Outdoor performance study of Poly and Mono Crystalline Photovoltaic Modules under varying environmental conditions

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A thesis submitted to the Department of Electrical and Electronic Engineering in partial fulfilment of the requirements for the degree of
Bachelor of Science in Electrical & Electronic Engineering

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

This study investigates the environmental impact on poly Si and mono Si Photovoltaic module in outdoor condition from the month of May to June 2019 in Dhaka, Bangladesh. Two solar modules with the same characteristics have been used to carry out the impacts of the environmental parameter i.e. temperature, humidity and wind speed on the solar PV module. The ambient temperature and the module surface temperature around the solar PV module was recorded at the same time with the output current to assess the impacts of the temperature on the PV module performance. Also the relative humidity and wind speed for the study area data obtained by a humidity sensor and an anemometer respectively. Results show that the temperature has the greatest impact on the performance of the PV module followed by relative humidity and cloud cover. In this study, poly Si module shows higher percentage values of short circuit current with respect to mono Si module for most of the days. It indicates the poly Si module performs better than the mono Si module throughout the study in outdoor conditions. Also it is notable that Short circuit current decrease 30% to 70% due the cloud effects.

Keywords: Temperature, humidity, wind speed, short circuit current, cloud effect.

Acknowledgement

Firstly, all thanks to the almighty Allah who gave the ability to complete our thesis without facing any major obstacles

The main factor that worked behind to complete our thesis successfully is the motivation we got from our respected thesis supervisor Dr.Mosaddequr Rahman and respected advisor Md. Mohaimenul Islam. Their constant support and faith helped us to climb through all the obstacles that we faced during the starting of the thesis.

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List of Acronyms

PV	Photovoltaic
LCA	Life Cycle Analyses
EPBT	Energy Pay Back Time
Isc	Short Circuit Current
Voc	Open Circuit Voltage
Rs	Series Resistance
Rsh	Shunt Resistance
V	Volt
Amp	Ampere

Chapter 1

Introduction

In this 21stcentury worldwide solar photovoltaic (PV) is one of the fastest growing renewable energy technology. The reason behind is the rapid depletion and adverse environmental impact of fossil fuels. With an annual increase of more than 47%, the global output of the PV component has remarkably increased from 0.26 GW in 2000 to 41.7 GW in 2013. Previous life cycle analyses (LCA) of photovoltaic (PV) systems have created a representative database of the fabrication steps of this rapidly developing industry. These previous studies have brought a better understanding of the critical parameters influencing the indirect solar electricity environmental impacts. Even if technological improvements are an important goal to both minimize the cost and environmental impacts of solar electricity there are other significant parameters those are marked responsible for the impact on pv system. Power is created in Bangladesh essentially from oil and coal also, little portion of gaseous petrol. The vitality utilization is generally from the petroleum gas (76.6%), oil (23.0%), hydropower (2.3%) and coal (1.7%). Bangladesh's total power generation capacity was 13,555 MW in June 2017 that gives an entrance to power among 77.9% population. The Renewable Energy has a very small share on the total electricity generation and is the lowest in the world. Despite the reason as Bangladesh has now made a vision to give power to most of the individuals by 2020, to accomplish this objective the legislature pronounced a clean sustainable vitality approach. The possibilities of sun-oriented vitality is an extraordinary for Bangladesh all things considered arranged inside 20.30◦ and 26.38◦ north scope, 88.04◦, and 92.44◦ east longitude that is entirely reasonable for the creation of sun oriented vitality. [1]. It was watched a greatest sun-based radiation, 4 to 6.5 kWh/m2 got in the long stretch of March to April and least on December to January. Despite having increased power generation everyday large amount of harmful products and toxic gases are released from the energy plants in our eco system, where saving the environment is one of the most important duty for us. To protect the livings and our genetics the best idea for the world now is to depend more and more on solar energy as it is both renewable and clean, it does not emit any toxic gases or products into our environment. Besides the resources oils, coals, etc. which are needed to generate power are going to extinct in near future. Now our only hope is this renewable form of energy that will always be there to support us for a very long time.

Literature review

As solar energy is a core topic now many researches and projects have been done through all over the world. Scientists and students have examined different projects theoretically and practically. Many papers and thesis books have been published in different journals and conferences. We have gone through different thesis papers and research papers to collect a vast knowledge about others' research works. In order to achieve our purpose, lots of theoretical analysis has been done.

Three researchers A Singla, K Singh and V K Yadav from India in their paper "environmental effects on performance of solar pv module" [2] discussed about the temperature effects on the solar performance. As a result, they found that the output power has an opposite relation with the temperature. The higher temperature rises the output power of the panels gets lower. High resistance also has negative effect on output power, but the output power is proportional with the shunt resistance of the system.

In another research paper published in "24th European Photovoltaic Solar Energy Conference, Hamburg: Germany (2009)"[3] researcher compared the results of a life cycle sensitivity analysis with values from previous researches.

'Performance analysis of mono-crystalline and poly-crystalline silicon solar cells understand different climate conditions: a comparative study' [4] a thesis from BRAC university based on the performance of mono and poly crystalline solar module in different times of the year under different environmental and indoor condition. They came up with a result that the energy output is different between indoor and outdoor experiment. They found the solar module more efficient in outdoor experiment and maximum energy is obtained in the month of March and April.

A conference paper "Performance Analysis of PV Cells under Monsoon Climate" which presented in the IAPE'19 Oxford University. [5] They found out that the radiation intensity of winter is around 54% of that intensity of summer, also the highest radiation intensity at the midday (around 12 pm). The output current of mono crystalline (m-Si) cells is higher than that of poly crystalline (p-Si) cells at all times in a day in the month of September and January. From 11 am to 12 pm, the value of current increased up to 37% in September and 15% in January. There is no noticeable variation observed in 11 am to 12 pm even the peak irradiance value observed at that time.

The real environmental impacts of crystalline silicon pv modules: an analysis based on up to date manufactures data. [6] It tells that together with a number of pv companies an extensive effort has been made to collect life cycle inventory data that represents the current status of production technology for crystalline silicon modules. On the basis of this new data it is shown that pv systems on the basis of c-Si technology are in a good position to compete with other energy technologies.

Scope of work

The scope of this work is to investigate the performance of poly Si and mono Si module in outdoor condition. Also how the outdoor condition can affect the output parameter of PV module can also be examined. This study can give more informed decision about the environmental parameter impact on PV module and the variation in performance over the time. This study also shows the month wise variation in short circuit current of PV module.

Objective

The main goal of this work is to analyse the performance of two different types of modules i.e. poly Si and mono Si under different climatic conditions in outdoor. Environmental parameter such as temperature, humidity and wind speed is taken into consideration for this study. The real time data has been collected from the month of May to June. A weather station is set up to collect the environmental data. Short circuit current is considered as output parameter of PV module to understand the performance.

Thesis Organization

The book is structured as follows. **Chapter 1** provides a general introduction followed by the background and the objectives of the work. **Chapter 2** demonstrates the theoretical background of this study. **Chapter 3** presents the necessary experimental set up. Results of analyses have been introduced and talked over in **Chapter 4**. Conclusion and future research suggestions are offered in **Chapter 5**.

Chapter 2

Theoretical Background

2.1 Single diode model:

A PV module consists of many PV cells wired in parallel to extend current and in series to provide a better voltage. The module is encapsulated on the front with tempered glass and a protective and water-resistant material on the back. The edges are sealed, and an aluminium frame holds everything together in a mountable unit. At the back of the module, a junction box holds all the electrical connections. An equivalent circuit of PV cell is depicted in Fig.

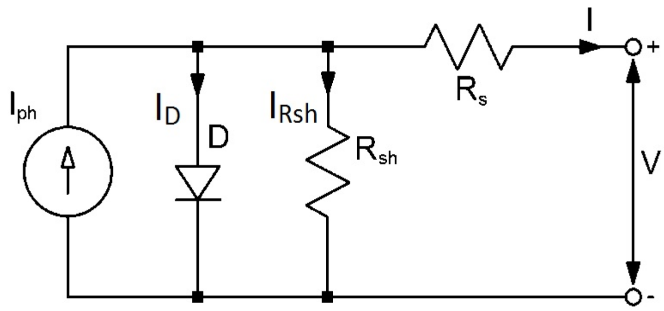

Figure 2 1: Equivalent circuit of solar cells

where a constant current source I_{ph} representing the light-induced current generated in the cell is in parallel with the p-n junction diode. R_s represents series resistance and R_{sh}representsthe shunt resistances of the cell. The output current (I) of the PV module can be expressed as [7]

$$I = I_{ph} - I_D - I_{R_{sh}} = I_{ph} - I_s\left(e^{\frac{q\left(\frac{V}{N_S}+IR_S\right)}{nkT}} - 1\right) - \frac{\frac{V}{N_S}+IR_S}{R_{sh}} \quad (1)$$

Types of Solar Panels:

There are 7 different types of solar modules which are categories in three generations [8].

1stgeneration solar module: These are the traditional types of solar panels made of mono crystalline silicon or poly silicon and are most commonly used in conventional surroundings.

Both mono crystalline and polycrystalline solar panels have the same functionality in the overall solar PV system. They capture energy from the sun and then turn it into electricity. They are both made from silicon, which is used for solar panels because it is an abundant, very durable element. The two types of solar panel is described below-

A) Mono crystalline solar panel:

Mono crystalline solar panels are normally considered as a premium solar product. The main advantages of mono crystalline panels are higher efficiencies and sleeker aesthetics. In order to produce solar cells for mono crystalline solar panels, first silicon is formed into bars and cut into wafers. These types of panels are called "mono crystalline" to indicate that the silicon used to produce the panel is single-crystal silicon. As the cell is composed of a single crystal, the electrons that generate a flow of electricity have more room to move. Thus, mono crystalline panels are more efficient than poly crystalline panels.

B) Poly crystalline solar panel:

Normally polycrystalline solar panels have lower efficiency than mono crystalline solar panels, but their advantage is that their price is comparatively lower. In addition, polycrystalline solar panels have a blue hue where mono crystalline panels have black hue.

Polycrystalline solar panels are also made from silicon. However, instead of using a single crystal of silicon, many fragments of silicon are melt together to form the wafers for the panel. Polycrystalline solar panels are also known as multi-crystalline or many-crystal silicon. It's because in each cell there are many crystals that gives less freedom to the electrons to move. Thus, polycrystalline solar panels have lower efficiency than mono crystalline panels.

2ndgeneration solar panel:

These cells are different types of thin film solar cells and are mainly used for photovoltaic power stations, integrated in buildings or smaller solar systems.

A) Thin-Film Solar Cells(TFSC)

B) Amorphous Silicon Solar Cell(A-Si)

3rd Generation Solar Panels

3rd generation solar panels include a variety of thin film technologies but most of them are still in the. Some of them generate electricity by using organic materials, others use inorganic substances (CdTe for instance).

A) Bio hybrid Solar Cell
B) Cadmium Telluride Solar Cell(CdTe)
C) Concentrated PV Cell (CVP and HCVP)

How do solar panels work to generate electricity?

A standard solar panel (also known as a solar module) consists of a layer of silicon cells, a metal frame, a glass casing, and various wiring to allow current to flow from the silicon cells. Silicon (atomic #14 on the periodic table) is a non-metal with conductive properties that allow it to absorb and convert sunlight into electricity. When light interacts with a silicon cell, it causes electrons to be set into motion, which initiates a flow of electric current. This is known as the "photovoltaic effect," and it describes the general functionality of solar panel technology. [9]

The general photovoltaic process, as described above, works through the following steps:

1. The silicon photovoltaic solar cell absorbs solar radiation
2. When the sun's rays interact with the silicon cell, electrons begin to move, creating a flow of electric current
3. Wires capture and feed this direct current (DC) electricity to a solar inverter to be converted to alternating current (AC)electricity

Effect of various environmental parameters on the performance on PV solar module

Solar is the most efficient natural energy source for the world right now. Though its natural power come originated from the sun, there are certain environmental parameters which have immense influence on the outcome of the solar module. Thus we unfortunately do not get the expected power outcome from the solar, or the result varies from place to place or time to time. For many years it’s one of the most valuable and desirable experiment for scientists to work with this topic.

