage Graph^[7]

Short Circuit Current (I_{sc})

Short circuit current is the maximum current produced by a solar panel when it is not connected to a load. Since the circuit is shorted i.e. positive and negative terminals are connected directly to each other so there would be zero voltage. I_{sc} is the maximum current value that we get from Solar panel under STC. This number tells us how many amps a connected device like inverter or solar charge controller can handle.

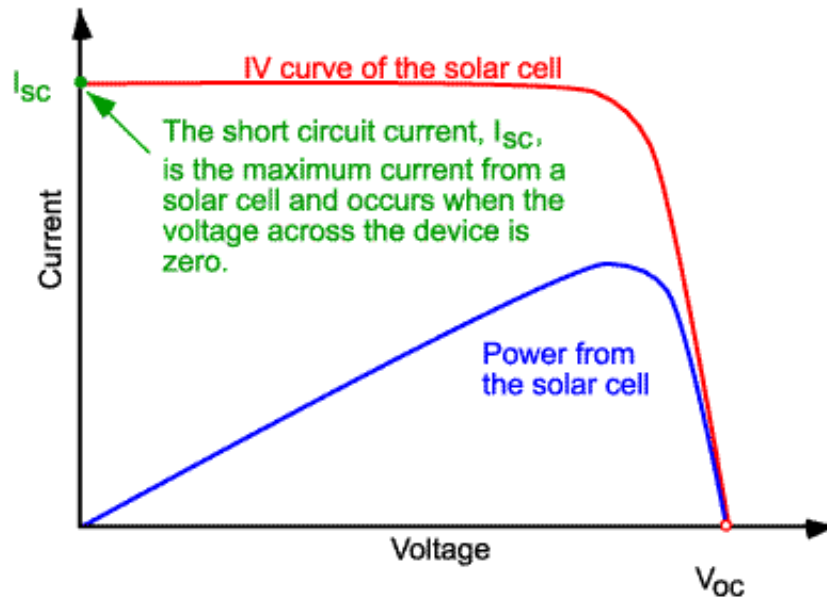


Figure 2-2: Short Circuit Current^[7]

2.5 Factors Effecting Voc and Isc

Generally, there are two factors which effect the output (I_{sc} and V_{oc}) of a PV system, which are Irradiance and temperature.

Temperature causes a decrease in output voltage while current of the PV module increases with an increase in irradiance.

Down below we will throw further light on how these factors effect I_{sc} and V_{oc} .

2.5.1 Irradiance

According to previous studies dependency of V_{oc} on irradiance is not very significant. However, a significant increase occurs in current with increase in irradiance. When light falls on the surface of PN junction in solar cell, it knocks out electrons from the depletion region which produces current. So, increase in irradiance leads to more current being produced [9].

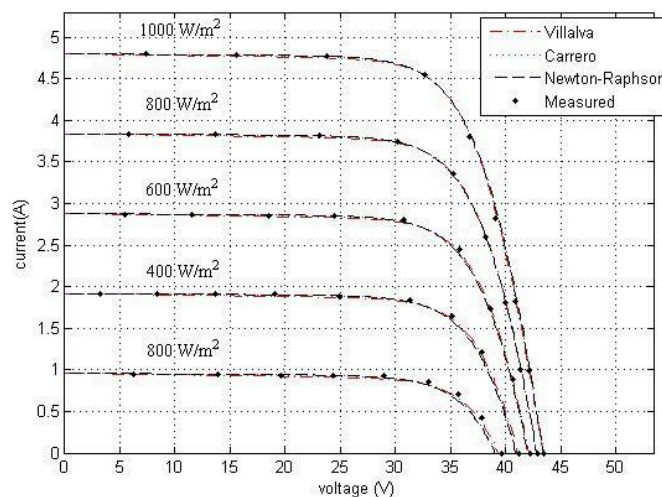


Figure 2-3: Irradiance Graph^[9]

2.5.2 Temperature

I_{sc} variation with temperature can usually be neglected i.e. for every degree C rise in temperature, current increases 0.05%. However, V_{oc} is highly dependent upon temperature. For every degree C rise in temperature 0.35% drop in voltage occurs i.e. -2.2mV/degree C [10].

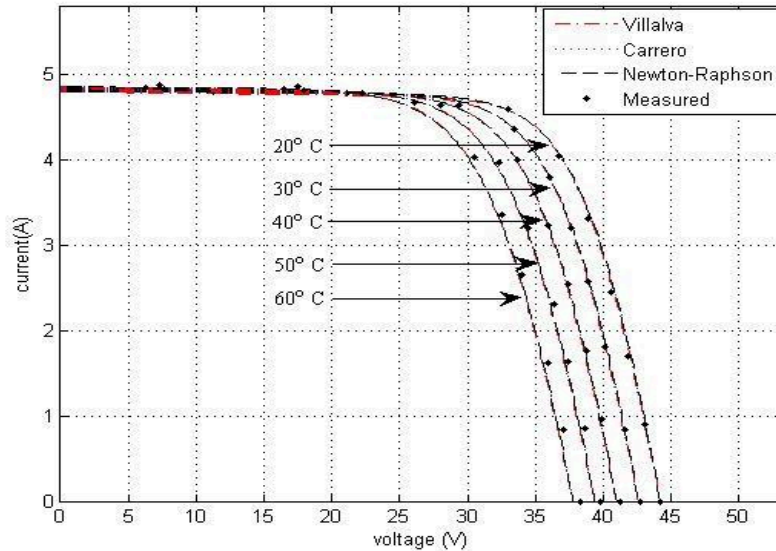


Figure 2-4: Temperature Graph^[9]

2.6 Solar Irradiance

Solar irradiance is the power per unit area received from the sun or we can say that the output of light energy from the entire disk of the sun measured at the earth surface is known as solar irradiance.

In SI units, solar irradiance is measured in Watt per square meter (W/m^2). Above the earth's atmosphere, solar radiation has an intensity of approximately $1380 W/m^2$. This value is known as the Solar Constant.

At the earth surface on a clear summer solar noon this value is approximately $1000 W/m^2$. The difference between this value and the Solar Constant is due to transmission loss to the atmosphere. The clear sky value is considerable less in the winter. Clouds can dramatically reduce this value by reflecting the solar radiations back to space.

Irradiance falling on the earth surface can and does vary from time to time, which is why it is important to remember that irradiance is a measure of power (rate at which energy is received) not the total amount of energy.

For total amount of energy, we introduce another term known as insolation.

2.7 Solar Insolation

Solar insolation is the total amount of solar energy that falls on the earth surface over a specified time or we can say that insolation is the power from the sun added up over some time period.

2.8 Azimuth

It is the angle between North, measured clockwise around the observer's horizon, and a celestial body such as moon or sun.

For example, Sun, due North has an azimuth of 0° , due East 90° , due South 180° and due West has an azimuth of 270° . Solar azimuth is represented by γ .

