Inspiring Excellence

COMPARATIVE STUDY OF COMMERCIAL AVAILABLE MONO-CRYSTALLINE AND POLY-CRYSTALLINE SILICON SOLAR PANEL

A Thesis submitted to the
Dept. of Electrical & Electronic Engineering, BRAC University
In partial fulfillment of the requirements for the
Bachelor of Science Degree in Electrical & Electronic Engineering

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Date: 24 December, 2017

Declaration:

We hereby declare that this thesis titled "Comparative study of commercial available mono-crystalline and poly-crystalline silicon solar panel" and the work presented in it and submitted to the Department of Electrical and Electronic Engineering of BRAC University is our own and has been generated by us as the result of our own original research. It is not submitted elsewhere for the award of any other degree or publication.

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Acknowledgement:

We sincerely thank our almighty God for the gift of life, knowledge and strength to accomplish this work. We feel very fortunate and grateful to be a part of our department of EEE where we have been trained to face any challenges to enlighten our knowledge. We learnt that, to accomplish a task there will be obstacles and failures but despite of that we shall never give up and success will definitely be achieved. Our heartfelt gratitude goes to our parents, family and friends for all the support that encouraged us to continue to the end. We want to express our utmost and deepest gratitude to our thesis supervisor Dr. Md. MosaddequrRahma, Professor of Department of EEE, BRAC University for his guidance and encouragement in completing our thesis work. Without his supervision and consistent help this thesis would not have been conceivable. His recommendations and precious directions helped us in successfully completing this thesis.

Abstract:

The objective of our thesis is to analyze the performance of two types of silicon panels that are mono-crystalline and poly-crystalline under different climatic conditions of Bangladesh. Temperature, wind speed, solar irradiation affects the performance of solar panel. In our work different parameters of the solar cells such as open circuit voltage, short circuit current, series resistance of a photovoltaic cell, maximum power output point, fill factor, maximum working current and maximum working voltage will be measured under different temperature and illumination conditions. Experiments will be conducted in indoors. Energy efficiency and cost effectiveness of mono-crystalline and poly-crystalline panel will be compared.

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CHAPTER-1

INTRODUCTION

1.1 Background:

Bangladesh has gained more access to electricity compared to the previous years, yet the national energy sector or PDB (Power Development Board) still fails to meet the needs of electricity for the growing population. Blackouts and shortages cost an estimated 0.5 percent of GDP annually being the country's unreliable power generation system [1]. The amount of electricity provided is never enough for the city dwellers due to shortage of gas which leads us to solar power, a smarter way of producing energy. For solar power, the energy source is sustainable and inexhaustible unlike other natural resources. We can never run out of electricity as the energy is coming directly from an infinite source –sun. Besides, it is eco-friendly since it does not discharge any greenhouse gasses while generating electricity. Also, the massive industrializations cause noise pollution which has become a threat in today's world. Solar energy does not create any sort of hazard towards the environment. It is a reliable source of energy that the world can depend on for adequate electricity.

1.2 Literature Review:

In our thesis we have worked with two types of solar cells which are mono-crystalline and poly-crystalline solar cells. At the beginning, we analyzed the simple existing electrical model of the solar cell and then we were introduced to various parameters of solar cell such as- short circuit current (Isc), open circuit voltage (Voc), maximum power output (Pmax), series resistance of cell (Rs). During the study process we came to know that temperature and illuminations are the key factors that affect the various parameters of the cell.

Firstly we analytically calculated the output of each solar panel. Later we compared the output of the cells by analyzing affects of the key factors- illumination and temperature on the panel parameters.

Our main purpose of this thesis work is to figure out which silicon solar cell is economically cost efficient by calculating the energy extracted from the two types of silicon cells. Concerning our purpose, we went through several theoretical inspections. After that we proceeded with our indoor monitoring system and we observed the variation of panel parameters with different temperatures. We used Newton-Raphson iteration method in MATLAB to iterate the value of current (I). It gave us the I-V characteristics curve from which we calculated the maximum power output. Furthermore, the energy was calculated by integrating the maximum power versus time curve. This whole process of calculation was individually carried out for both the solar cells. In order to calculate the illumination we considered the temperature data and climatic condition of Dhaka city over the year 2016.

1.3 Scope of work:

The scope of our thesis work included mainly indoor monitoring. During indoor monitoring we worked with a sun simulator that has 10 bulbs, each having 200W. We controlled the temperature and illumination by switching on different numbers of bulbs. We used rheostats to control the current flow by varying resistance. We monitored the variation of panel parameters such as- Voc (open circuit voltage), Isc (short circuit current), Pmax (maximum power output), Rs (series resistance) considering the temperature and illumination.

1.4 Thesis organization:

This thesis is organized in such a manner where the basic concepts are explained first and gradually enclosing the detailed concepts that include major factors. The concept of solar-radiation that consists of the intensity equation is well explained. Before proceeding towards the result and analysis, the basic theory of solar cell is explained briefly. Besides, all the experiments are explained step by step along with relevant diagrams. The contents of the chapter in this paper are explained in brief below:

1.4.1 Solar-Radiation:

Here we explained the components of sunlight, air mass (AM). Also the position and angle of the sun depending on the air mass is clarified. The equation of intensity is deduced as well. The formula consists of declination angle, solar altitude and hour angle which are needed to calculate the variation of solar illumination with time. The panel parameters are dependent on solar illumination.

1.4.2 Basic theory of solar cell:

Here we discussed about the solar cell that includes p-n junction, photocurrent. Also we discussed the different structure and materials of two different solar cells, effect of temperature on the short circuit current (Isc) , open circuit voltage (Voc) and reverse saturation current (Io). The calculation of the series resistance (Rs) of the solar panel is also shown and explained. The panel parameters are explained through derivation of the equations.

1.4.3 Experimental result and analysis (Indoor-monitoring system):

In this chapter we get a synopsis of the behavior of various parameters (Isc, Voc, Pmax, FF, Rs) due to temperature change. We mainly focused on explaining the indoor-monitoring system. For the indoor-monitoring we started off with a circuit configuration that is shown in a diagram with brief explanation. The MATLAB simulation graphs and results obtained from it are also described. Here the ideality factor of the panel is calculated as well. All the values obtained from this indoor monitoring system have a crucial role in our calculation of energy extracted from the panels.

1.4.4 Power and energy calculation:

This chapter explains the calculation of power using MATLAB. Similarly the energy calculation is explained. The respective graphs are shown as well. This chapter also consists of brief discussion of variation of average monthly temperature and illumination of Dhaka city for the year 2016 and energy extracted on different times of the year from both the panels. Based on the result of analytical study of the two panels, the comparison is done.

This chapter concludes with the ultimate resolution for the resemblance between the analytical results with practical data.

Conclusion:

The final chapter concludes with a discussion about the different outputs of the two different solar panels and their efficiency. It gives a brief conclusion of all the works we have done through the thesis work.

CHAPTER-2

Solar Radiation

2.1 Introduction:

Solar radiation is an incandescent energy discharged by the sun through a nuclear fusion reaction that produces electromagnetic energy. The downright solar radiation obtained directly from the sun that reaches the earth's surface cannot be used to produce electricity. Many factors to be considered that creates variation to reach the sunlight as some of them are scattered, some are reflected, some are absorbed by the earth's atmosphere and some even entering unaffected but later might absorbed or reflected by the ground level while reaching the surface of earth. These factors of sunlight radiation have been given names of their own types. For instance, **Direct** or **Beam Radiation** is the sunlight that reaches the earth's surface without scattering. Besides, scattered sunlight is called **Diffusion Radiation**. Another is called **Albedo Radiation** that is reflected from the ground. Altogether these three combinations of sunlight radiation called **Global Radiation.**

There are more things to consider such as the length of distance travelled by the light wave through the atmosphere that varies the amount of sunlight absorbed and scattered. The path length is compared with a vertical path directly to sea level which is denoted as **Air Mass (AM)** as it satisfies the condition **Air Mass=1**. This air mass changes depending on the position of the sun by determining different angles of sun. When the sun is directly overhead, the AM will be less that unity and for non-vertical sun angles, the AM will be more than unity. During AM1, the global radiation intensity is reduced from 1367 W/m^{2}at the top of the atmosphere to just over 1000 W/m^{2}at sea level after the absorption has been made. Therefore, the intensity of sunlight is decreased to 70% of its original AM0 value for an AM1path length. The equation in order to find the intensity would be,

$$I=1367(0.7)\,\hat{}\,(AM)^{0.678} \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (2.1)$$

Here,
I= solar illumination
AM= air mass

To perform this equation we need to find the air mass in order to calculate the intensity. For this, we needed to follow some steps and factors such as different angles of sun consisting of altitude, azimuth, zenith and hour angles that are explained below along with relevant figure:

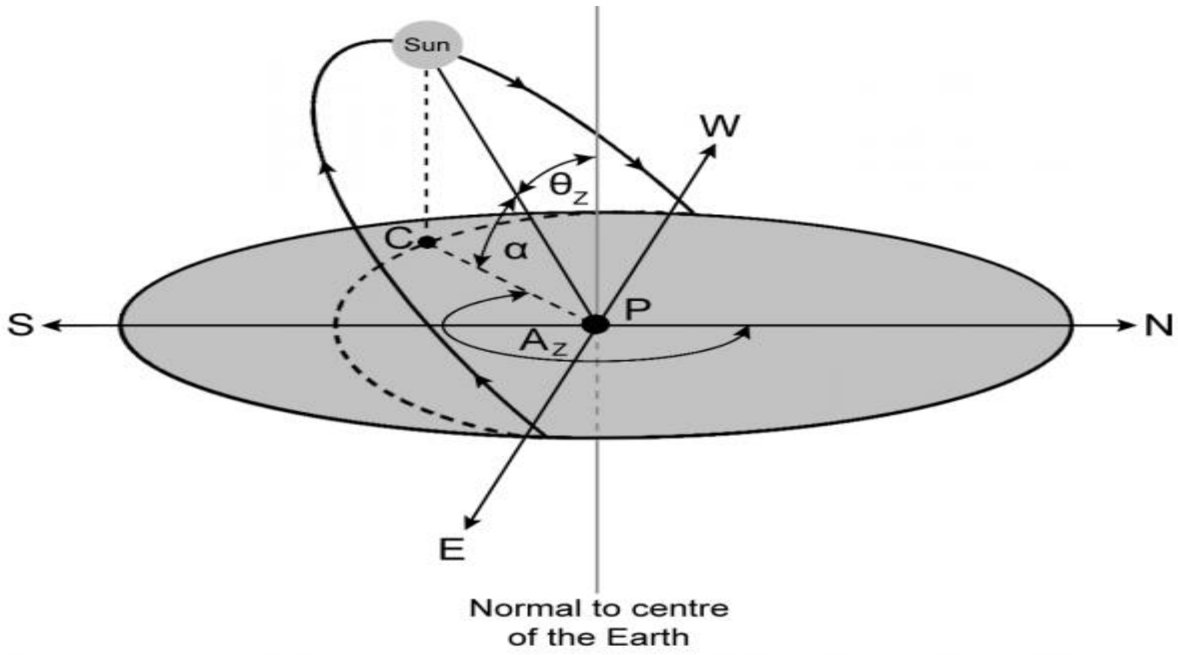


Figure (2.1): Sun angles, showing altitude, azimuth, zenith and hour angle.

2.2 Finding Air Mass Value:

The equation to calculate air mass is given below,

$$AM= AM(90^o) \csc\alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots(2.2)$$

To execute the equation we need to figure out the value of α . Here α is the solar altitude that is the complement of the **Zenith Angle**, $\theta_{z.}$ This represents the angle between the horizon and the incident solar beam in a plane determined by zenith and the sun. The zenith is the line perpendicular to the earth and the zenith angle is defined as the angle between the sun and the zenith.

2.3 Declination Angle Calculation:

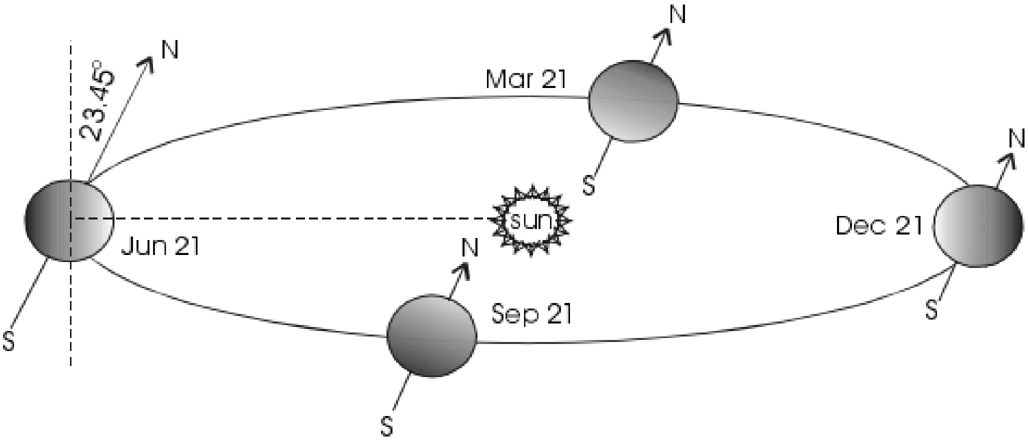
A crucial factor to be considered is the **Declination Angle** which is defined as the angle of the sun directly above the equator, δ. If angles north of the equator are considered as positive and angles south of the equator are considered negative, then at any given day of the year, n, the declination can be found from the equation below,

$$\delta = 23.45^o \sin \left(\frac{360(n-80)}{365}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

This formula is apparently an approximation since the year is not exactly 365 days long. As the sun is directly overhead on the first day of summer at solar noon on the Tropic of Cancer, it becomes evident that,

$$\theta_z = \phi - \delta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.4)$$

Where, ϕ represents the latitude or angular distance from the equator, since when the declaration and latitude are the same, zenith angle is zero. This is only true at given latitude during solar noon as both ϕ and δ are constant for any given day in any given location. This equation is mainly used to locate the position of the sun. So by this equation we find the zenith angle.



2.4 Hour Angle Calculation:

Another useful factor to be considered is the Hour Angle. The hour angle is the difference between noon and the desired time of the day in terms of a 360^{O}rotation in 24 hours. The equation for finding the hour angle, ω is given below,

$\omega = \frac{12-T}{24} * 360^{o}$ ……………………………… (2.5)

Here, T is the time of the day expressed to a solar midnight on a 24 hour clock. By relating ω to the other angles previously discussed, we get the sunrise angle as given below,

$\omega_s = \cos^{-1}(-\tan\phi \tan\delta)$ ………………………. (2.6)

Which means that the sunset angle is given by, $-\omega_s$. This formula enables one to determine the number of hours on a specific day at a specific latitude that the sun is above the horizon.

Conclusion:

We already know the values for δ, ϕ and ω . Therefore, the value of α can be now determined by the formula given below,

$\sin\alpha = \sin\delta\sin\phi + \cos\delta\cos\phi\cos\omega$ ……………….... (2.7)

Now putting this value in the air mass equation, we get AM value and by AM value we accomplish the intensity using the intensity equation (2.1).

The illumination variation of a particular date (Jan-15, Feb-15…….. Dec-15) of 12 different months of the year 2016 in Dhaka city is shown below by MATLAB simulation.

CHAPTER 3

Fundamental Hypothesis OF Sun powered CELL

3.1 Introduction:

For an introduction, we can start from Energy which comes from the sun to Earth in tiny pieces usually called photons. Characteristics of is that Photons can hit atoms and give off energy, as they give of energy that is why they produces heat. Photovoltaic cells are another name of solar panel because they can produce electricity from light. Here “photo” is Greek for light and “volt” is a unit of electricity. It works by capturing a photon from the sun using semiconductors. Using a semiconductor instead of heat electricity is produced. That is why to build a solar panel semiconductors are used. A most common semiconductor material used for building photovoltaic cell or solar panel is silicon. In collision process with the photons, the silicon releases electrons which are further collapsed by the panel structure and its direction is made one way flow of electrons which in return produces current in the solar panel. Solar must be in used areas with high sunlight intensity, especially hilly areas are most suitable for solar panel. Bandarban, Khagrachari and other hilly areas of the southern part of Bangladesh are becoming suitable with producing electricity through this process and the uses of solar cell are high in rate there.

Solar cells are used on spaceships like the International Space Station pictured below,

Figure: International_Space_Station_after_undocking_of_STS-132

3.2 Prologue to thought of arrangement:

Doped silicon, with several layers is like the buzz word for formation of photovoltaic cell in present days. It is also the same core semiconductor material used to make computer chips. Their functional process mostly depends upon the movement of charge-carrying entities between successive silicon layers. In pure silicon, when sufficient energy is added (for example, by heating), some electrons in the silicon atoms can break free from their bonds in the crystal, leaving behind a hole in an atom's electronic structure. These freed electrons move about randomly through the solid material searching for another hole with which to combine and release their excess energy. Functioning as free carriers, the electrons are capable of producing an electrical current, although in pure silicon there are so few of them that current levels would be insignificant. However, silicon can be modified by adding specific impurities that will either increase the number of free electrons (**n**-silicon), or the number of holes (missing electrons; also referred to as p-silicon). Because both holes and electrons are mobile within the fixed silicon crystalline lattice, they can combine to neutralize each other under the influence of an electrical potential. Silicon that has been doped in this manner has sufficient photosensitivity to be useful in photovoltaic applications.