There are different environmental parameter which have impact on solar module. For example, Solar Irradiance, The ambient temperature, the surface temperature of the module, the wind speed, the humidity, Dust, height etc. Among all these parameter, solar irradiance and Temperature are the key role players here.

Effect of Temperature

In semiconductor, temperature measures the amount of movement of the electrons and the holders for those electrons. Let’s think and compare the situation with the shelf and the bin of balls, when a semiconductor is hotter, we can think it as if the balls are churning and bouncing around in the bin and for that the shelf above is vibrating up and down.

Like that in a hot solar cell, the balls bounce around, so it’s become easier for the sunlight to pick them up and put them on the shelf. As the shelf is vibrating up and down, for the balls it's also become easier to get onto the shelf, but as they aren't that high, they don't roll as fast. Thus when a silicon solar cell gets hotter, it generates more current but less voltage (Figure 2.2). Actually, the change in current is little but the change in voltage is quite more, so in result the power decreases. This means the efficiency of solar cells decreases with the

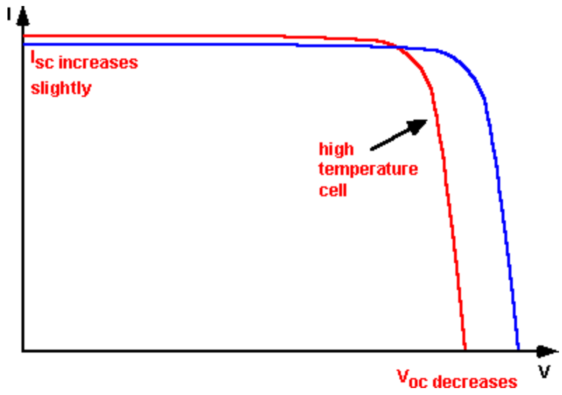

Figure 2 2: Effect of temperature on module short circuit current and open circuit voltage increasing of cell temperature or the ambient temperature and V_{oc} is more sensitive to temperature where the I_{sc} isn't much sensitive to temperature.

From calculations we can see that the relation between voltage and temperature is inversely proportional for silicon cell and (dV_{oc}/dT) is approximately equal to -2mV/ºC, which means that the efficiency of the cell drops by about 0.4 % for the increase of every 1 degree Celsius. [10] A silicon cell of 20% efficiency at 20ºC will reduce to 16% at 30ºC.

Effect of relative humidity

The air humidity means the amount of water content in the air. The water content of the air can be expressed in several ways. Relative humidity is one of those ways to indicate the air humidity.

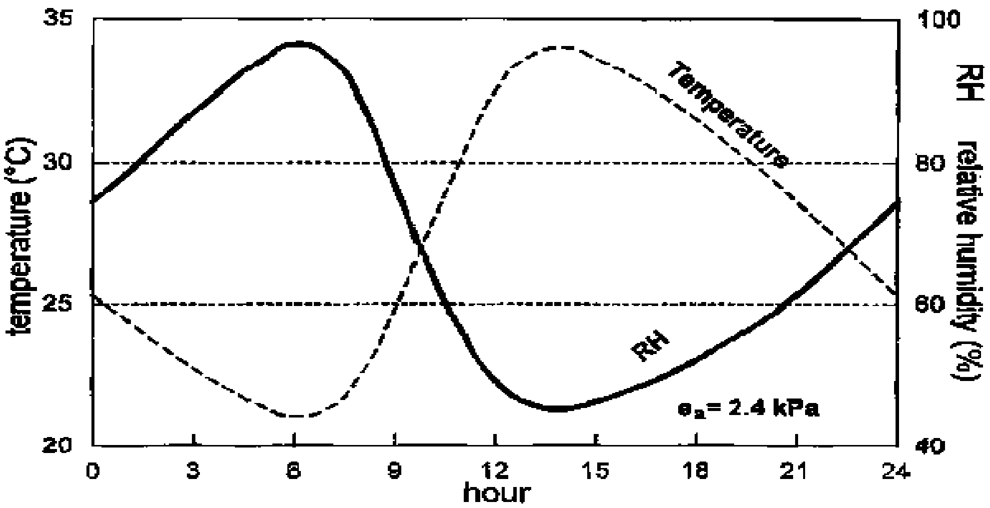

Figure 2 3: Variation of the relative humidity over 24 hours for a constant actual vapour pressure of 2.4 kPa

Relative humidity simply referees to the ratio between the amount of water the ambient air actually, holds at a particular time and the amount it can hold at a same temperature. It is dimensionless. Its unit is given as a percentage. The relative humidity usually fluctuates between the time period of a maximum near sunrise and a minimum sunrise around early in the afternoon (Figure 12). As the temperature changes during the day, the relative humidity also changes accordingly. [11]

The relative humidity (RH) expresses the degree of saturation of the air as a ratio of the actual (e_a) to the saturation (e°(T)) vapour pressure at the same temperature(T)

Measurement

Relative humidity is measured directly with hygrometers or using humidity sensor. The measurement is based on the nature of some material such as, hair, which changes its length if comes in touch of the changes in air humidity. It's also can be measured using a capacitance plate, where the electric capacitance changes with RH

The RH is the amount of moisture in the air, which can be found by dividing the moisture amount by the maximum amount of moisture that could exist in the air at a specific time.

$$RH= \frac{E}{E_s} * 100\%$$

This changing in humidity has an impact on PV solar cell efficiency. A decrease in relative humidity results in higher output current. Low relative humidity means there is low water vapour in the atmosphere which gives rise to a high solar flux and thus enhance the production of the current or electricity. As the current production increases with a low humidity in the atmosphere, so it's absurd that the efficiency of the solar module is better in low relative humidity condition. [12]

Effect of wind speed

Solar panels are installed with an angle equal to the latitude of the site. Many studies have shown that as wind impinges on an inclined solar panel, it flows around it inducing an unequal pressure on its two surfaces. Thereby the surfaces of the solar panels experience the drag force in the direction of the wind flow and lift force in the direction perpendicular to the wind flow. These forces produce the torque.

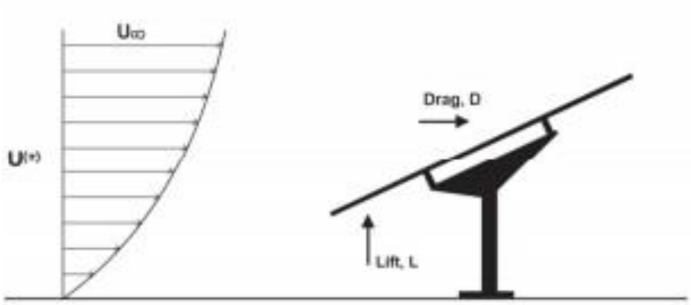

Figure 2 4: Vertical profile of wind approaching a solar panel

It may not be a correct concept to say that solar PV efficiency is directly affected by wind velocity, however it has a major role to play in PV generation. When the wind doesn't give the sun's light rays any extra oomph while powering panels, the effect of wind then works as a boost in solar efficiency. When a solar panel is too hot, it's efficiency decreases due to the science behind the generation of electricity. On the other hand, in case of cooler solar panel its efficiency improves. In short, the effect of temperature on solar cell performance is like this: cooler panels allow more energy to get through like an electric current than hot panels do. [Fig2.4]

When the wind flows basically temperature of solar cell drops. The wind cools the solar panels resulting in producing less vibration of the electrons so the electrons can carry more energy while moving to upper state. Solar panels cooled by 1 degree Celsius are 0.05 percent more efficient. This percentage adds up over time.

Science behind a solar panel generating electricity:

Inside a hot solar cell, the atoms vibrate at a faster rate than the atoms in the solar cell when is cool. Normally the electrons within the atoms are energized to a higher level with the sunlight, and thus generate electricity. When the electrons move from one energy state (rest) to a higher one (excited) the cells produce power. When a solar panel is hot, the difference between the rest state and the excited energy state is smaller, so the cells produce less energy.

The opposite happens when a solar panel is cooler. Inside a cool solar cell, the electrons are still getting excited by the sunlight and they're easily able to move up to the higher level of energy. This is because the atoms aren't vibrating. Though the electrons move slower, the ones that make it through carrying more energy than the electrons in a heated state.

Chapter 3

Experimental Setup

In order to perform the experiment in outdoor condition an experimental set up is necessary. For this we have to choose a place without shadow. This experiment is done on the top floor of the Building 4, Brac University, Mohakhali, Dhaka. The building is a 15thstoried building. Our set up is on the roof top of this building. From the Figure 3.1 the experimental set up is observed. The PV modules are in a fixed set up. The tilt angle is 23.77^{o}. There are two 20 watt PV modules; one is poly Si and another is mono Si. To measure the short circuit current ammeter is used. To collect the environmental data several sensors are used. For these a weather station is designed with temperature, wind speed and humidity sensor. All the sensors data are collected in real time and stored in a computer. We have used real time clock to collect the real time data. For temperature sensor we have used Dallas DS18B20 temperature sensor to collect the module surface temperature. To obtain the ambient temperature and humidity we have used DHT 11 sensor. To collect the wind speed we have used Anemometer.

Figure 3 1: Experimental Setup on the top of Building 4, Brac University

Specifications of PV Module

Poly Si MODEL:XH20P	Typical Electrical Characteristics
Rated Maximum Power (Pmax)	20Wp
Tolerance	0-3%
Voltage at Pmax (Vmp)	17.5V
Current at Pmax (Imp)	1.15A
Open-Circuit Voltage (Voc)	21.6V
Short-Circuit Current (Isc)	1.33A
Nominal Operating Cell Temp (NOCT)	47 ± 2°C
Maximum System Voltage	600VDC
Maximum Series Fuse Rating	10A
Operating Temperature	-40°C to +85°C
Note: All technical data standard test condition AM=1.5, E=1000W/m² TC=25°C	

Mono Si MODEL:SP20-18-M	Typical Electrical Characteristics
Rated Maximum Power (Pmax)	20W
Tolerance	0~+3%
Voltage at Pmax (Vmp)	17.35V
Current at Pmax (Imp)	1.16A
Open-Circuit Voltage (Voc)	21.16V
Short-Circuit Current (Isc)	1.27A
Nominal Operating Cell Temp(NOCT)	47±2°C
Maximum system Voltage	1000VDC
Maximum Series Fuse Rating	10A
Operating Temperature	-40°C to +85°C
Application Class	Class A
Cell Technology	Mono-Si
Weight (kg)	1.92
Dimensions (mm)	510*360*25
Note: All technical data standard test condition AM=1.5, E=1000W/m², TC=25°C	

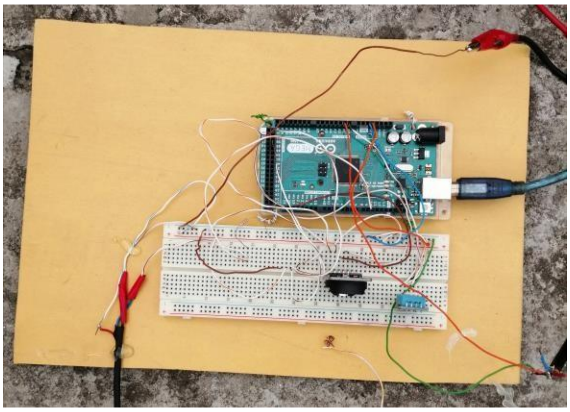

Figure 3 2: Weather Station Circuit

Weather Station

To collect the environmental parameter a weather station is designed like as Figure 3.2. The main controller is an Arduino Mega. The Dallas, DHT and Anemometer along with the real time clock are connected with the Arduino. Arduino controls the sensors and display the real time data on the computer screen. All the sensors connection and performance is discussed below.