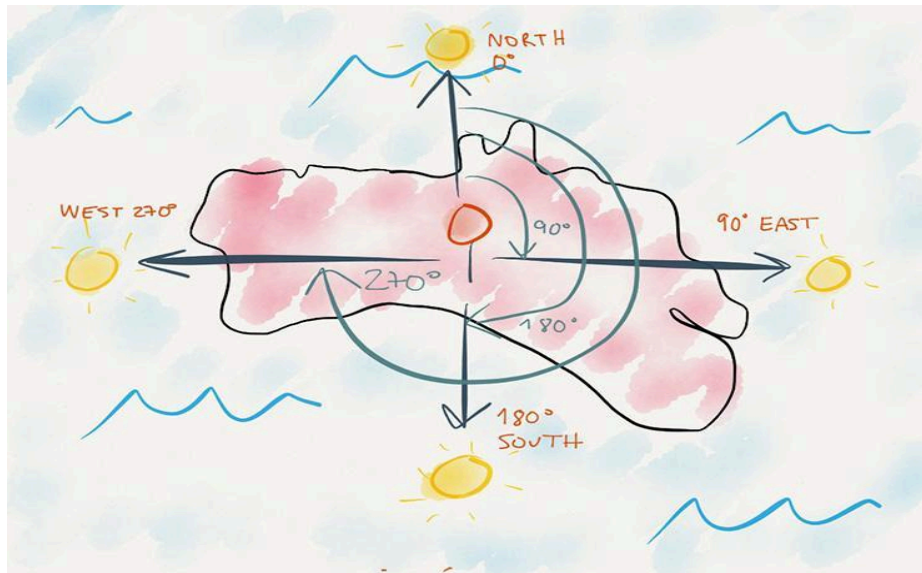


Figure 2-5: Azimuth^[10]

This definition seems a bit confusing so in short, the direction your roof faces the sun is referred to as its Azimuth angle. For sun rays, it is the angle measured in horizontal plane from true south for northern hemisphere and true north for the southern hemisphere.

2.9 Tilt Angle

It is also often termed as the Elevation angle. Tilt describes the vertical angle of our solar panels or we can say that it is the angle between the horizontal plane and the solar panel. Tilt is represented by β .

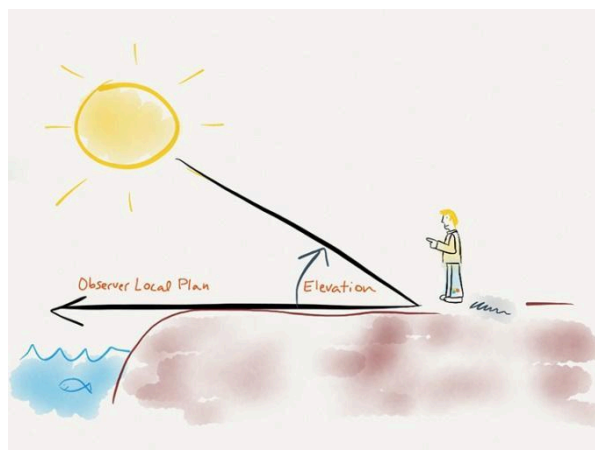


Figure 2-6: Tilt Angel^[10]

Optimum Tilt and Azimuth are very crucial in getting the desired output from a solar system. So, to put it in a line Azimuth shows sun's position and Elevation/Tilt shows sun's altitude.

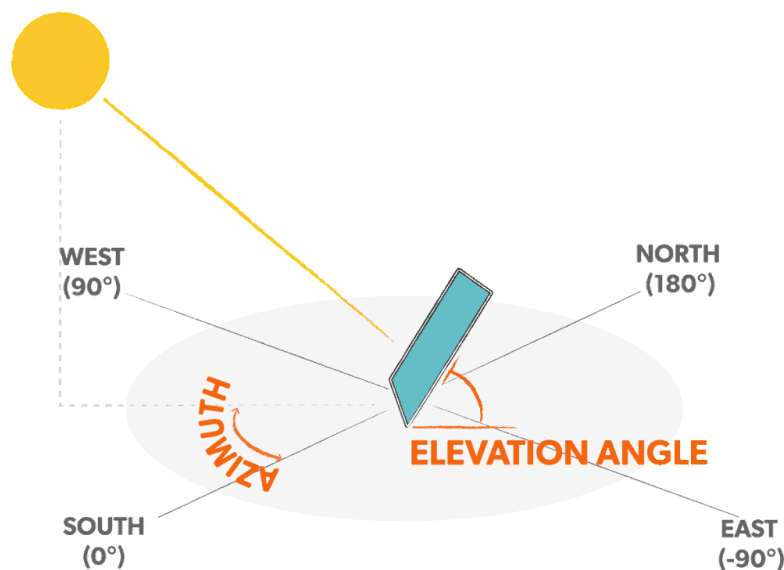


Figure 2-6: Azimuth and Tilt^[10]

2.10 Solar Incident Angle

Angle which a ray of sun makes with normal of the solar panel surface is known as solar incident angle. A surface directly facing the sun has an angle of incidence of zero (Sun above the solar panel at noon) will give maximum output while a surface parallel to the sun has an incident angle of 90° (When a sun rise strikes a horizontal rooftop). At an angle of 90° , the amount of light falling on the panel's surface is zero and we don't get an output because light simply doesn't strike the solar surface.

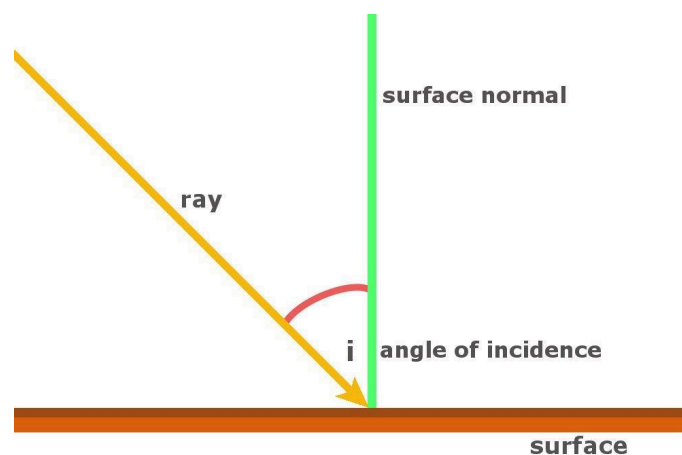


Figure 2-7: Solar Incident Angel^[10]

2.11 Cosine Losses

When the incident angle is not zero i.e. the incident rays are not perpendicular to the incident surface, part of the incident energy or whole (When angle is 90) will be lost due to Cosine effect. When irradiance (G) falls on the solar panel surface at angle θ (where θ doesn't equal to 0) it will lower efficiency of the cell. To calculate the reduction, we will resolve vector G into its parallel and perpendicular components where;

G perpendicular

Useful component that would be absorbed and give us some output power which is equal to $G \cos\theta$ where G is irradiance in W/m^2 and θ is incident angle,

G parallel

Useless component that would be reflected or somehow lost

Let us understand it better with the help of an example.

Let the sun rays strike normal of the solar panel surface at an angle of 30° . Now the useful component or irradiance absorbed by the surface would be,

$$G_{||} = G \cos 30$$

Let's say it's a clear sunny summer afternoon and $G = 1000 \text{ W/m}^2$.

$$G_{||} = (1000 \text{ W/m}^2) \cos 30$$

$$G_{||} = 866 \text{ W/m}^2$$

So, the surface is absorbing 86.6% of the available solar power.

From the above discussion regarding different angles and Cosine losses it is clear that Sun's position and tilt angle of the solar panel have severe effects on the output power of solar cell. To mitigate this unfavorable effect on the output of PV cell and create a higher energy yield, scientists and engineers introduced Solar trackers.

2.12 Solar Tracker

Solar tracker maintains position of solar panel in such a way that the sun rays strike the panel perpendicular. Unlike fixed-tilt PV systems, Solar tracker makes solar panels follow the sun's path throughout the day.

By keeping the panel perpendicular to the sun, more sunlight strikes the panel, less light is reflected and thus more energy is absorbed which is converted into power through PV process.

