PERFORMANCE ASSESSMENT OF MONOCRYSTALLINE AND POLYCRYSTALLINE SOLAR PANEL TYPES USED IN OWERRI, SOUTH EASTERN NIGERIA

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CERTIFICATION

I certify that this work **"Performance assessment of monocrystalline and polycrystalline solar panel types used in Owerri, South Eastern Nigeria"** was carried out by **Onuoha Elizabeth (20124764838)** in partial fulfilment of the requirements for the award of the Degree of Master of Science in Physics (Solar Energy option) in the Department of Physics, Federal University of Technology, Owerri.

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DEDICATION

This research is dedicated to God, the giver of life.

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ABSTRACT

The performance assessment of monocrystalline and polycrystalline silicon solar panels was conducted in Owerri. The solar panels made in Germany were produced by Flames Company and rated 100W. Both solar panels were subjected to the same weather conditions. The solar panels were placed side by side on the roof top and the outdoor testing was carried out in both the raining and dry season for 28days. Each of the solar panel was connected to 12V, 15A charge controller and to a load of 40Ohms. The open-circuit voltage (V_{OC}), short-circuit current (I_{SC}), load voltage (V_L) and load current I_L were measured using a digital multimeter. The maximum power (P_M) and load power (P_L) were calculated from the V_{OC}, I_{SC}, V_L and I_L. The results indicated that V_{OC} for monocrystalline silicon solar panel was high during the early and late hours of the day while V_{OC} for polycrystalline silicon solar panel increased as the insolation increases for both season. The monocrystalline silicon solar panel produced more current than the polycrystalline silicon solar panel. It was observed that both panels had high performance between 10am and 3pm of the day in the rainy season. The polycrystalline silicon produced the highest maximum power output of 96.80W while the monocrystalline had a maximum power output of 94.24W. The solar panels had a low performance during the dry dusty harmattan season as low sunlight weather condition was observed. (maximum power of 52.06W for the monocrystalline silicon solar panel and 50.95W for the polycrystalline silicon solar panel). Cloudy weather conditions affected the solar panel performance as both the voltage and current dropped whenever it rained. The polycrystalline silicon solar panel also has a fairly constant voltage (between 16.06V to 17.98V) while voltage for the monocrystalline silicon fluctuates (between 15.01V to 17.99V). The study showed that the polycrystalline silicon solar panel is widely used and cheaper even when the users may not have known the advantage of higher power output than the monocrystalline silicon panel.

Keywords: Monocystalline, Polycrystalline, Voltage, Current, Solar panels, power output

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Solar energy is utilized in homes in two ways, one: using it to supply heat to warm up spaces through solar collector, and two, using it to generate electricity through Photovoltaic (PV) cells. Although the use of solar energy for heating water is relatively low cost and wide spread, PV technology is relatively costly and its implementation is mostly limited to scientific processes. In addition to its low cost nature energy produced by solar cells, is environmentally friendly, safe, and has neither gas emissions nor generates noise. (Al-Salaymeh *et. al*, 2009).

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect. The crystalline solar cell can be classified into: monocrystalline, polycrystalline and amorphous. This was based on the discovery by Alexandre-Edmond Becquerel who noticed that some materials release electrons when light rays are incident on them and electrical current is produced. Later, the first solar cell was constructed by Charles Fritts in the 1880s. Although the prototype selenium cells converted less than 1% of incident light into electricity, both Ernst Werner von Siemens and James Clerk Maxwell recognized the importance of this discovery. Following the work of Russell Ohl in the 1940s, researchers, Gerald Pearson, Calvin Fuller and Daryl Chapin created the silicon solar cell in 1954. These early solar cells cost 286 USD/watt and reached efficiencies of 4.5-6%. (Wikipedia encyclopedia, 2009).

The solar energy that is used in solar cell is renewable. Renewable energy system can be a useful instrument to provide reliable power.

Solar thermal, however is already a well-tested technology and has almost universal appeal, but through lack of education or human inertia is still under utilized in many developed and developing countries. Domestic take-up of these panels differ dramatically from country to country, with Germany having reached a level of 50% of domestic homes with solar thermal, against the UK with around 2%. Nigeria is obviously negligible due to slow technological advancement. (Oladokun and Adeshiyan 2012).

Meeting the power need of Nigeria has remained a serious challenge to government and the crisis in the power sector has literally grounded the economy under this situation, solar cell application and usage may provide a highly cost effective option and can provide power for a wider range of uses too. The high cost of solar cells has become a major challenge for users of solar cells as no funding is provided from developmental aid. (Oladokun and Adeshiyan 2012).

The three basic steps in the design of a PV system are;

1) Estimation of load and load profile,

2) Estimation of available solar radiation and

3) The design of solar system based on 1&2.

These steps which entails proposing a design concept that involves a fourth component is shown in Figure 1.1. The fourth component is important in the design as it shows the PV modules, battery bank, etc. that would be used during the design. The inclusion of a designed input into the conventional solar installation helps to achieve a lower energy demand at a lower upfront cost.

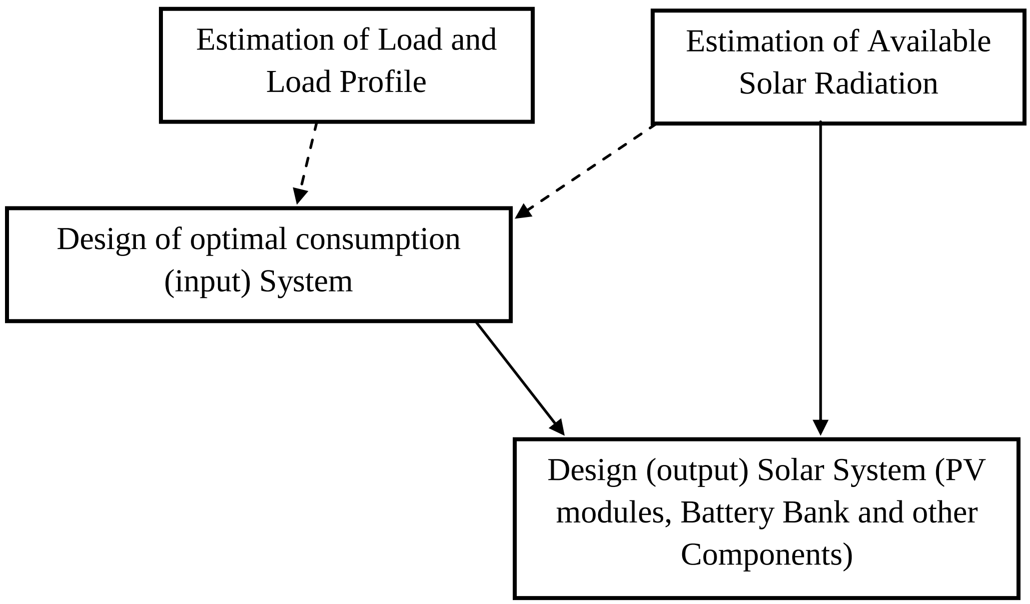


Figure 1.1: Input–Output (Demand Management) based solar power system

Source: (Oladokun and Adeshiyan 2012).

Solar cells convert light into electricity directly. When light shines on the surface of the solar cell, electrons are liberated in the *p*-type region and holes produced in the *n*-type region; this lowers the potential energy barrier at the junction. The separation of the charge carriers creates the potential difference. A current flows and establishes an external potential difference. Solar cells act in a way similar to the diode, so that current can flow in only one direction when the cell is exposed to light.

1.2 STATEMENT OF PROBLEM

It has been observed that some of the solar panels mounted in our homes and streets do not live up to the expected life time. To this effect, there is the need to investigate the types of solar panels mounted on the streets and also determine the suitability of these solar panels in the environment.

1.3 AIMS AND OBJECTIVES OF STUDY

The aim of this study is to investigate the types of solar panels used in our homes and streets with particular emphasis in Owerri. Specifically, the objectives of the study are to;

(a) Carry out an outdoor testing of the available solar panel types in Owerri.

(b) Determine the optimum characteristics of each of the solar panel type.

(c) Determine the solar panel type that is more suitable to be used in Owerri, South Eastern Nigeria.

1.4 Physics of solar cells

Solar cells rely on the photoelectric effect to function. The photoelectric effect can generate electrons with the condition that the electrons do not leave the surface of the material. In most materials, recombination of the electron with the hole is almost immediate. Recombination is a process where excess charge carriers created in a semiconductor by absorption of light is annihilated after the source of light is turned off. Only materials or devices in which it is possible to prevent recombination are suitable for solar cell production or fabrication. Semiconductors have been found very useful in fabricating solar cells. The most used semiconductor is the silicon because of its advanced technology.

To prevent recombination, two different types of doped semiconductor are grown together to make the solar cell. Pure silicon is grown in a furnace in the presence of silicon vapor. The silicon vapor is doped with acceptors or donors (*p*-type or *n*-type semiconductors) to deposit layers of *p*-type or *n*-type material. An acceptor atom is a dopant atom that is added to a semiconductor to form a p-type region and donor atom is a dopant atom that is added to a semiconductor to form an n-type region. A p-type semiconductor is a doped semiconductor that contains mostly free holes and an n-type semiconductor is a doped semiconductor that contains mostly free electrons. The extra electrons move around in the *n*-type material in response to an external potential while in the *p*-type material, the holes move around in response to an external potential (that is, an external electric field that is applied). Such materials therefore conduct electricity.

When two different types of semiconductor are bonded together to form a p-n junction, there are combinations of the electrons in the *n*-type region with the holes in the *p*-type in the region near the boundary. The free charges are removed from the boundary and are set up in a region of internal electric field inside the semiconductor thereby preventing any more charges from moving. When an external electric field is applied, it could either act against the internal field or in the same direction as the internal field at the boundary. A current can flow in response to an external electric field in only the one direction in which the internal electric field is reduced.

1.5 Photovoltaic activity

According to Fig. 1.2 shown below, when the p–n junction is illuminated by solar energy, electron–hole pair is generated by the photons that have energy greater than the band gap. The number of electron–hole pair is proportional to the insolation. This is because of the electric field in the depletion region. The presence of ionized impurity atoms causes the electrons to drift toward the n-side and the holes toward the p-side in the depletion region. The electron–hole pairs generated within a distance of diffusion length from the edge of the depletion region contribute to the photo current because of the diffusion of excess carriers up to the space charge region.

When the p–n junction illuminated by solar energy is open-circuited as shown in Fig.1.2c, voltage is generated due to the charge carrier separation. When the p- and n-side are short-circuited, the current is called short-circuit current *Isc* and equals to the photo generated current I_L if the series resistance is zero. When the p- and the n-side are isolated, electrons move toward n-side and holes toward p-side, resulting in the generation of potential. The voltage developed is called the open-circuit voltage *Voc*.