Dallas Temperature Sensor:DS18B20

Temperature sensor is a device; to measure the temperature through an electrical signal it requires a thermocouple or RTD (Resistance Temperature Detectors). The thermocouple is

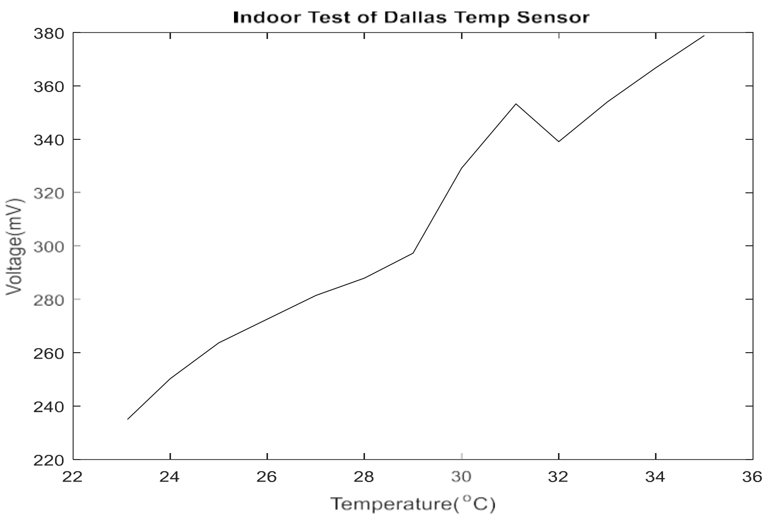

Figure 3 3: Output voltage of temperature sensor versus temperature reading.

prepared by two dissimilar metals which generate the electrical voltage indirectly proportional to change the temperature. The RTD is a variable resistance, it will change the electrical resistance indirectly proportional to changes in the temperature in a precise, and nearly linear manner. The measurement of the temperature sensor is about the hotness or coolness of an object. The working base of the sensors is the voltage that read across the diode. If the voltage increases, then the temperature rises and there is a voltage drop between the transistor terminals of base & emitter, they are recorded by the sensors. If the difference in voltage is amplified, the analogue signal is generated by the device and it is directly proportional to the temperature [13]. Following the information from above, we tested our Dallas sensor and its voltage increased proportionally with the temperature increasing shows in Figure 3.3. Figure 3.4 shows the typical connection diagram with the Arduino.

We measured the output for outdoor condition of Dallas sensor for a particular time of a mid-day-(10thFebruary, 2019) which is depicted in Figure 3.5.

DS18B20 Sensor Specifications are as follows.[14]

- Programmable Digital Temperature Sensor
- Communicates using 1-Wiremethod

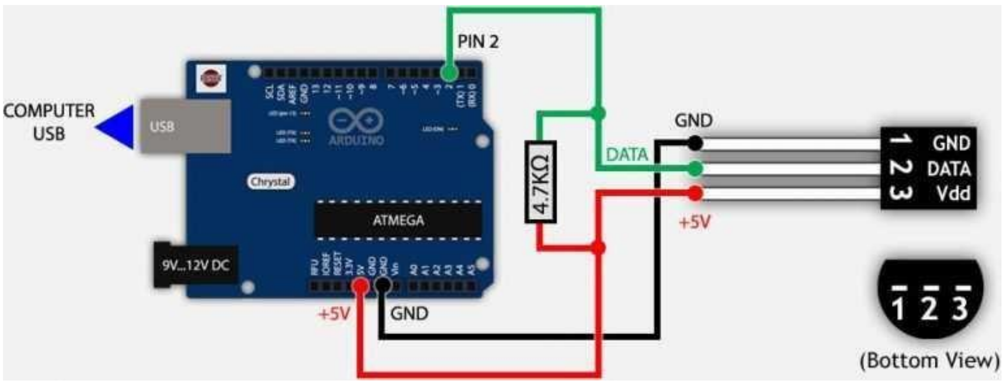

Figure 3 4: Connection Diagram of Dallas Temperature sensor with Arduino.

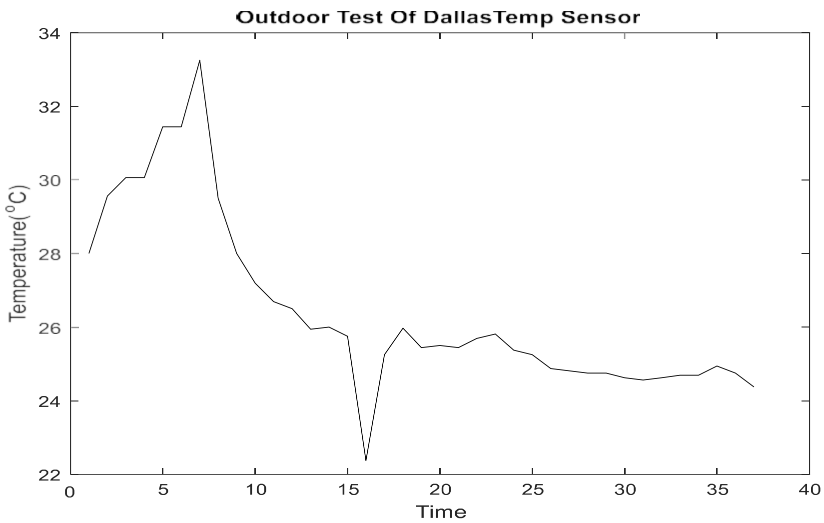

Figure 3 5: Outdoor test of dallas temperature sensor

- Operating voltage: 3V to5V
- Temperature Range: -55°C to+125°C
- Accuracy:±0.5°C
- Output Resolution: 9-bit to 12-bit(programmable)
- Unique 64-bit address enables multiplexing
- Conversion time: 750ms at12-bit
- Programmable alarm options
- Available as To-92, SOP and even as a water proof sensor

Humidity sensor DHT11

Humidity is one of the most commonly measured physical quantities and is of great importance in a wide variety of commercial and industrial applications. Humidity is defined as a measure of the water vapour present in a gas. Two common parameters in associated with humidity measurement are absolute humidity and relative humidity.

Table: 3.1. Technical specifications of DHT 11

Item	Measurement Range	Humidity Accuracy	Temperature Accuracy	Resolution	Package
DHT11	20-90%RH 0-50 °C	±5%RH	±2°C	1	4 Pin Single Row

For measuring humidity they use the humidity sensing component which has two electrodes with moisture holding substrate between them. Figure 3.6 shows the electrodes. So, as the humidity changes, the conductivity of the substrate changes or the resistance between these electrodes changes. This change in resistance is measured and processed by the IC which makes it ready to be read by a microcontroller. Figure 3.7 shows the typical connection diagram with Arduino. Table 3.1 shows the technical specifications of the sensor used in this study. The humidity sensor is tested which shows inverse relationship with the temperature

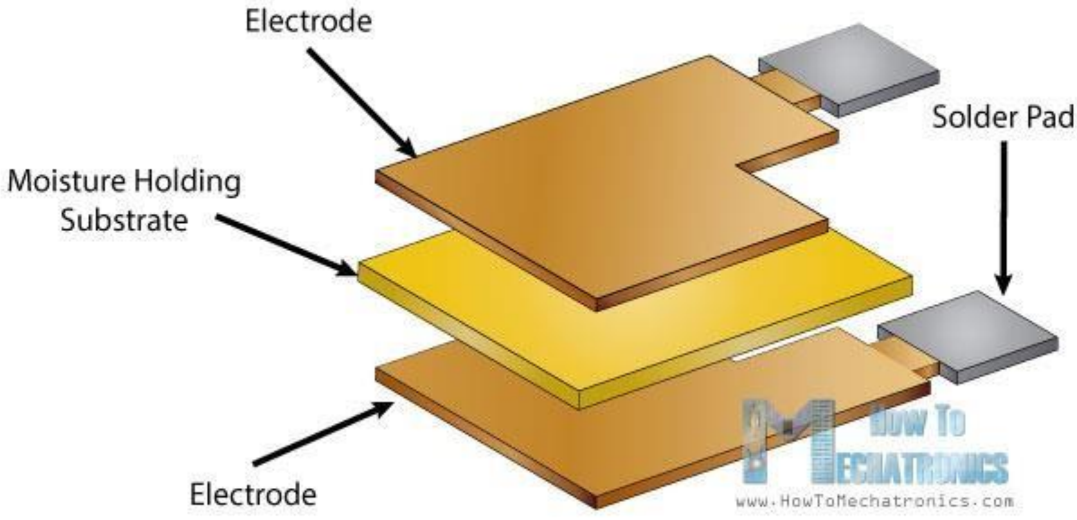

Figure 3 6: Electrodes of Humidity sensor

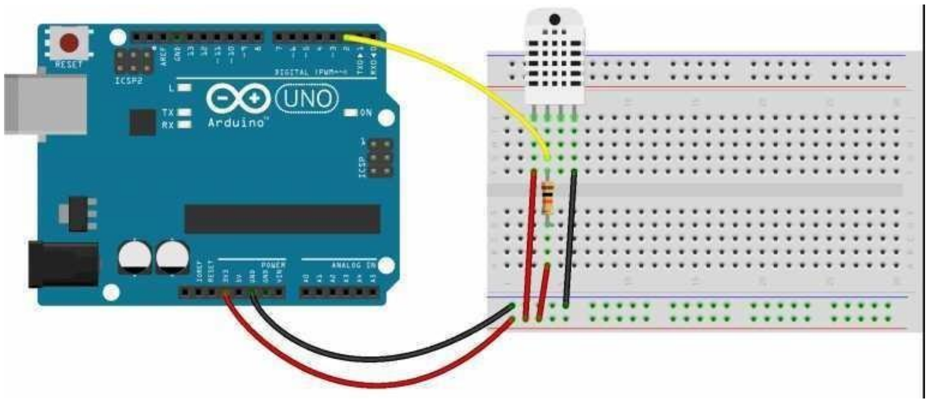

Figure 3 7: Connection Diagram of DHT 11 sensor with Arduino

Reading shows in Figure 3.8. It shows almost 2% change in relative humidity percentage per degree Celsius temperature. Figure 3.9 shows the typical outdoor values of relative humidity tested on 10 February, 2019.

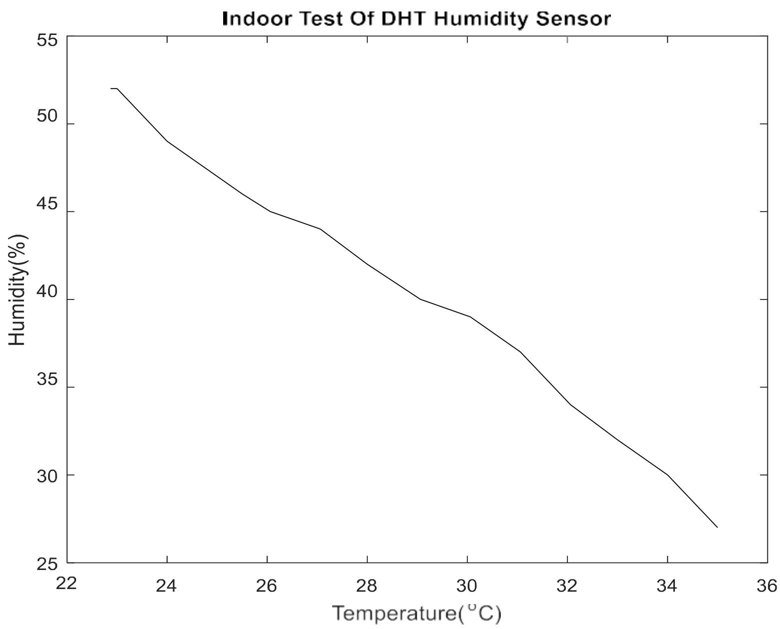

Figure 3 8 : Relative humidity versus temperature reading.