2.13 Working of Solar Tracker

Solar trackers normally are electro-mechanical systems consisting of motors and LDR (Light dependent resistor) sensor circuit. LDR sensor circuit instructs the motor to turn the panel according to the changing position of the sun by detecting the sun rays. Due to solar tracker, solar panels accumulate almost 95% of the accessible solar energy.

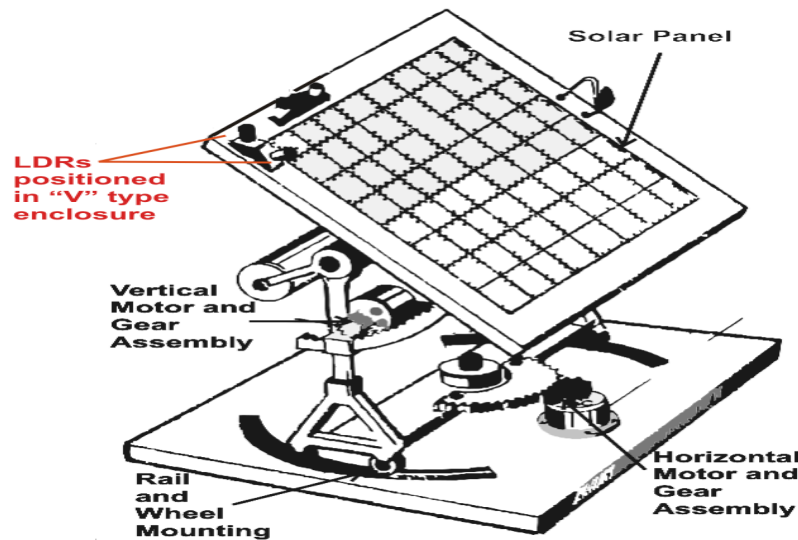


Figure 2-9: Working of Solar Tracker^[3]

2.14 Types of Solar Tracker

On the basis of drive system, solar panels can be divided into two types.

2.14.1 Passive Solar Tracker

Passive Solar trackers use a low boiling point compressed gas fluid to cause the tracker to move and follow the sun rays in response to an imbalance. Heat energy to the fluid is not provided by external source (Which is one of the main differences between passive and active solar trackers) but from the sunlight itself. So, the sun's heat moves the fluid from side to side, allowing gravity to turn the panel and follow the sun.

Passive trackers are advantageous in a sense that they have very little equipment's to fail i.e. no motors and gears but are not that popular because the trackers are too slow to follow the sun in extreme cold conditions as the fluid would not heat up quickly.

2.14.2 Active Solar Tracker

Active solar trackers use motors and electronic sensors to move the panel in direction of the sun. Unlike passive solar trackers, active solar trackers must be provided with energy for the actuators to run.

2.14.3 Comparison

Although Passive solar tracker is inexpensive and has a simple design as compared to its counterpart yet passive solar trackers are not popular because of its inability to employ accurate positioning of solar panels, no monitoring and alarm system, being ineffective at morning and evening and lack of ability of automatic lockup in extreme wind conditions.

2.15 Types of Active Solar Tracker

Active solar tracking systems are of the following two types:

2.15.1 Single Axis

A single axis solar tracker is used to arc the panel from east to west and track the sun as it rises and sets. It can improve the efficiency up to 35% as compared to its fixed tilted counterpart.

2.15.2 Dual Axis

A dual axis solar tracker allows panel to move in two axis, aligned both north-south and east-west. Dual axis tracker helps track seasonal variations in the position of the sun along with normal daily motion. It improves the efficiency up to 45% as compared to a typical static solar panel of similar type.

Because of its very high cost, even among large scale projects they are not very popular. The only situation where Dual axis trackers are useful when we have less space constraints or if you live in high altitudes where sun's position changes abruptly.

1) Single axis tracker

2) Dual axis tracker



Figure 2-10: Single and Dual Axis Tracker^[3]

2.16 Cons of Solar Trackers

Some of the disadvantages of Solar trackers are discussed below.

- a) It is way more expensive than fixed solar systems.
- b) The moving parts of tracker comes with a reliability of 5-10 years so we will have to bear additional cost after few years' time.
- c) Trackers are often limited to ground mounted systems as they are too heavy to be installed on roof tops.

Despite the fact that solar trackers are more efficient than their static counterparts, still consumers are hesitant to install them because of their heavy price, low reliability and high maintenance cost/

2.17 Soiling

The accumulation of dust particles, dirt, snow, bird droppings, pollens and leaves on a solar panel surface is known as soiling. Output power of a solar panel highly depends upon irradiance falling on its surface. Many factors reduce the intensity of irradiance reaching the

PV module, however soiling is one of the contributing factors which directly effects the output of PV module by reducing the sunlight reaching its surface.

PV power loss increases with an increase in quantity of soil on the panel surface. Annual soiling losses generally are in the range of 1-7%. These losses could be even more, depending upon the environmental conditions of that area.



Figure 2-11: Soiling^[13]

2.18 Shadowing Effect

Shadowing effect occurs when a PV system does not receive the same amount of irradiation level throughout the system due to soiling. Because of the series connection all the cells operate having the same current, the shaded cell within a module becomes reverse biased which leads to power dissipation in the form of heat.

Bypass diodes are used to reduce the impact of shadowing effect by providing a current path and to protect the solar panel.

2.19 Shading

Whenever a PV system does not receive optimum sunlight due to a shaded obstruction, it results in lowering the output power of that PV system. This phenomenon is known as shading.

Obstructions can be of different types such as nearby trees or poles obstructing the light to reach the panel, self-shading due to nearby panels or shading due to soiling as discussed above.

Shading could be divided into two categories.

2.19.1 Soft Shading

Soft shading occurs when a hazy day or pollution in the atmosphere or soiling on the panel partially block the sunlight to reach the panel i.e. it filters the light and lowers its intensity. Due to lower level of light the current provided by the module decreases but voltage

remains the same. Voltage remains the same because all the cells are still receiving light in smaller amount.

2.19.2 Hard Shading

Hard shading occurs when something such as an obstruction above the panel surface or soiling on the surface blocks the light completely from reaching the PV system. If all cells of the module are blocked then there will be no output but if some cells are blocked then shaded cells act as resistance to current generated by other cells. This causes the shaded cell to heat up which leads to a hot spot on the module and can eventually damage the module.

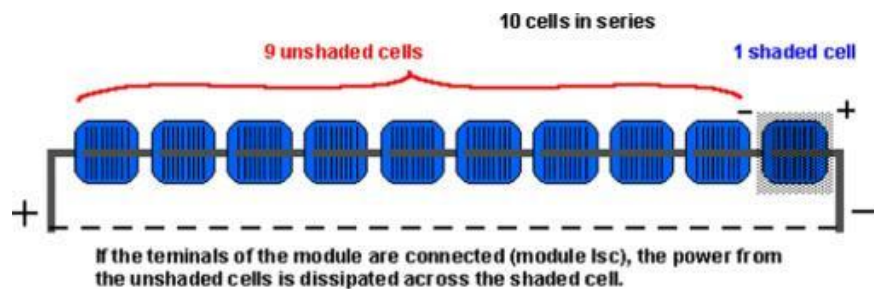


Figure 2-12: Hard Shading Without Bypass Diode^[4]

This problem of hotspot can be avoided by installing a bypass diode which makes sure that the shaded cell doesn't block the incoming current from other cells and provides the current with another path.