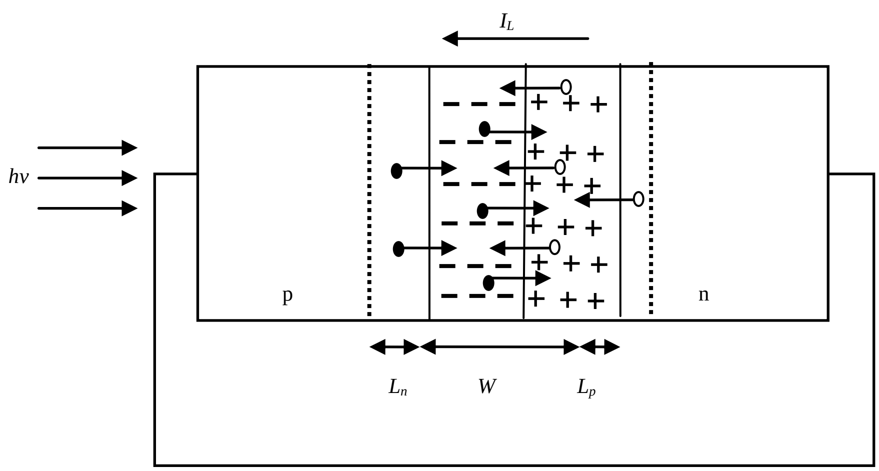
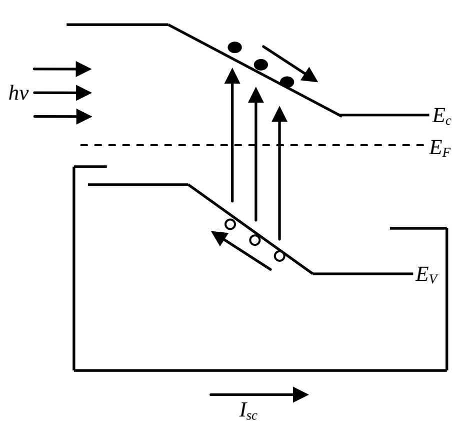


Fig. 1.2(a): Schematic illustration of carrier flow in illuminated p-n junction in the case of short- circuited and Energy band diagrams of illuminated p-n junction



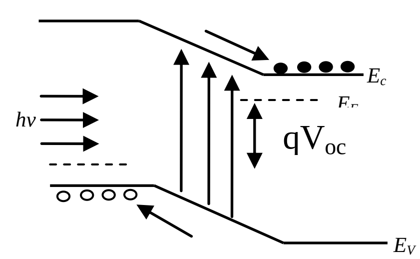


Fig.1.2(b) is the short-circuited mode **Fig1.2(c) is the open-circuited mode**

Source: (Soga, 2006).

1.6 Classification of Solar Cells

Solar cells can be classified into two groups namely; inorganic and organic solar cells. Inorganic solar cells are made up of silicon solar cells and non silicon solar cells such as cadmium telluride, etc. Non silicon solar cells include thin films and concentrated photovoltaics.

1.6.1 Cadmium Telluride

Cadmium telluride (CdTe) is a stable crystalline compound formed from cadmium and tellurium. It is mainly used as the semiconducting material in cadmium telluride photovoltaics and an infrared optical window. It is usually sandwiched with cadmium sulfide to form a p-n junction solar PV cell. In cadmium telluride solar cells, the lower electrode is made from a layer of copper-doped carbon paste while the upper layer is made of tin oxide (SnO_2) or cadium-based stannous oxide (Cd_2SnO_4). Between the upper layer and the semiconductor cadmium telluride, cadmium sulfide (CdS) is placed.

Solar panels based on CdTe are the first and only thin film photovoltaic technology to surpass crystalline silicon PV in cheapness for a significant portion of the PV market, namely in multi-kilowatt systems. The major advantage of this technology is that the panels are manufactured at lower costs than silicon based solar panels. (http://www.solar-facts-and-advice.com)

CdTe panels have several advantages over traditional silicon technology.

The advantages include:

(a). Ease of manufacturing: Cadmium sulfide and cadmium telluride molecules produces the necessary electric field that converts solar energy into electricity. A simple mixture of the molecules produces the required properties and simplifies manufacturing compared to the joining of two different types of doped silicon in a silicon solar panel.

(b). Good match with sunlight: Cadmium telluride absorbs sunlight at close to the ideal wavelength thereby capturing energy at shorter wavelengths than is possible with silicon panels

(c). Cadmium is abundant: Cadmium is abundant, produced as a by-product of other important industrial metals such as zinc. It has no price swings like the silicon

The drawbacks are:

(a). Lower efficiency levels: Cadmium telluride solar panel has a lower efficiency of 21.0% compared to the efficiency of silicon solar cell which is 25.6%. (Green *et al*. 2016).

(b). Tellurium supply: While Cadmium is relatively abundant, Tellurium is not. Tellurium (Te) is an extremely rare element. Most of it comes as a by-product of copper, with smaller byproduct amounts from lead and gold. Therefore the availability of tellurium will eventually limit the number of panels that can be produced with this material.

Since CdTe is now regarded as an important technology in terms of PV's future impact on global energy and environment, the issue of tellurium availability is significant. Recently, researchers have added an unusual twist – astrophysicists identify tellurium as the most abundant element in the universe with an atomic number over 40. (http://www.solar-facts-and-advice.com). This surpasses heavier materials like tin, bismuth, and lead, which are common. Researchers have shown that well-known undersea ridges (which are now being evaluated for their economic recoverability) are rich in tellurium and by themselves could supply more tellurium than we could ever use for all of our global energy. It is not yet known whether this undersea tellurium is recoverable, nor whether there is much more tellurium elsewhere that can be recovered. (http://www.solar-facts-and-advice.com).

(c). Toxicity of Cadmium

Cadmium is one of the top 6 deadliest and toxic materials known. However, CdTe appears to be less toxic than elemental cadmium, at least in terms of acute exposure.

A study has shown that highly reactive surface of cadmium telluride quantum dots triggers extensive reactive oxygen damage to the cell membrane, mitochondria, and cell nucleus. (http://www.solar-facts-and-advice.com). In addition, the cadmium telluride films are typically recrystallized in a toxic compound of cadmium chloride.

The disposal and long term safety of cadmium telluride is a known issue in the large-scale commercialization of cadmium telluride solar panels. Serious efforts have been made to understand and overcome these issues. Researchers from the U.S. Department of Energy's Brookhaven National Laboratory have found that large-scale use of CdTe PV modules does not present any risks to health and the environment, and recycling the modules at the end of their useful life resolves any environmental concerns. During their operation, these modules do not produce any pollutants, and furthermore, by displacing fossil fuels, they offer great environmental benefits. CdTe PV modules appear to be more environmentally friendly than all other current uses of Cd. (http://www.solar-facts-and-advice.com).

1.6.2 Copper Indium Gallium Selenide

Copper indium gallium (di) selenide (CIGS) is a semiconductor material consisting of copper, indium, gallium, and selenium. The material is produced by a solid solution of copper indium selenide (often abbreviated "CIS") and copper gallium selenide. CIGS is a tetrahedrally bonded semiconductor, with the chalcopyrite crystal structure, and a band gap varying continuously with x from about 1.0 eV (for copper indium selenide) to about 1.7 eV (for copper gallium selenide). A chalcopyrite crystal structure is a copper iron sulfide mineral that crystallizes in the tetragonal structure. (Wikipedia encyclopedia, 2015).

So far the promise of CIGS solar cell technology has been greater than the reality, but certain advantages of this technology are beginning to emerge, namely:

(a). The active layer (CIGS) can be deposited in a polycrystalline form directly onto molybdenum coated glass sheets or steel bands. This uses less energy than growing large crystals, which is a necessary step in the manufacture of crystalline silicon solar cells. Also unlike crystalline silicon, these substrates can be flexible.

(b). One environmental advantage of CIGS solar cell technology have over Cadmium Telluride solar cell panel is that it uses a much lower level of cadmium, in the form of cadmium sulfide. Although in some designs, zinc is sometimes used instead of cadmium sulfide all together.

3. Like Cadmium Telluride panels, CIGS solar cell panels show a better resistance to heat than silicon based solar panels.

1.6.3 Copper Zinc Tin Sulfide

Copper Zinc Tin Sulfide (CZTS) is a quaternary semiconducting compound which has received increasing interest since the late 2000s for applications in solar cells. The classes of related materials include copper zinc tin selenide (CZTSe) and the sulfur-selenium alloy CZTSSe. CZTS offers favorable optical and electronic properties similar to CIGS (copper indium gallium selenide) making it well suited for use as a thin-film solar cell absorber layer, but unlike CIGS (or other thin films such as CdTe), CZTS is composed of only abundant and non-toxic elements. Concerns with the price and availability of indium in CIGS and tellurium in CdTe, as well as toxicity of cadmium have been a large motivator to search for alternative thin film solar cell materials. Recent material improvements for CZTS have increased efficiency to 12.0% in laboratory cells, but more work is needed for their commercialization. (Wrinker *et al*. 2013)

1.6.4 Silicon Solar Cells

These are solar cells made from silicon. Silicon is a non toxic material and abundant in the earth crust. Silicon is safe for the environment and one of the most abundant resources on Earth, representing 26% of crustal material. The abundance and safety of silicon as a resource, grants the silicon solar cell a prominent position among all the various kinds of solar cells in the PV industry. An annual PV cell production of 100 GW_p is expected to be achieved by 2020, and the silicon PV cell is the most viable material to meet this demand from the point of view of suitability for large-volume production. (Tatsuo, 2010).

The silicon solar cells are fabricated from monocrystalline, polycrystalline and amorphous.

The PV cell is essentially a diode with a semiconductor structure, and in the early years of solar cell production, many technologies for crystalline silicon cells were proposed on the basis of silicon semiconductor devices. The synergy of technologies and equipment developed for other silicon-based semiconductor devices, such as large-scale integrated circuits and the many different kinds of silicon semiconductor applications, with those developed for PV cells supported progress in both fields. Process technologies such as photolithography helped to increase energy conversion efficiency in solar cells, and mass-production technologies such as wire-saw slicing of silicon ingots developed for the PV industry were also readily applicable. However, the value of a PV cell per unit area is much lower than that for other silicon-based semiconductor devices. Production technologies such as silver-paste screen printing and firing for contact formation are therefore needed to lower the cost and increase the volume of production for crystalline silicon solar cells. To achieve parity with existing mains grid electricity prices, known as 'grid parity', lower material and process costs are as important as higher solar cell efficiencies. The realization of high-efficiency solar cells with low process cost is currently the most important technical issue for solar cell manufacturers. Cutting the cost of producing expensive high-purity crystalline silicon substrates is one aspect of reducing the cost of silicon solar cell modules. This review covers the historical and recent technological advances in crystalline silicon solar cells from the perspective of industrial application (Tatsuo, 2010).

Silicon solar cells are classified into three groups namely:

a. Monocrystalline solar cells

b. Polycrystalline solar cells

c. Amorphous solar cells

1.6.4.1 Monocrystalline Solar Cells

Monocrystalline photovoltaic electric solar energy panels have been the go-to choice for many years. They are among the oldest, most efficient and most dependable ways to produce electricity from the sun.

Each module is made from a single silicon crystal, and is more efficient, though more expensive, than the newer and cheaper polycrystalline and thin-film PV panel technologies. You can typically recognize them by their color which is typically black or iridescent blue.

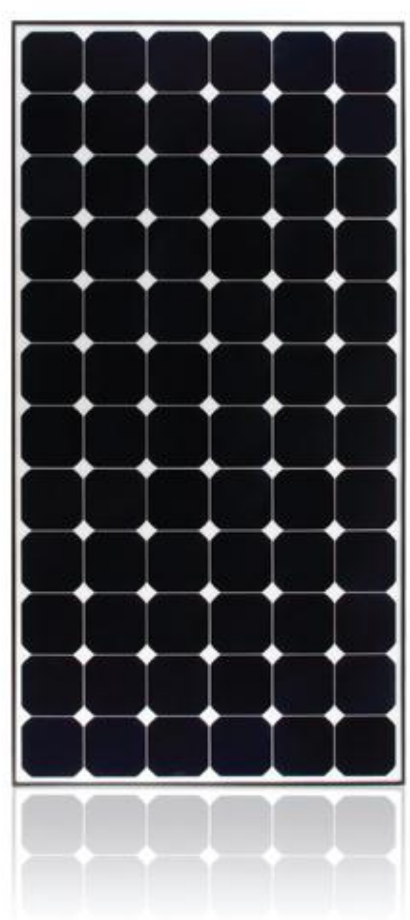


Fig 1.3: Schematic diagram showing monocrystalline solar panel.

Source: (http://www.solar-facts-and-advice.com).

In single crystal silicon, the molecular structure—which is the arrangement of atoms in the material—is uniform because the entire structure is grown from the same crystal. This uniformity is ideal for transferring electrons efficiently through the material. To make an effective PV cell, however, silicon has to be "doped" with other elements to make n-type and p-type layers.

To create silicon in a single-crystal state, high purity silicon must first be melted. It is then reformed or solidified slowly while in contact with a single crystal "seed." The silicon adapts to the pattern of the single crystal seed as it cools and gradually solidifies. Since it starts from a seed, the process is called "growing" a new rod (often referred to as a boule) of single-crystal silicon out of molten silicon.