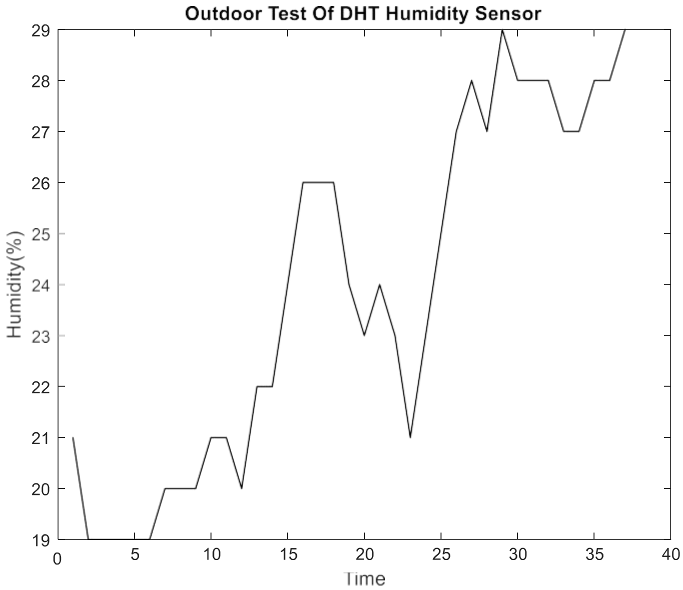

Figure 3 9: Outdoor test of Humidity sensor

Anemometer

An anemometer is a device used for measuring wind speed, and is also a common weather station instrument. The term is derived from the Greek word anemos, which means wind, and is used to describe any wind speed instrument used in meteorology.

Anemometer measures the wind speed from an analogue signal it gets when the cups of the anemometer rotate. When cups rotate the rod spins and measuring the rod's spinning value motor gives an analogue value by which voltage is measured by using a formula and based on a datasheet following the voltage values anemometer gives the value of wind speed

Formula: V=6*U

Table 3.2 shows the Anemometer datasheet value of wind speed and corresponding voltages .Figure 3.10 shows the testing data which shows the linear relationship and follows the standard data from datasheet. The connection diagram is shown in Figure 3.11.

Table 3.2: Relation between wind speed and output value

Wind Speed	Value	Wind Speed	Value
1	0.17	11	1.83
2	0.33	12	2
3	0.5	13	2.17
4	0.67	14	2.33
5	0.83	15	2.5
6	1	16	2.67
7	1.17	17	2.83
8	1.33	18	3
9	1.5	19	3.17
10	1.67	20	3.33

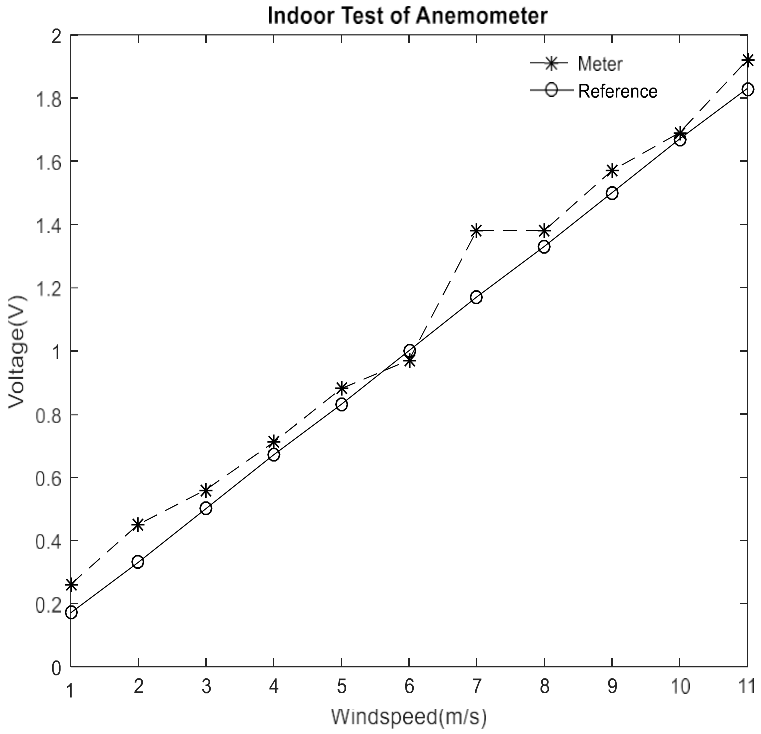

Figure 3 10: Anemometer testing data

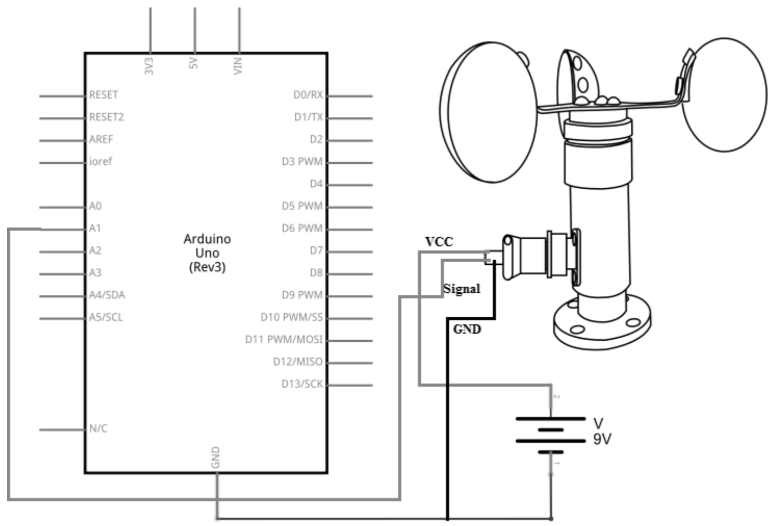

Figure 3 11: Connection diagram of Anemometer

We tested our anemometer sensor for a day for a particular time period outside where we setup our weather station and the result we found is shown below in Figure 3.12.

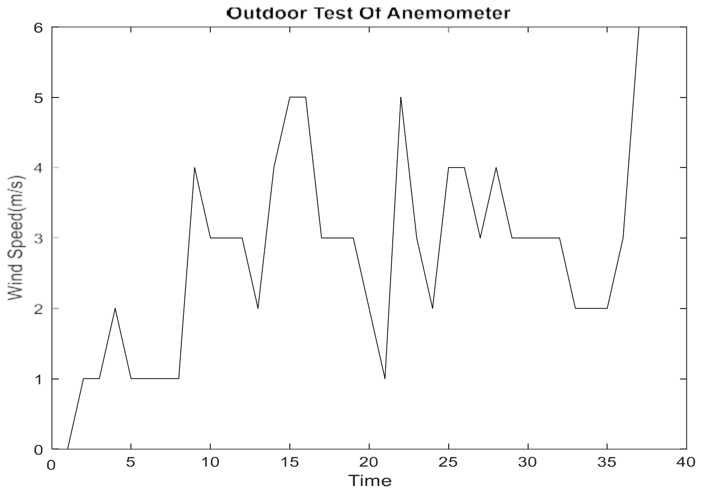

Figure 3 12: Anemometer outdoor testing data

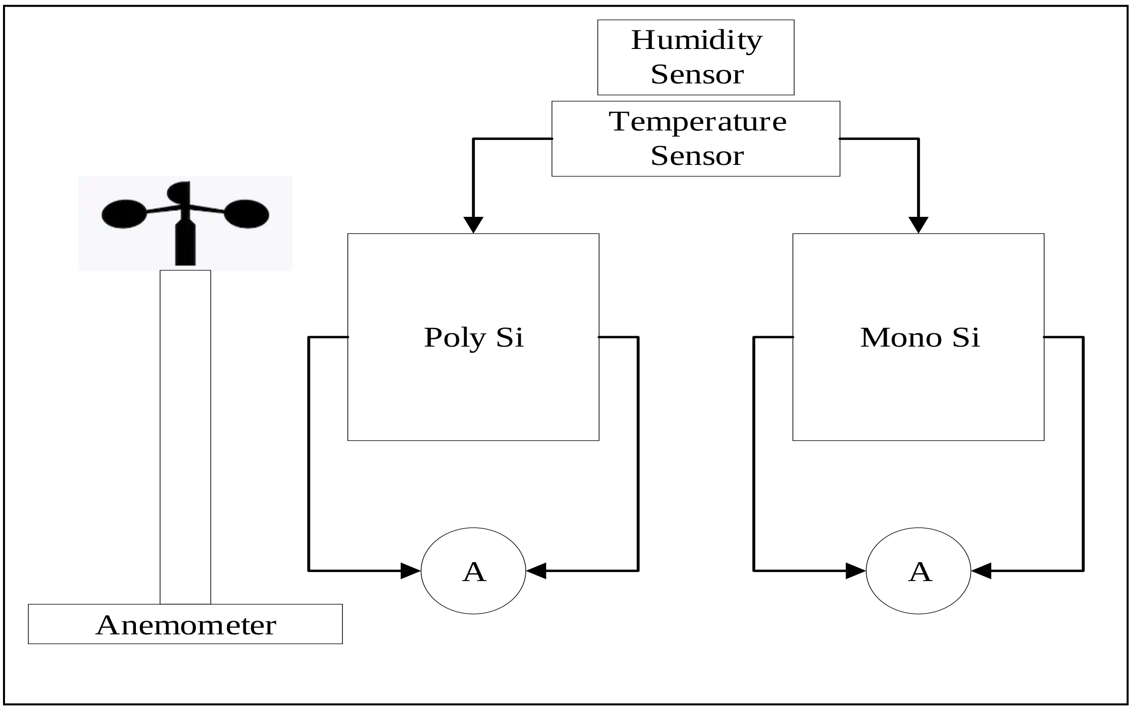

Figure 3.13: Experimental setup diagram of PV module with sensors

Chapter 4

Results Analysis and Discussion

In this chapter all the collected data will be analysed with the help of different plots. We have collected the short circuit current data for a specific period of time. Also, the environmental parameters i.e. ambient temperature, module surface temperature, humidity and wind speed have been collected. Here we have discussed how these parameters affect the short circuit current of the poly and mono Si module in real outdoor condition.

4.1 Data Plots for Sunny Days

We have started to collect data from the month of May, 2019 and continued our data collection upon the end of June, 2019. Here we have presented the sunniest days data to understand the effects of environmental parameters easily. We have discussed the data plots of different days in this subsection.

9th May, 2019

Figure 4.1 shows the outdoor short circuit current data of poly and mono Si modules along with ambient and module surface temperature, humidity and wind speed of 9th May, 2019. The short circuit current plot shows that values varies with respect to time. Data is collected from 12:00 pm to 3:00 pm. At the time of 1:00 pm, $I_{sc}$of two sample PV modules decreases drastically. The I_{sc}values changes 60.34% for poly Si and 51.46% for mono Si module from 12:45 pm to 1:00 pm. The reason behind this fluctuation is cloud effects. Also, after 2:00 pm I_{sc}values gradually decrease with time because the PV modules are in fixed axis setup and the sun falls down to the west; As a result, solar intensity decrease gradually.