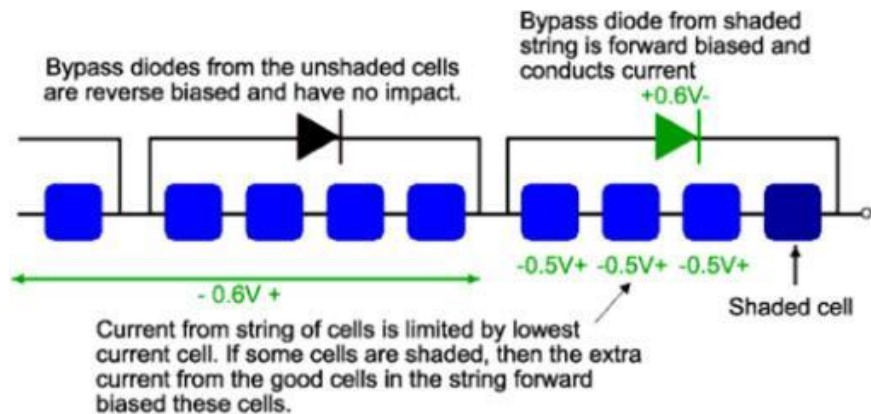


Figure 2-13: Hard Shading with Bypass Diode^[4]

In this chapter, we have studied how an incorrect tilt angle and wrong orientation of the panel can lead to a low power output. To mitigate that effect, we install solar trackers to our system but due to high cost and some other drawbacks, consumers (especially residential) are reluctant to install it to their systems.

Furthermore, we studied how soiling can reduce not only the efficiency of PV modules but can also reduce its lifespan in severe cases. So the question arises what is the proposed solution for such situations. We conducted a research over 12 weeks in 2 cities of Pakistan and observed how output changes with soiling and how different environments lead to

different soiling conditions. We will discuss that in details in the next chapters and also provide a possible solution to attenuate the soiling effect in light of our research.

CHAPTER 3 EXPERIMENTAL WORK

In this chapter we will describe the procedure of our experimental work and explain how we carried out each step. Moreover, we will state the reason behind our chosen methods. From selecting the two different locations for our research, we will proceed step by step till finding out the difference in amount of soiling in these two different locations. Our research work will show how different amount and quality of dust particles have different effects over solar panel's output power. At the end, we will prove with a little experiment how moderate rain fall doesn't clean the panels unlike the common public opinion that rain fall is enough to wash away the dirt from solar panels.

3.1 Data Collection

In order to examine the effect of soiling on solar module's output in outdoor conditions and compare the amount of soiling in different locations, we made two experimental setups of the same type in two major cities of Pakistan, Peshawar and Swat. The setup consists of a 5-watt polycrystalline solar module on a ground mounted rack. The tilt angle could be changed with the help of knob in the rack. Both the setups were located on rooftops almost 15 meters above the ground. Data was taken from both the solar modules from May 15th- August 15th on weekly basis in Peshawar and only two set of values were recorded in Swat on first and last day of the experiment. We took data at different tilt angles i.e. 0°, 30° and 60° and compared the values of I_{sc} and V_{oc} at these three different angles. Data was taken at solar noon to get an irradiance of nearly 1000 W/m² and a possible zero incident angle so that we could change our tilt angle in correspondence to that. Solar noon at both these cities for these 3 months was around 12-12:30 pm. Temperature range at the time of our experiment in Peshawar was 36°-44° C and 32°-40° C in Swat. At the end of our experiment I_{sc} and V_{oc} graphs with respect to time were plotted with the help of Excel and Power point.

In Peshawar where data was taken on weekly basis, two polycrystalline modules were setup on an adjustable rack. Out of the two, one was cleaned every week before taking readings and the other is left for natural soiling.

In Swat where we took data only twice, i.e. at the start and end of our 3-month experiment, only one solar module was setup on a similar adjustable rack and was left to accumulate natural dust.

All the 3 solar modules were left in open air for natural soiling and were protected from rain with the help of overhead protections.

3.2 Experiment 01

As mentioned above, we conducted experiments at two different locations. Experiment 1 was performed in Peshawar on weekly basis at Solar noon for 3 months (May-August). Peshawar is sixth largest city of Pakistan with a population of over 2 million. The coordinates of Peshawar are 34° North and 71.5° East. According to a study conducted in 2015, the particulate matter (PM) is increasing day by day in Peshawar due to rapid growth in

urbanization and industrialization. Overhead bridges, roads and building constructions and the use of several transportation activities have badly affected the atmosphere of this city. Their results revealed that soil dust, brick kiln, vehicular, industrial emissions and household combustion emissions are the main reasons of suspended PMs in the atmosphere.

In this experiment, two 5W solar modules of similar type (Polycrystalline Silicon) were setup on an adjustable rack. Every week, readings of Isc and Voc were taken at 0° , 30° and 60° tilt angles with the help of digital multi-meter. We changed the tilt angle with the help of knob in the rack and that's why we call it adjustable rack. Out of the two panels, one was left to the open air to accumulate dust while the other would be cleaned with a soft cloth before every set of readings. To protect the uncleaned panel from rain, an overhead protection was made for the solar system [3].

3.3 Experiment 02

Another setup was made with only one polycrystalline Silicon module on a similar rack in Swat. As compared to Peshawar the environment is Clean and far less polluted. Coordinates of Swat are 35° North and 72.4° East. Solar module was left to open air for natural soiling. Unlike experiment 1, only 2 readings were taken, one at the start of the experiment and one on the last day of experiment as our main purpose of installing the panel in Swat was to compare the soiling of the two cities.

At the end of both experiments the accumulated dusts on the uncleaned modules were measured with high precision balance.

3.4 Dust measurement

To weigh the dust on the solar panels at the end of experiment, we first took a soft cloth, on which we would later clean the surface of the module and put it inside an envelope. We measured the mass of the envelope and cloth on a high precision balance with an accuracy of milligrams. Then we collected the soil in the envelope and removed the remaining sticky soil on the panel with the help of cloth and put it inside the envelope. We measured the mass of envelope again with the same balance. Now to find the mass of the dust we subtracted the initial mass from the later one.

Another setup was made with only one poly crystalline Silicon module on a similar rack in Swat. As compared to Peshawar, the environment is Clean and far less polluted. Coordinates of Swat are 35° North and 72.4° East. Solar module was left to open air for natural soiling. Unlike experiment 1, only 2 readings were taken, one at the start of the experiment and one on the last day of experiment as our main purpose of installing the panel in Swat was to compare the soiling of the two cities.

At the end of both experiments the accumulated dusts on the uncleaned modules were measured with high precision balance.



Figure 3.1: Digital Balance

3.5 Purpose of Two Experiments at a Time

Deposition of dust on PV panels changes with region to region depending upon the environment. The impact of soiling on PV output depends upon the pollution type i.e. the particles' composition and origin not just the total mass accumulated. According to a research conducted by J.K. Kaldellis and his team, while comparing the effect of three different types of pollutants on PV output they found that Red soil particles cause the highest reduction, followed by limestone and finally by Carbon based ash [11].

The reason we started two experiments at a time was to find the soiling effects of two different environmental conditions at the same time of the year. So in a span of three months we found how output of two similar types of solar modules would be affected by dust on exposing to natural environment. If we were to perform the research separately at different times of the year, first there would be a major temperature difference. Second the irradiance level might not have been the same for both the experiments as irradiance changes as the season shifts and there is change in temperature. So to mitigate the effects of difference in temperature and irradiance from our work we started the two experiments at same time of the year.