Several processes can grow a boule of single-crystal silicon. The most established and dependable are the Czochralski (Cz) method and the float-zone (FZ) technique.

1.6.4.1.1 Advantages of Monocrystalline Silicon Solar Cells

The advantages of monocrystalline silicon cells are listed below:

(a). Longevity

Monocrystalline solar panels being the first generation solar technology, has provided evidence of their durability and longevity. The technology, installation and performance issues are all understood. Single crystal panels can withstand the rigors of space travel and can last up to 25 years.

Although this type of solar panel can last a long time, a time will come when newer panels might replace the monocrystalline panels especially if the efficiency of newer panels continues to increase (b). Efficiency

PV panels made from monocrystalline solar cells has an efficiency of 22 to 22.5%. Consequently, Monocrystalline panels are a great choice for urban settings or where space is limited.

(c). Other Environmental Concerns

. Monocrystalline solar panels are not hazardous to the environment. Some thin film solar products uses cadmium telluride (CdTe). Cadmium is a heavy metal that accumulates in plant and animal tissues. Cadmium is a 'probable carcinogen' in humans and animals. While cadmium telluride doesn't pose a threat while the panel is in service, disposal of this toxic waste when the product reaches the end of its life could be harmful to the environment if it is not properly handled

(d). Greater Heat Resistance

Like other types of solar panels, monocrystalline solar panel suffer a reduction in output once the temperature from the sunlight reaches around fifty degrees Celsius/a hundred and fifteen degrees Fahrenheit.

(e). More Electricity

Monocrystalline solar panels produce more electricity. Monocrystalline panels reduce the amount of electricity needed from local power plants, reducing the dependence on fossil fuels. The greater benefit is a reduction in the use of limited fuel sources and greenhouse gases being pumped into the environment.

1.6.4.1.2 Disadvantages of Monocrystalline Solar Panels

1. Initial Cost

The process of making PV panels from single-cell silicon crystals is one of the most complex and there are costly ones around. Also, the cost of making a single pure crystal is time-consuming and therefore costly, PV panels from monocrystalline solar cells generally cost more per panel than competing PV technologies. Based on the analysis, monocrystalline solar panels are typically the most economical over the life of the installation (http://www.solar-facts-and-advice.com)

1.6.4.2 Polycrystalline Solar Cells

Polycrystalline silicon solar cells are solar cells made from multiple crystals of silicon. Polycrystalline cells are currently the most widely produced cells, making up about 48% of world solar cell production in 2008. Standard polycrystalline industrial cells offer efficiencies of 15–17%, roughly 1% lower than for monocrystalline cells fabricated on the same production lines. The efficiencies of polycrystalline cell modules, however, are almost the same as those for monocrystalline cells (14%) due to the higher packing factor of the square polycrystalline cells.

They are the middle choice in the marketplace, almost as good as single cell monocrystalline silicon panels but generally with a better efficiency than thin film solar panels.

Polycrystalline cells can be recognized by a visible grain, a “metal flake effect”. The solar cells are generally square in shape, and may have a surface that looks somewhat like a mosaic. That’s because of all the different crystals that make up the module.

Fig 1.4: Schematic diagram showing polycrystalline solar panel.

Source: (http://www.solar-facts-and-advice.com).

Techniques for the production of polycrystalline silicon are simpler, and therefore cheaper, than those required for single crystal material. However, the material quality of polycrystalline material is lower than that of single crystalline material due to the presence of grain boundaries. Grain boundaries introduce high localized regions of recombination due to the introduction of extra defect energy levels into the band gap, thus reducing the overall minority carrier lifetime from the material. In addition, grain boundaries reduce solar cell performance by blocking carrier flows and providing shunting paths for current flow across the p-n junction.

Polycrystalline silicon can be produced in variety of ways. The most popular commercial methods involve a process in which molten silicon is directly cast into a mold and allowed to solidify into an ingot. The starting material can be refined lower-grade silicon while a highergrade semiconductor is required for single-crystal material. The cooling rate is one factor that determines the final size of crystals in the ingot and the distribution of impurities. The mold is usually square, which produces an ingot that can be cut and sliced into square cells that fit more compactly into a PV module. (Round cells have spaces between them in modules, but square cells fit together better with a minimum of wasted space).

1.6.4.2.1 Advantages of Polycrystaline Solar Cells

The advantages of polycrystalline solar cells are listed below:

(a). Lower Per Panel Costs

They are much simpler to produce, and cost far less to manufacture. This makes them much less expensive for buyers, especially those with small to medium sized roofs.

(b). Durability and Longevity

Polycrystalline solar panels are durable and can provide solar power for consumers that cannot afford the monocrystalline.

(c). Environmental Enhancements

The polycrystalline solar panel produce energy from the sun and thus help to reduce greenhouse gases and related environmental problems of extracting fossil fuels .

(d). Lower Electric Bills

Polycrystalline solar panel lowers electric bills since it produces electricity.

1.6.4.2.2 Disadvantages of Polycrystalline Solar Cells

(a). Lower Efficiency

Polycrystalline solar modules are less efficient than those made from a single crystal.

(b). Fragile

Polycrystalline solar panels are somewhat fragile, and can be broken if hit by a falling branch of a tree.

(c). Competitive

There is strong price competition between polycrystalline manufacturers, and this can be both a good thing (in that it tends to keep prices low) or a bad thing (some manufacturers may not be able to withstand the competition and won't be around to honor their product or performance warranties) (http://www.solar-facts-and-advice.com)

1.6.4.3 Differences between Monocrystalline and Polycrystalline Solar Cells

Monocrystalline cells are black and even in colour while polycrystalline cells are blue-ish in colour and have a characteristic metal hard pattern on the surface.

Monocrystalline cells are square with missing corners while polycrystalline cells are square shaped.

Polycrystalline cells are of lower efficiency than monocrystalline cells.

Polycrystalline solar cells are more sensitive to heat, losing efficiency more quickly as temperature rise and so produce slightly less energy each year.

Monocrystalline cells are made from single crystals grown in the shape of a round pillar while polycrystalline silicon wafer is made by pouring molten silicon into a cube shaped mould and letting it cool and solidify. The solidified block of silicon is sliced into pillars and they are in turn sliced into perfectly square cells.

1.6.4.4 Amorphous Solar Cells

Amorphous silicon is the non-crystalline form of silicon. It is the most well developed of the thin film technologies having been on the market for more than 15 years. The word “amorphous” literally means shapeless. The silicon material is not structured or crystalized on a molecular level, as many other types of silicon-based solar cells are. It is widely used in pocket calculators, but it also powers some private homes, buildings, and remote facilities.

Amorphous silicon panels are formed by vapor-depositing a thin layer of silicon material – about 1 micrometer thick – on a substrate material such as glass or metal. Amorphous silicon can also be deposited at very low temperatures, as low as 75 degrees Celsius, which allows for deposition on plastic as well.

In its simplest form, the cell structure has a single sequence of p-i-n layers. However, single layer cells suffer from significant degradation in their power output (in the range 15-35%) when exposed to the sun. The mechanism of degradation is called the Staebler-Wronski Effect, after its discoverers.

Better stability requires the use of a thinner layer in order to increase the electric field strength across the material. However, this reduces light absorption, hence cell efficiency. This has led the industry to develop tandem and even triple layer devices that contain p-i-n cells stacked one on top of the other.

One of the pioneers of developing solar cells using amorphous silicon is Uni-Solar. They use a triple layer system (see illustration in fig. 1.5) that is optimized to capture light from the full solar spectrum).

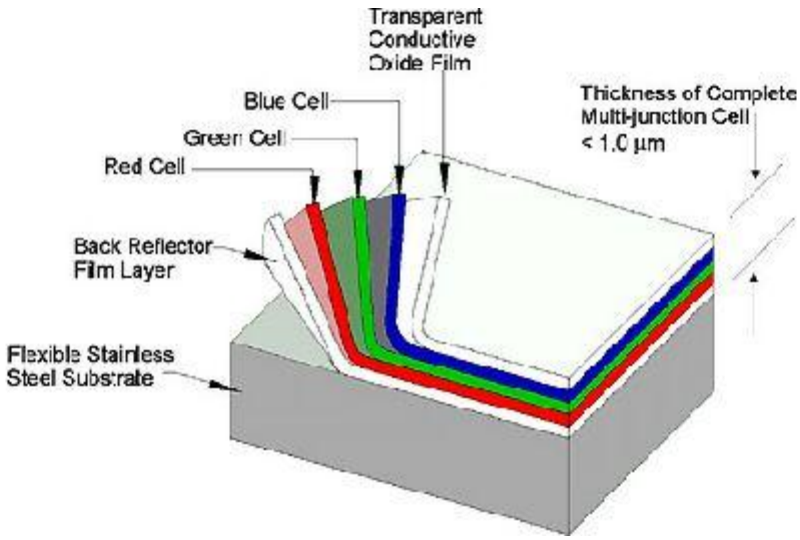


Fig 1.5: Schematic diagram showing amorphous solar cells.

Source: (http://www.solar-facts-and-advice.com)

As you can see from the illustration, the thickness of the solar cell is just 1 micron, or about 1/300th the size of mono-crystalline silicon solar cell.

While crystalline silicon achieves a yield of about 18 percent, amorphous solar cells' yield remains at around 7 percent. The low efficiency rate is partly due to the Staebler-Wronski effect, which manifests itself in the first hours when the panels are exposed to sunlight, and results in a decrease in the energy yield of an amorphous silicon panel from 10 percent to around 7 percent.

1.6.4.4.1 Advantages of Amorphous Silicon

The principal advantage of amorphous silicon solar cells is their lower manufacturing costs, which makes these cells very cost competitive.

One of the main advantages of a-Si over crystalline silicon is that it is much more uniform over large areas. Since amorphous silicon is full of defects naturally, any other defects, such as impurities, do not affect the overall characteristics of the material too drastically.

Amorphous silicon can be produced in a variety of shapes and sizes (e.g., round, square, hexagonal, or any other complex shape. This makes it an ideal technology to use in a variety of applications such as powering electronic calculators, solar wristwatches, garden lights, and to power car accessories. Small solar cells used in pocket calculators have been made with a-Si for many years.

Unlike crystalline solar cells in which cells are cut apart and the recombined, amorphous silicon cells can be connected in series at the same time the cells are formed, making it easy to create panels in a variety of voltages (e.g, for use in solar battery rechargers). Amorphous silicon solar cells are sensitive to light and can also be used as light sensors (e.g., outdoor sensor lights, etc).

Some amorphous solar panels also come with shade-resistant technology or multiple circuits within the cells, so that if an entire row of cells is subject to complete shading, the circuit won't be completely broken and some output can still be gained. This is especially useful when installing solar panels on a boat.

The development process of a-Si solar panels also renders them much less susceptible to breakage during transport or installation. This can help reduce the risk of damaging one’s significant investment in a photovoltaic system.

Another principal advantage of this type of technology is greater resistance to heat. According to a four year NREL study – it was observed that amorphous silicon PV modules experience higher results as temperatures increase (http://www.solar-facts-and-advice.com).

The drawback of amorphous silicon solar cell is basically lower efficiency and shorter lifetime.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter shall discuss some studies carried out by different investigators on silicon solar panels where the effects of temperature, irradiance, humidity, angle of inclination or tilt angle and dust scattering affected the performance of solar panels.

2.2 Effect of temperature on the performance of silicon solar panels

Temperature has a role to play in the performance of silicon solar cells. Researchers have discovered that there is a direct relationship between the ambient temperature and power output of solar panels. According to Sanusi *et al*. (2011), they carried out a research to determine the effect of ambient temperature on performance of amorphous silicon at Ogbomoso, Nigeria. The research was carried out by monitoring the variation in power output of the system with ambient temperature of the area for three years. They concluded that the application of photovoltaic technology in the conversion of solar energy to electricity is favorable during high ambient temperature period than low temperature period.