Temperature plot of Fig. 4.1 shows that, ambient temperature throughout the day was steady. The surface temperature of PV modules gradually decreases from 12:00 pm and after 1:00

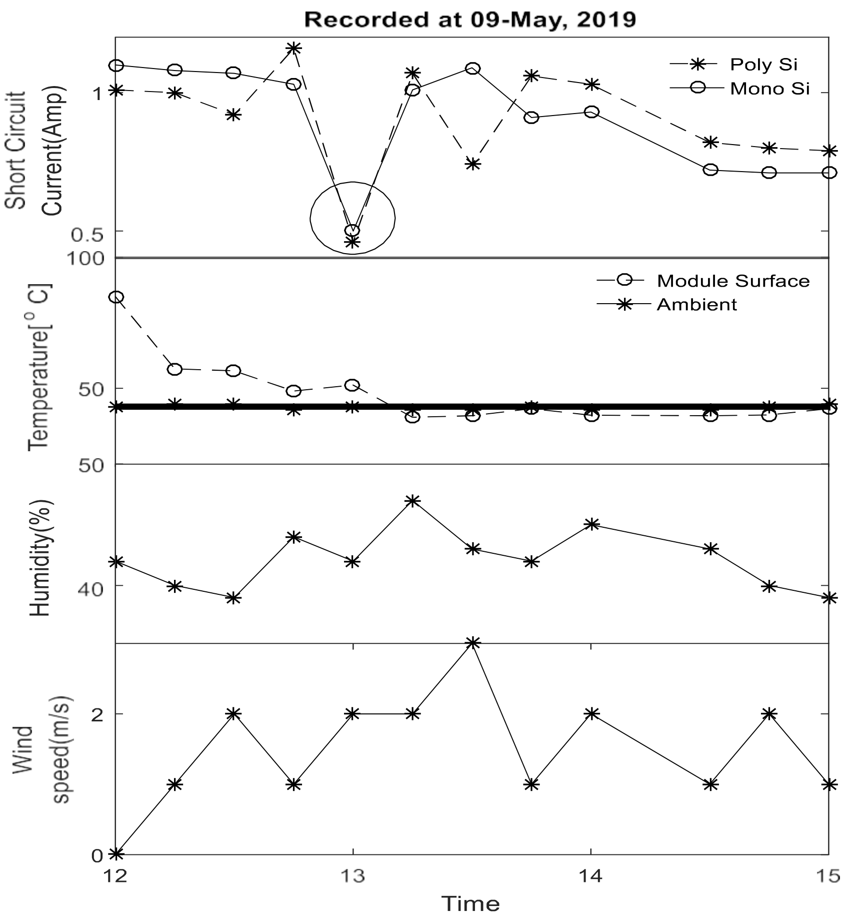

Figure 4 1: Plots of short circuit current (*Isc*) along with the environmental parameters collected on 09May, 2019

pm it shows almost similar values with ambient temperature. From the figure it has been seen that humidity and wind speed also changed with time. Wind speed and humidity shows highest values in between 1:00 pm to 1:30 pm.

On that day, module surface temperature was affected by the wind speed and humidity after 1:00 pm. Poly Si module is affected by the surface temperature from 12:00 pm to 12:45pm. That time the I_{sc} shows lower value than mono Si module. But after 1:45 pm I_{sc} of poly Si module shows increased value than mono Si module for decrement of surface temperature.

At 12:00 pm Poly Si module shows 8.18% lower value of I_{sc} than mono Si. But at 2:00 pm poly Si shows 9.71 % higher value than mono Si module.

14th May, 2019

Figure 4.2 shows the outdoor short circuit current data of poly and mono Si modules along with ambient and module surface temperature, humidity and wind speed of 14th May, 2019. The short circuit current plot shows almost similar values from 10:00 am to 12:00 pm. Data is collected from 10:00 am to 3:00 pm. At the time of 12:15 pm, 1:15 pm, 2:00 pm I_{sc} of two sample PV modules decreases significantly. The I_{sc} values decrease 62.38%, 71.43% and 65.77% for poly Si and 54.24%, 62.60% and 52.94% for mono Si module at 12:15 pm, 1:15 pm and 2:00 pm respectively. The reason behind this fluctuation is shadow of the clouds. It is observed that the day was affected with clouds after 12:00 pm.

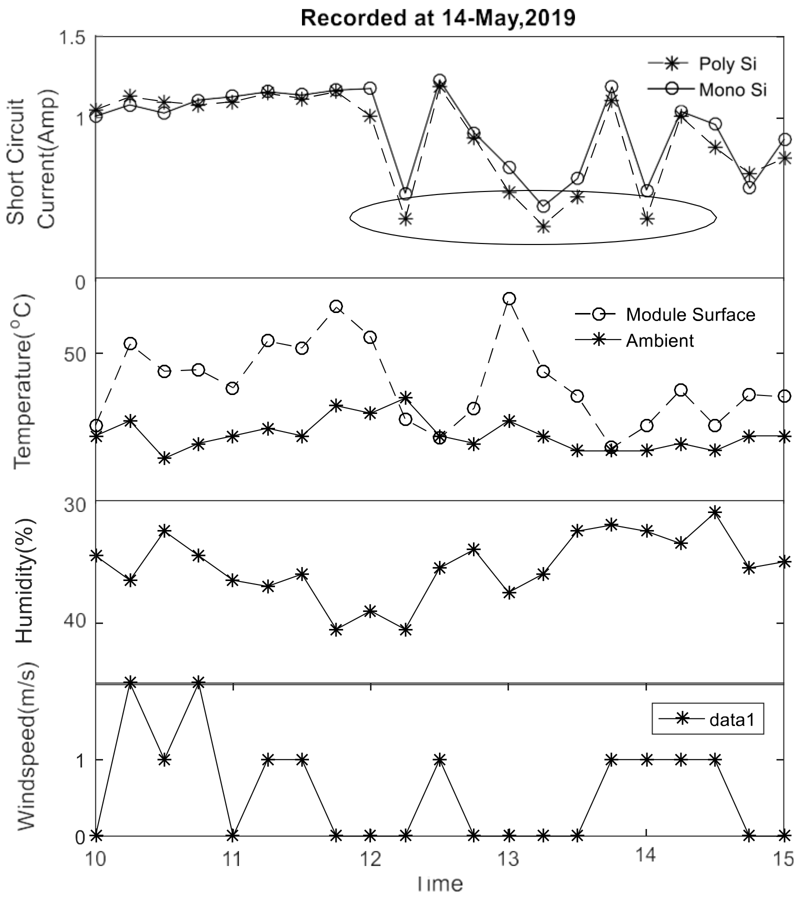

Figure 4 2: Plots of short circuit current (*Isc*) along with the environmental parameters collected on 14May, 2019

Temperature plot of Fig. 4.2 shows that, ambient temperature throughout the day fluctuates in a range of 37 ^{o}C to 43 ^{o}C. The surface temperature of PV modules was high enough from 10:00 am to 12:00 pm. But after 12:00 pm it fluctuates and starts to decrease. From the figure it has been seen that humidity and wind speed also changed with time. Humidity gradually starts to decrease from 10:00 am and shows the lowest humidity at 12:15 pm. After 12:15 pm it starts to increase and shows the highest value at 2:30 pm. On that time surface temperature shows decreasing value.

23rd May, 2019

Figure 4.3 shows the short circuit current of poly and mono silicon module in outdoor condition as well as the output of the ambient and surface temperature of both module, relative humidity and wind speed of 23rdMay, 2019. Data was taken from 10.30 am to 3.00 pm on that day. In the short circuit current graph, we can see that from 10.30 am to around 10.50 am in the morning on that day output of *Isc* of mono silicon module was higher than ploy silicon module. But from 12 pm to 3.00pm of the day the *Isc* of poly silicon module was higher than mono silicon module. Later from 10.45 am to 11.00 am *Isc* falls for both modules, for poly *Isc* falls about 27.18% and for mono *Isc* falls about 36.8%. At around 11.20 am *Isc* again rises. Later from 11.30am to 11.45 am the *Isc* again falls, for poly *Isc* falls about 42.86% and for mono *Isc* falls about 37.80%. Later from 1.45 to 2 pm the *Isc* for poly decreases about 34.86% and the *Isc* for mono decreases about 47.31%. Then from 12.00 pm to 1.45 pm the *Isc* was in a constant position.

The temperature graph from figure 4.3 shows the frequent ups and downs of the ambient and module surface temperature from 10.30 am to 3.00 pm. The graph shows that the module surface temperature was higher than the ambient temperature. At 10.30 am the ambient and module surface temperature both was the lowest. At 10.45 am the module surface temperature rises up to around 45°C from around 34°C. After that up to 11.00 am the

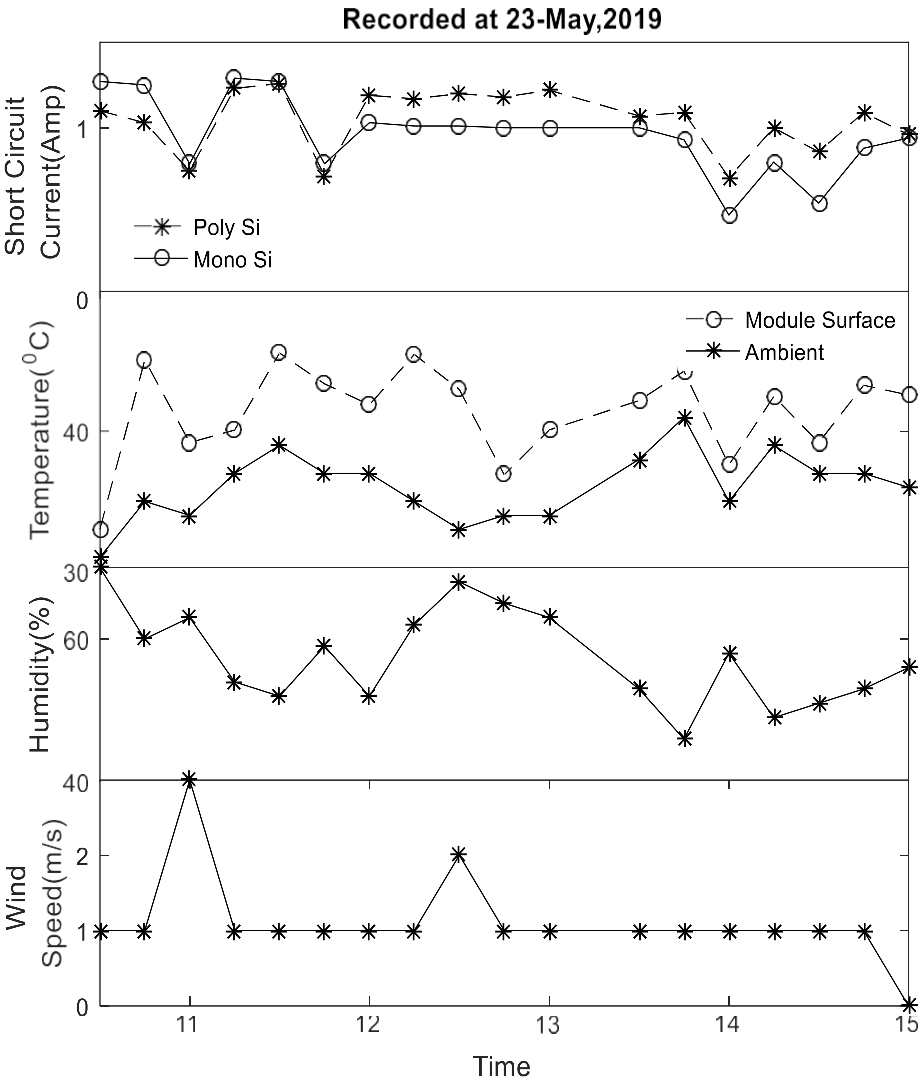

Figure 4 3: Plots of short circuit current (I_{SC}) along with the environmental parameters collected on 23rd May, 2019

temperature decreases. After 11.00 am until 12.15 pm the temperature was in higher mood. At 12.45 pm the module surface temperature falls significantly. Again at 2.00 pm and 2.30 pm we notice fall of the temperature.