3.6 Choice of Site

Reason to choose two different cities for our research work was due to their different environmental conditions. Pollutant particles in both cities are quite different from each other. Among the sources of particulate matter (PM) in Peshawar are red soil and brick kiln emission which are found rarely in Swat so definitely the results due to soiling would be different in both cities for the same time period. One could point out the comparatively cooler temperature of Swat having an effect on output of PV cell, yes that would have an effect on the output but the results due to temperature change would be so minor that it would not have a negative impact on our work.

CHAPTER 4 RESULTS AND DISCUSSION

In this chapter, we are going to discuss the results we got through our research work and will summarize the whole discussion into one paragraph towards the end of the chapter.

4.1 Experiment 01

Experiment performed over both clean and uncleaned Solar modules in Peshawar.

4.1.1 Variations in Current Due to Soiling

On day 1 of our research, values of I_{sc} were recorded from both the cleaned and uncleaned solar modules. Both the readings were almost similar due to the fact that both these modules were clean and of the same type. The current readings from the cleaned module remained same throughout 12 weeks with some negligible variations.

Contrary to the cleaned solar module, I_{sc} decreases as soil accumulates on the uncleaned module. The rate at which current decreases is quite significant. This is due to the fact that soiling reduces the direct beam of solar radiations and decrease in irradiance results in lower output current.

Data taken by our team shows that I_{sc} decreases from 290mA to 125mA at 0° tilt angle, from 281mA to 116mA at 30° tilt angle and from 242mA to 102mA at 60° tilt angle. On average the current value decreased by 155mA over the course of 12 weeks which is quite significant loss in I_{sc} .

We put our work in the form of a current-time graph which shows the decrease in current over 12 weeks at all the 3 tilt angles (0° , 30° and 60°) at which we conducted our experiment.

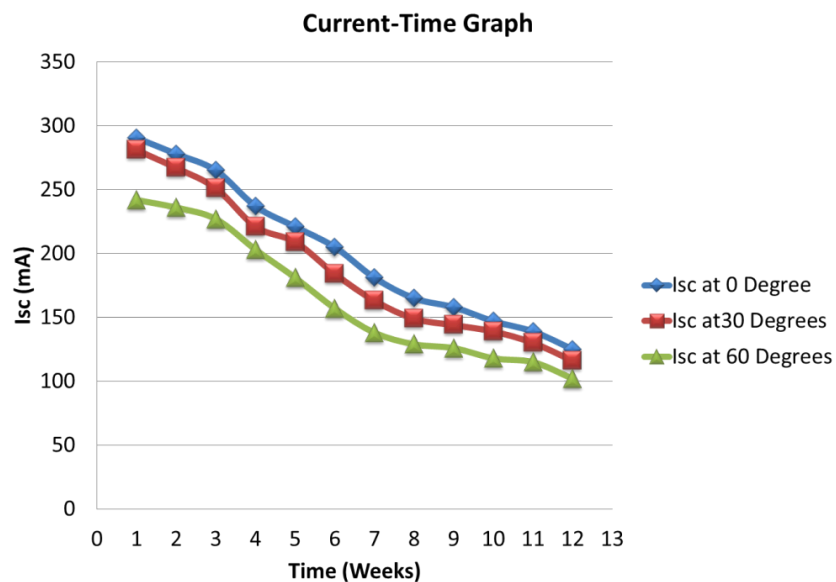


Figure 4.1: Current-Time Graph

4.1.2 Variations in Voltage Due to Soiling

As discussed in the previous topic, on first day of the experiment, readings of V_{oc} were recorded from both cleaned and uncleaned solar modules and as expected both had similar values since both modules are of similar type and were cleaned. These values of V_{oc} remained same throughout 12 weeks for the cleaned module with some very minor changes due to increase in temperature [11]. Since that decrease in V_{oc} due to temperature increase is too little to have an impact on our work so we don't take it into consideration.

On the contrary to I_{sc} , soiling didn't have any major impact on the voltage values at all the 3 tilt angles. This is due to the fact that the dust accumulated on our solar module was merely for 12 weeks so it didn't result in hard shading which completely blocks the sunlight and results in zero output voltage [2]. Soft shading affects the I_{sc} which our experiment proves but it has very little impact on V_{oc} .

Data taken by our team shows that V_{oc} changes from 10.11V to 9.50V over the course of 12 weeks for 0° tilt angle. Similarly, V_{oc} drops from 10.02 to 9.41 for 30° tilt angle and from 9.92 to 9.31 at 60° tilt angle. On average the voltage decreases 0.6 volts which is quite insignificant decrease.

We plot the voltage change over time in X and Y axis for all the 3 tilt angles.

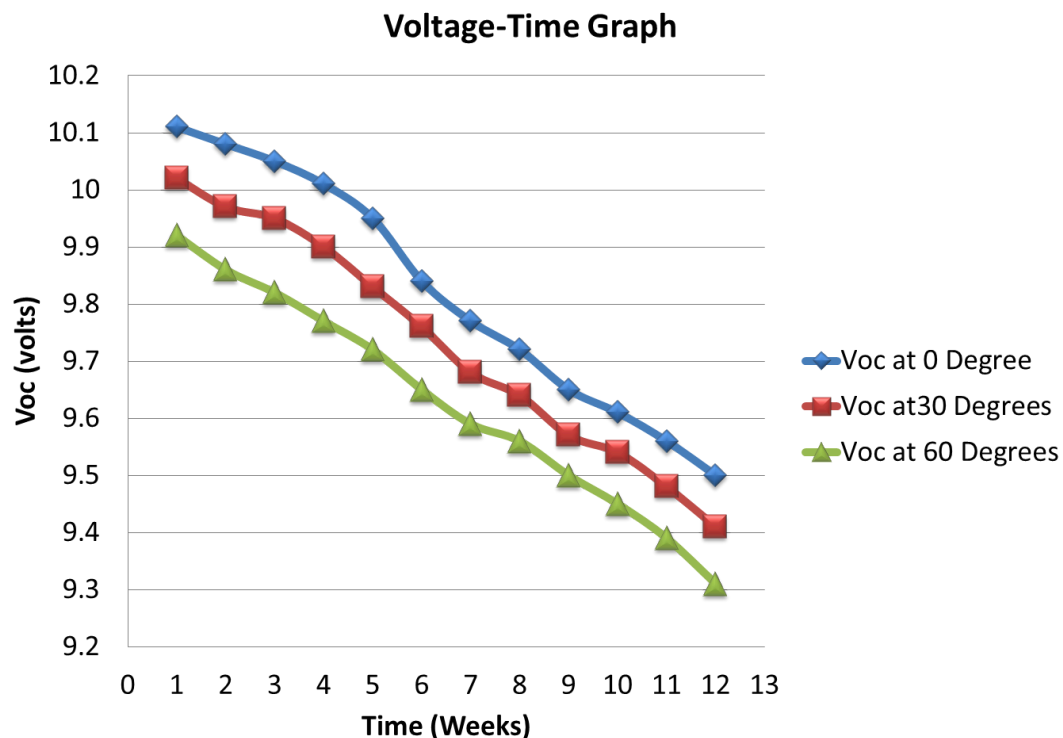


Figure 4.2: Voltage-Time Graph

4.1.3 Variations in Power Output Due to Soiling

Since power is simply the product of voltage and current, it remains the same over the span of 12 weeks for the cleaned module but drops significantly for the uncleaned module.