Also Mustapha *et al.* (2013) carried out a research on performance evaluation of polycrystalline solar photovoltaic module in weather conditions of Maiduguri, Nigeria. According to the researchers, many solar PV modules exhibit significant loss in their expected performance due to variations in weather conditions such as ambient temperature and solar irradiance which results in inaccurate prediction of the module performance in the field. Obviously, the Standard Test Conditions (STC) and the Nominal Operating Cell Temperatures (NOCT) do not represent real operating conditions of PV module at the site of installation. The performance of a solar PV module is strongly dependent on some environmental conditions such as solar irradiance and temperature. Mustapha *et al*. (2013) used KD 315 PV module which provides 315W maximum power at STC and contain 80 polycrystalline Si solar cells connected in series. The model of the PV module was implemented using a MATLAB program and the model parameters were evaluated using daily data of temperature and solar irradiance obtained from Maiduguri for a period of one year. From their research work, they observed that power generated varied with seasons. For example more power was generated in the dry season (February to May) than in the rainy season (June to September) for the year 2010. The sunniest month in the year which was April had an average insolation of 0.8 kW/m^2, which was about 37.5% more than the least sunny month in the year that is August, which received an average insolation of 0.5 kW/m^2.

In conclusion, they discovered from their simulation results that there is a direct relationship between solar irradiation, temperature, output current and output power of the photovoltaic module.

Similarly, the effect of temperature on the I-V characteristics of polycrystalline solar cell was conducted by Karki (2015). He cooled the PV modules to lower its temperature below the ambient temperature before the experiment. (Ideally less than 10^0C). The experiments were performed during an approximately half hour period around solar noon on a cloudless, clear day. The researcher found out that current parameters of each module increase with increasing temperature but voltage parameters of each module decrease with increasing temperature.

2.3 Effect of angle of inclination/tilt angle on the performance of silicon solar cells.

Angle of inclination/tilt angle is among the factors that affect the performance of silicon solar cells. According to Salih and Kadim (2014), they carried out a research on effect of tilt angle orientation on photovoltaic module performance. In their research, the effect of tilt angle (azimuth and elevation) on PV performance was simulated. The simulation involves a PV module tilted at 0°, 15°, 30°, 45°, and 60° (in both x and y directions). The researchers used a Solara®-130 W PV module which provides a nominal maximum power of 130 W, and has 36 series-connected polycrystalline silicon cells. Data are based on measurements made in a solar simulator under standard test conditions.

The effect of the tilt angle on the performance of a PV module was investigated in the x and y directions. Incident solar radiation values on various inclined surfaces with different orientations were calculated. In conclusion, they observed that the output power of the module could be significantly affected by the angular difference in both azimuth and elevation. The maximum power was obtained at 0^o in the x and y directions. With the same values of tilt angles in the x and y directions, the obtained power from the module in the x direction was greater than the corresponding value in the y direction.

Also, Ihiara and Nishihara (2001) carried out a research on outdoor performance of amorphous silicon solar cells. In this research, several solar modules were installed on the premises of Fuji Electric Corporate Research and Development Limited in Yokosuka city and the power generating status of the modules were measured in order to compare the amorphous solar cells to the crystalline Si solar cells, compare the power generating performance of amorphous solar cells with different device structures and evaluate the effects of module installation conditions (azimuth and tilt angle). Each of the module was placed at the standard tilt angle of (31^0). The effects of installation conditions were evaluated using Ge tandem modules and the modules were installed on the roof of research facilities. They were able to verify that the Si/Ge tandem structure amorphous solar cell, currently being developed by Fuji Electric, provides 10% higher generated power than crystalline Si solar cells. This is due to the excellent power generating characteristics of amorphous Si solar cells at high temperatures.

Ogueke *et al*. (2013) also carried out a research on the effect of seasonal variation and angle of inclination on the performances of solar photovoltaic in south eastern Nigeria. They used three photovoltaic panels, each with a rated capacity of 60 W in each of the locations considered. Three installation positions considered were: horizontal, an angle equal to the local latitude of location and an angle 5º greater than the local latitude of location. Power outputs from these panels were measured at fixed time interval from dawn to dusk for 12 months. They found out that solar panels perform at about 50% of their rated capacity in most cities in south eastern Nigeria. Also, solar panel installation in the south east of Nigeria does not need to be at an angle equivalent to the local latitude which is the current practice. A horizontally mounted panel will perform better considering that solar radiation is predominantly diffuse in these locations. This is also the case for any location that experiences more diffuse solar radiation than direct solar radiation.

2.4 Effect of dust scattering on the performance of silicon solar cells.

Dust scattering on the surface of silicon solar panels affect the performance of the panels. A research was conducted by Sanusi (2012) to determine the performance of amorphous Silicon PV System under harmattan dust conditions in a tropical area. He used two amorphous silicon photovoltaic systems of the same dimensions and materials set-up. One served as control experiment which was constantly cleaned-up before each daily reading commenced, while the other served as the test system for the period of the experiment. He observed that due to the daily aggregation of dust particles on the surface of the system's solar array, the performance of the clean surface of the system was better than the unclean surface by 20% during harmattan periods as a result of reduction in the solar flux intensity. This was as a result of absorption, scattering, and reflection by dust particles common during the periods of the years. The obtained results show that the application of photovoltaic technology in the conversion of solar energy to electricity within the region under study is not favorable during Harmattan period compared to period of reasonable clean and clear atmosphere.

He concluded that harmattan dusts have a strong influence on the conversion efficiency of photovoltaic system. However, it is advisable that for the better performance, especially during harmattan dust period, cleaning device should be incorporated into the arrays of photovoltaic systems.

Sulaiman *et al*. (2011) also carried out a research on effects of dust on the performance of photovoltaic panels. They used a monocrystalline solar panel rated 50W and artificial dust (mud and talcum) was used for the experiment. Experiments were performed by applying artificial dusts on a layer of plastic sheet, prior to placing the set onto the solar PV panel. Tests were conducted also with the clean plastic sheet and with bare panel in order to quantify the effects of dust on the performance of the PV panel. They found out that accumulated dust on the surface of solar photovoltaic panel can reduce the system's efficiency by up to 50%.

2.5 Effect of irradiance on the performance of silicon solar panels.

Irradiance affects the performance of silicon solar cells. According to Bashir *et al.* (2015), they carried out an experiment investigating the performance of photovoltaics in Pakistan. Three commercially available photovoltaics which include: monocrystalline Si, polycrystalline Si and single junction amorphous silicon were used for the outdoor testing and the purpose of the research was to compare the performance of the three photovoltaics under the weather of Pakistan in January. They found out that the monocrystalline Si and polycrystalline Si modules perform better at high irradiance and show poor performance at low irradiance conditions.

Amorphous Si solar module has shown better light absorption characteristics and performs better in low irradiance.

Ugwuoke and Okeke (2012) also carried out a research on performance assessment of three different modules as a function of solar insolation in south eastern Nigeria using Nsukka as a case study. Three silicon photovoltaic modules of Siemens product (55WP monocrystalline Si, 50WP polycrystalline Si and 10WP amorphous silicon modules) were simultaneously deployed outdoor to evaluate their performances as a function of solar radiation. They found out that the maximum power output and efficiencies of the modules tested were significantly lower than their rated performances. At irradiance of 1000 W/m^2, the power output reduced by about 31.88%, 42.32% and 30.6% of the manufacturer's specifications for the monocrystalline Si, polycrystalline Si and amorphous silicon PV modules respectively. Maximum efficiencies of 12.97%, 9.67% and 4.94% were achieved at irradiance of 600W/m^2 for the monocrystalline Si, polycrystalline Si and amorphous silicon modules respectively. However, at irradiance of 1000W/m^2, the efficiencies dropped to 9.61%, 7.65% and 3.62% for the monocrystalline Si, polycrystalline Si and amorphous silicon PV modules respectively. These results indicate that the design of photovoltaic systems for use in our local environment based on the rated performances would be very much in error.

Also, Parthasarathy *et al.* (2013) carried out investigations on the outdoor performance characteristics of multicrystalline silicon solar cell and module. Multicrystalline silicon solar cell and its module with 18 cells connected in series were mounted on an inclined rack tilted 12° South were used in the course of the research**.** Solar irradiance was measured using an optical Pyranometer. Results shows that the cell and module output voltage got saturated at a critical value of illumination, which is ~46.3% of the STC value for the module and 17.3% of the STC value for the cell. Moreover, this critical illumination was found to increase to 47.1% for module and 25.3% for the cells, respectively, in the evening hours. The researchers argued that this increase in the critical illumination may be related to the effective temperature losses incurred upon exposure to the outside. In conclusion, the demonstrated stability in output voltage indicates that the solar cell and modules can be operated for ~9.10 hours and 7.18 hours in the voltage-stabilized mode, respectively.

2.6 Effect of humidity on the performance of solar panels.

Humidity affects the performance of silicon solar cells. A study was conducted by Panjwani and Narejo (2014) to determine the effect of humidity on the efficiency of solar cell in Pakistan. A 50W BP solar panel was used for the experiment and hygrometer was used to calculate the humidity.. They found out that the power produced from the solar panel decreases up to 15 – 30% when the humidity level remains high thereby affecting the performance of the solar panel. Ettah *et al*. (2012) also carried out a research on the effect of relative humidity on the efficiency of solar panels in Calabar, Nigeria. They used an 18W solar panel and digital weather meter to measure the relative humidity during the experiment. They found out that low relative humidity between 69% and 75% show an increase in output current from solar panels. Voltage output also increased with decrease in relative humidity but stabilized between relative humidity values of 70% and 75%. This means that efficiency of solar panel is high during low humidity period. Therefore, relative humidity affects efficiency of solar panel as it affects the current of solar panels but has little effect on the output voltage.

2.7 Outdoor testing/ performance of solar panels.

Outdoor testing of solar panels have been carried out to determine the performance of the panels. According to Ali *et al*. (2016), an outdoor testing of photovoltaic modules was carried out during summer in Taxila, Pakistan. The modules used in this outdoor testing include: monocrystalline Si, polycrystalline silicon and single junction amorphous silicon. The hourly performance data of three commercially available PV modules were reported for three summer months and are compared with the already published data of peak winter month for the same site. Results show that crystalline silicon modules are more sensitive to the incident light showing sudden decrease of output power at low light conditions (low irradiance). The output of amorphous Si module is more stable as it performs better in low light as well. It was found that module temperature has significant effect on the output of PV modules. In the analysis of summer months, monocrystalline Si module showed average module efficiency of 11.4% which is higher than the other modules used in this study. The amorphous Si module showed low module efficiency but has shown higher average performance ratio. The module efficiency and performance ratio of PV modules decreased with the increase of solar irradiance and module temperature.

Maluta (2011) also carried out an outdoor testing of amorphous and crystalline silicon solar panels at Thohoyandou. The outdoor testing was conducted to measure solar radiation, open-circuit voltage, short circuit current, current-voltage (I-V) curve, fill-factor and conversion efficiency and hence to compare the performance of the two types of panels. The researcher observed that the measured values of open-circuit voltage and short-circuit current for crystalline and amorphous modules reveals that these values are very close to the values given by the manufacturer under STC. However, in the crystalline module, the variation is more prominent in comparison with an amorphous module. The fill factor and the sharpness of the I-V curves are almost similar for the crystalline and amorphous modules.

Also, Agroui *et al*. (2011) carried out an indoor and outdoor photovoltaic performance based on thin film solar cells. The thin film modules used in this research were amorphous Si triple junctions and copper imdium selenide. Tests were operated in outdoor exposure and under natural sunlight of URAER located in Saharan region of Ghardaïa and these tests have shown that the STC values quoted by manufacturers for their amorphous PV modules do not necessarily match those observed in STC measurements.

So far the measured maximum power values have remained within the values guaranteed by the manufacturers. Also for the US64 PV module (3j: a-Si) the deviation was more varied with the IEC 60891method than the J. Anderson and G. Blaesser methods.