Electron and Current Flow in Solar Cells

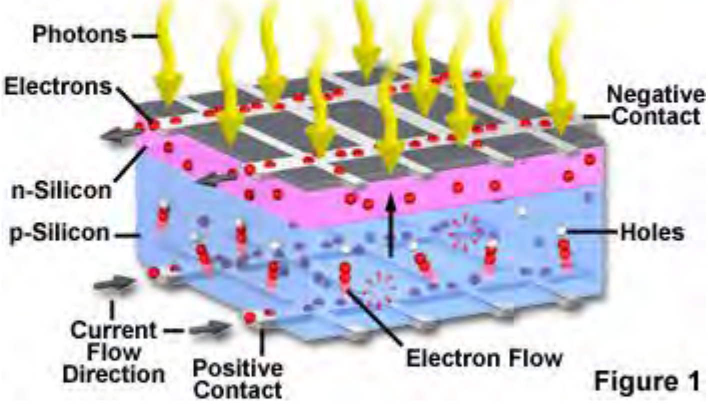


Figure 1

3.3 Interior Elements of a photovoltaic sun based cell:

3.3.1 P-n intersection: The structure of a typical photovoltaic cell consist of n-layer and p-layer semiconductors or doped silicon semiconductors which is tightly bonded by each other (illustrated in Figure 1). The different charges of the two layers start to combine and hence create a huge traffic along the junction and as a result of such electrical imbalance, when it reaches equilibrium condition; a fixed electrical field is created along the boundary junction.

Then the light of appropriate wavelength and energy hits the layers creating random movement of the electrons along the junction by absorption of light. Electrons over the junction can be easily float into any direction but once they cross the boundary they cannot return to other direction against the field and thus creates charge imbalance. Electrons floated in the n-layer

have the tendency to return to the other layer for avoiding charge imbalance. Electrons look for another path to reach the other layer. An external circuit is provided with production of continuous flow of electricity as long as the light strikes the solar cell. Electrons close to the junction can be swept across it by the fixed field. The construction of photovoltaic cell includes the metal contact layer which is provided to the outer faces of the semiconductor layers and creates the path for external circuit which connects the layers. Thus as a result electrical power is being produced from the energy of light.

A p-n intersection is shaped by joining p-sort semiconductor material and n-sort semiconductor material. P-sort comprises of high grouping of openings and n-sort is shaped high convergence of electrons. On joining the p and n sort material gaps frame the p-sort material diffuse into the n-sort material and the other way around. Because of this impact a consumption district is shaped in the middle of the p-n intersection where an electric field is delivered. This procedure proceeds until the point that a harmony states is built up.

3.3.2 Photocurrent:

At the point when light is occurrence on a p-n intersection electron gap match is created. Electron gap match is just produced when the photon have adequate vitality than the band hole vitality. The gaps in the n-sort material and the electrons in the p-sort material are exceptionally non stable and they exist just for a period of time equivalent to the minority transporter lifetime before they recombine. In the event that they recombine than no current is created as all the electron gap combine are lost.

P-n intersection keeps this recombination, which isolate the electron and gaps. The electric field in the p-n intersection isolates the bearers. At the point when the photograph created bearers achieve the exhaustion locale they are pulled over the opposite side by the activity of the electric field. These bearers than move through the outside circuit, comprising the stream of electric current.

3.4 The Manufacturing process

1
- Purging the silicon
- Making single precious stone silicon

2
- Making silicon wafers
- Doping
- Putting electrical contacts

3
- The counter intelligent covering
- Epitomizing the cell

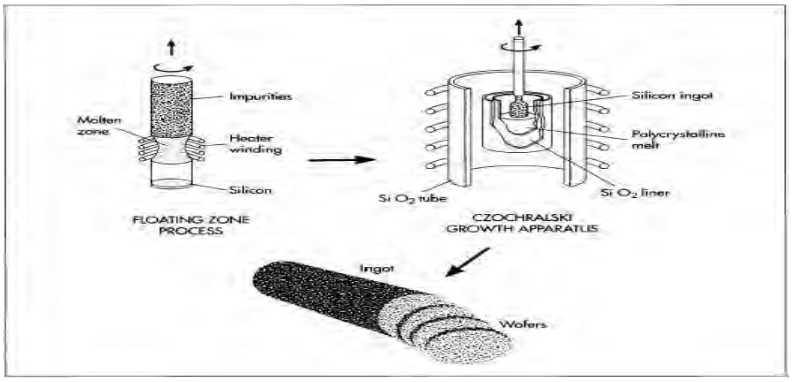


Figure: after the underlying purging, the silicon is additionally refined in a coasting zone process. In this procedure, a silicon bar is gone through a warmed zone a few times, which serves to 'drag" the polluting influences toward one end of the pole. The sullied end would then be able to be expelled. Next, a silicon seed gem is put into a Czochralski development mechanical assembly, where it is dunked into liquefied polycrystalline silicon. The seed precious stone turns as it is pulled back, framing a barrel shaped ingot of exceptionally unadulterated silicon. Wafers are then cut out of the ingot.

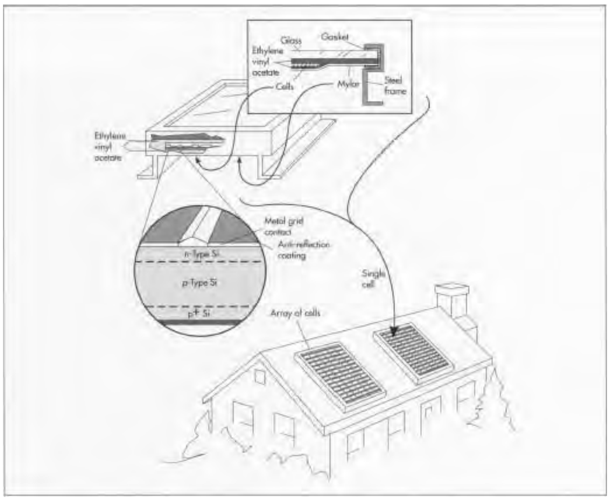


Figure: this delineation demonstrates the cosmetics of a normal sunlight based cell. The cells are epitomized in ethylene vinyl acetic acid derivation and put in a metal casing that has a mylarbacksheet and glass cover.

3.5 Control regarding Quality of the solar panel

Quality control is critical in sun based cell make since error in the many procedures and variables can antagonistically influence the general effectiveness of the phones. The essential research objective is to discover approaches to enhance the proficiency of each sunlight based cell over a more drawn out lifetime. The Minimal effort Sun based Exhibit Undertaking (started by the Assembled States Bureau of Vitality in the late 1970s) supported private research that expected to bring down the cost of sun based cells. The silicon itself is tried for virtue, precious stone introduction, and resistivity. Producers likewise test for the nearness of oxygen (which influences its quality and protection from twist) and carbon (which causes surrenders). Completed silicon plates are examined for any harm, chipping, or twisting that may have happened amid sawing, cleaning, and carving.

Amid the whole silicon plate producing process, the temperature, weight, speed, and amounts of dopants are consistently checked. Steps are likewise taken to guarantee that pollutions noticeable all around and on working surfaces are kept to a base.

The finished semiconductors should then experience electrical tests to see that the present, voltage, and protection for each meet suitable guidelines. A prior issue with sunlight based cells was an inclination to quit working when incompletely shaded. This issue has been eased by giving shunt diodes that lessen perilously high voltages to the cell. Shunt protection should then be tried utilizing in part shaded intersections.

An imperative trial of sunlight based modules includes giving test cells conditions and force of light that they will experience under typical conditions and afterward verifying that they perform well. The cells are likewise presented to warmth and cool and tried against vibration, contorting, and hail.

The last test for sunlight based modules is field site testing, in which completed modules are set where they will really be utilized. This gives the specialist the best information for deciding the productivity of a sun based cell under surrounding conditions and the sun oriented cell's viable lifetime, the most vital elements of all.

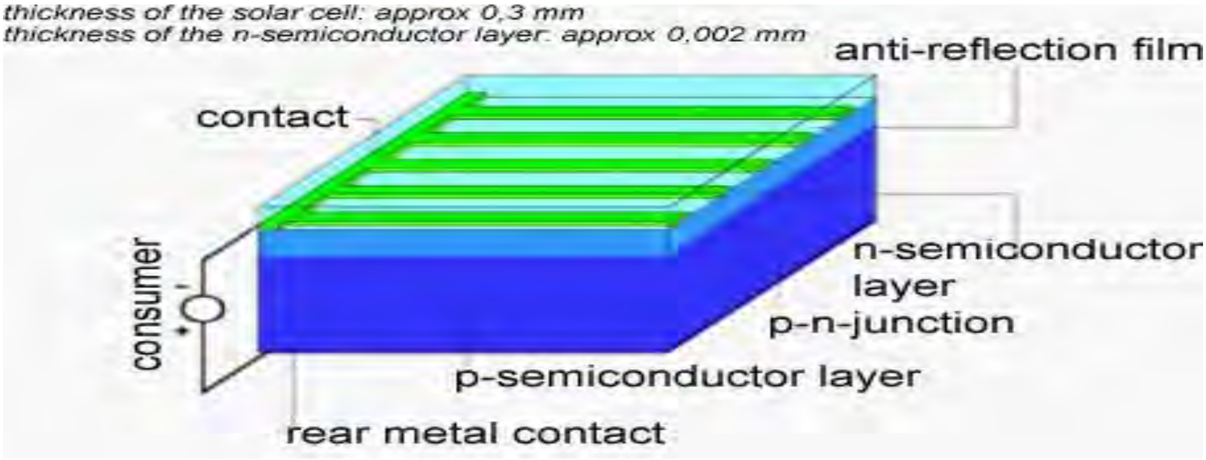


Figure: Structure of a solar cell

3.6 Mono crystalline silicon solar cell:

Mono-crystalline sun based cells are produced using alleged single crystalline sun powered cells and effortlessly conspicuous from its shading and its uniform look which shows that there is a high virtue of silicon. It is comprised of silicon ingots and has a round and hollow shape. Keeping in mind the end goal to improve its execution and lessen the cost the four sides of its cells are sliced to make round and hollow ingots from which barrel shaped wafers can be made, which recognizes it from others. They are dull dark shading sun based cells.

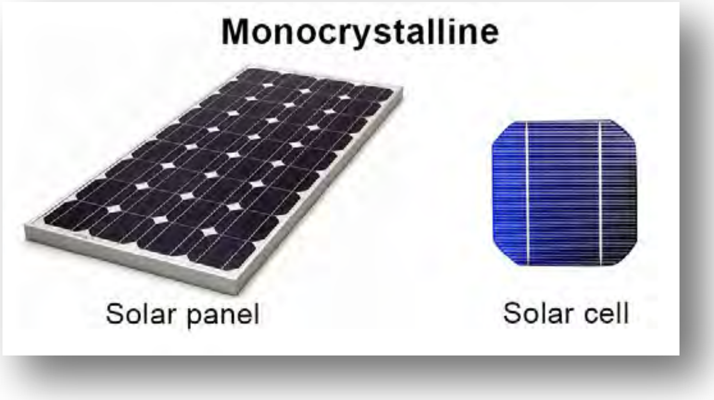


Figure: Mono-crystalline silicon solar panel

3.7 Poly-crystalline silicon solar cell:

Poly-crystalline silicon is material comprising of numerous little silicon precious stones. Polycrystalline silicon are softened and filled square shape, which is cooled and cut into superbly square wafers. They are not uniform so they are light and dim blue shading

.

Figure: Poly-crystalline silicon solar panel

3.8 Difference between mono-crystalline and poly-crystalline silicon solar cell:

As for poly crystalline boards, mono crystalline board have a higher proficiency and are more accessible than poly silicon sun powered cells. Mono crystalline sunlight based cells is space-proficient, i.e. they yields most elevated power yield and minimal measure of room than the polycrystalline. Mono crystalline boards are more costly than polycrystalline and furthermore have higher warmth resilience. Mono crystalline boards have a more drawn out life expectancy than the others and they have a tendency to be more productive.

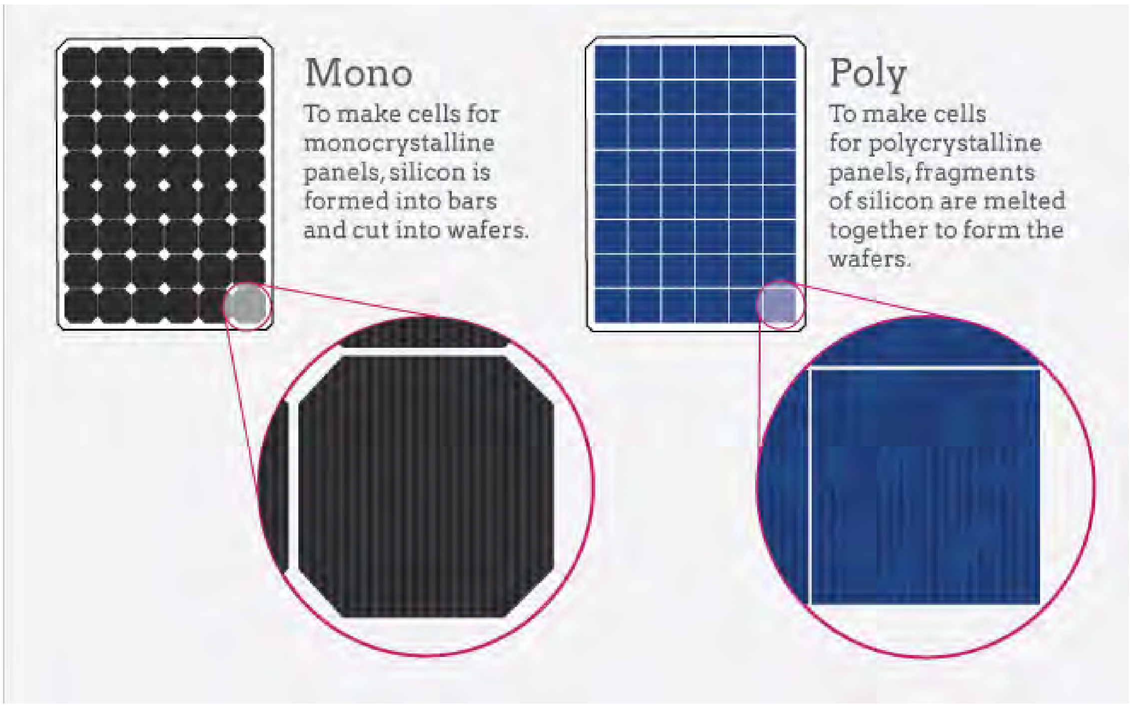


Figure: differences of poly and mono crystalline solar cell

3.8.1: Advantages of Monocrystalline solar panels

1.Monocrystalline sun oriented boards have the most astounding productivity rates since they are made out of the most astounding evaluation silicon.

2.Monocrystalline silicon sun oriented boards are space-productive. Since these sunlight based boards yield the most astounding force yields, they additionally require minimal measure of room contrasted with some other sorts. In any case, monocrystalline sunlight based boards deliver insignificantly more power per square foot of room utilized as a part of an exhibit thus.

3. Monocrystalline Boards have a long life expectancy. Most sunlight based board producers put a 25-year guarantee on their monocrystalline sun powered boards. Since the two sorts of crystalline sun powered boards are produced using crystalline silicon, an exceptionally inactive and stable material it is likely that these sun oriented boards will last any longer then their 25 year guarantee life.

4. Mono-crystalline sun based boards have a tendency to be more productive in warm climate. With every single sunlight based cell power generation falls as temperature goes up. Be that as it may, this debasement of yield is less extreme in mono-crystalline boards than polycrystalline sun powered boards. Be that as it may, practically speaking the distinction is little. The level to which

each sun based boards generation falls as temperature increment sister called the temperature co-effective and is distributed with the details for each board.

3.8.2: Disadvantages of Mono-crystalline solar panels

1. Mono-crystalline sun based boards are the most costly. Lately a rash in establishment of polycrystalline ingot, cell and module generation efficiencies have imply that polycrystalline sun oriented board have turned out to be more typical and have profited from costs points of interest over mono boards. Most makers that still influence mono boards to have focused on the top notch end of the market.

3.8.3: Advantages of Polycrystalline solar panels

1. The procedure used to make polycrystalline silicon is easier and taken a toll less. The measure of waste silicon is less contrasted with monocrystalline.

2. Polycrystalline sunlight based boards have a tendency to have marginally brought down warmth resilience than monocrystalline sun based boards. Polycrystalline sun oriented boards will have a tendency to have a higher temperature co-productive than sun powered modules made with mono cells. This implies as warmth expanded yield for this kind of cell will fall less. In any case, practically speaking these distinctions are exceptionally minor.

3.8.4: Disadvantages of Polycrystalline solar panels

1. The effectiveness of polycrystalline-based sun powered boards is commonly 14-16%. On account of lower silicon virtue, polycrystalline sun powered boards are not exactly as proficient as monocrystalline sun oriented boards.