Data taken by our team shows that output power changes from 2.937W to 1.188W over the course of 12 weeks for zero tilt angle. Similarly, power drops from 2.816W to 1.092W for 30° tilt angle and from 2.40W to 0.95W at 60° tilt angles. On average the P_{output} decreases 1.64W which is quite significant loss.

By putting the values of V_{oc} and I_{sc} in Excel we get the following graph for Power output.

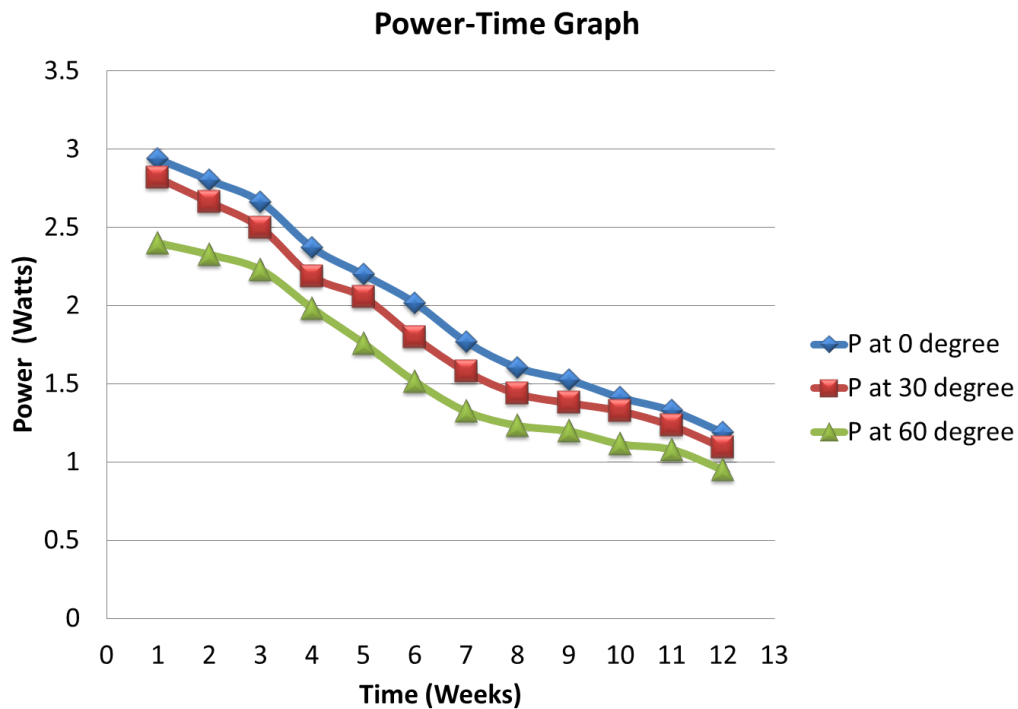


Figure 4.3: Power-Time Graph

4.1.4 Variations in Current Due to Tilt Angle

This has been one of the most interesting outcomes of our work. On changing the tilt of the uncleaned module from 0° to 30°, on average I_{sc} decreases by 15mA which makes it 5mA drop per 10° tilt increase. Beyond 30° tilt, this pattern changes and as we shift from 30° to 60°, the drop is 27.4mA which is 9.1mA reduction per 10° tilt increase.

The reason behind this increase in drop beyond 30° tilt is because of the reduction in Solar irradiance falling on the module's surface.

4.1.5 Variations in Voltage Due to Tilt Angle

Changing the tilt of solar module didn't have any major impact on output voltage. The change in voltage reduction was same throughout the 60°. For every 30° rises in tilt, voltage drop is 0.1V which makes it 0.033 volt drop per 10° rises in tilt. This is somehow in correspondence with the results taken earlier in the Variations of V_{oc} due to soiling [5]. From

these two results, we concluded that soiling which results in soft shading and changing tilt of the panel have very little impact on the output voltage of PV cell.

4.1.6 Variations in Power Due to Tilt Angle

Since change in V_{oc} is not noticeable due to increase in tilt angle so decrease in output Power will automatically follow the pattern of I_{sc} . As we go from 0° tilts to 30° , on average output power decreases by $0.148W$ which is $0.049W$ per 10° rises in tilt. From 30° to 60° , P_{output} has an average reduction of $0.251W$ which is $0.084W$ drop per 10° rises in tilt.

4.2 Experiment 02

Experiment 2 was conducted in Swat over one solar module of the similar type as that in Peshawar and it was left uncleaned to the natural environment for 12 weeks.

Unlike Peshawar only 2 readings were taken in Swat, one at the start of experiment and another reading after 12 weeks. Our main purpose of installing a setup in Swat was to compare the soiling effect of Peshawar with a city having comparatively cleaner environment and less polluted.

4.2.1 Variation in Current Due to Soiling

I_{sc} recorded on day 1 was almost similar to that in Peshawar. This is due to the fact that we took readings on bright sunny day at solar noon in both cities so irradiance level was almost same for both the solar modules in the two cities.

After 12 weeks when the readings were taken again we saw a significant decrease in I_{sc} as expected. Current drops from $286mA$ on day 1 to $181mA$ after 12 weeks for 0° tilt. From $278mA$ to $172mA$ for 30° tilt and from $241mA$ to $147mA$ for 60° tilt.

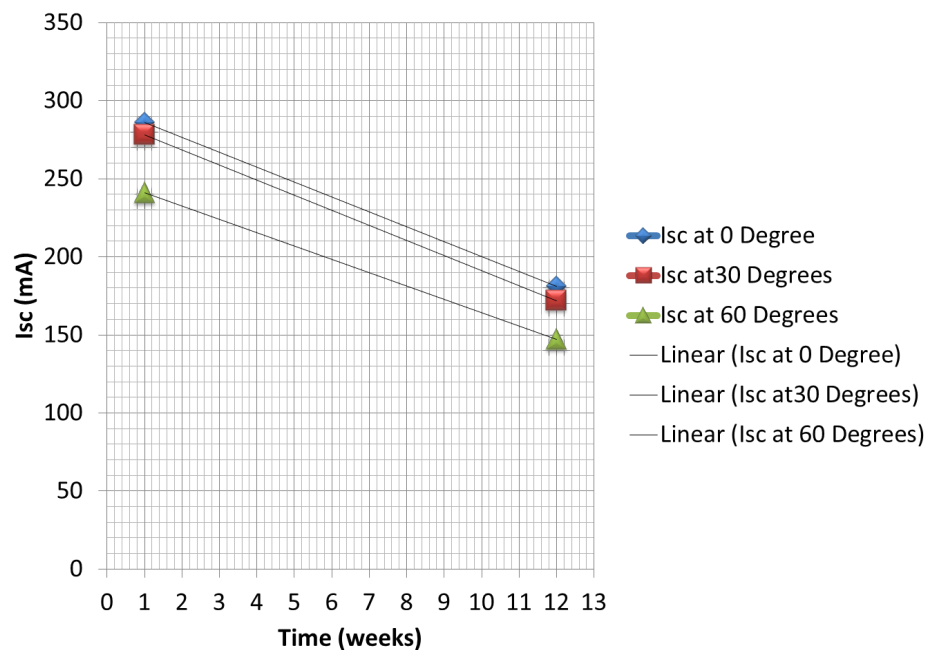


Figure 4.4: Current-Time Graph

4.2.2 Variations in Voltage Due to Soiling

On day 1, voltage output was similar to the voltage output we got from setup in Peshawar due to similar conditions in both cities. After 12 weeks, we saw a minor drop in voltage output for all 3 tilt angles.