The work of Abdelkader *et al* (2010) was on the comparative analysis of the performance of monocrystalline Si and multicrystalline Si PV Cells in semi arid climate conditions, the case of Jordan. He concluded that the comparison of the efficiency of the multicrystalline Si and mono-crystalline Si PV panels indicates that despite similar behavior of both PV modules in the selected days and months, monocrystalline Si panel efficiency was higher than that of the multi-crystalline Si panel.

Chukwu *et al*. (2016) did a study on the comparative study of photovoltaic modules and their performance in the tropics, a case study of Lagos, Nigeria. They used four commercially available photovoltaic (PV) modules namely: polycrystalline silicon , triple junction amorphous silicon , monocrystalline silicon and copper-indium-selenide. The experiment was carried out for three consecutive days. They found out that the monocrystalline Si and polycrystalline Si perform better under hot sun and the amorphous Si while the triple junction amorphous and copper-indium-selenide perform better at cloudy weather conditions.

Kalu *et al.* (2016) also did a work on comparative study of three different photovoltaic technologies. They used a simulation approach for the comparative analysis three different photovoltaic technologies which are the monocrystalline silicon, polycrystalline silicon and thin film PV. They found out that array efficiency of the polycrystalline Si was higher than that of the monocrystalline Si while the thin film PV has lower array efficiency. They preferred the polycrystalline Si because it has a very high array efficiency and a very low area (space requirement for the installation).

In conclusion, several factors considered from these researches carried out have effect on the performance of solar panels. This research is necessary to determine the solar panel that works optimally in the South Eastern Nigeria using Owerri as a case study so as to guide would-be users of solar panels on the type of solar panel to purchase.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The methodology involved an outdoor testing of the monocrystalline Si and polycrystalline Si solar panels which was conducted to measure the open-circuit voltage, load voltage, short circuit current, load current and hence to compare the performance of the two types of panels.

The solar panels were purchased in the open market having the following ratings.

Specification	Monocrystalliine Si	Polycrystalline Si
Manufacturer	Flames	Flames
Peak power (Pmax) (W)	100	100
Maximum power voltage (Vmax) (V)	17.5	17.5
Maximum power current (Imax) (A)	5.72	5.72
Open-circuit voltage (V_{OC}) (V)	22.05	22.05
Short-circuit current (I_{SC}) (A)	6.40	6.40

The outdoor testing was carried out at Egbeada in Owerri having latitude 5° 29' 0'' N and longitude 7° 2' 0'' E.

The experiment was carried out for both the rainy and dry season. The duration of the experiments conducted during the rainy and dry season was 26th of June to 9th of July 2016 and

6th January, 2017 to 19th January, 2017 respectively (two weeks each). Two different solar panels namely; 100W monocrystalline silicon solar panel and 100W polycrystalline silicon solar panel were used for both experiments. The solar panels were mounted on a roof top facing the sun using a ladder. The monocrystalline silicon solar panel was placed beside the polycrystalline silicon solar panel on the roof top and each of the solar panel was connected to a 12V 15A charge controller and the charge controller was connected to a 13A switch. The DC fan was connected across the switch for each of the solar panels .The block diagram of the set up is shown in Fig 3.1

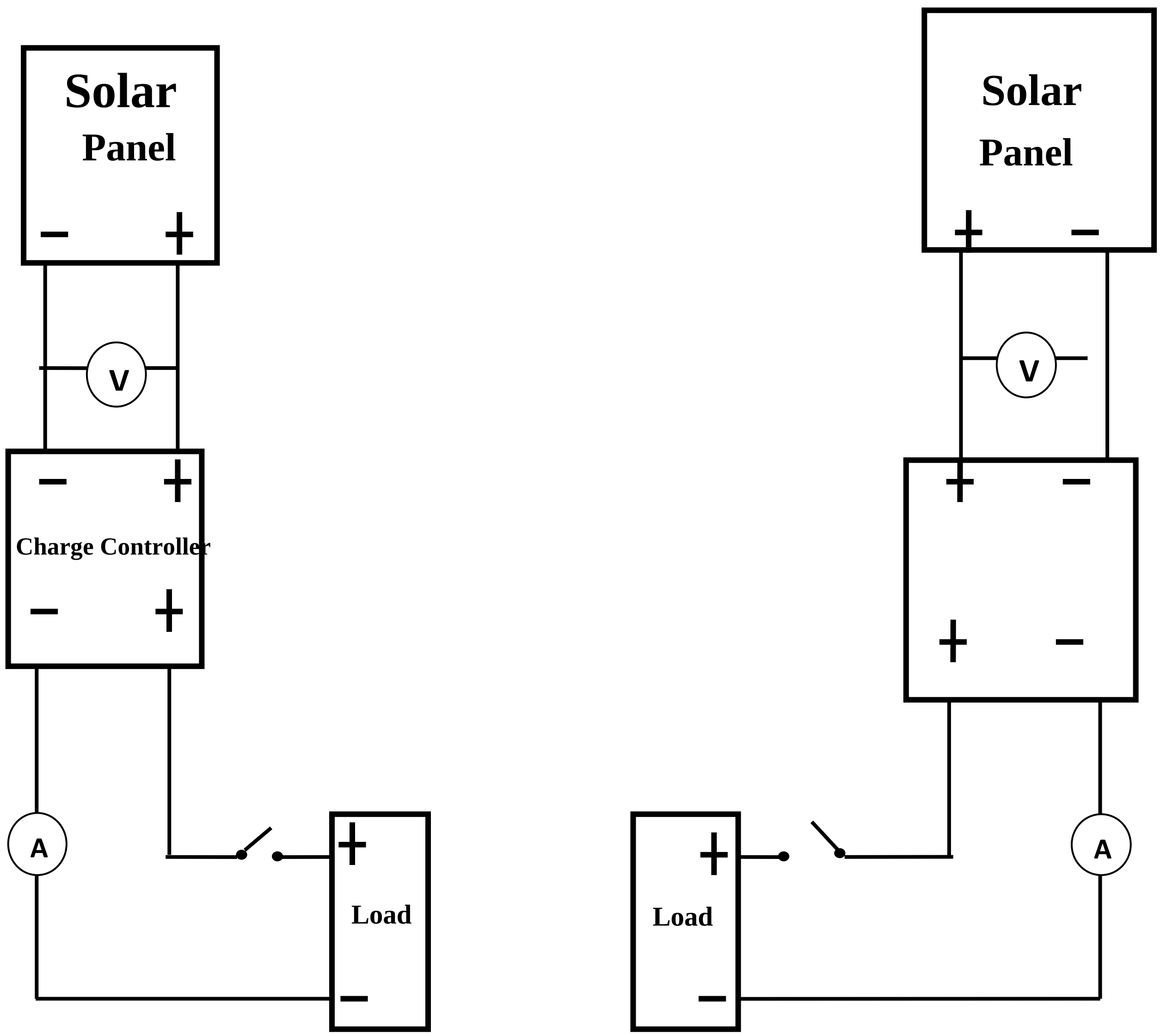


Fig 3.1: Block diagram showing the solar panel connected to load through the charge controllers.

(a) is for monocrystalline solar panel while (b) is for polycrystalline solar panel

A DT9205A digital multimeter was used to measure the open circuit voltage (Voc), load voltage (V_L), short circuit current I_{SC} and load current (I_L) generated by the solar panels. Readings were taken daily from the solar panels at an interval of one hour (1hr) between 07:00 and 18:00 hrs local time. For each of the readings taken, the switch was turned OFF for the open circuit voltage and short-circuit current for each of the panel to be recorded while the switch was turned ON for the load voltage and load current to be recorded.

3.2 Description of the Experimental Set Up

A solar panel consists of a number of solar cells that convert solar energy to electrical energy. The terminal of the solar panel was connected to the charge controller. A charge controller limits the amount of current from the solar panel to the load. The terminals of the charge controller were connected to 13A switch. The load which was a DC fan was connected to the switch. The digital multimeter was connected at the terminal of the charge controller to record the readings of the open-circuit voltage V_{OC} when the switch was turned OFF. The load voltage V_L was recorded when the switch was turned ON.

The following parameters were recorded during the outdoor testing which include the: open-circuit voltage V_{OC}, load voltage V_L, short circuit current I_{SC} and load current I_L. The maximum power was calculated by multiplying V_{OC} and I_{SC}, according to equation (3.1a)

Maximum power,

$$P_M = V_{oc} x I_{sc} \quad \textbf{(3.1a)}$$

The load power was also calculated by multiplying the load voltage and the load current, as shown in equation (3.1b)

$$P_L = V_L x I_L \quad \textbf{(3.1b)}$$

CHAPTER FOUR

RESULTS AND DISCUSSION

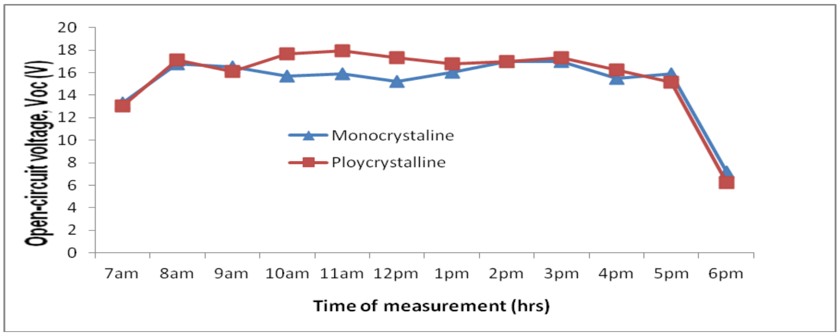
4.0 RESULTS AND DISCUSSION

The following results were obtained for each day during the outdoor testing of the solar panels for the rainy season.

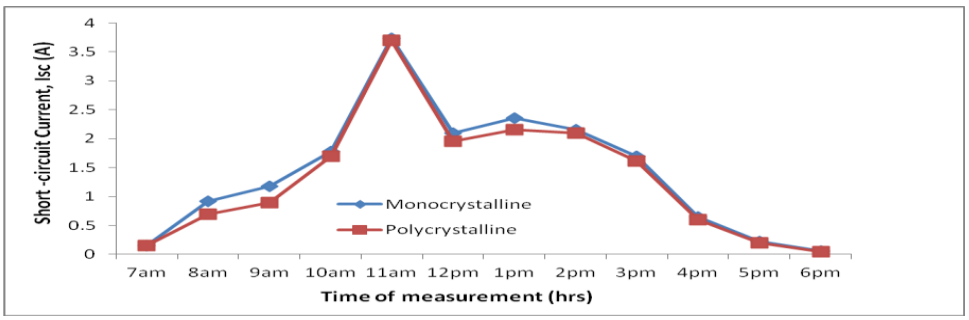
Day 1

Table 4.1: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day one (26th June, 2016).