2. Lower space-productivity. You by and large need to cover a bigger surface to yield an indistinguishable electrical power from you would with a sun powered board made of monocrystalline silicon. Be that as it may, this does not mean each monocrystalline sun powered board performs superior to those in light of polycrystalline silicon.

3. Monocrystalline and thin-film sunlight based boards have a tendency to be all the more stylishly satisfying since they have a more uniform look contrasted with the dotted blue shade of polycrystalline silicon.

3.9 Working Process of Solar Cell and its' advancement till today:

The voltage created by sun based cells shifts with the wavelength of episode light, yet commonplace cells are intended to utilize the expansive range of sunshine gave by the sun. The measure of vitality delivered by the cell is wavelength-subordinate with longer wavelengths producing less power than shorter wavelengths. Since ordinarily accessible cells deliver just about as much voltage as a spotlight battery, hundreds or even thousands must be coupled together keeping in mind the end goal to create enough power for requesting applications. Various sunlight based controlled vehicles have been assembled and effectively worked at thruway speeds using an extensive number of sun based cells. In 1981, an air ship known as the Sun oriented Challenger, which was secured with 16,000 sun based cells creating more than 3,000 watts of energy, was flown over the English Channel controlled exclusively by daylight. Accomplishments, for example, these rouse enthusiasm for extending the employments of sunlight based power. Be that as it may, the utilization of sunlight based cells is still in its early stages, and these vitality sources are still to a great extent limited to fueling low request gadgets.

Current photovoltaic cells utilizing the most recent advances in doped silicon semiconductors change over a normal of 18 percent (achieving a greatest of around 25 percent) of the occurrence light vitality into power, contrasted with around 6 percent for cells delivered in the 1950s. Notwithstanding enhancements in effectiveness, new strategies are additionally being conceived to deliver cells that are more affordable than those produced using single gem silicon. Such enhancements incorporate silicon films that are developed on substantially less costly

Polycrystalline silicon wafers. Formless silicon has additionally been attempted with some achievement, as has the dissipation of thin silicon films onto glass substrates. Materials other than silicon, for example, gallium arsenide, cadmium telluride, and copper indium dieseline, are being explored for their potential advantages in sun powered cell applications. As of late, titanium dioxide thin movies have been produced for potential photovoltaic cell development. These straightforward movies are especially fascinating in light of the fact that they can likewise serve twofold obligation as windows.

CHAPTER 4

EXPERIMENTAL RESULT AND ANALYSIS

4.1 Introduction

We are going to make a comparative study between mono-crystalline and poly-crystalline Silicon solar module for that purpose we are analyzing the performance of silicon solar cells under different climatic conditions,As we focus on different climatic conditions, that's why, temperature effects on solar module parameters play a vital role of consideration. Here, we are analyzing the different parameters of the solar cell using indoor monitoring system under illumination of light, where temperature and illumination of light can be controlled according to our needs. There are different parameters in a solar cell and we are to find how parameters vary with temperature. Such parameters are open circuit voltage-V_{oc}, short circuit current-I_{sc}, series resistance of a photovoltaic cell-R_s, shunt Resistance R_{sh}, maximum power output point- P_{max}, fill factor-FF, we need to find how these parameters varies with temperature so that we plot a graph against each of these parameter verses the temperature and see how these effect on temperature .The temperature coefficients of these parameters are very essential to find the output of the panel and amount of the energy which we get from the both panels. Furthermore, temperature co efficient also effect on the behavior of the panel.

4.2 Indoor- monitoring system:

We need to test solar panel in the outdoor to collect data but this is not possible for us because of some restriction. Moreover, we cannot control many parameters while being there. That's why, we developed an indoor system to test the panel and collect data. We can control many parameters like temperature, illumination through this system. The system is very simple. We make a wooden box and we use ten bulb each containing 200W which is attached in the box.

The box is fully wrapped with Aluminum paper so that all the light reflected from the box will fall in the panel. This method will help us to get perfect illumination and temperature.

4.3 Calculation of the ideality factor (n) of the solar module

4.3.1 Theoretical Analysis for the calculation of the ideality factor (n):

To find the ideality factor (n), of a Silicon solar cell, we need to experiment a predefined electrical model on a photovoltaic cell; we get different equation by analyzing below circuit.

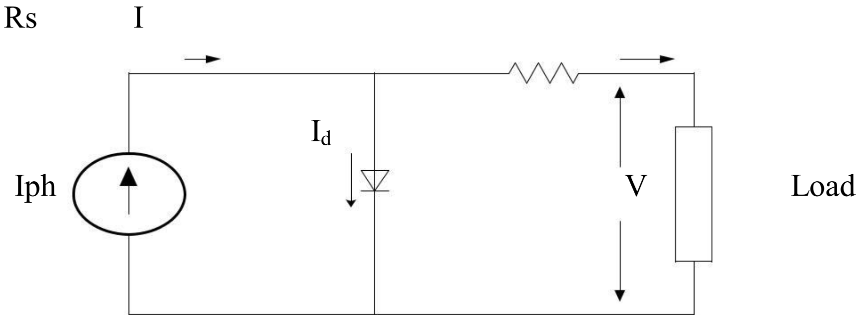


Figure-4.1: Simplified Equivalent Circuit Model for a Photovoltaic Cell connected with a load.

$$I_{ph}= I+I_d \qquad (4.1)$$

Where I_{ph} is the photocurrent, $I_d$is the diode current and I is the load current.

$$I_{ph}=I_{sc} \qquad (4.2)$$

In the equation (4.1), $I_{sc}$is the short circuit current which is equal to the photocurrent. We know the equation for the diode current is:

$$I_d= I_o exp(V+IR_s)/nV_t) \qquad (4.3)$$

Where I_o is the reverse saturation current, R_s is the series resistance and $V_t$is the thermal voltage and this was been calculated by the formula:

$$V_t= kT/q(4.4)$$

Where, k= Boltzmann constant,

T= temperature in Kelvin,

q= Charge of an electron,

Using the equations (4.1), (4.2) and (4.3) we finally get the main equation for the load current, I.

$I=I_{sc}-I_0\exp((V+IR_S)/nV_t)$(4.5The analysis might have led in no load condition; no current flows through the circuit, in that situation we get the open circuit voltage, and when shorted we get the short circuit current, provided I=0, then equation (5) can be rewrite as:

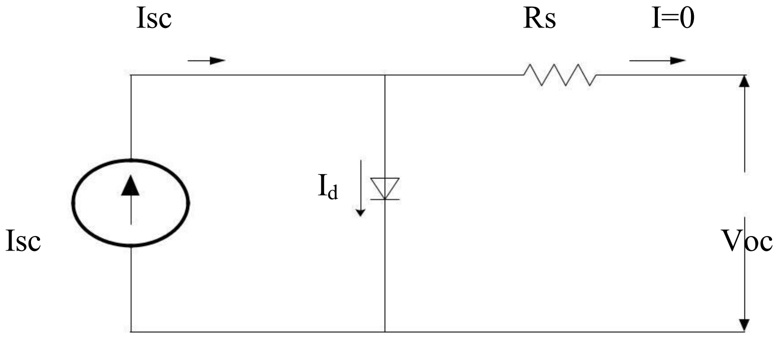


Figure-4.2: Simplified Equivalent Circuit Model for a Photovoltaic Cell connected without any load.

$I_{SC}=I_0\exp(V_{oc}/nV_t)$ (4.6)

The reverse saturation current is kept constant by keeping the surface temperature of the panel constant and varied the illumination. So for different illumination we can rewrite equation (6) as:

$I_{SC1}=I_0\exp(V_{oc1}/nV_t)$ (4.7)

$I_{SC2}=I_0\exp(V_{oc2}/nV_t)$ (4.8)

Then by dividing equation (4.7) by equation (4.8), we get

$I_{sc1}/I_{sc2}=\exp[V_{oc1}/nV_t]/\exp[V_{oc2}/nV_t]$ (4.9)

From this relation the equation for n become

$n=(V_{oc1}-V_{oc2})/V_t\ln(I_{sc1}/I_{sc2})$ (4.10)

Using this equation we get the value of ideality factor for the whole 20W solar panel, so to get the value of n for one cell we need to divide the n of the whole panel by 36 which is the number of cells in the solar panel, . Hence, the equation for one cell:

$$n=(V_{oc1}-V_{oc2})/N_S Vt\ln(I_{sc1}/I_{sc2}) \qquad (4.11)$$

4.3.2 Experimental Analysis for calculating ideality factor (n):

4.3.2.1 Block Diagram of the experiment

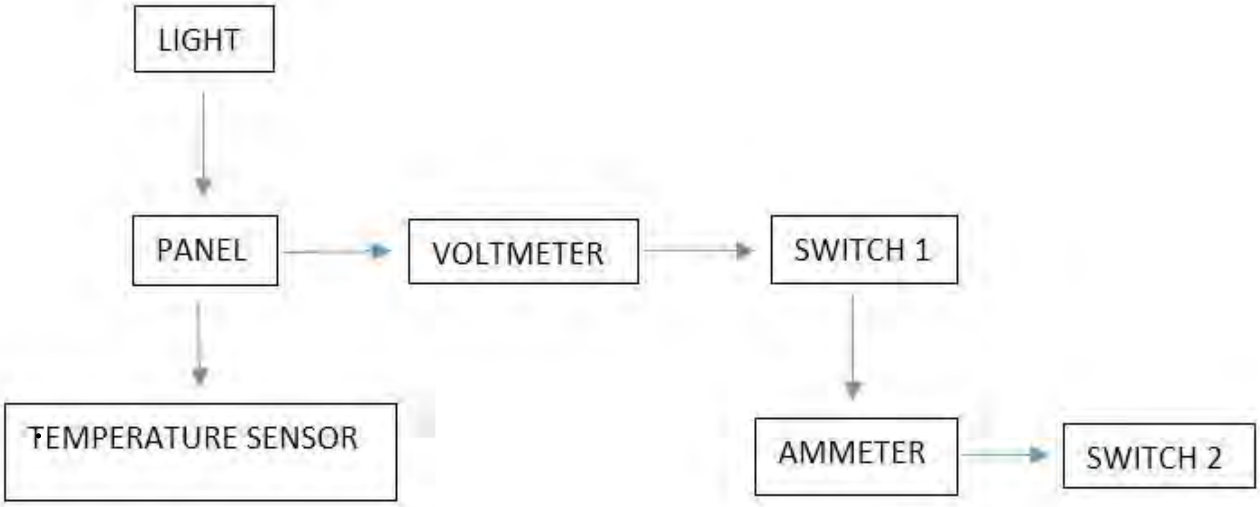


Figure-4.3- Block Diagram of the experiment set up.

4.3.2.2 Description of the experimental process:

The indoor experimental setup was an insulated box within which ten 200 W bulbs were set so that we could change the illumination inside the box. We recorded two sets of data at first keeping eight bulbs turned on, and recorded the first set of data of I_{sc1}, V_{oc1} and then by changing the illumination with four bulbs turned on, we recorded the second set of data of I_{sc2}, V_{oc2} then using the above equation for one cell, we calculated the experimental value forn. The motive of turning on eight bulbs first, was to keep the temperature of the solar module constant, if we turn on four bulbs first, then it will keep on rising its temperature with eight bulb on. But when eight bulbs is turned on at first, and we turn off the four bulb, the temperature of the panel will not rise much quickly, and we can collect the two sets of data at the same temperature.

4.3.2.3 Result and Analysis of the experimental value of n:

We maintained one condition to find the ideality factor that we kept temperature constant and vary the illumination. We calculated the value of ideality factor, n by using the values of Voc1, Voc2 and Isc1, Isc2 that we got from the experiment.

Theoretically for mono crystalline the value of (n) is 1. But experimentally we found 1.4 .Theoritical analysis will vary from practical analysis. This is because there is some error while doing experiment. We can say that our result is very close to theoretical analysis. When we short circuit the panel the voltage was not exactly zero as there may be some resistance for that reason some error occur.

$$n=(V_{oc1}-V_{oc2}) /N_S Vt\ln (I_{sc1}/I_{sc2})$$

The values obtained for Mono-crystalline panel are

Voc1=20.5, Isc1=0.37
Voc2=19.8, Isc2=0.21

n=1.335=1.4(Approx.)
N_{S}=36 ,Vt=25.7025

Same goes for Poly crystalline panel theoretically the value of (n) is 1 to 1.5 but experimentally, we found 1.9.Theoritical analysis will vary from practical analysis as said before, because thereis some error while doing experiment. We can say that our result is very close to theoreticalanalysis. When we short circuit the panel the voltage was not exactly zero as there may be some resistance for that reason some error occur.

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$$n=(V_{oc1}-V_{oc2}) /N_S Vt\ln (I_{sc1}/I_{sc2})$$

The values obtained for poly-crystalline panel are
Voc1=20.5,Isc1=0.4
Voc2=19.4,Isc2=0.21
n=1.8449=1.9(Approx.)

4.4 Obtaining the I-V characteristic curve of the solar module for different temperature:

4.4.1 Theoretical Analysis for plotting I-V characteristic curves of a solar module

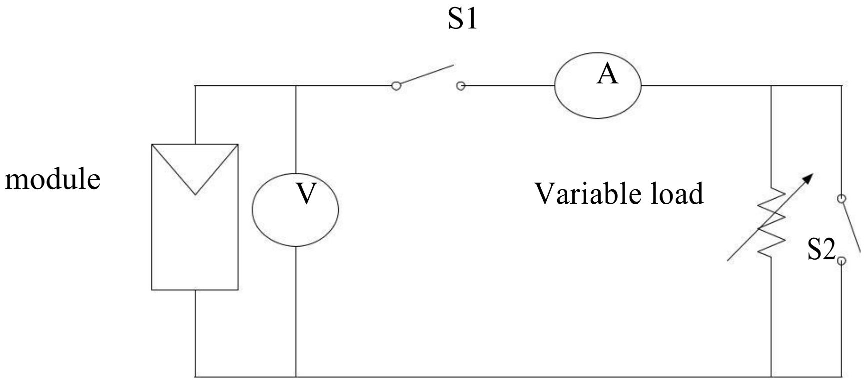

Figure: 4.4 - a solar module is connected with a variable load and meters via switch.

With this circuit we are analyzing the I–V characteristics of the solar panel at different temperature. To plot the I-V curve, we need a set of data of both current and voltages and varying the resistance of the load does this and respectively and we have I-V graph at different temperature.

4.4.2 Experimental Analysis for plotting I-V sweep curves of a solar module:

4.4.2.1 Description and conditions of the experimental procedure:

Many I-V curves was obtained with an interval of 5ºC starting from 25ºC to75ºC, during this time temperature at each 5ºC interval was kept constant. We used a variable load with a resistance of 100Ω.We varied the resistance from 0Ω to 100Ω . Firstly, S1 and S2 was kept closed and that condition we measured short circuit current and then we kept open S1 and S2 both open and that condition we measure open circuit voltage. The I_{SC} and V_{OC} was not found accurate as the switches were not ideal and the wires had voltage drop in them.

For determining the current (I) and voltage (V) of the panel to determine I-V characteristics switch S1 was closed and S2 was open. We tried to do the experiment by keeping the temperature constant.As, the temperature of the panel changes very rapidly,we tried to record data as soon as possible. To keep the temperature constant we put a fan in the hole of the box and put on the AC so that we can control the temperature .

In order to obtain the I-V sweep curves at different temperature we kept the illumination constant. All the eight lights were turned on and waited for few minutes for the illumination to stabilize. We also kept the temperature constant and took the readings for different illumination. In order to do this we varied the load applied for each and every curve obtained at different temperature level.

4.4.2.2 Block diagram of the experimental setup for getting I-V sweep curves:

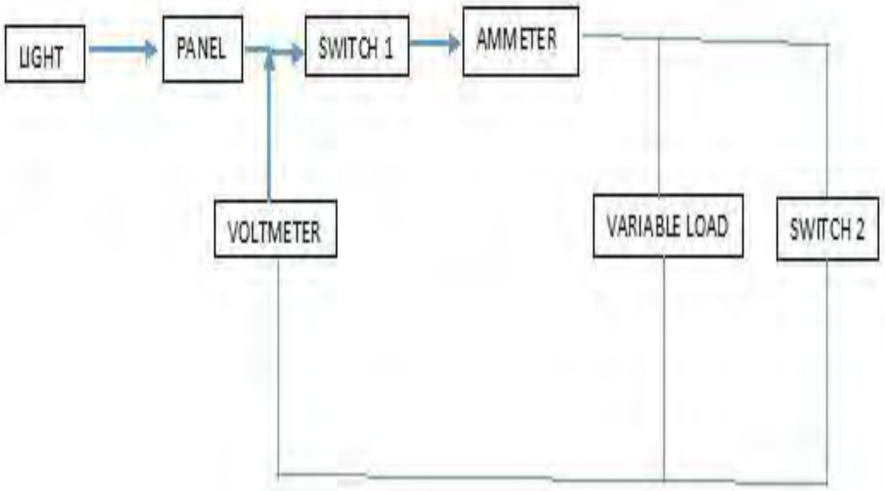

Figure-4.5: Block diagram of the experimental set up.