The humidity graph shows that, at 10.30 am the humidity was the highest (more than 65%) on that day. After 10.30 am until 12.00 pm humidity keeps falling. At 12.30 pm the humidity increasesup64%. After that it keeps falling again and reaches about 42%.Figure4.3shows that the wind speed was steady most of the time. At 10.30 am the wind speed was the highest. Later at 12.30 pm wind speed rises for once.

18th June,2019

Figure 4.4 shows the output current of mono and poly silicon module along with the ambient temperature, module surface temperature, relative humidity and wind speed of 18th June,2019. Data is taken from 10.30 am to 2.00 pm. The short circuit graph shows that for the whole time of collecting data the *Isc* of poly silicon module is higher than mono silicon module. From 10.30 am to 10.45 am the *Isc* for both poly and mono silicon module increases. Then up to 11.30 am the *Isc* was quite constant. At 11.30 am to 11.45 am the *Isc* for both poly and mono decreases. For poly *Isc* decreases 54.62% and for mono *Isc* decreases 51.28%. But then after 11.45 am *Isc* again rises. Later from 1.10 pm to 1.30 pm the *Isc* for poly decreases about 36.45% and *Isc* for mono decreases about51.55%.

The temperature graph in figure 4.4 shows that whole time both ambient and module surface temperature fluctuates a lot. From 10.30 am to 12.15 pm the ambient temperature was higher than the module surface temperature. From 12.15 pm to 1.00 pm the module surface temperature was higher. But then again after 1.00 pm the ambient temperature gets higher. At around 2.00 pm the module temperature gets higher. Alongside the temperature the humidity graph shows that the humidity of the day also fluctuates quite a bit. From 11.00 am to 11.15 am the humidity decreases significantly. That time the ambient temperate was the highest and the humidity was the lowest. Then again at 12.15 pm and 1.15 pm the humidity decreases.

On the other hand, the wind speed was steady most of the time. At 11.00 am we see a rise at wind speed and at 1.00 pm we see a fall in wind speed.

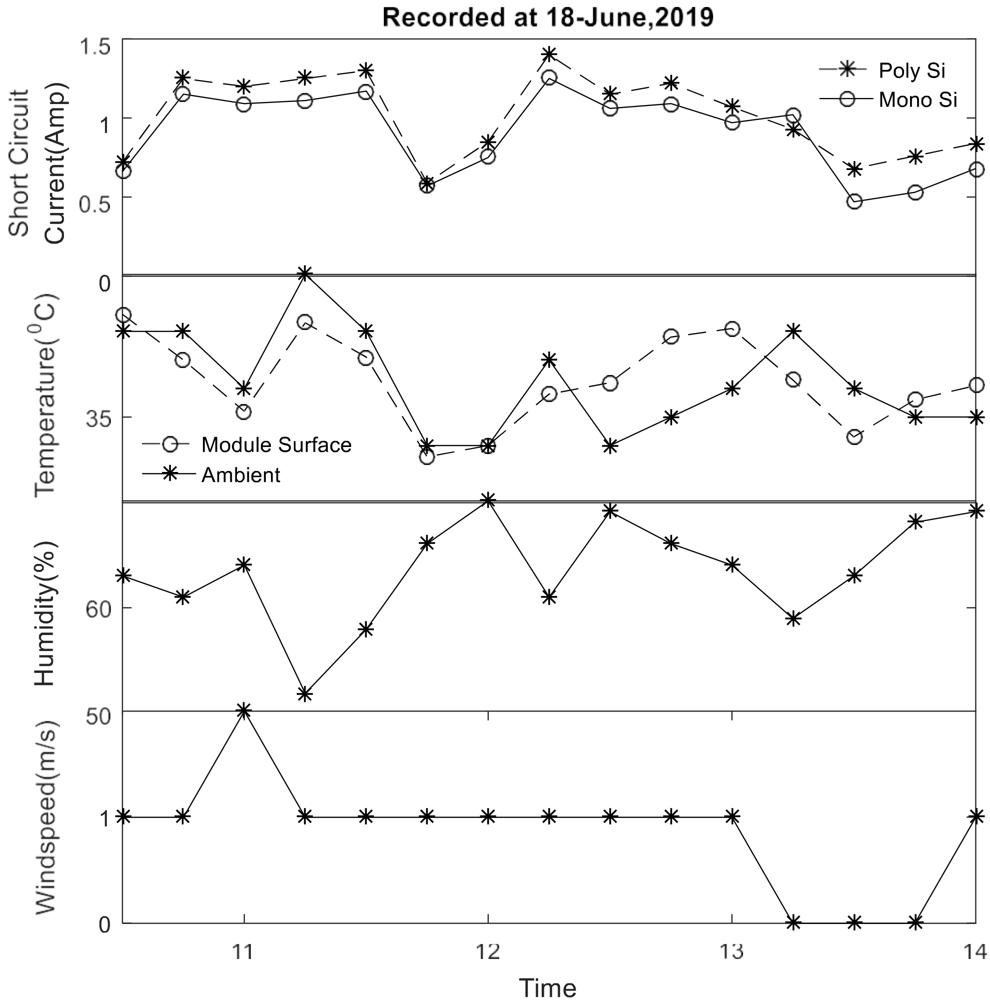

Figure 4 4: Plots of short circuit current (*Isc*) along with the environmental parameters collected on 18thJune, 2019

23rdJune, 2019

Figure 4.5 shows the change in short circuit current of both poly and mono silicon module, the ambient and module surface temperature, the change in humidity and wind speed on 23rdJune, 2019. Data was taken from 11.00 am to 3.00 pm on that day. In short circuit current graph, we see that the *Isc* of poly silicon is higher than the *Isc* of mono silicon module. Most of the time *Isc* for both poly and mono doesn't fluctuate in a noticeable way. But from 11.15 am to 11.30 am *Isc* for poly decreases about 60.84% and *Isc* for mono decreases about 66.92%. then up to 1.30 pm the *Isc* was steady. From 1.45 pm to 2.00 pm *Isc* for poly decreases about 44.38% and *Isc* for mono decreases about 42.12%.

The temperature graph in figure 4.5 shows the output of ambient and module surface temperature from 11.00 to 3.00 pm on 23rd June. In the graph we see that until 12.50 pm the module surface temperate was higher than the ambient temperature. After 12.50pmthe

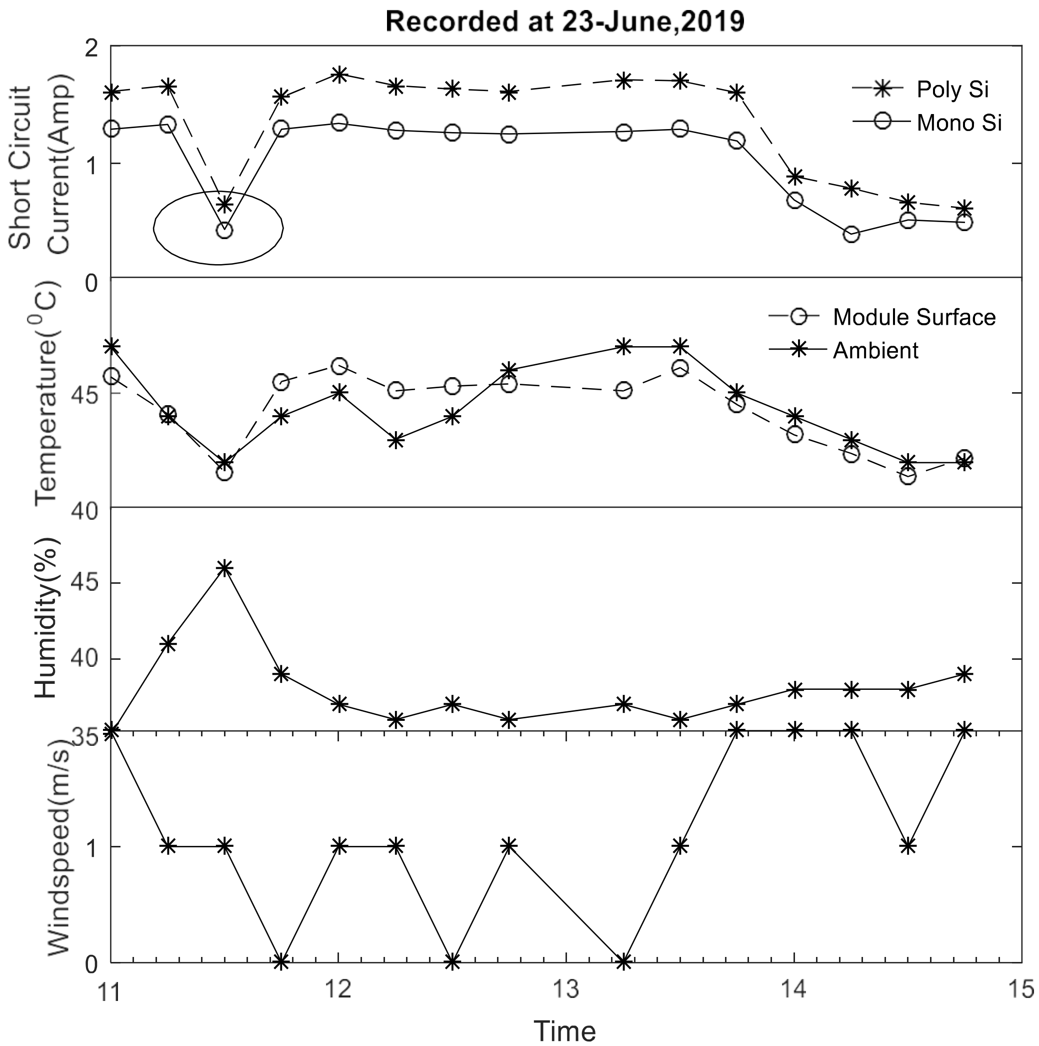

Figure 4 5: Plots of short circuit current (*Isc*) along with the environmental parameters collected on 23rd June, 2019 ambient temperature gets higher and continues up to 3.00 pm. Though the temperature doesn't have a significant change at 11.30 the ambient temperature falls from 48°C to 38°C. The humidity graph shows that at 11.30 am the humidity increases around 42% in noticeable way from rest of the time. Most of the time output of humidity was quite steady. The wind speed fluctuates a lot on that time period on that day. At mid-day the wind speed falls frequently.