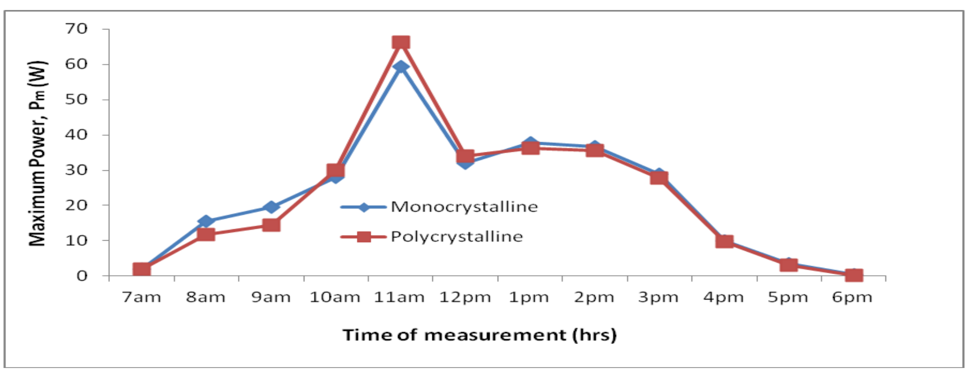
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	P_M(W)	I_L(A)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	13.28	5.93	0.15	1.99	0.10	0.59	13.04	3.48	0.15	0.08	1.96	0.28
8am	16.78	16.48	0.92	15.44	0.30	4.94	17.12	15.29	0.69	0.29	11.81	4.43
9am	16.52	16.26	1.18	19.49	0.33	5.37	16.09	15.78	0.90	0.32	14.48	5.05
10am	15.67	15.48	1.78	27.89	0.39	6.04	17.69	17.08	1.70	0.38	30.07	6.49
11am	15.90	15.39	3.73	59.31	0.38	5.85	17.93	17.49	3.70	0.37	66.34	6.47
12pm	15.24	15.10	2.10	32.00	0.34	5.13	17.30	16.72	1.96	0.34	33.91	5.68
1pm	16.02	15.54	2.36	37.81	0.36	5.59	16.78	16.18	2.16	0.35	36.24	5.66
2pm	16.96	16.72	2.16	36.63	0.35	5.85	16.96	16.47	2.10	0.34	35.62	5.60
3pm	16.99	16.06	1.70	28.88	0.31	4.98	17.30	16.74	1.61	0.30	27.85	5.02
4pm	15.50	14.95	0.65	10.08	0.29	4.34	16.25	15.60	0.60	0.28	9.75	4.37
5pm	15.92	14.42	0.22	3.50	0.16	2.31	15.14	13.95	0.20	0.12	3.03	1.67
6pm	7.19	3.46	0.06	0.43	0.04	0.14	6.24	2.03	0.05	0.03	0.31	0.06



(a)



(b)



(c)

Fig 4.1: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) Pm versus time

4.1 Discussion

Table 4.1 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panel for Day 1(26th June, 2016). Also fig.4.1 (a-c) represent the time history of the measured parameters; Fig.4.1a shows the (V_{OC} - t) plot, fig.4.1b shows the (I_{SC} - t) plot while fig.4.1c shows the (P_M - t) curve.

The open-circuit voltage V_{OC} recorded for both the monocrystalline Si and polycrystalline Si showed similar trends. The polycrystalline Si had a higher V_{OC} from 9am to 4pm and is fairly constant while V_{OC} for monocrystalline Si varied and was high at 5pm.

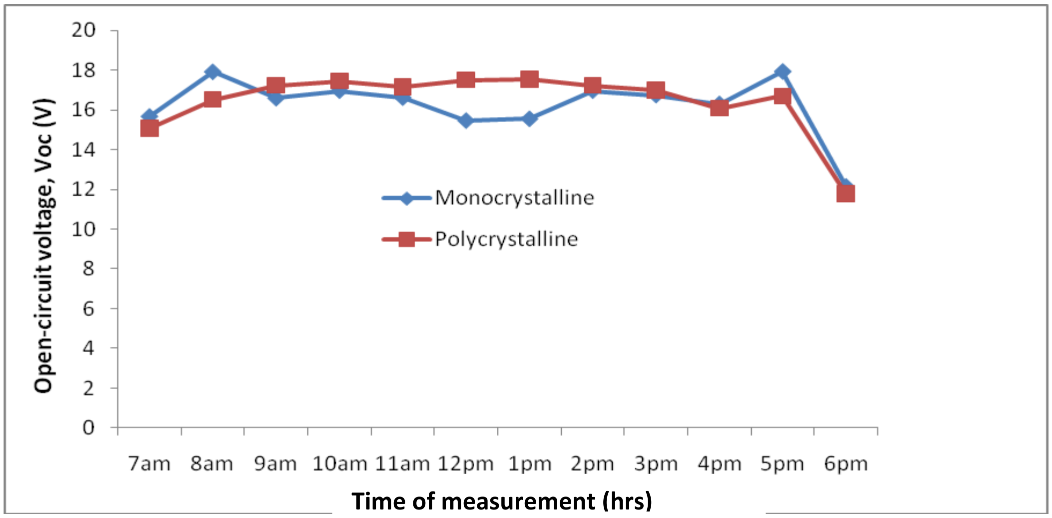
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si also showed similar trend. The short-circuit current for monocrystalline Si was higher than that of the polycrystalline Si. It increased from 7am and peaked at 11am before decreasing gradually from 12pm and increased again at 1pm before declining.

The maximum power, P_M is dependent on the current. For this particular day, the maximum power for the monocrystalline Si was 59.31W and that of the polycrystalline Si was 66.34W and this happened at 11am at the very time the current reached its maximum. Both solar panels show similar trend with the monocrystalline Si being high from 7am to 10am but the polycrystalline Si solar panel produced a higher maximum power output (P_M) than the monocrystalline Si for the first day.

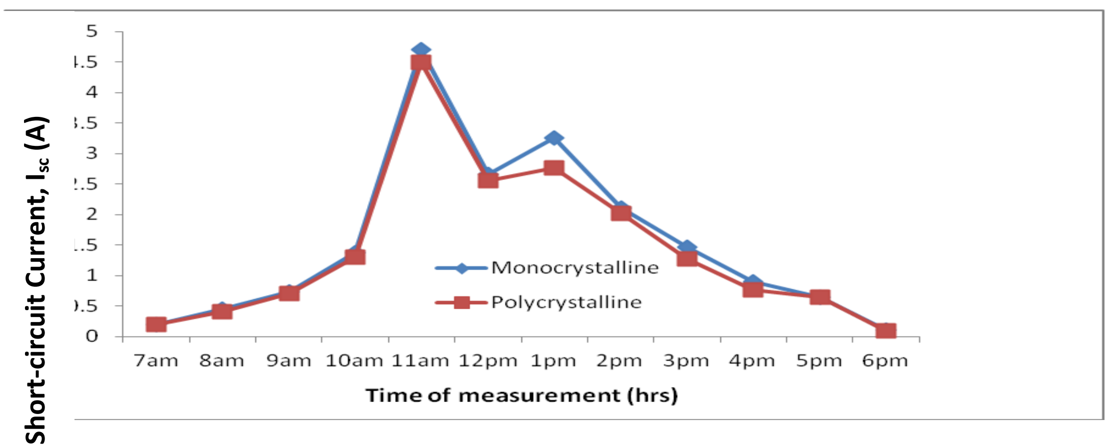
Day 2

Table 4.2: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline Si and polycrystalline Si solar panels for day two (27th June, 2016).

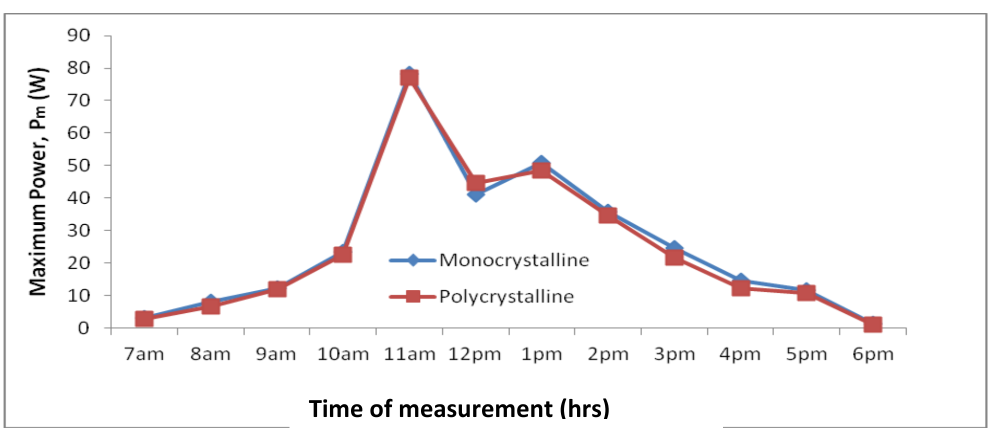
Monocrystalline Si							Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	15.68	13.05	0.20	0.13	3.14	1.70	15.04	5.66	0.19	0.11	2.86	0.62
8am	17.93	17.51	0.45	0.28	8.07	4.90	16.50	11.44	0.41	0.26	6.77	2.97
9am	16.60	16.33	0.74	0.40	12.28	6.53	17.21	15.43	0.70	0.38	12.05	5.86
10am	16.98	16.00	1.38	0.37	23.43	5.92	17.44	16.67	1.30	0.36	22.67	6.00
11am	16.63	15.99	4.70	0.39	78.16	6.24	17.15	16.25	4.50	0.37	77.18	6.01
12pm	15.47	15.33	2.66	0.35	41.15	5.37	17.50	16.99	2.55	0.34	44.63	5.78
1pm	15.56	15.42	3.26	0.38	50.73	5.86	17.50	16.99	2.76	0.35	48.38	5.95
2pm	16.98	16.93	2.11	0.36	35.83	6.09	17.21	16.62	2.02	0.34	34.76	5.65
3pm	16.76	16.56	1.47	0.28	24.64	4.64	16.98	16.16	1.27	0.25	21.56	4.04
4pm	16.31	16.08	0.90	0.22	14.68	3.54	16.06	15.49	0.76	0.20	12.21	3.10
5pm	17.95	17.66	0.65	0.15	11.67	2.65	16.68	14.78	0.65	0.10	12.21	1.48
6pm	12.15	6.36	0.11	0.08	1.34	0.51	11.76	3.18	0.10	0.05	1.18	0.16



(a)



(b)



(c)

Fig 4.2: A plot of **(a)** **V_{OC} versus time**
(b) **I_{SC} versus time**
(c) **Pm versus time**

4.2 Discussion

Table 4.2 shows experimental results recorded during the 2nd day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (27th of June 2016). Also fig.4.2 (a-c) represent the time history of the measured parameters; Fig.4.2a shows the (V_{OC} - t) plot, fig.4.2b shows the (I_{SC} - t) plot while fig.4.2c shows the (P_M - t) curve.

For the monocrystalline Si, the open-circuit voltage fluctuated more from 8am to 5pm compared to the polycrystalline Si. This shows that the voltage was more sensitive to the intensity of the sun for the monocrystalline Si panel.

The short circuit current increased gradually from 8am and peaked at 11am for both panels. It can be said that the irradiance that hit the solar panels was high at 11am and the trend for both solar panels was similar as shown in figure 4.2

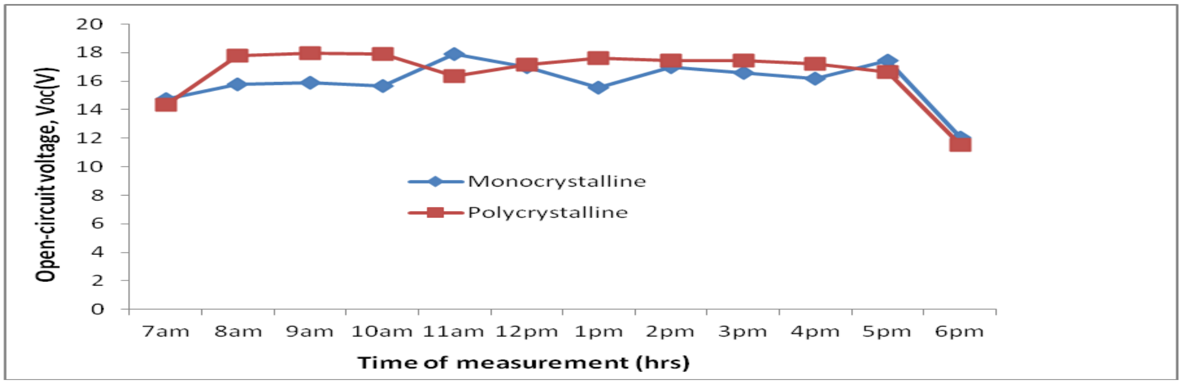
The maximum power, P_M for the monocrystalline Si was 78.16W and that of the polycrystalline Si was 77.18W and this happened at 11am at the very time the current reached its maximum. The both panels also show the same trend. This is because the voltage for both panels seems to be constant and they depend on the current.

For the 2nd day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si.