4.5 Results and Analysis:

4.5.1 I-V characteristic curves at different temperatures:

We used MATLAB to plot the data andobtained I-V characteristic curve. In thoses curve, we noticed that short circuit current rises where as the open circuit voltage decreases with the increasing temperature. We can also take out many other parameters from this set of I-V curves, that is how the P_{max}, FF are varying with the temperature, are going to discuss about each of the curves plotted against temperature.

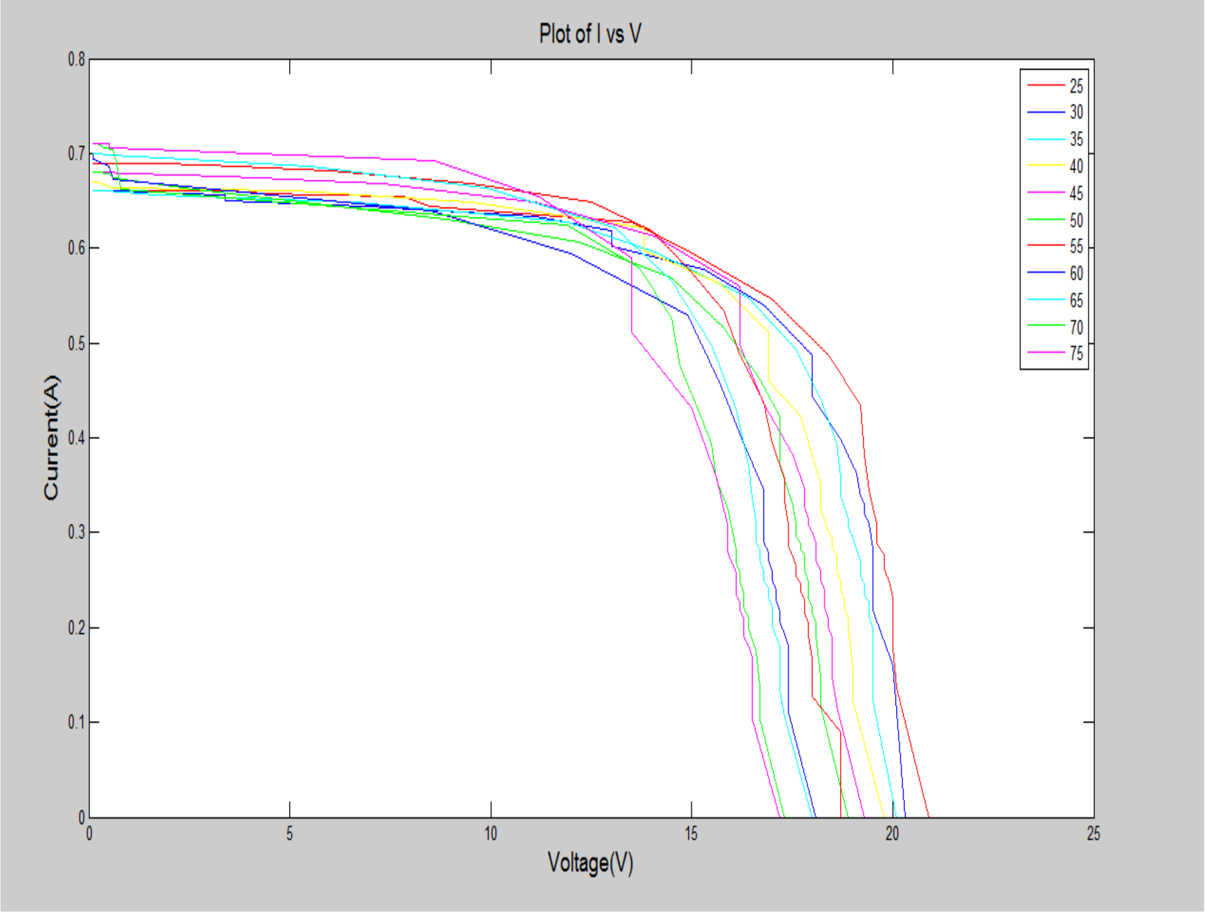

Figure-4.6: I-V characteristic curve at different temperatures of Mono-crystalline Silicon module(36 cells)

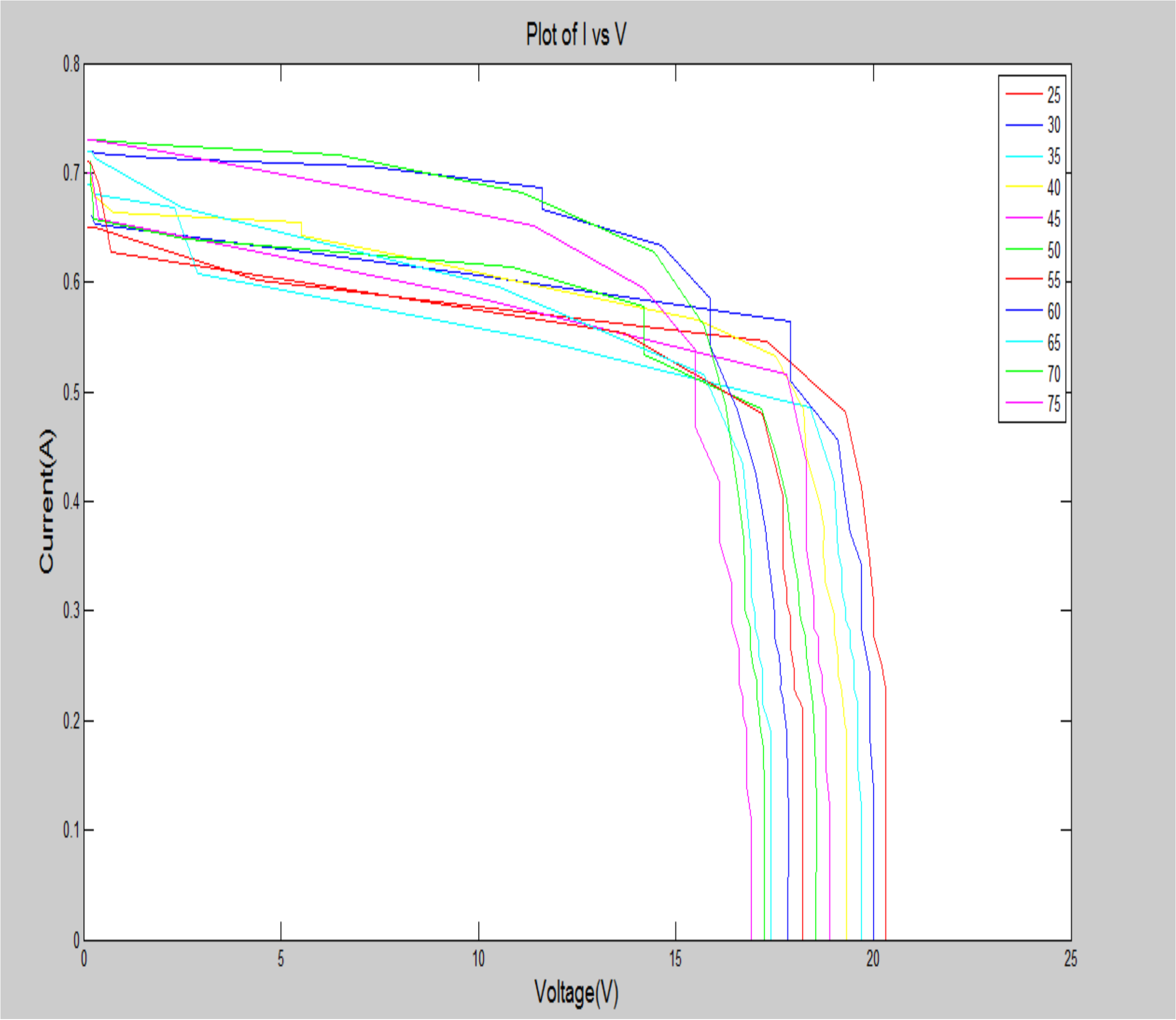

Figure-4.7: I-V sweep curve at different temperatures of Poly-crystalline Silicon module (36 cells)

4.5.2 Effect of temperature on short circuit current:

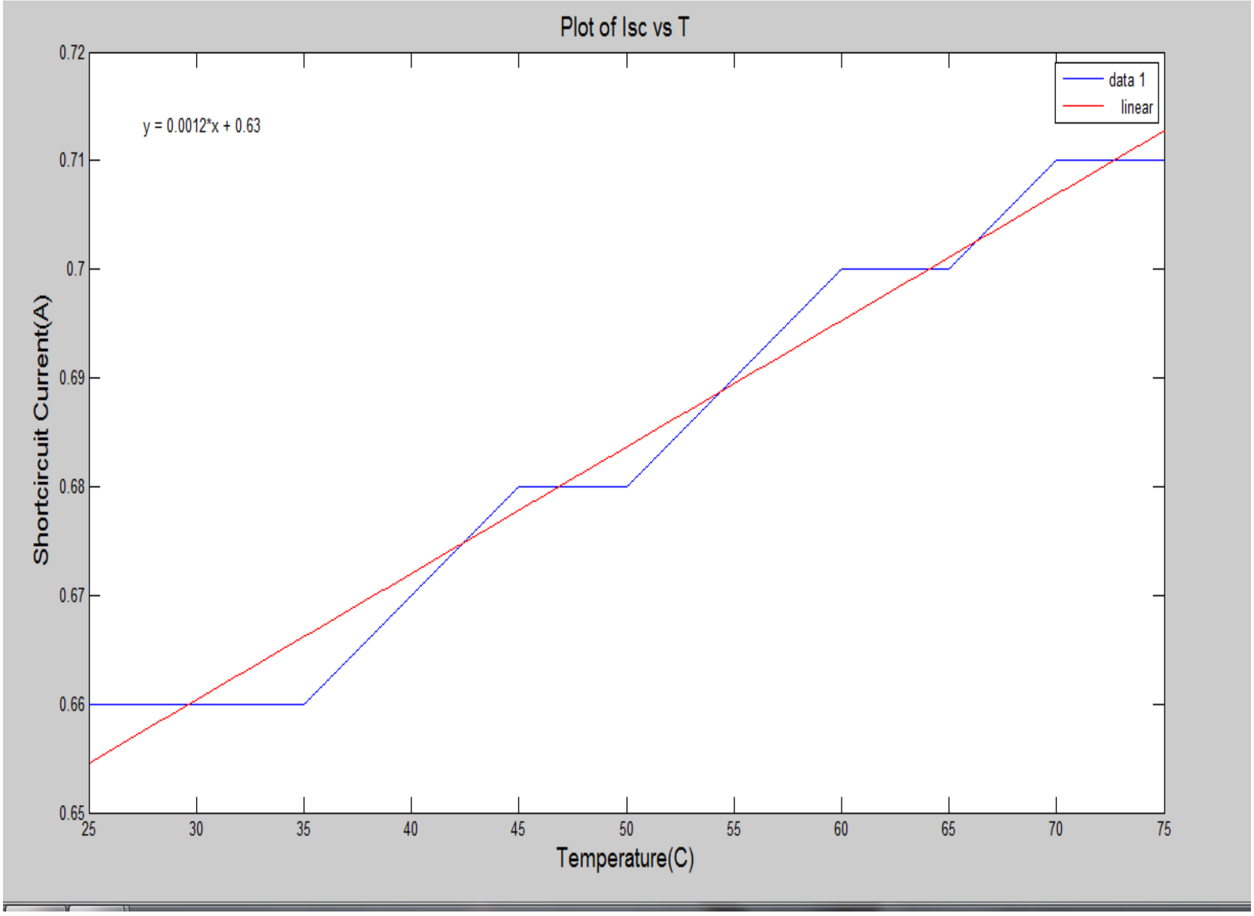

Figure-4.8: Variation of short circuit current of Mono-crystalline Silicon module with temperature.

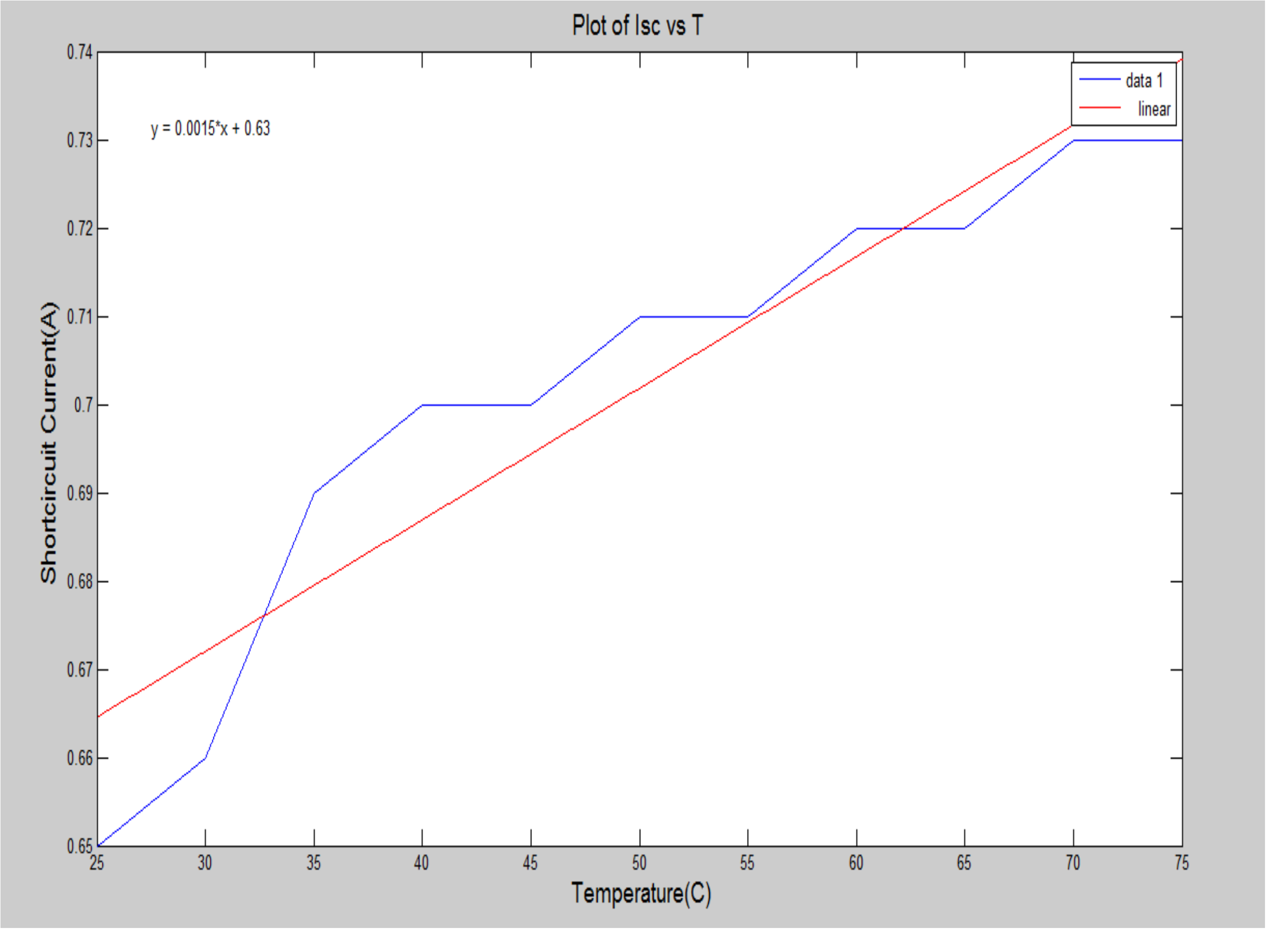

Figure-4.9: Variation of short circuit current of Poly-crystalline Silicon module with temperature.