Data taken by our team shows that voltage drops from 10.12V on day 1 to 9.49V on last day for 0° tilt angles. Similarly from 10.04V to 9.40V for 30° tilts and from 9.90V to 9.35V for 60° tilts. The reason behind output voltage remaining almost the same throughout 12 weeks is due to the fact that irradiance has very little impact upon voltage output.

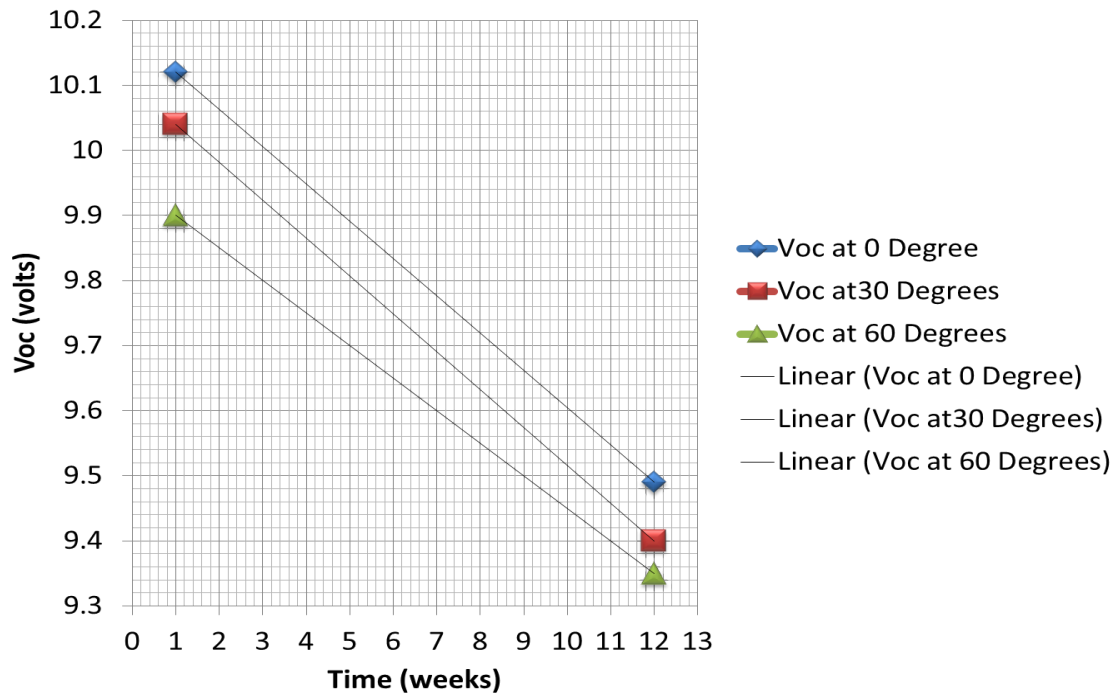


Figure 4.5: Voltage-Time Graph

4.2.3 Variations in Output Power Due to Soiling

Since power is the product of voltage and current and we saw that change in voltage due to soiling is very little so output power will follow the same pattern as that of I_{sc} with V_{oc} having very little impact over it.

Data recorded by our team shows that Power output drops from 2.894W to 1.718W for 0° tilts over the span of 12 months, from 2.791W to 1.617W at 30° tilts and from 2.386W to 1.374W for 60° tilts.

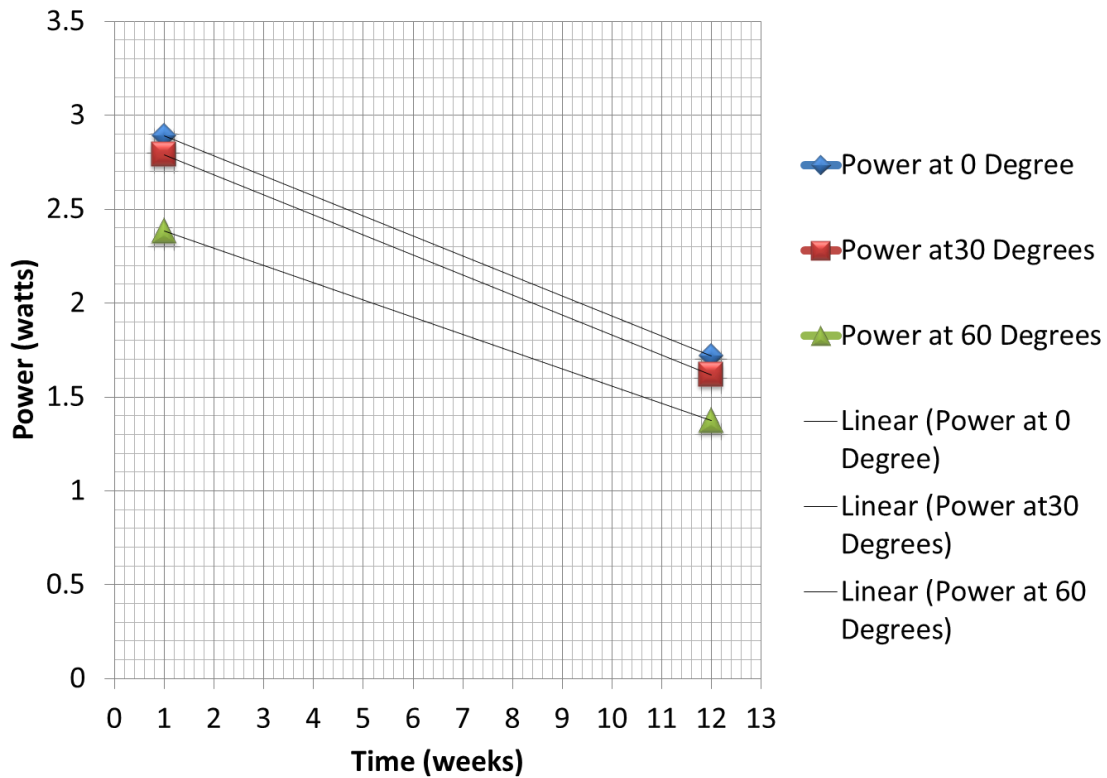


Figure 4.6: Power-Time Graph

4.3 Results Comparison

If we compare the output power from the uncleaned modules in both cities we would see a quite significant difference. Power output in Peshawar drops from 2.936W to 1.187W for 0° tilts, from 2.815W to 1.091W for 30° tilts and from 2.40W to 0.949W for 60° tilts. In comparison, values in Swat drops to 1.718W for 0° tilts, 1.617W for 30° tilts and 1.374W for 60° -degree tilt.