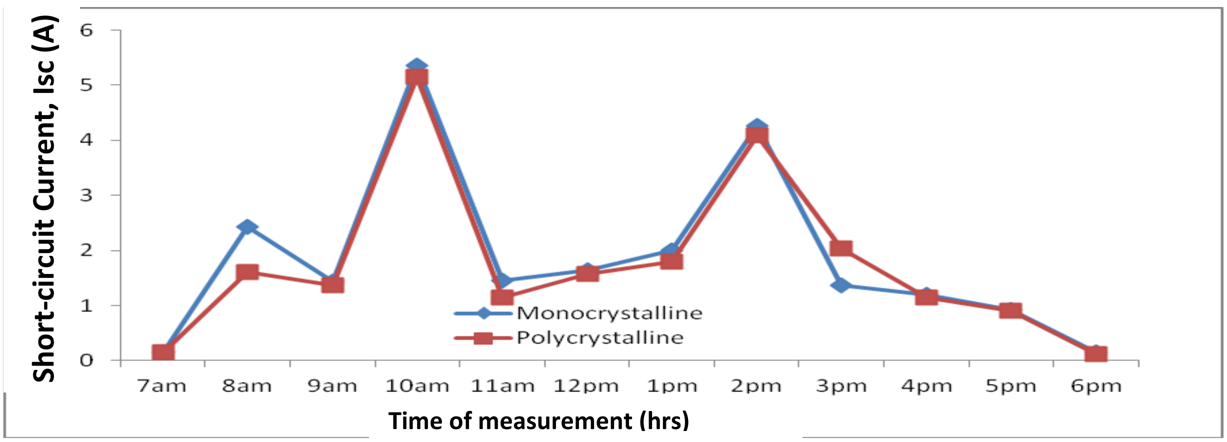
Day 3

Table 4.3: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short circuit current (I_{SC}) of monocrystalline Si and polycrystalline Si solar panels for day three (28th June, 2016).

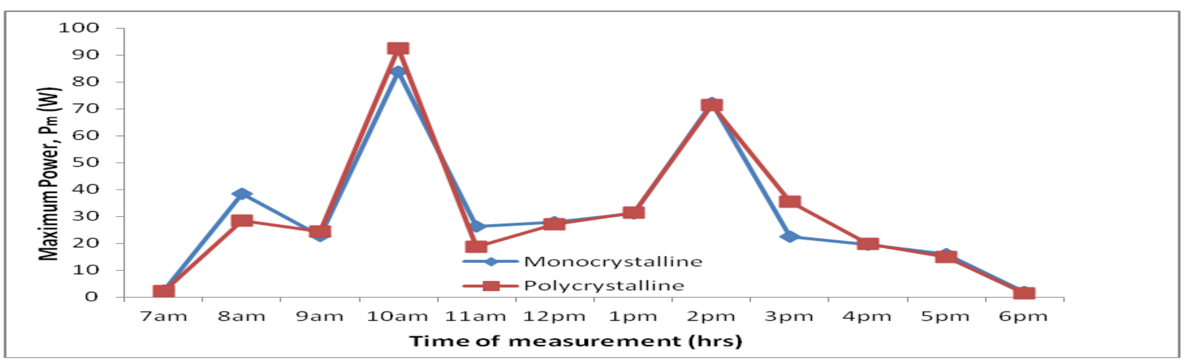
Monocrystalline Si							Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	14.76	12.15	0.16	0.02	2.36	0.24	14.36	4.65	0.16	0.01	2.30	0.05
8am	15.77	15.63	2.43	0.22	38.32	3.44	17.79	17.24	1.60	0.20	28.46	3.45
9am	15.91	15.01	1.43	0.28	22.75	4.20	17.98	17.61	1.36	0.25	24.45	4.40
10am	15.63	15.17	5.36	0.47	83.78	7.13	17.90	17.53	5.16	0.45	92.36	7.89
11am	17.92	17.03	1.46	0.36	26.16	6.13	16.36	15.55	1.15	0.35	18.81	5.44
12pm	16.97	16.02	1.65	0.38	28.00	6.09	17.16	16.52	1.58	0.36	27.11	5.95
1pm	15.52	15.48	2.00	0.36	31.04	5.57	17.60	16.96	1.79	0.34	31.50	5.77
2pm	16.98	16.93	4.26	0.30	72.33	5.08	17.46	17.23	4.09	0.29	71.41	5.00
3pm	16.55	16.42	1.36	0.31	22.51	5.09	17.41	16.63	2.03	0.30	35.34	4.99
4pm	16.20	15.91	1.20	0.33	19.44	5.25	17.23	16.95	1.15	0.32	19.81	5.42
5pm	17.42	14.65	0.92	0.25	16.03	3.66	16.61	16.10	0.90	0.24	14.95	3.86
6pm	12.05	4.52	0.15	0.03	1.81	0.68	11.50	3.62	0.12	0.02	1.38	0.07



(a)



(b)



(c)

Fig 4.3: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.3 Discussion

Table 4.3 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (28th June 2016). Also fig.4.3 (a-c) represent the time history of the measured parameters; Fig.4.3a shows the (V_{OC} - t) plot, fig.4.3b shows the (I_{SC} - t) plot while fig.4.3c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si has a higher V_{OC} from 8am to 10am and 12pm to 4pm while the monocrystalline Si was only high at 11am and 5pm. From figure 4.3, the V_{OC} for the polycrystalline Si was fairly constant from 11am to 5pm while the V_{OC} for the monocrystalline Si was fairly constant from 7am to 10am and varied after then.

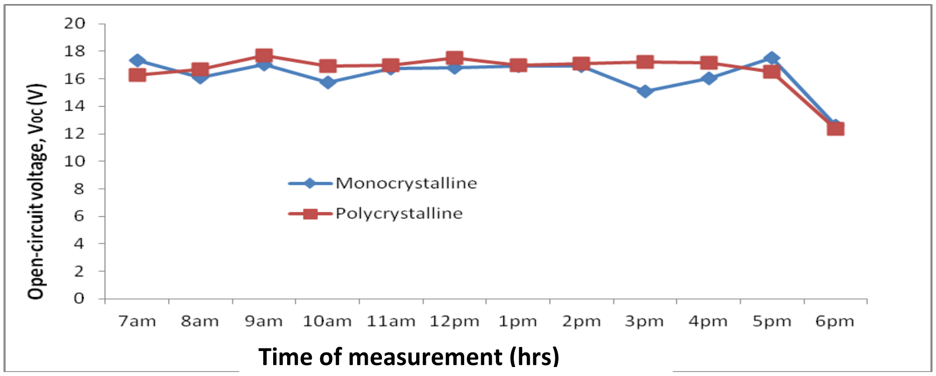
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend. The short-circuit current for monocrystalline Si was higher than that of the polycrystalline Si. The short-circuit current for both panels increased from 7am and peaked at 10am then decreased from 11am and further increase again at 2pm before decreasing gradually. The decrease was as a result of cloudy weather condition. .

The maximum power, P_M is dependent on the current. For the 3rd day, the maximum power for the monocrystalline Si was 83.78W and that of the polycrystalline Si was 92.36W and this happened at 10am at the very time the current reached its maximum. Both solar panels show similar trend with the monocrystalline Si being high at 8am while the polycrystalline Si solar panel produced the high maximum power output for the 3rd day.

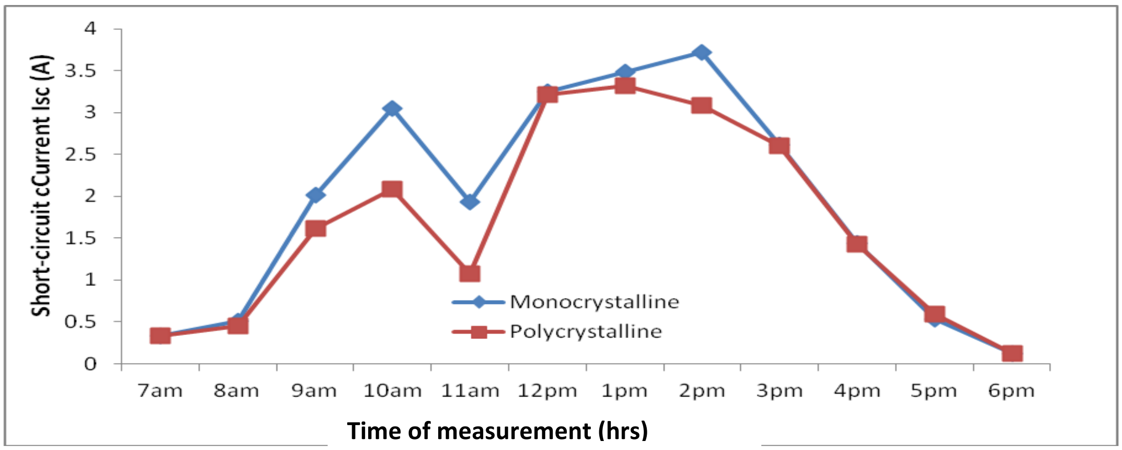
Day 4

Table 4.4: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline Si and polycrystalline Si solar panels for day four (29th June, 2016).

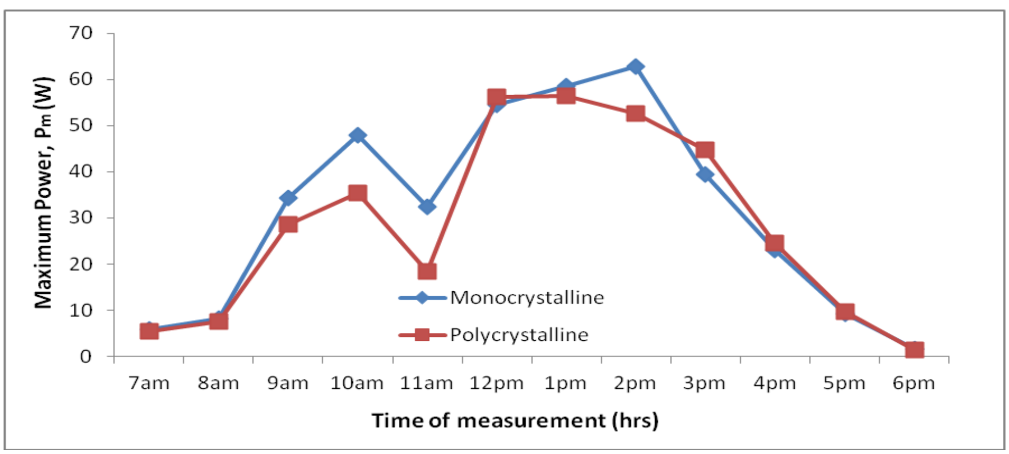
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	17.33	12.50	0.34	0.20	5.89	2.50	16.26	6.46	0.33	0.18	5.37	1.16
8am	16.08	13.48	0.51	0.28	8.20	3.77	16.66	13.17	0.45	0.26	7.50	3.42
9am	17.04	16.46	2.02	0.33	34.42	5.43	17.70	17.45	1.61	0.30	28.50	5.24
10am	15.73	15.64	3.05	0.39	47.98	6.10	16.95	16.21	2.09	0.37	35.43	6.00
11am	16.74	16.58	1.93	0.35	32.31	5.80	16.97	16.45	1.08	0.34	18.33	5.59
12pm	16.78	16.52	3.25	0.36	54.54	5.95	17.49	17.11	3.21	0.35	56.14	5.99
1pm	16.92	16.54	3.48	0.37	58.88	6.12	16.98	16.64	3.32	0.36	56.37	5.99
2pm	16.90	16.09	3.72	0.40	62.87	6.44	17.08	17.02	3.08	0.38	52.60	6.47
3pm	15.11	15.01	2.61	0.32	39.44	4.80	17.20	17.13	2.60	0.31	44.72	5.31
4pm	16.05	15.76	1.44	0.29	23.11	4.57	17.16	17.04	1.43	0.28	24.53	4.77
5pm	17.50	13.34	0.53	0.27	9.28	3.60	16.48	16.27	0.59	0.25	9.72	4.07
6pm	12.60	3.75	0.12	0.06	1.51	0.23	12.34	6.44	0.12	0.05	1.48	0.32



(a)



(b)



(c)

Fig 4.4: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.4 Discussion

Table 4.4 shows experimental results recorded during the 4th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (29th of June 2016). Also fig.4.4 (a-c) represent the time history of the measured parameters; Fig.4.4a shows the (V_{OC} - t) plot, fig.4.4b shows the (I_{SC} - t) plot while fig.4.4c shows the (P_M - t) curve.