The curve shows I_{SC} rises with the increase in temperature but due to error in the data the curve is not proper liner but it still shows the increasing trend. When we used basic fittingtool in MATLAB then the equation of the curve is I_{SC}=0.0012*t+0.63 for the mono crystalline panel, so the temperature coefficient is 1.2 mA/°C of the I_{sc} of the Mono-crystalline Silicon module. The equation of the curve is I_{SC} = 0.0015*t+0.63 for poly crystalline solar cell and the temperature coefficient is 1.5 mA/°C

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4.5.3 Effect of Temperature on Open circuit voltage:

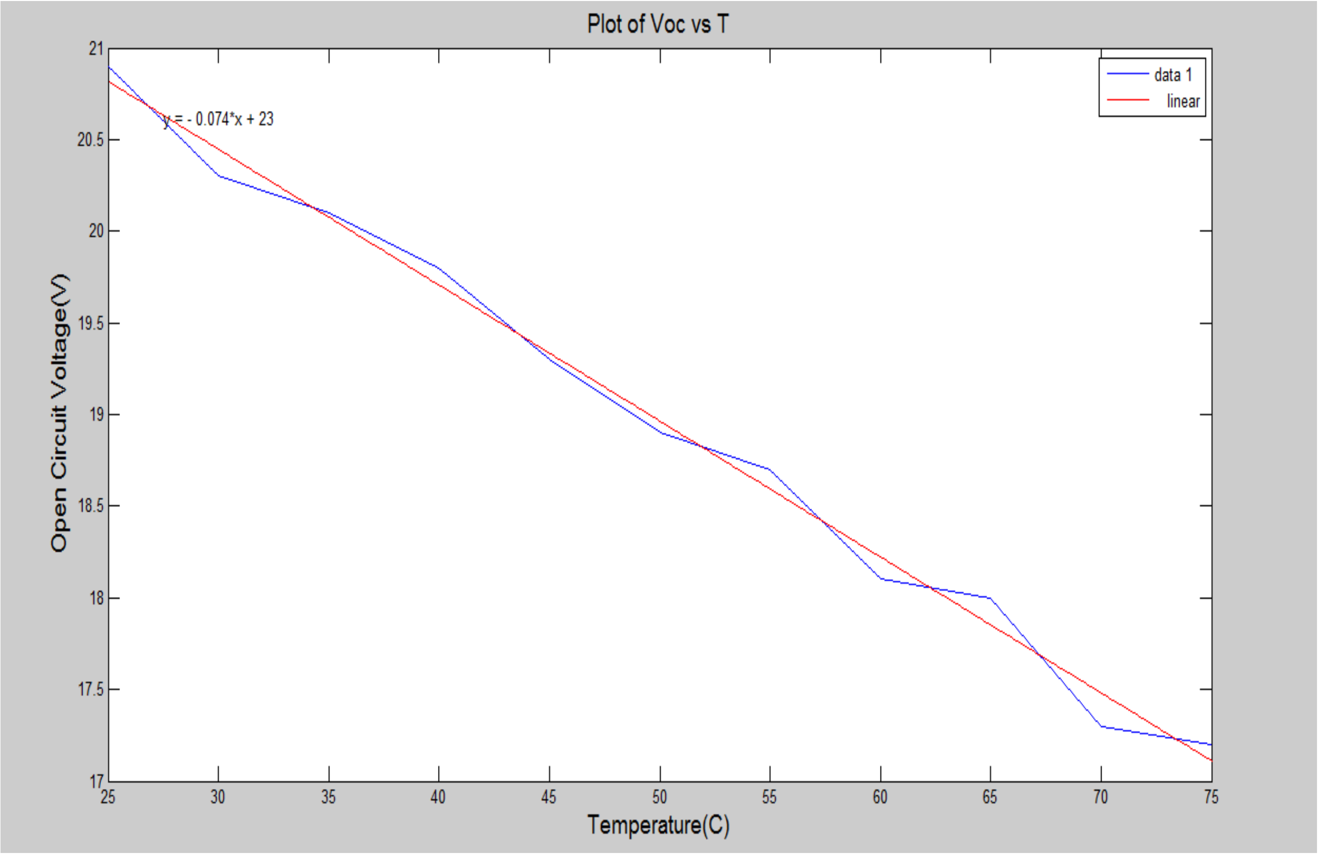


Figure-4.10:Variation of open circuit voltage of Mono-crystalline Silicon module with temperature.

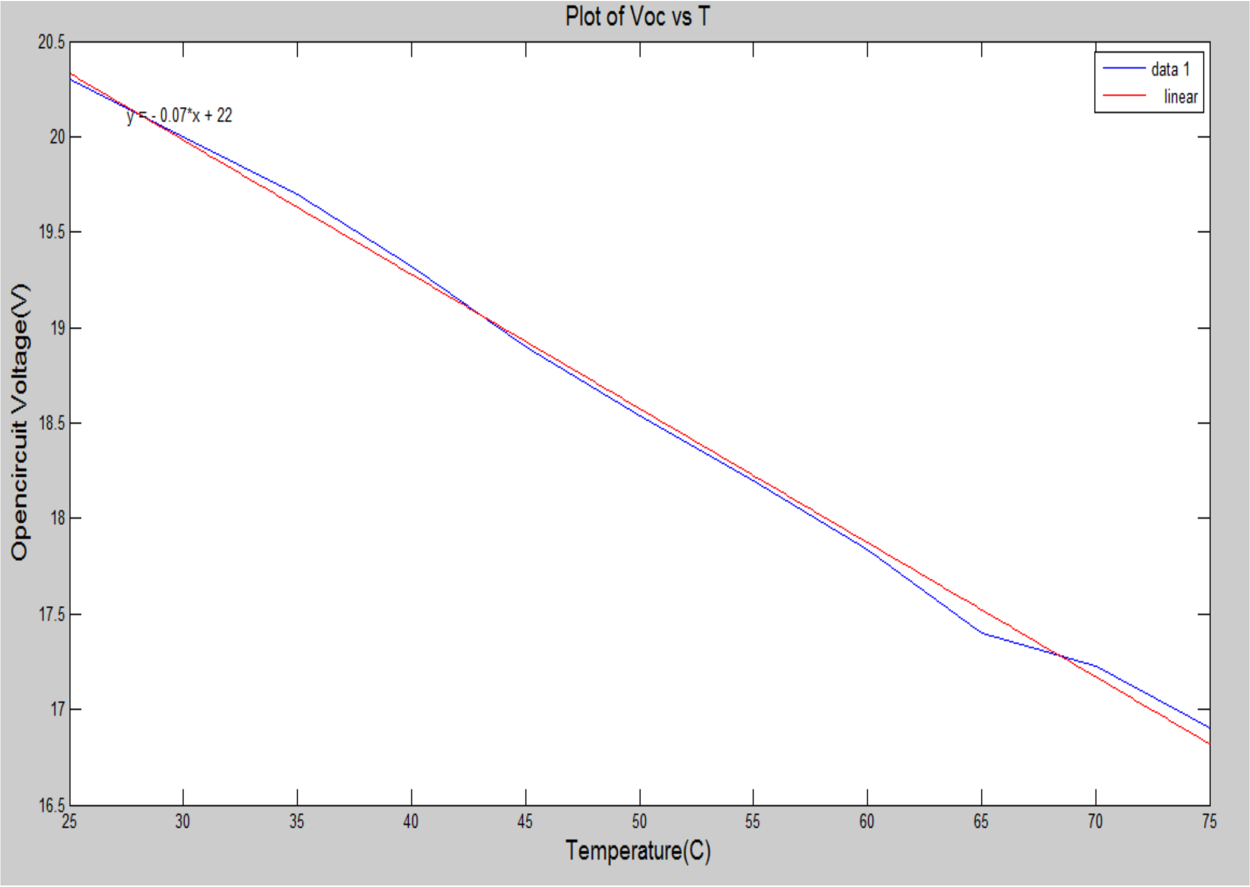


Figure-4.11:Variation of open circuit voltage of Poly-crystalline Silicon module with temperature.

The curve shows that the V_{oc}decreases with the temperature, but due to some experimental errors it does not fully follow a linear path, for that reason we used the basic fitting tool in Matlab, and got the relation of $V_{oc}$and temperature as follows:

$V_{OC} = -0.074*t +23$

So the temperature coefficient is -74mV/°C of the V_{OC} for Mono-crystalline Silicon module

The V_{OC} for poly crystalline is
$V_{OC} = -0.0070*t + 22$
The temperature coefficient -70mV/°C for poly crystalline silicon solar cell

4.5.4 Effect of Temperature on maximum power point- P_{max}:

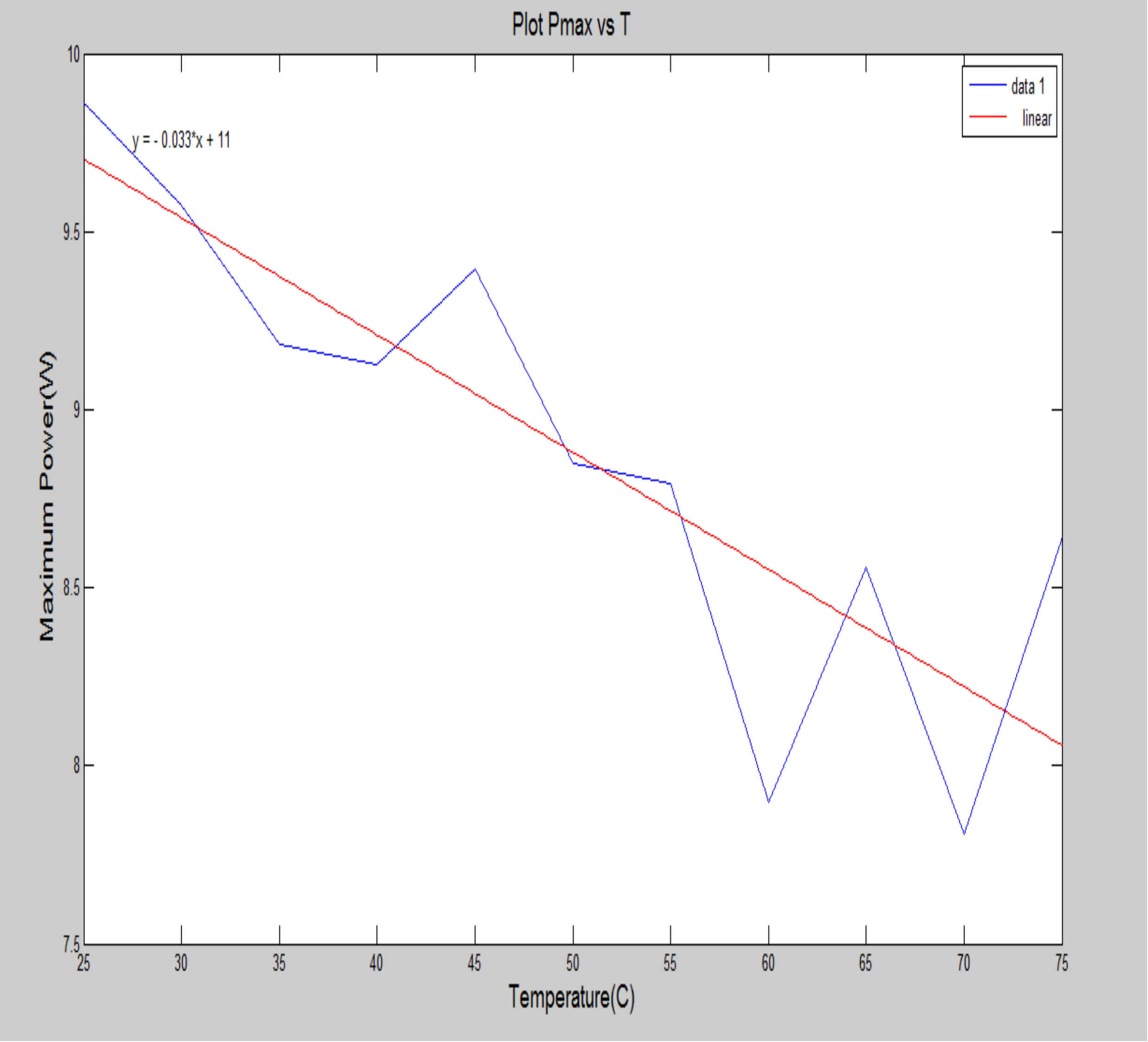


Figure-4.12: Variation of P_{max} of the Mono-crystalline Silicon module(36cells) with temperature.

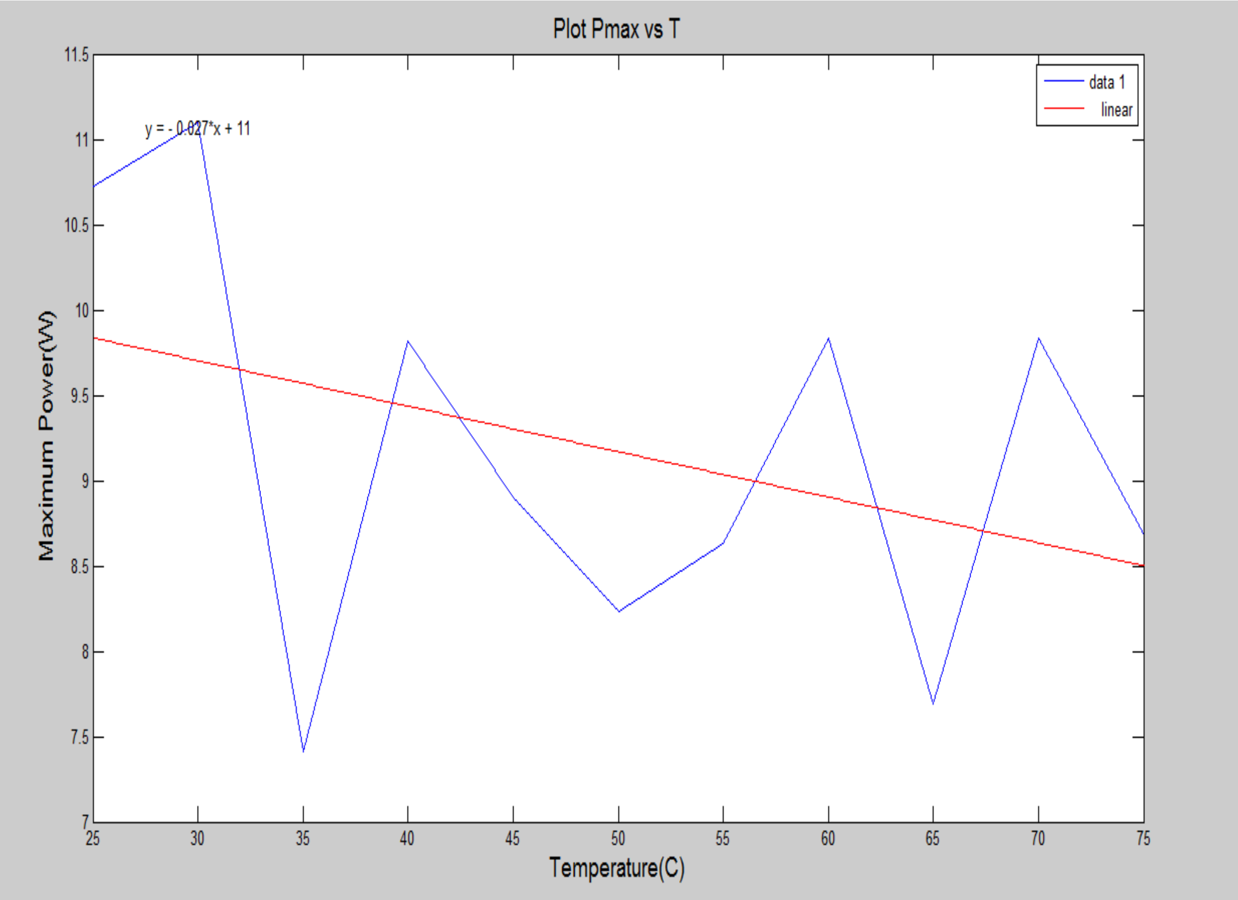


Figure-4.13: Variation of P_{max} of the Poly-crystalline Silicon module(36cells) with temperature

The curve shows that the P_{max} slightly decreases with the increase in Temperature. We calculated the power by multiplying a set of voltage with current by the help of the Matlab, and also took out the maximum power from the array.

The curve should be in the decreasing order, as the decrease in voltage is greater than the increase in current, but there is no uniformity in the curve as it rises high and then rises low again, because of some error in collecting value. That's why; we do some basic fitting in MATLAB for obtainian exact equation for P_{max} depending on temperature.

4.5.5 Effect of temperature on FF:

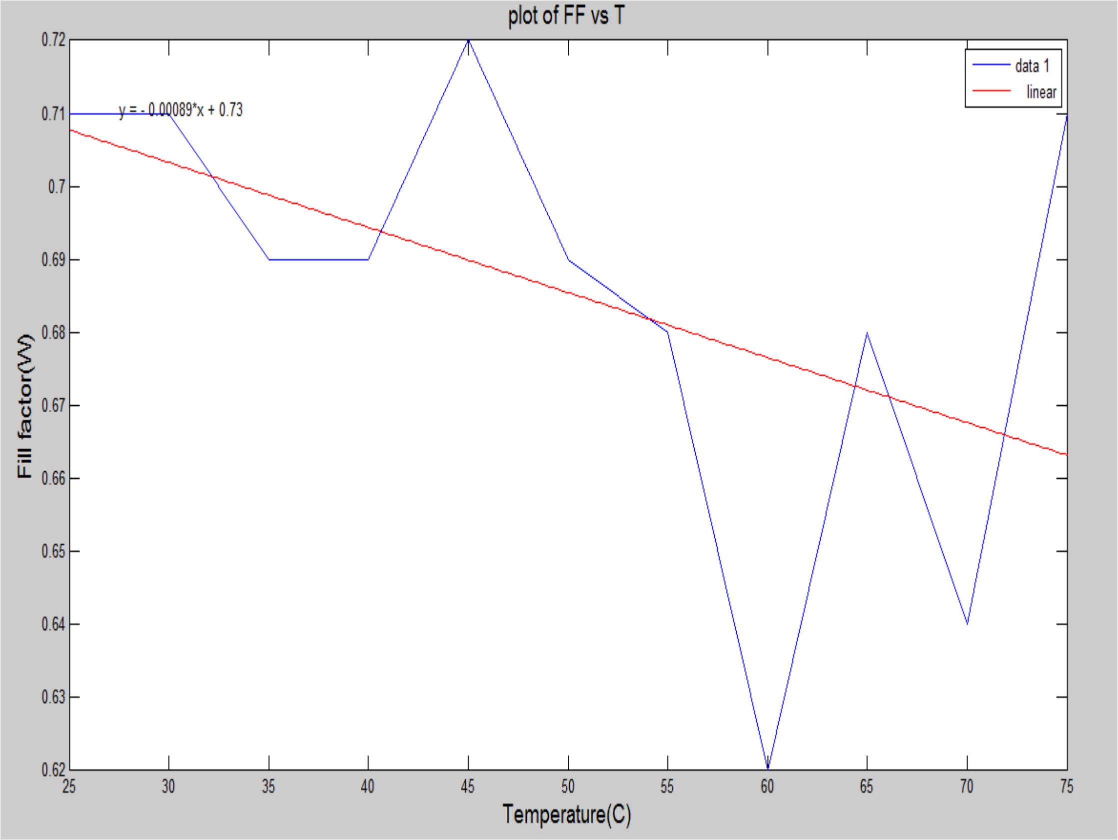


Figure-4.14: Variation of Fill Factor of Mono-crystalline Silicon module with temperature.