26thJune, 2019

Figure 4.6 shows the output current of mono and poly silicon module along with the ambient temperature, module surface temperature, relative humidity and wind speed of 26th June,

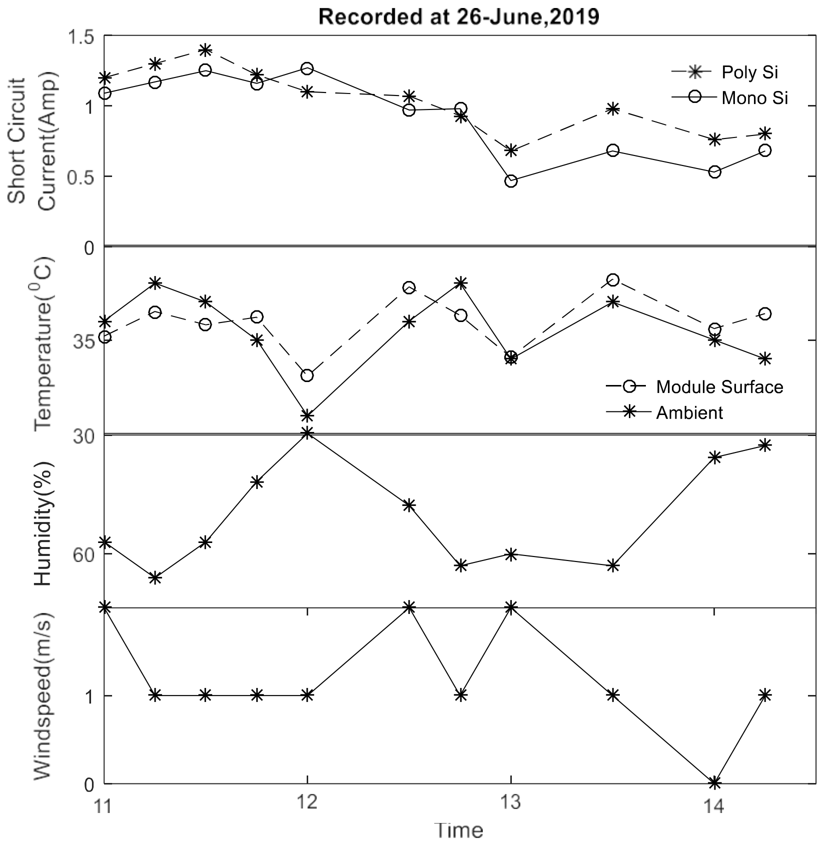

Figure 4 6: Plots of short circuit current (I_{SC}) along with the environmental parameters collected on 26thJune, 2019

2019. Data is taken from 11.00 am to 2.30 pm. In the short circuit current graph, we can see that most of the time output current of poly is higher than mono silicon module. From 12.30 pm to 1.00 pm of the day the *Isc* of poly silicon module decreases about 36.44% but the *Isc* of mono silicon module in that time increases about51.54%.

The temperature graph shows a frequent change in ambient and module surface temperature. At 12.00 p the ambient temperature falls from 38°C to 31°C. Then again at 1.00 pm the ambient temperature decreases. From the graph we see that the ambient temperature fluctuates more than the module surface temperature.

Same way the humidity graph shows the ups and downs of humidity from 11 to 2.30 pm in the figure 4.6. At 12.00 pm the humidity was the highest (around 68%). Then at 12.45 pm it decreases and up to 1.30 pm humidity was lower. Then at 1.30 pm humidity rises. The wind graph shows the wind speed fluctuation. At 11.00 pm, 12.30pm and 1.00 pm the wind speed was higher. At 2.00 pm wind speed decreases significantly.

Short circuit current characteristics with respect to time

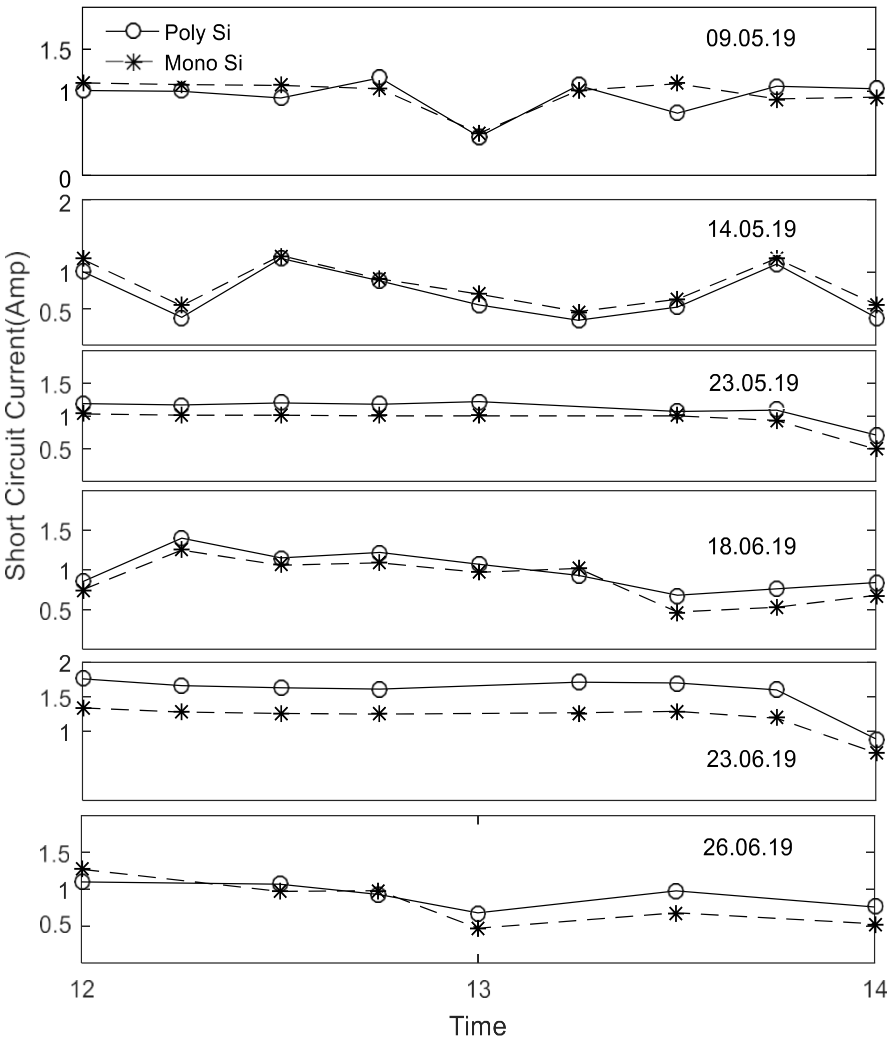

Figure 4 7: Six days Short-Circuit Current from 12:00pm – 2:00pm

The Figure 4.7 represents the short circuit current characteristics with respect to time. These data have been taken from six different days with an estimated peak time value which is from 12pm to 2 pm, as the sun light intensity is high at this time frame.

From this figure we can see that short-circuit current shows steady value for 23rdMay and 23rdJune at 12:00pm to 2:00pm time frame both for mono Si and ploy Si.

We have collected data for month of May and June, at that time the season is summer in Bangladesh which means the sun intensity is high enough. Also, it is important that summer season have cloud effects. It is seen at 23rdJune short circuit current shows the highest value because sun intensity was high and all other weather parameters were friendly with respect to the solar module. So, we consider 12:30pm data (Poly Si 1.63Amp, Mono Si 1.26A) of 23rdJune as our reference value to compare the others data of12:30pm.

Ambient and surface temperature characteristics with respect to time:

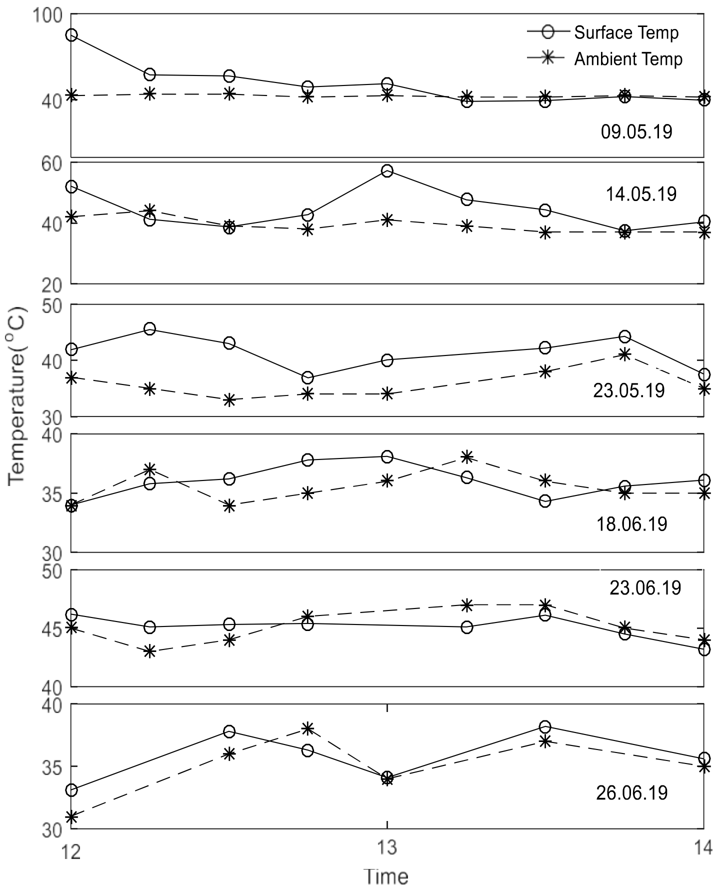

Figure 4 8: Six days temperature from 12:00pm – 2:00pm

Figure 4.8 shows the surface temperature and ambient temperature in one plot. From the figure we can see that the temperature of 23rd June shows the least fluctuation. That's why we consider the temperature data of 23rd June as our reference value to compare the other days data for specific time at 12:30 pm. The objective of taking the time and the day as reference is to show how temperature effects the short circuit current of solar module.

Comparison of weather parameter with respect to Poly Si and Mono Si

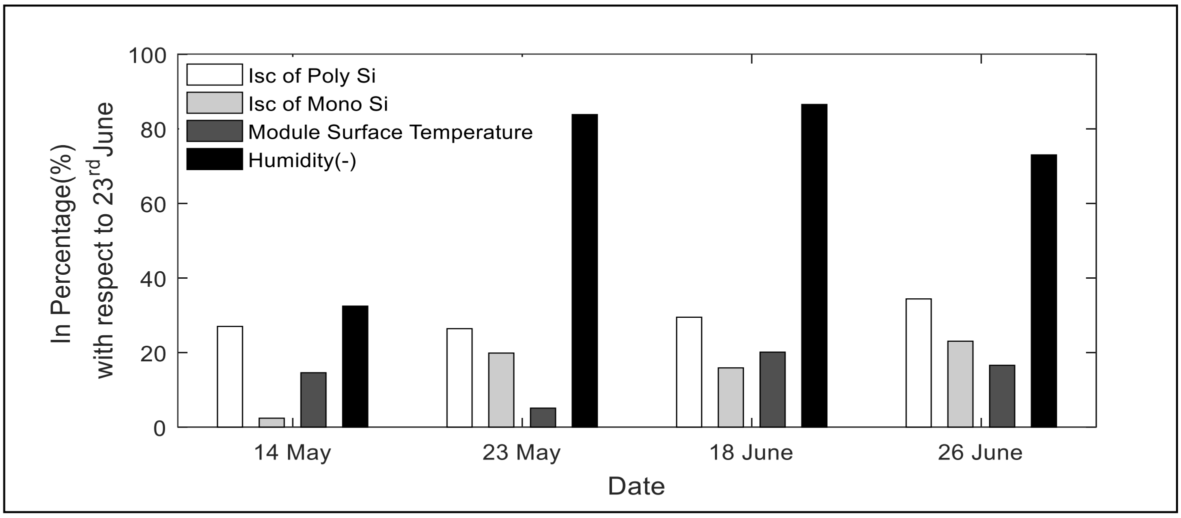

Figure 4 9 : % of short circuit current, module surface temperature and humidity at 12:30pm with respect to the sunniest day of 23rd

Figure 4.9 shows the percentage of short circuit current values lowered than that of the sunniest day (23rd June). Short circuit current shows almost 26% to 34% lower value for poly Si and 2% to 23% lower value for mono Si than the sunniest day (23rd June) from May to June. That means the variation is high for the poly Si module. Figure 4.10 shows the percentage of surface temperature values lowered than that of 23rd June. Surface temperature shows 5% to 20% lower values than the 23rd June. So, it is very clear that the highest value of short circuit current comes for the higher temperature. Such as at 23rd May the temperature variation percentage is only 5% with respect to 23rd June and on that day the short circuit current shows the lowest percentage of change with respect to 23rd June. Mono Si module shows slightly diffracted values which is probably for the wind speed or humidity effects. The effects of temperature were high enough during the data collection days and the humidity and wind speed have a small effect on the short circuit current values of the two modules. Also, the other days shows lower *Isc* values due the lower temperature values for the reference time at 12.30 pm. Other parameter such as humidity shows an inverse relationship with temperature. Figure 4.9 shows that 18th June shows the highest humidity percentage with respect to 23rd June and on that day temperature value shows the lowest value than 23rd June.