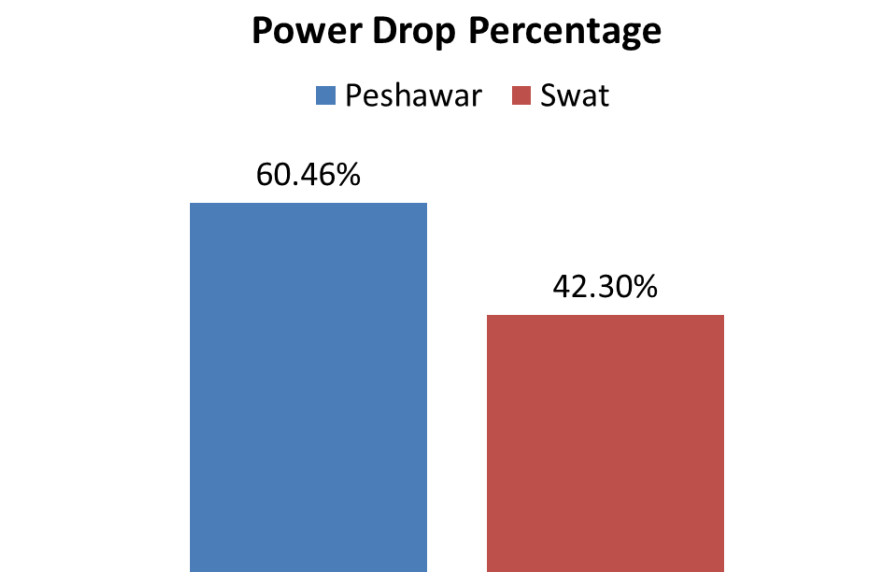


Figure 4.7: Power Drop Comparison

These results were quite remarkable as the average decrease in output power in Peshawar was 60.42% and that in Swat was 42.3%. This clear difference in power output from the two cities motivated us to carry our research further ahead and find the mass of the accumulated dusts on the panels.

4.4 Mass of the Dust Accumulated

We calculated mass of the dust from both modules through high precision balance having accuracy up to milli grams. To find the mass of the dust we first measured mass of a soft cloth (through which we will clean the module) and envelope (In which we will put the accumulated dust and cloth). After taking the initial readings we cleaned the solar module with the help of that cloth, collected the dust and put the cloth in the same envelope which we weighed earlier through digital balance. To find the mass of the dust we subtracted initial reading from the final one.

Total mass of envelope + cloth before cleaning the module = $m_1 = 4.869\text{g}$

Total mass after cleaning the module = $m_2 = 5.781$

Mass of the dust accumulated = $m_p = 0.912\text{g}$, where p stands for Peshawar

We applied the same procedures to find the mass of dust accumulated on the module in Swat and the results are given below.

Mass before cleaning = $m_1 = 4.742\text{g}$

Mass after cleaning = $m_2 = 5.524\text{g}$

Mass of dust accumulated = $m_s = 0.782\text{g}$, where s stands for Swat.

4.5 Density of Accumulated Dust

Area of our solar modules is exactly the same since they are of the same type.

Accumulated density of $m_p = m_p / \text{Area of solar module} = 2.58 \times 10^{-3}\text{g/cm}^2$.

Accumulated density of $m_s = m_s / \text{Area of solar module} = 2.22 \times 10^{-3}\text{g/cm}^2$.

Both the panels were left in natural environment for equal time span (12 weeks) to accumulate dust. Both the panels were protected from rain drops and still the power drop in Peshawar was 18.12% more than that of Swat. Apparently, this is because of the dust quantity on both modules. It is true that the mass deposition density in Peshawar is greater in our research work and the amount of dust falling on a module plays an important role in reducing the output power and efficiency of a module but this is not the only reason. The mitigation in output current not only depends upon the density of dust accumulated but also on the type of dust. So, we went on to have a little research about the particulates' types that what type of suspended dust particles are there in the atmosphere of these two cities.

4.6 Types of Particulate Matter (PM)

According to a research work road/soil dust, vehicular and industrial emissions and brick kiln emissions are the major sources of particulate matters in Peshawar while in Swat the majority contributors to the environment are pollen grains, vehicular and ash from home combustion emissions. Moreover, red soil is in abundance in Peshawar as compare to Swat where you would hardly find it and red soil is one of the main reasons in the mitigation of power output in Peshawar. This is in accordance with a study which reveals that a density of 0.2g/m^2 of Red soil has the same impact over efficiency reduction as that of 2.01g/m^2 of Ash. [4]

4.7 Rain vs Accumulated Dust

People often do not clean their solar panels because they believe that rain will wash away the dirt on their solar panels. To clear this misconception, we conducted a simple experiment at the end of our research. We put some artificial dust on a solar module of the same type in Peshawar. Mass of the dust was about 1.5g. The dust got settled on the module in a while, after that we left the module in open air for 2 weeks. On 15th day there was a moderate shower of 6-8 mm for one and a half hour which is the norm in Peshawar and many other places in Pakistan. When the rain stopped there was still a lot of scattered dust left on the module. This is also in accordance with a paper which tells that at least 20 mm of rain is required to clean the solar panels. So, little rain fall does not clean the panel and it often deteriorates the performance of PV panels because after rain fall the dust often settles to one or few places on the panel and results in hard soiling which blocks the sunlight from few cells and thus mitigates the output voltage. This imbalance in output voltages from solar modules could result in failure of many components in the PV system. Moreover, another study revealed that no matter how heavy the rain shower is still it can't wash away dust particles having diameter less than 10 micro meters.

4.8 Summary

The PV output not only depends upon the temperature and irradiance falling on the panel's surface but also decreases with an increase in tilt angle. Moreover, contrary to the established theory that we should clean our panels every 3-9 months, we proved through our work that time span for cleaning the solar panels depend upon not only your geographical location but also on environmental conditions as results from our work shows that power loss in Peshawar is about 60% and in Swat it is about 40% despite the fact that both the modules were left in open air for the same duration. Type of dust particles in the air should also be taken into consideration before setting up a scheduled cleaning process for your solar panels

because the amount of dust as seen by naked eye could often be misleading. It's true that output degradation of PV panel depends upon the amount of soiling but more importantly the type of dust particles. At last but not the least consumers should not depend merely on rain water to clean their solar panels as little rain could often disturb the activity of PV system.

CHAPTER 5 CONCLUSION AND FUTURE WORK

5.1 Conclusion

We conducted this research to analyze the impact of soiling and tilt angle on photovoltaic output and to compare the effect of soiling in two such regions where the pollution causes are different from each other.

To analyze the impact of soiling and tilt angle on PV's output we conducted experiment 1 and it reveals that output power decreases as the amount of dust gradually increases on the module's surface. Moreover, some interesting changes occur with increasing tilt angle as for the first 30 degrees the output current decreases at one rate and for the next 30 degrees, comparably I_{sc} decreases with a rapid rate.

The mitigation in power output not only depends upon the amount of dust accumulated on the solar panel but also the type of dust which is accumulated. To analyze this effect, experiment 2 was conducted by our team. Results from experiment 2 shows that despite the modules being set in an open air for same time span, the amount of dust gathered is different on both solar modules. Reduction in output power over the span of 12 weeks in Peshawar is 60% and for the same time span in Swat it is 42%. This crystal-clear change in Power reduction over the two regions motivated us to study the environment of the two regions. Upon research, we came to know that majority of dust particles in Peshawar are from Red soil which has the property to influence output power more than the other dust particles in Peshawar and Swat.

Towards the end we conducted a little experiment which shows that even a moderate rain shower is not efficient to clean the solar panel. So that's why we propose that it is important to take the type of pollutants into consideration along with irradiance and temperature so that the consumer may get a more efficient and reliable Solar module.

5.2 Future Work

Photovoltaic based energy production is on the rise and many successful attempts have been made in the last few years to improve its efficiency and reliability. However, the soiling situation at the consumer's end is different from region to region. Consumers are asked to clean their solar panels after 3-9 months depending upon the soiling situation in their region. In light of our research work we propose that manufacturers should start collaborating with Meteorological departments, climate data processing centers and other research centers who are at the forefront of air pollution research.

Simply take the data about the aerosols and particulate matters suspended in the environment as the data is already available on their websites regarding major cities throughout the world. In this way, the manufacturers will get a detailed analysis of the pollutants' particles in every region and they could easily propose a cleaning schedule for their solar panels across every region in the world.

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