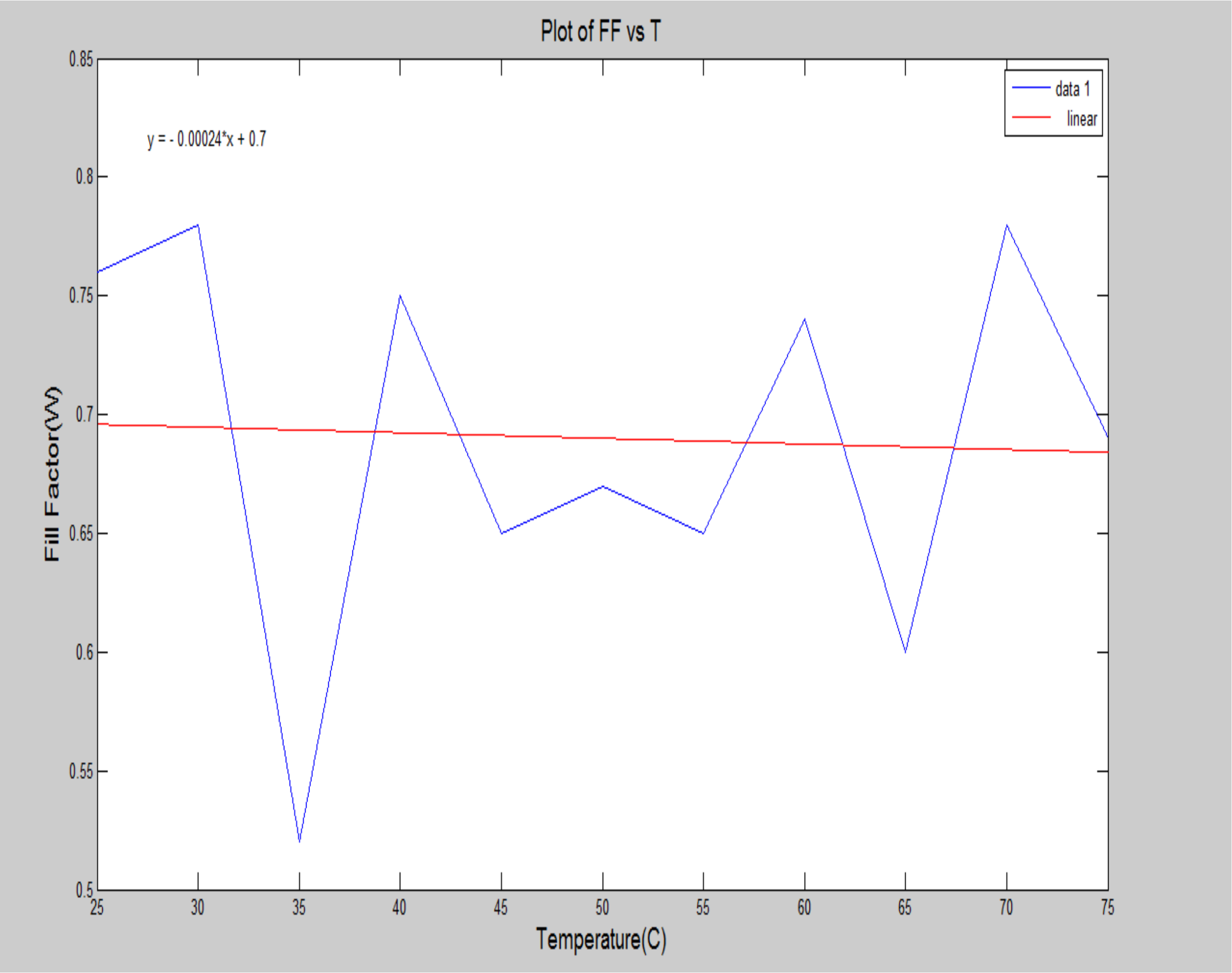


Figure-4.15: Variation of Fill Factor of Poly-crystalline Silicon module with temperature.

The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}.

$$FF= P_{max}/V_{oc}*I_{sc} \quad (4.12)$$

The P_{max} decreases with the increasing temperature because Isc does not increase in that rate whichVoc decreases. The rate of decreasingVoc is higher than the rate of increasing Isc. That's why, FF vs Temperature curve will be like the P_{max} curve.

4.5.6 Effect of temperature on series resistance (R_s) of the Silicon solar module:

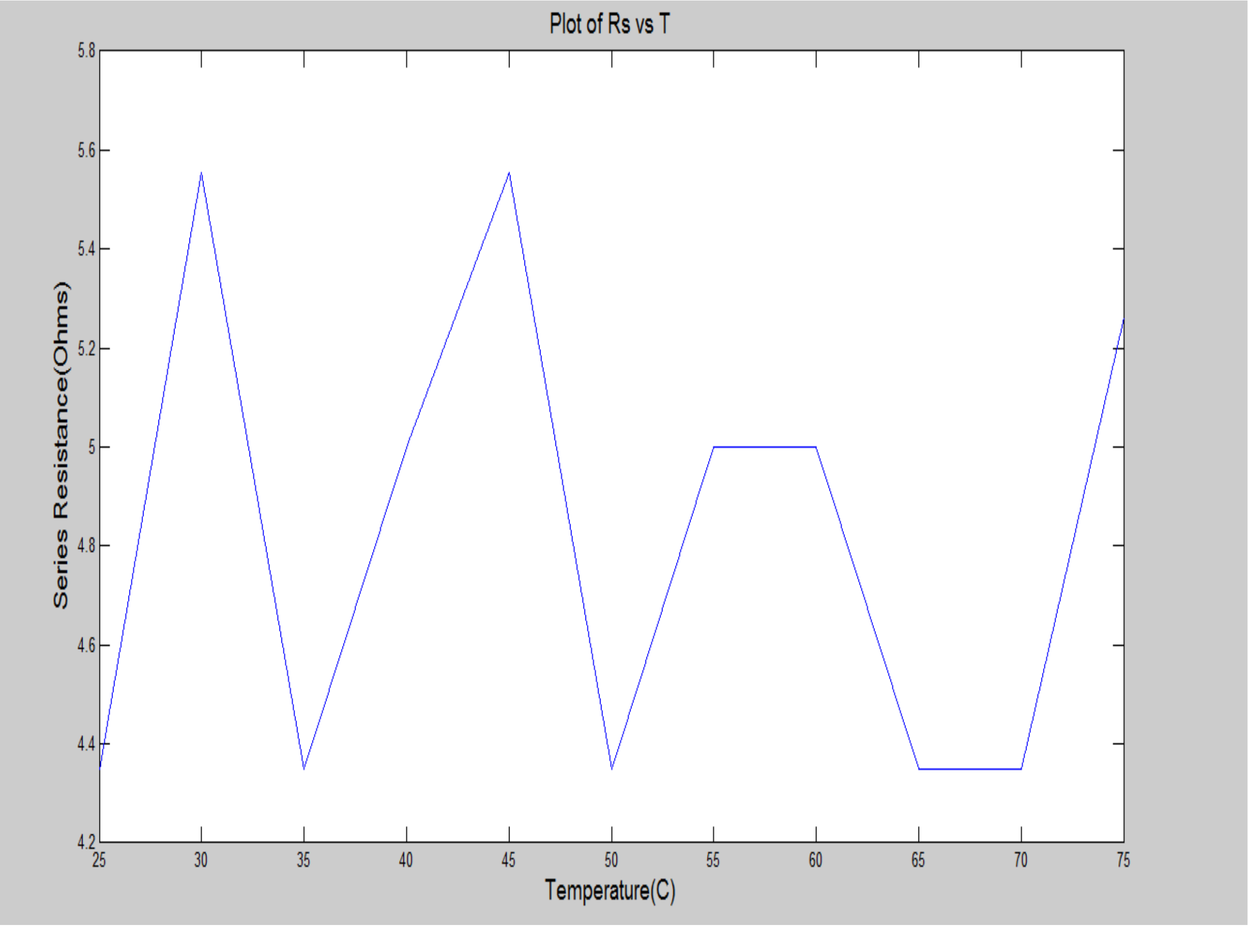


Figure-4.16: Variation of Rs of Mono-crystalline Silicon solar module with temperature.

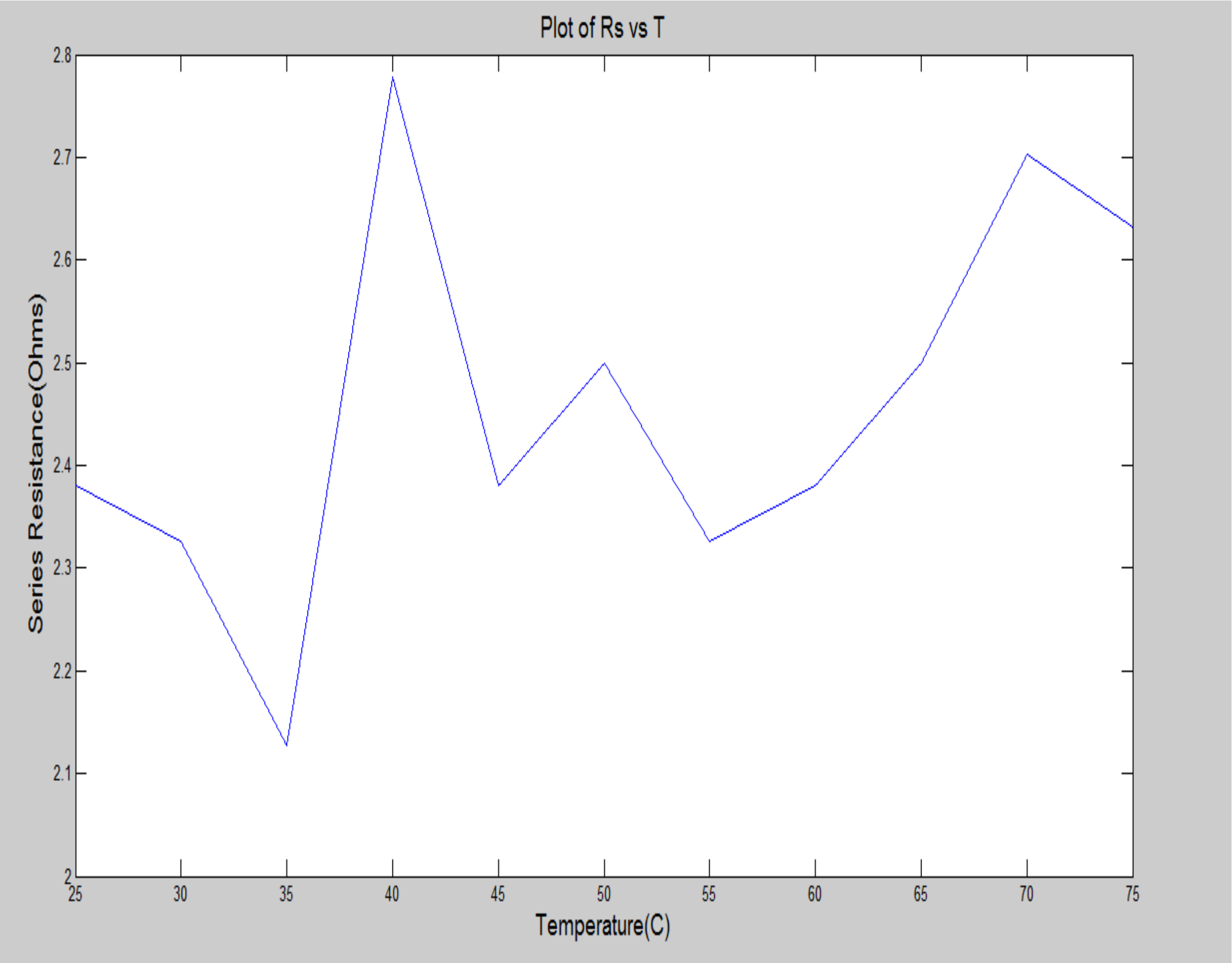


Figure-4.17: Variation of Rsof Poly-crystalline Silicon solar module with temperature.

The curve is the relationship between Temperature and R_S. The curve shows Rs is constant with the increase in temperature but there are lots of bumps. As we took the reading manually, we found many error in reading. the readings was taken manually. That's why,we calculate the average the value of Rs for further calculation.

4.5.7Effect of temperature on shunt resistance (R_{sh}) of the Silicon solar module:

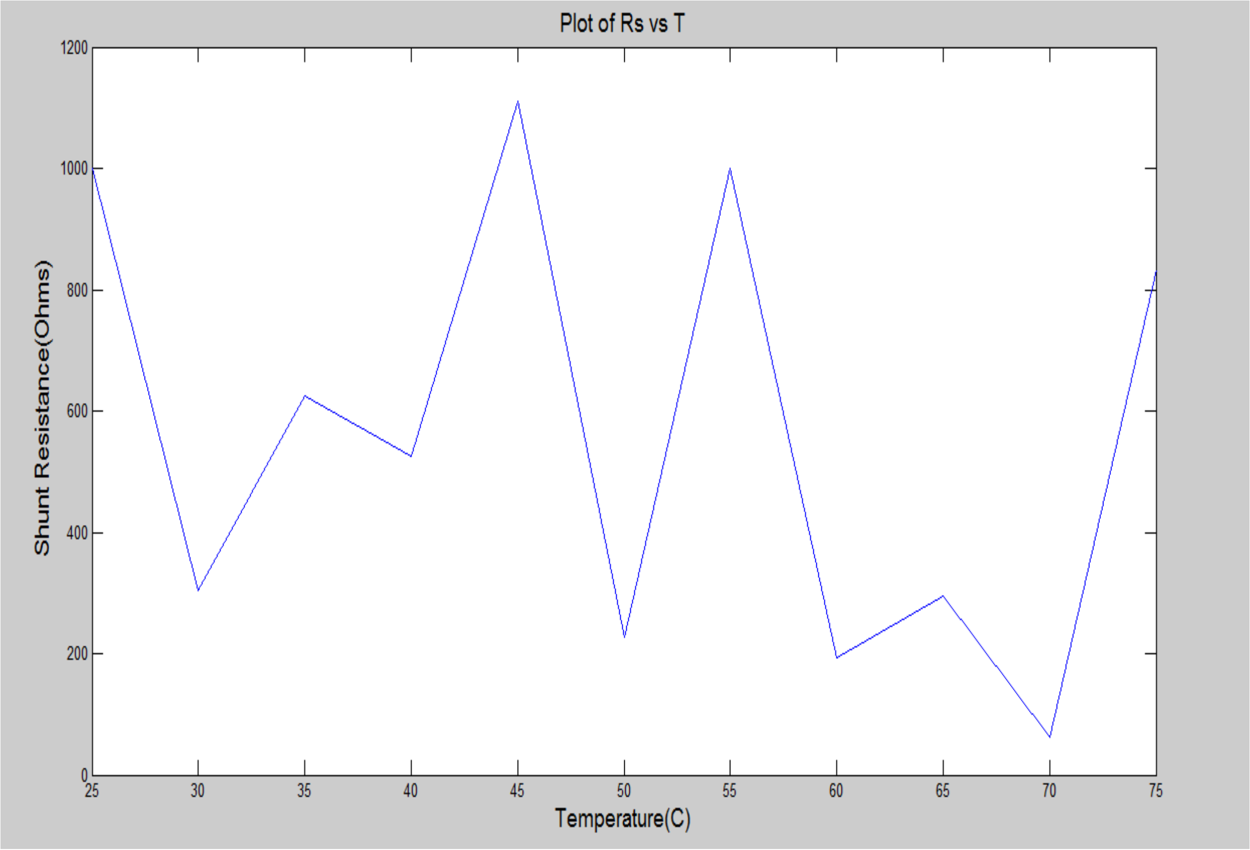


Figure-4.18: Variation of Rshof Mono-crystalline Silicon solar module with temperature.