Comparison of short circuit current of Mono Si with respect to Poly Si

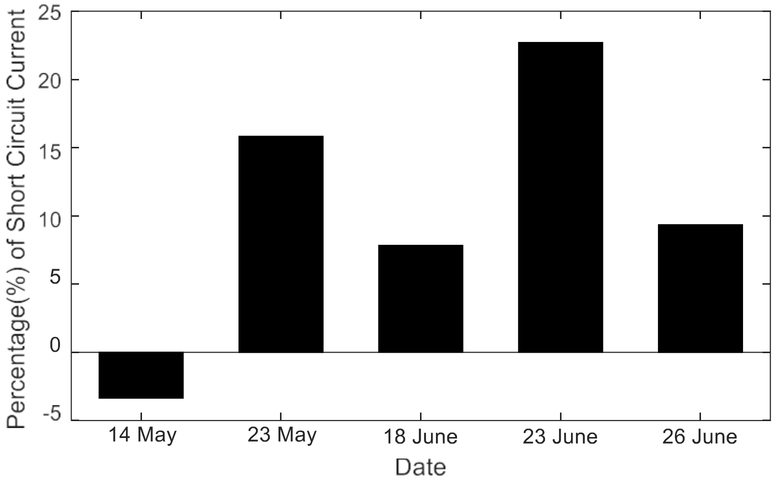

Figure 4 10 :% of Short Circuit Current of mono Si with respect to poly Si at 12:30 PM at different day.

Figure 4.10 shows that poly Si module shows higher percentage values of short circuit current with respect to mono Si module for most of the days. It shows the highest value (around 20% high) for poly Si than the mono Si at 12.30 pm on 23rd June. This indicates that the sample module of poly Si performance is better than the mono Si module in outdoor condition for sunny days. If all the days are full sunny days, the poly module would probably show the better performance throughout the days. But summer in our region affects by heavy clouds' shadow. Also, the weather changes frequently throughout the days. That's why it is very difficult to understand the module performance accurately. This study shows a performance assessment in outdoor condition of the two mono and poly Si module from which we can see the better short circuit current for poly Si module. It somewhat indicates the performance of poly Si module is good enough than the mono Si module.

Chapter 5

Conclusions and Future Works

This study investigates the outdoor performance of two photovoltaic modules. The performance measured based upon the short circuit current. The main outdoor parameters which were considered as follows; temperature, humidity and wind speed. All the data is collected throughout the month May to June, 2019. All the data is studied here are of sunny days data. As the month May and June are from summer, cloud affects is observed. The module temperature as well as humidity and wind speed are observed changing throughout the day. The cloud decreases the short circuit current in a percentage range of 30% to 70% with respect to sunny condition short circuit current for both modules.

Also short circuit current shows low values in percentage for poly Si module with respect to the sunniest day short circuit current of 23rd June Surface temperature shows 5% to 20% lower values than the 23^{rd}June. So, it is very clear that for the higher temperature the highest value of short circuit current is obtained. Humidity shows an inverse relationship with temperature. Results show the dominating parameter is temperature undoubtedly. In this study, poly Si module shows higher percentage values of short circuit current with respect to mono Si module for most of the days. It indicates the performance of poly Si module is good enough than the mono Si module throughout the study.

In this study we have considered temperature, humidity and wind speed as environmental parameter which affects the PV module. In future dust impact can be analysed. Also, we have collected our data during May-June, which are summer months. Seasonal variation can also be studied in outdoor condition.

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Appendix

Table No.01 Recorded at 09 May2019

Time(Hour)	DHT(°C)	Humidity (%)	Dallas(°C)	Wind(m/s)	P1(Amp)	M1(Amp)
12	43	42	85	0	1.01	1.1
12.25	44	40	57.4	1	1	1.08
12.5	**44**	**39**	**56.6**	**2**	**0.92**	**1.07**
12.75	42	44	48.9	1	1.16	1.03
13	43	42	51.2	2	0.46	0.5
13.25	42	47	38.9	2	1.07	1.01
13.5	42	43	39.5	3	0.74	1.09
13.75	43	42	42.2	1	1.06	0.91
14	42	45	39.7	2	1.03	0.93
14.5	42	43	39.5	1	0.82	0.72
14.75	43	40	39.8	2	0.8	0.71
15	44	39	42.2	1	0.79	0.71

Table No.02 Recorded at 14 May2019

Time(Hour)	DHT(°C)	Humidity (%)	Dallas(°C)	Wind(m/s)	P1(Amp))	M1(Amp)
10	39	51	40.4	0	1.05	1.01
10.25	41	47	51.2	2	1.13	1.08
10.5	36	55	47.6	1	1.1	1.03
10.75	38	51	47.8	2	1.08	1.11
11	39	47	45.4	0	1.1	1.13
11.25	40	46	51.6	1	1.15	1.16
11.5	39	48	50.7	1	1.12	1.14
11.75	43	39	56.1	0	1.16	1.17
12	42	42	52.1	0	1.01	1.18
12.25	44	39	41.2	0	0.38	0.54
12.5	**39**	**49**	**38.7**	**1**	**1.19**	**1.23**
12.75	38	52	42.7	0	0.88	0.91
13	41	45	57.2	0	0.55	0.7
13.25	39	48	47.6	0	0.34	0.46
13.5	37	55	44.3	0	0.52	0.63
13.75	37	56	37.4	1	1.11	1.19
14	37	55	40.3	1	0.38	0.56
14.25	38	53	45.1	1	1.01	1.04
14.5	37	58	40.4	1	0.82	0.96
14.75	39	49	44.5	0	0.66	0.57
15	39	50	44.2	0	0.75	0.87

Table No.03 Recorded at 23 May2019

Time(Hour)	**DHT(°C)**	**Humidity (%)**	**Dallas(°C)**	**Wind(m/s)**	**P1(Amp)**	**M1(Amp)**
10.5	31	70	33	1	1.1	1.27
10.75	35	60	45.1	1	1.03	1.25
11	34	63	39.2	3	0.75	0.79
11.25	37	54	40.1	1	1.23	1.29
11.5	39	52	45.6	1	1.26	1.27
11.75	37	59	43.4	1	0.72	0.79
12	37	52	41.9	1	1.19	1.03
12.25	35	62	45.5	1	1.17	1.01
12.5	**33**	**68**	**43**	**2**	**1.2**	**1.01**
12.75	34	65	36.9	1	1.18	1
13	34	63	40.1	1	1.22	1
13.5	38	53	42.2	1	1.07	1
13.75	41	46	44.3	1	1.09	0.93
14	35	58	37.6	1	0.71	0.49
14.25	39	49	42.5	1	1	0.8
14.5	37	51	39.2	1	0.86	0.56
14.75	37	53	43.3	1	1.09	0.88
15	36	56	42.6	0	0.96	0.94

Table No.04 Recorded at 18 June2019

Time(Hour)	**DHT(°C)**	**Humidity (%)**	**Dallas(°C)**	**Wind(m/s)**	**P1(Amp))**	**M1(Amp)**
10.5	38	63	38.6	1	0.72	0.66
10.75	38	61	37	1	1.25	1.15
11	36	64	35.2	2	1.2	1.09
11.25	40	52	38.3	1	1.25	1.11
11.5	38	58	37.1	1	1.3	1.17
11.75	34	66	33.6	1	0.59	0.57
12	34	70	34	1	0.85	0.75
12.25	37	61	35.8	1	1.4	1.25
12.5	**34**	**69**	**36.2**	**1**	**1.15**	**1.06**
12.75	35	66	37.8	1	1.22	1.09
13	36	64	38.1	1	1.07	0.97
13.25	38	59	36.3	0	0.93	1.02
13.5	36	63	34.3	0	0.68	0.47
13.75	35	68	35.6	0	0.76	0.53
14	35	69	36.1	1	0.84	0.68

Table No.05 Recorded at 23 June2019

Time(Hour)	**DHT(°C)**	**Humidity (%)**	**Dallas(°C)**	**Wind(m/s)**	**P1(amp)**	**M1(Amp)**
11	47	35	45.7	2	1.61	1.29
11.25	44	41	44.1	1	1.66	1.33
11.5	42	46	41.6	1	0.65	0.44
11.75	44	39	45.5	0	1.56	1.29
12	45	37	46.2	1	1.76	1.34
12.25	43	36	45.1	1	1.66	1.28
12.5	**44**	**37**	**45.3**	**0**	**1.63**	**1.26**
12.75	46	36	45.4	1	1.61	1.25
13.25	47	37	45.1	0	1.71	1.27
13.5	47	36	46.1	1	1.7	1.29
13.75	45	37	44.5	2	1.6	1.19
14	44	38	43.2	2	0.89	0.69
14.25	43	38	42.4	2	0.79	0.4
14.5	42	38	41.4	1	0.67	0.52
14.75	42	39	42.2	2	0.62	0.5

Table No.06 Recorded at 26 June2019

Time(Hour)	**DHT(°C)**	**Humidity (%)**	**Dallas(°C)**	**Wind(m/s)**	**P1(Amp)**	**M1(Amp)**
11	36	61	35.2	2	1.2	1.09
11.25	38	58	36.5	1	1.3	1.17
11.5	37	61	35.8	1	1.4	1.25
11.75	35	66	36.2	1	1.22	1.16
12	31	70	33.1	1	1.1	1.27
12.5	**36**	**64**	**37.8**	**2**	**1.07**	**0.97**
12.75	38	59	36.3	1	0.93	0.98
13	34	60	34.1	2	0.68	0.47
13.5	37	59	38.2	1	0.98	0.68
14	35	68	35.6	0	0.76	0.53
14.25	34	69	36.39	1	0.8	0.68

Code

```
#include <OneWire.h>

#include <DallasTemperature.h>

OneWireoneWrie(10);
DallasTemperature sensors(&oneWrie);

#include
<dht.h>dht
DHT;
#define DHTpin A1



void setup()
  {
  sensors.begin();
  Serial.begin(57600);
  }

void loop() {
  // put your main code here, to run repeatedly:
sensors.requestTemperatures();
    float currentTemp0;
    currentTemp0 = sensors.getTempCByIndex(0);



    Serial.print("\ndallas Temp = ");
    Serial.print("\t");
    Serial.print(currentTemp0,2);
```

```
DHT.read11(DHTpin);
  Serial.print("\nTemp = ");
  Serial.print(round(DHT.temperature));
  Serial.println(" C");
  Serial.print("Humidity = ");
  Serial.print(round(DHT.humidity));
  Serial.print("%\n");

   int sensorValue = analogRead(A0);
   float outvoltage = sensorValue * (5.0 / 1023.0);
   Serial.print("outvoltage = ");
   Serial.print(outvoltage);
   Serial.println("V");
   int Level = 6*outvoltage;//The level of wind speed is proportional to the output voltage.
   Serial.print("wind speed is ");
   Serial.print(Level);
   Serial.println(" level now");
   Serial.println();
   delay(1000);
}
```