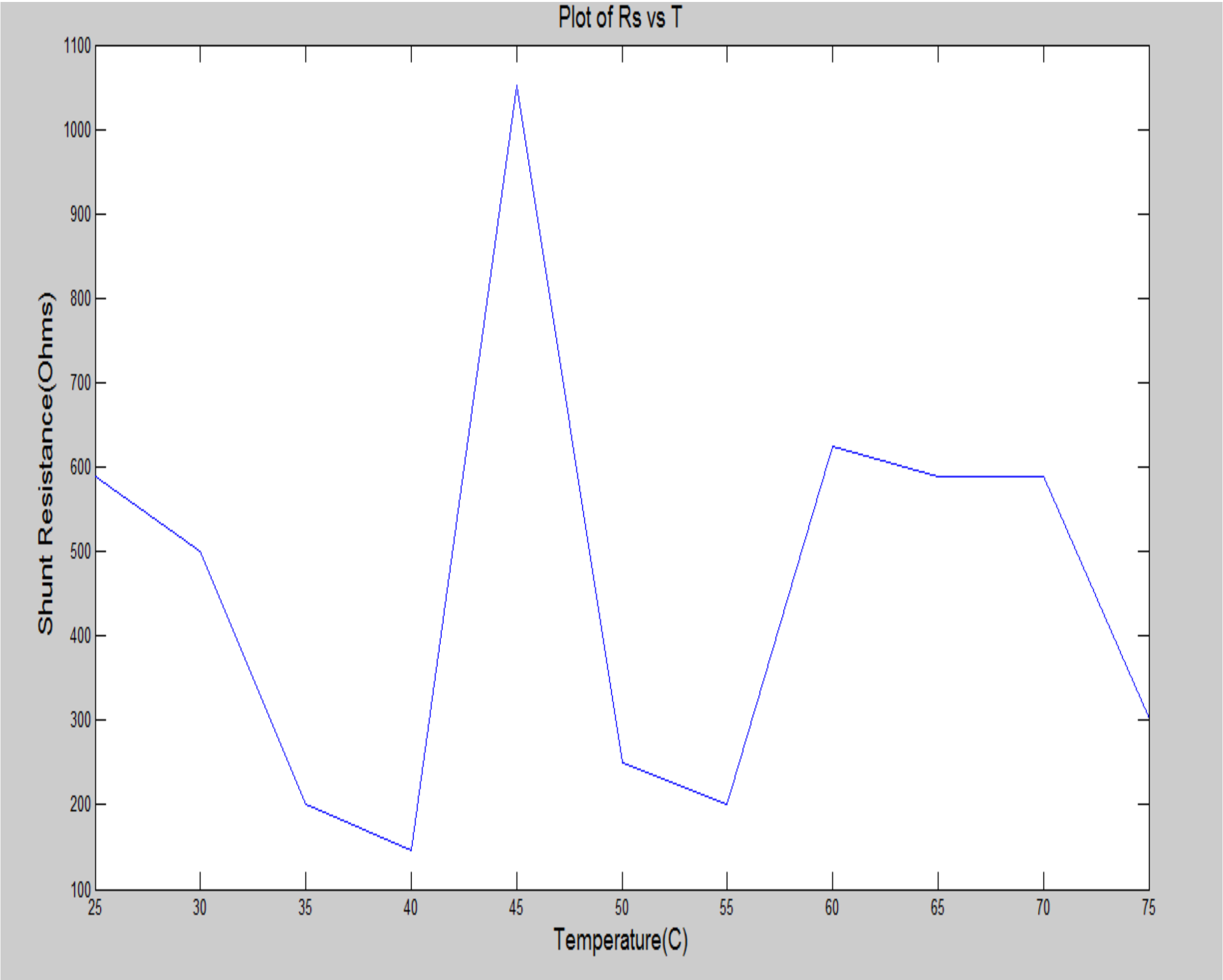


Figure-4.19: Variation of Rshof Poly-crystalline Silicon solar module with temperature.

The curve is the relationship between Temperature and R_{Sh}. The curve shows Rsh is constant with the increase in temperature but there are lots of bumps, which shows that there was error in reading as the readings was taken manually. That’s why,we calculate the average the value of Rsh for further calculation.

4.6 Power and Energy

4.6.1 Introduction

Our main motive in this research is to calculate the power over a year that can be extracted from a 100W mono-crystalline solar panel, and a 100W poly-crystalline solar panel. From that power, we also calculate the energy over a year .Output of the solar panel depends on many factors.But in our work we have considered only two factors, that is the illumination of the solar radiation and the surface temperature of the panel.

To calculate the Power, we need to calculate the current flowing in the solar cells since power is the product of voltage and corresponding current and the current is dependent upon both temperature and illumination, so in order to calculate the current, we need to know the illumination of that particular place and time, and the corresponding surface temperature of the solar cell.

Equations which are used to calculate the solar radiation for Dhaka at the year of 2016 is already explained in Chapter-2 of this paper and from that we calculate the solar energy by integrating the power.now here we are explaining how we have calculated the power of a single day in MATLAB, then the energy that can be extracted over the year is calculated by the similar manner.

4.6.2Solar energy

From the value of solar radiation (every month of 2016) wecalculate the solar energy for Dhaka at the year of 2016.

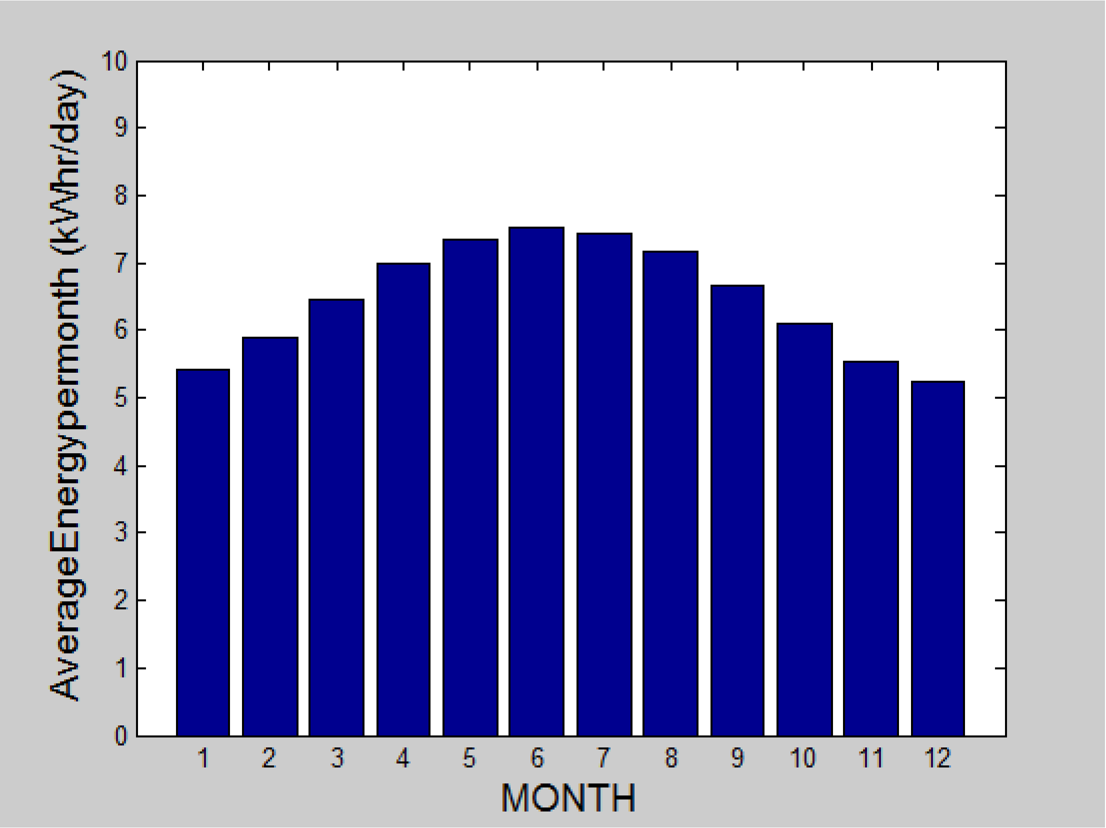


Figure-4.22: Barchartof average solar energy per month of year 2016

4.6.3 Power and Energy calculation

We analyze the electrical circuit for a single diode model of a solar cell and defined equation the of I

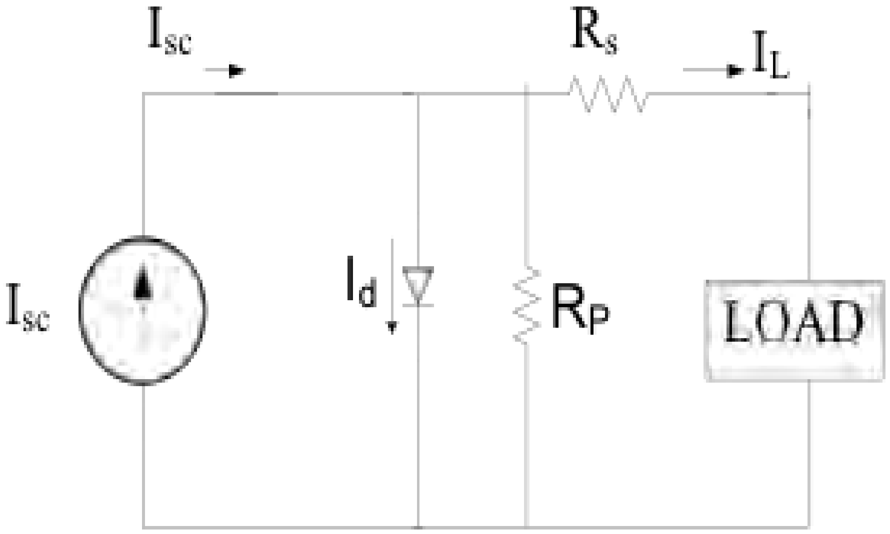


Figure-4.21: Simplified single diode model of a solar cell

The equation of I which we get from the above circuit is

I =Isc-(Isc/exp(Voc/nVt)*exp[V+IRs/nVt]-(V+IRs)/Rsh (4.13)

4.6.4 Process of Energy calculation:

We need to solve the below equation and equation of I to get the value of V and I then calculate the power by doing product of V and I. after that,we find maximum power and then calculate energy by integration the Pmaxvs time.

Isc(G,To)=Isco*G/Go (4.14)

Here,G-value of intensity

Go-1000 W/m^2 [from panel]

Isco=1.31A [From panel]

3. Isc(G,T)= Isc(Go,To)*[1+α(T-To)] (4.15)

Here, α= temperature co-efficient of ISC

To= 25 degree Celcius

T=cell temperature

4. Cell temperature,

T=Ta+(NOC-20/0.8)*G (4.16)

Here, NOC(Nominal Operating Cell temperature=25 degree Celcius

Ta=[ambient temperatue

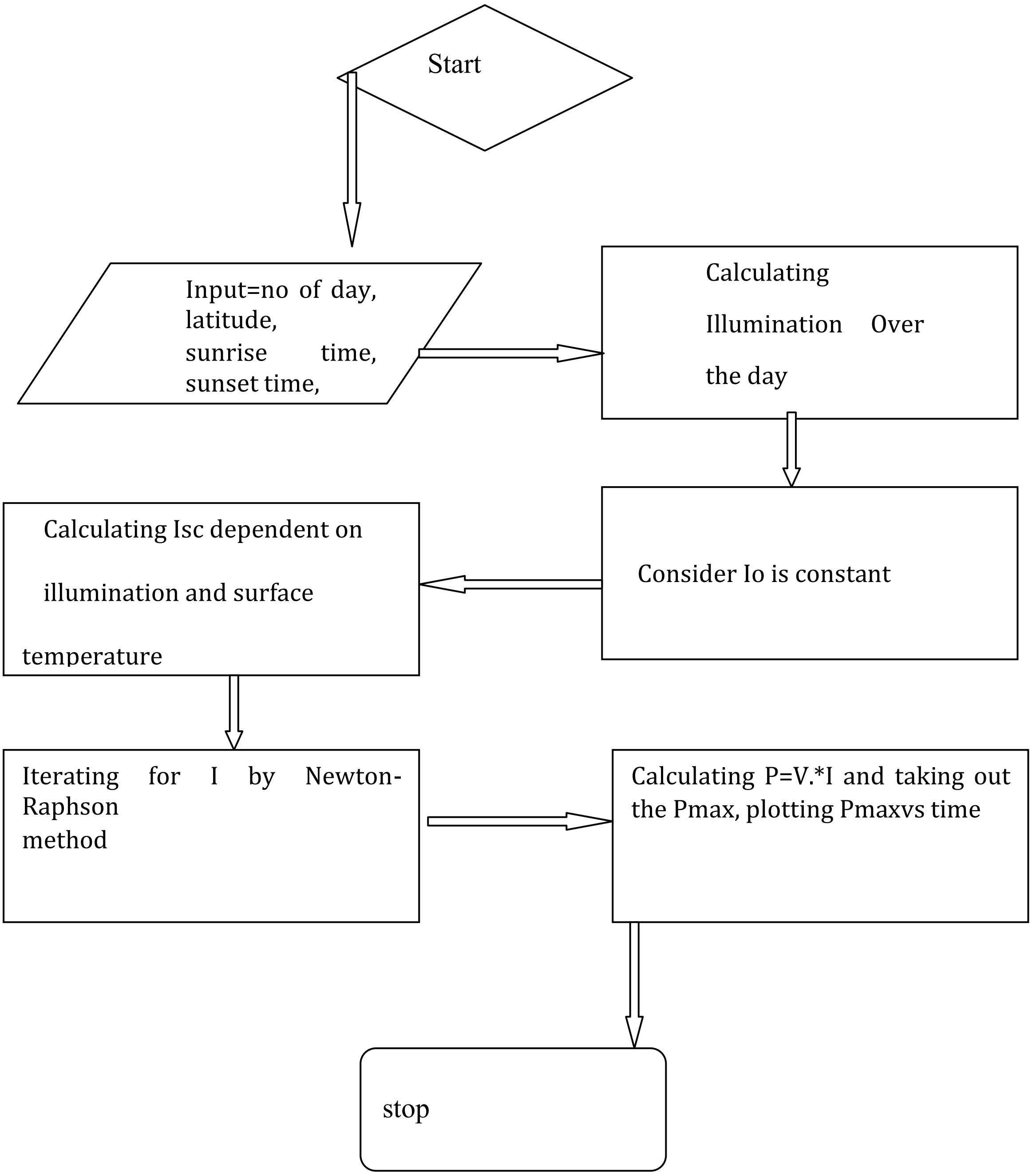


Figure-4.22: Flowchart of energy calculatuion solar cell

4.6.5 Result and Analysis

For this above equation we got the average energy (kwh/m^2/day) both panel per month and we notice that the energy of mono is higher than energy of poly. We also calculate the energy over a year of both panels .

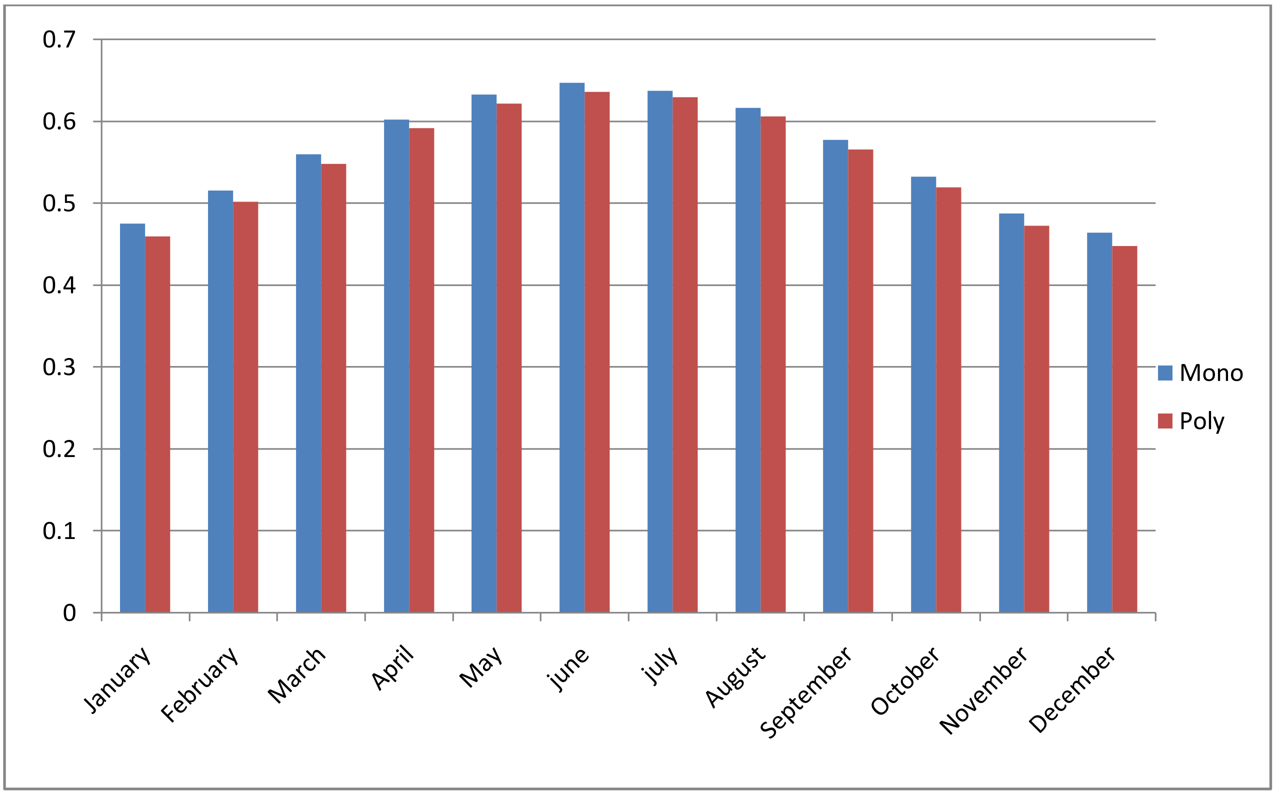


Figure-4.22: Bar chart of both panel's Average energy

Whole year energy of mono panel-0.6907kwh

Whole year energy of poly panel-0.6763kwh

4.7 Conclusion

The results that we get from the experiment and curve are not the exact result that we expected from the theoretical study.We need to improve our measurement taking accuracy, and introducing automatic data logger system, by which the reading of the current, voltage, temperature and illumination would be recorded directly and perfectly for analysis.

We just focused only the effect of temperature and the parameters which varies with increasing temperature. We tried to find out the exact value of parameters . As data taken by manually, we found some error in our calculation. However, this parameters used in the calculation of power and energy.

Moreover, we calculated the whole year energy of both panel using this parameters value which

We measure from the indoor illumination system and we get that the energy of mono-crystalline solar panel is higher than the energy of poly-crystalline solar panel.

CHAPTER-5

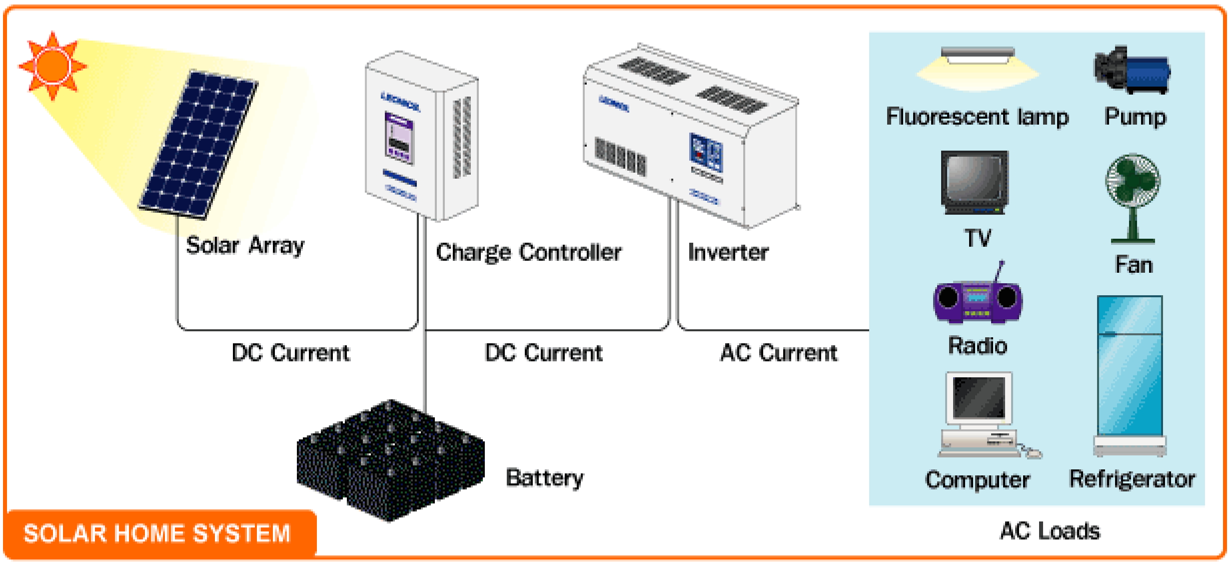
Economic Analysis

5.1 Introduction:

There are many issues to be considered to calculate the costs of PV system such as acquisition costs, maintenance costs and replacement costs. This chapter accounts for all expenses associated with a PV system over its lifetime considering the time value of money, present worth factor and present worth. The time value depends on two factors- inflation rate (i) which is a measure of the decline in value of money and discount rate (d) which relates to the amount of interest that can be earned on principle that is saved. We analyzed the social cost of solar PV systems and tried to figure out the cost differences between the two panels in establishing a solar home system.

5.2 Solar Home System:

A solar home system consists of solar panels, batteries, controllers and inverters. In this case rechargeable batteries are used. During the day, the battery is charged by the electricity generated to power the house. At night the electricity is provided by the stored power in the battery.



5.3 Energy Extracted:

Our experiment was based on two different solar panels- mono crystalline and poly crystalline solar panels. We observed that the energy extraction value is different from each other. The resulting energy for mono-crystalline panel was 0.6907kWh and for poly-crystalline panel was 0.6763kWh from 100W panels.

5.4 Equations used for estimating the set-up cost:

We tried to set up a solar home system consisting of five LED tube lights, five ceiling fans, one refrigerator, one microwave and one TV. Using the equations below, we estimated the cost of a solar home system over a period of 30 years based on daily use.

Total rated power of loads= 1,890W

Total energy of loads= 12,700 Wh/day= 12.7kWh/day

Inverter Size:

Inverter output= total load+ line loss= 1,890W+ 2%=1890.02W

Inverter input= $\frac{output}{efficiency}$= $\frac{1{,}890.02W}{0.93}$= 2032.3 W

Output current=$\frac{output\ \ power}{output\ \ voltage}$=$\frac{1890W}{240V}$= 7.88A

Input DC current=$\frac{input\ \ power}{input\ \ voltage}$=$\frac{2032.3W}{48V}$=42.34 A

We need to choose an inverter with current and power rating at least 1.25 times the calculated values (1890.02*1.25=2362.5 W). This value can be taken approximated to 2500W.

Size of the inverter= 2500W

Battery Size:

Total energy of load= 12,700Wh

Days of autonomy= 3 days

Inverter output= $\frac{total\ \ load}{98\%(\ 2\%\ line\ \ loss)}$=$\frac{12700Wh}{0.98}$=12959.2Wh

Inverter input= $\frac{inverter\ \ output}{efficiency}$ $\frac{12959.2Wh}{85\%}$= 15,246.12 Wh

Input DC voltage=$\frac{inverter\ \ input}{input\ \ DC\ voltage}$=$\frac{15246.12Wh}{48V}$=317.63 Ah/day

Total Ah required= inverter input Ah* days of autonomy=317.63*3=952.89

Battery capacity= $\frac{952.89}{0.8*0.85}$= 1401.3 Ah

If we use 12V, 1500Ah lead acid deep cycle battery then, we will have to set 4 batteries.

Array sizing:

Battery input required= $\frac{\frac{energy\ \ to\ be\ supplied}{inverter\ \ input}}{battery\ \ efficiency\ *coulombic\ \ charge}$= 19929.57Wh

Required array output=$\frac{19929.57}{0.8*0.8}$= 27,679.96 Wh/day

Poly-crystalline panel:

Energy insulation= 0.5920 kWh/day

PV array output required= $\frac{27.68\ kWh/day}{0.5920kWh/day}$=46.75

Considering size of a single panel=20W

No. of panels required=$\frac{46.75}{20}$= 3 panels

Mono-crystalline panel:

Energy insulation = 0.6025kWh/day

PV array output required= $\frac{27.68kWh/day}{0.6025kWh/day}$= 45.942

Considering size of a single panel= 20W

No. of panels required= $\frac{45.942}{20}$= 3 panels

Assuming,

inflation rate (i)=3%

discount rate (d)=10%

x=(1+i)/(1+d)=0.9364

Present Worth, Pa=x^n ; (n=30Years)

=13.533

Pa1= x*Pa= 0.9364*13.533=12.672

5.5 Solar Home System Cost Consideration:

Component	Initial Cost	Quantity	Unit Price	Present Worth (PW)	Lifespan
Mono	740tk*3	3	37tk/W	2,220tk	30y
Poly	980tk*3	3	49tk/W	2,940tk	30y
Batteries	4118tk*4	4	4,118tk	16,472tk	30y
Battery 5y (PW=0.719)	16,472tk	4	4,118tk	11,843tk	
Battery 10y (PW=0.518))	16,472tk	4	4,118tk	8,532tk	
Battery 15y (PW=0.373)	16,472tk	4	4,118tk	6,144tk	
Battery 20y (PW=0.269)	16,472tk	4	4,118tk	4,431tk	
Battery 25y (PW=0.193)	16,472tk	4	4,118tk	3,179tk	
Charge Controller	12,400tk	1	12,400tk	12,400tk	30y
Charge Con 10y (PW=0.518))	12,400tk		12,400tk	6,432tk	
Charge Con 20y (PW=0.269)	12,400tk	1	12,400tk	3,336tk	
Inverter	14,000tk	1	14,000tk	14,000tk	30y

Inverter 10y (PW=0.518)	14,000tk	1	14,000tk	7,252tk
Inverter 20y (PW=0.269)	14,000tk	1	14,000tk	3,766tk

LCC (MONO)	**1,00,007tk**
ALCC (LCC/Pa1)	**7,892tk**

LCC(POLY)	**1,00,727tk**
ALCC	**7,949tk**

CHAPTER 6

CONCLUSION

The photovoltaic home system was the main focus of our comparative study. To establish a cost effective and successful solar home system was the basic of experiment performed indoor with a setup of 10 light bulbs fitted in a wooden box. The indoor experimental setup was carried out by performing a circuit function by switching off and on certain number of light bulbs at different temperature. The illumination from the bulbs was used to make fall on the solar panels and then through circuit operation, different parameters were determined theoretically and experimentally. Besides temperature and illumination there are other factors also to influence the activity of the solar cell.Output energy of the two solar cells was observed with difference in their values between the two cells. We took every 15th day of each month and varied the energy and power graph. It was observed that the graph for mono and poly both represented a significant rise in the middle month (April, June, July) of the year and stayed low key in the end and the starting of the year. Both the graph differs in case of mono and poly with differences in theoretical analysis. Our calculations suggest that mono-crystalline panel would be better for household purpose rather than polycrystalline. It is more cost efficient and energy extraction is more thinking in long term conditions.

Reference:

1. http://aboutdigitalbangladesh.blogspot.com/2010/04/load-shedding-problem-inbangladesh.html
2. http://www.theindependentbd.com/index.php?option=com_content&view=article&id =212828:load-shedding-make-lives-miserable&catid=187:onlineedition&Itemid=223
3. www.google.com.bd/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact =8&ved=0CCsQFjAC&url=http%3A%2F%2Fwww.dhakatribune.com%2Fbanglades h%2F2013%2Fjun%2F18%2Fload-shedding-doubles-five-years&ei=lu6TVL31DMiXuATVh4DICw&usg=AFQjCNF6luD7LTffGHU5_e5nDjgEhyPdg&sig2=C0wQ9dfzGUWG_ZgwWLt7nQ&bvm=bv.82001339,d.c2E
4. http://www.solarpoweristhefuture.com/why-is-solar-power-important.shtml
5. http://greenliving.lovetoknow.com/Advantages_and_Disadvantages_of_Solar_Power
6. http://www.solarpowernotes.com/why-solar-energy.html#.VJOhqV4CA
7. Roger A. Messenger and Jerry Ventre, “The Sun”, Photovoltaic Systems Engineering, second edition, CRC Press , Boca Raton, Florida, 2003, pp.21-30
8. http://freemeteo.gr/weather/dhaka/history/daily-history/?gid=1185241&date=2014-01-02&station=9660&language=english&country=bangladesh
9. http://www.imagesco.com/articles/photovoltaic/photovoltaic-pg4.html
10. http://www.alpstechnologyinc.com/products/5-inches-multicrystalline-silicon-solarcell
11. http://en.wikipedia.org/wiki/Solar_cell#mediaviewer/File:Solar_cell.png

APPENDIX

For solar radiation and Energy Calculation Code

```
clc;
clearall;
closeall;

day=15;
X=((360*(day-80))/365);
Y=sind(X);
delta=(23.45)*Y;

Z=(-tand(23.7104)*tand(delta));
ws=acosd(Z);

n=100;
TSR=6.7;
TSS=17.53;
T=TSS-TSR;
T1=T/n;
tJAN=TSR:T1:TSS;
w=-ws+(((2*ws)/T).*(tJAN-TSR));

alpha=(sind(delta)*sind(23.7104))+(cosd(delta)*cosd(23.7104)*cosd(w));
l=length(tJAN)
for m=1:l;
if alpha(m)<0.01
alpha(m)=0.01,
end
end

altitude=asind(alpha);

AM=1./(sind(altitude));
P=(AM).^(0.678);
IJ=1367.*(0.7).^(P);

angle1=0
angle2=180
angle= angle2-angle1,

theta=(angle.*(tJAN-TSR))/T;
IJAN=((IJ.*sind(theta)))
dx=T1;

b=length(IJAN);
a=0

for index = 1:b
   a=a+IJAN(index)
end
  r=0.5*(IJAN(1)+IJAN(101));
  y=a-r;
  E=y*dx
plot(tJAN,IJAN),xlabel('Time','Fontsize',14),ylabel('Intensity','Fontsize',14')
```

For Panel’s output Calculation code

For Mono

```
clc;
closeall;
clearall;
isc0=1.31;

[G]=illumination(15,6.7,17.53);
isc1=1.31*(G/1000);
T=24+(((25-20)/0.8)*(G/1000));
p=1+(0.0012*(T-25));
ISC2=isc1.*p;
for c=1:101;
if ISC2(c)<0.01
        ISC2(c)=0.01,
end
end
voc0=21.6/36;
Tk=T+273;
k=1.38*10^(-23);
q=1.6*10^(-19);
VT=(k*Tk)/q;
n1=100;
TSR=6.7;
TSS=17.53;
t=TSS-TSR;
T1=t/n1;
tJAN=TSR:T1:TSS;

max_iteration=1000;
tol=1e-5;
n=1.335; %Ideality factor for mono
rs=4.82/36; % AVERAGE VALUE OF SERIES RESISTANCE
rsh=561.35;
% AVERAGE OF SHUNT RESISTANCE

fori=1:length(G)
     ISC0=ISC2(i);
     VT0=VT(i);
     n2=100;
delI=ISC0/n2;
v(1)=0  ;

     I=ISC0:-delI:0

for m=1:101

  f= @(v) ISC0-((ISC0/exp(voc0/(n*VT0)))*(exp((v+(I(m)*rs))/(n*VT0))))-((v+(I(m)*rs))/rsh)-I(m)
df=@(v) -((ISC0/(exp((voc0)/(n*VT0))))*((exp((v+(I(m)*rs))/(n*VT0)))*(1/(n*VT0))))-(1/rsh)
for c=1:max_iteration

v(c+1)=v(c)-(f(v(c))/df(v(c)));
err=abs((v(c+1)-v(c))/(v(c+1)));
if (err<tol)
break

end
end

V(m)=v(c+1)
v(1)=V(m)
end
```

```
  P=I.*(V*36);

Pm(i)=max(P)

end
plot(tJAN,Pm)

a=sum(Pm(1:101));

  b=0.5*(Pm(1)+Pm(101));
  y=a-b;
  E=y*T1;

energy=(E)/1000 % FOR 36 CELL
%UNIT KWH
```

For Poly

```
clc;
closeall;
clearall;
isc0=1.22;

[G]=illumination(15,6.7,17.53)
isc1=1.22*(G/1000);
T=24+(((25-20)/0.8)*(G/1000));

p=1+(0.0015*(T-25));
ISC2=isc1.*p;
voc0=21.24/36;
for c=1:101;
if ISC2(c)<0.01
     ISC2(c)=0.01,
end
end


Tk=T+273;
k=1.38*10^(-23);
q=1.6*10^(-19);
VT=(k*Tk)/q;

n1=100;
TSR=6.7;
TSS=17.53;
t=TSS-TSR;
T1=t/n1;
tJAN=TSR:T1:TSS;
max_iteration=1000;
tol=1e-5;
n=1.8449; %Ideality factor for mono
rs=2.45/36; % AVERAGE VALUE OF SERIES RESISTANCE
rsh=458.2023;
% AVERAGE OF SHUNT RESISTANCE

fori=1:101
```

```
    ISC0=ISC2(i);
    VT0=VT(i);

delI=ISC0/n1;
v(1)=0;

    I=ISC0:-delI:0

for m=1:101

    f= @(v) ISC0-((ISC0/exp(voc0/(n*VT0)))*(exp((v+(I(m)*rs))/(n*VT0))))-((v+(I(m)*rs))/rsh)-I(m)
df=@(v) -((ISC0/(exp((voc0)/(n*VT0))))*((exp((v+(I(m)*rs))/(n*VT0)))*(1/(n*VT0))))-(1/rsh)

for c=1:max_iteration

v(c+1)=v(c)-(f(v(c))/df(v(c)));
err=abs((v(c+1)-v(c))/(v(c+1)));
if (err<tol)
break

end
end

V(m)=v(c+1);
v(1)=V(m);
end

  P=I.*(V*36);

Pm(i)=max(P)

end

plot(tJAN,Pm)

a=sum(Pm(1:101));

  b=0.5*(Pm(1)+Pm(101));
  y=a-b;
  E=y*T1;

energy=(E)/1000 % FOR 36 CELL
%UNIT KWH
```