For the monocrystalline Si, the open-circuit voltage fluctuated more from 8am to 5pm compared to the polycrystalline Si. This shows that the voltage was more sensitive to the intensity of the sun for the monocrystalline Si panel. The polycrystalline Si has a higher voltage than the monocrystalline Si from 8am to 4pm.

The short circuit current increased gradually from 8am and peaks at 2pm for both panels. The monocrystalline Si produced a higher current than the polycrystalline Si from 8am to 2pm. Both solar panels had the same trend as shown in figure 4.4

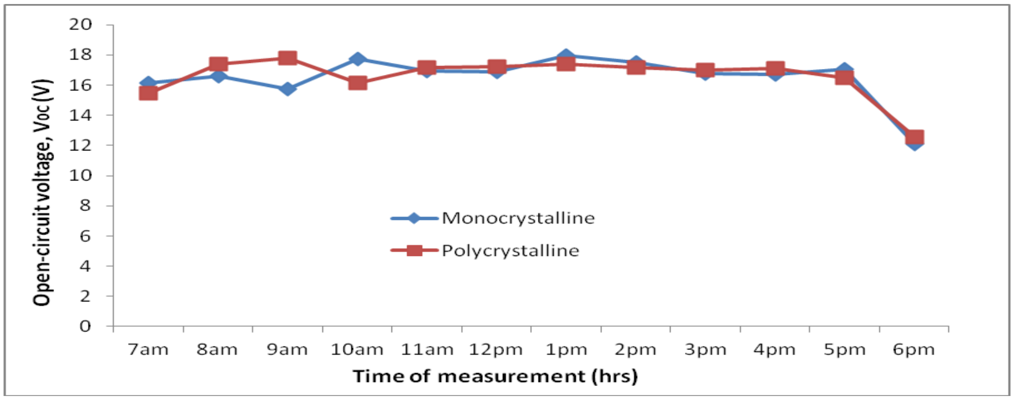
The maximum power, P_M for the monocrystalline Si was 62.87W and that of the polycrystalline Si was 52.60W and this happened at 2pm at the very time the current reached maximum.

For the 4th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si. The fourth day was fairly a clear day with no cloudy weather

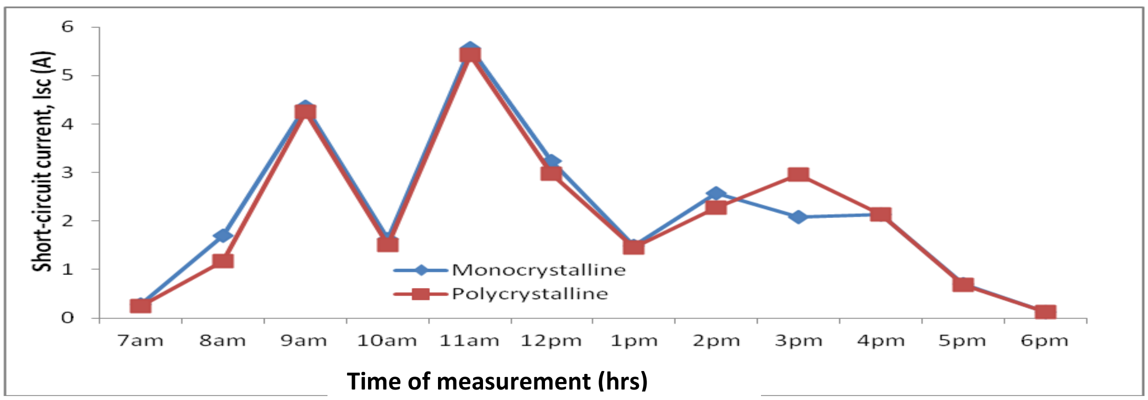
Day 5

Table 4.5: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day five (30th June, 2016).

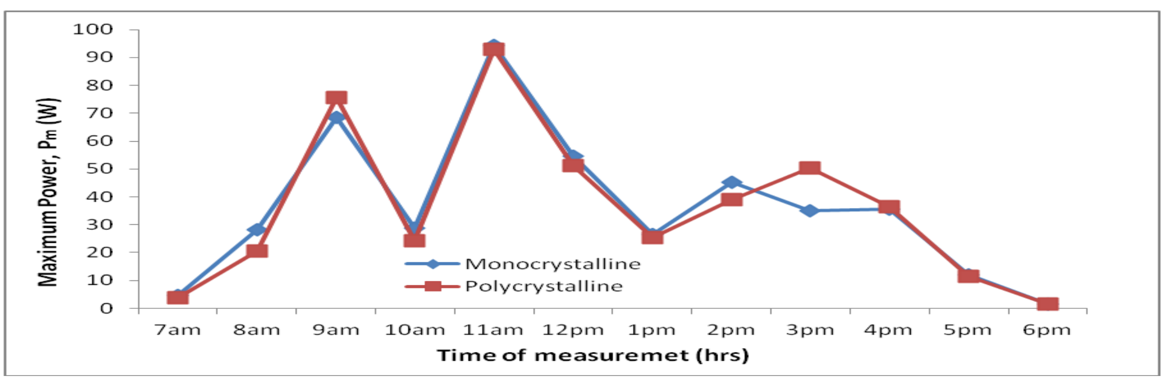
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	16.15	7.15	0.28	0.15	4.52	1.07	15.45	14.70	0.25	0.15	3.86	2.21
8am	16.60	16.42	1.70	0.24	28.22	3.94	17.40	17.22	1.18	0.23	20.53	3.96
9am	15.73	15.07	4.35	0.35	68.43	5.27	17.79	17.72	4.25	0.34	75.61	6.02
10am	17.74	17.00	1.63	0.38	28.92	6.46	16.13	16.07	1.50	0.36	24.20	5.79
11am	16.95	16.43	5.56	0.42	94.24	6.90	17.17	17.13`	5.42	0.40	93.06	6.85
12pm	16.90	16.19	3.23	0.39	54.59	6.31	17.23	17.08	2.97	0.38	51.17	6.49
1pm	17.94	16.75	1.48	0.36	26.55	6.03	17.37	17.20	1.46	0.33	25.36	5.68
2pm	17.53	16.44	2.58	0.37	45.23	6.08	17.16	17.10	2.28	0.35	39.12	5.99
3pm	16.79	16.15	2.08	0.33	34.92	5.33	16.98	16.92	2.96	0.32	50.26	5.41
4pm	16.71	16.44	2.13	0.35	35.59	5.75	17.12	17.02	2.13	0.34	36.47	5.79
5pm	17.05	15.39	0.70	0.33	11.94	5.08	16.48	16.28	0.69	0.31	11.37	5.05
6pm	12.09	3.05	0.12	0.08	1.45	0.24	12.56	6.71	0.12	0.05	1.51	0.34



(a)



(b)



(c)

Fig 4.5: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.5 Discussion

Table 4.5 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (30th June, 2016). Also fig.4.5 (a-c) represent the time history of the measured parameters; Fig.4.5a shows the (V_{OC} - t) plot, fig.4.5b shows the (I_{SC} - t) plot while fig.4.5c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si was high from 8am to 9am while the monocrystalline Si was only high at 10am. From figure 4.5, the polycrystalline Si was fairly constant from 10am to 5pm while the monocrystalline Si varied from 9am to 5pm.

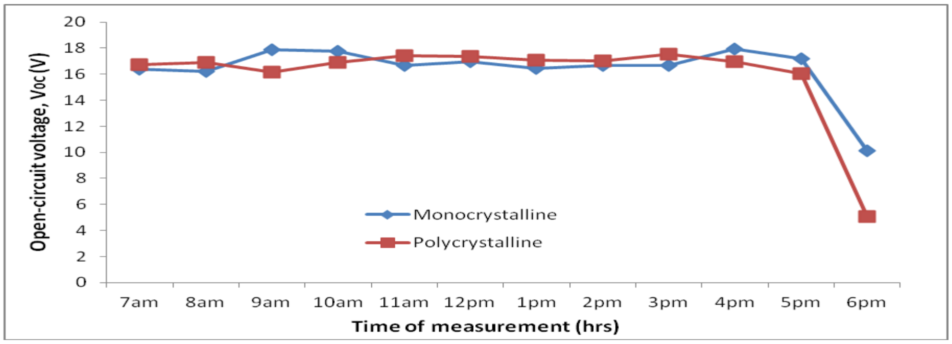
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend. The short-circuit current for monocrystalline Si was higher than that of the polycrystalline Si. The short-circuit current for both panels increased from 7am and peaked at 11am then varied before decreasing gradually. The decrease was as a result of cloudy weather condition. .

For the 5th day, the maximum power for the monocrystalline Si was 94.24W and that of the polycrystalline Si was 93.06W and this happened at 11am at the very time the current reached its maximum. Both solar panels show similar trend. The monocrystalline Si solar panel produced a high maximum power than the polycrystalline Si. The fifth day was fairly a clear day with no cloudy weather.

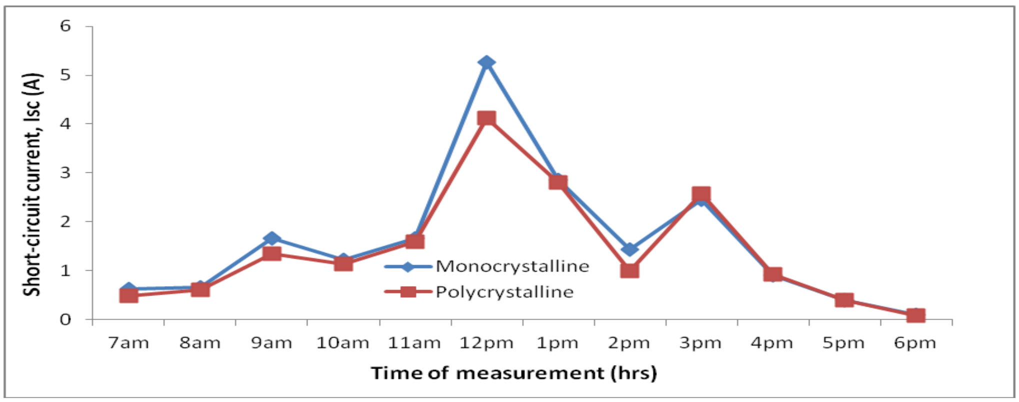
Day 6

Table 4.6: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day six (1st July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	16.38	13.31	0.63	0.27	10.32	3.59	16.73	16.44	0.48	0.26	8.03	4.27
8am	16.22	15.40	0.66	0.29	10.70	4.47	16.90	16.61	0.61	0.28	10.31	4.65
9am	17.91	17.27	1.66	0.32	29.73	5.53	16.16	16.07	1.35	0.30	21.82	4.82
10am	17.74	17.03	1.22	0.35	21.64	5.96	16.91	16.74	1.14	0.34	19.28	5.69
11am	16.67	16.03	1.66	0.38	27.67	6.09	17.42	17.37	1.59	0.36	27.70	6.25
12pm	16.98	16.43	5.26	0.39	89.31	6.41	17.37	17.30	4.12	0.38	71.56	6.57
1pm	16.46	16.20	2.85	0.37	46.91	5.99	17.10	17.05	2.80	0.35	47.88	5.97
2pm	16.66	15.60	1.43	0.34	23.82	5.30	17.04	16.07	1.00	0.32	17.04	5.14
3pm	16.70	15.42	2.46	0.37	41.08	5.71	17.52	17.05	2.57	0.36	45.03	6.14
4pm	17.95	15.57	0.91	0.31	15.88	4.83	16.98	16.71	0.92	0.30	15.62	5.01
5pm	17.17	16.38	0.39	0.20	6.70	3.28	16.06	15.68	0.40	0.18	6.42	2.82
6pm	10.13	3.95	0.10	0.06	1.01	0.24	5.05	4.05	0.07	0.04	0.35	0.16



(a)



(b)

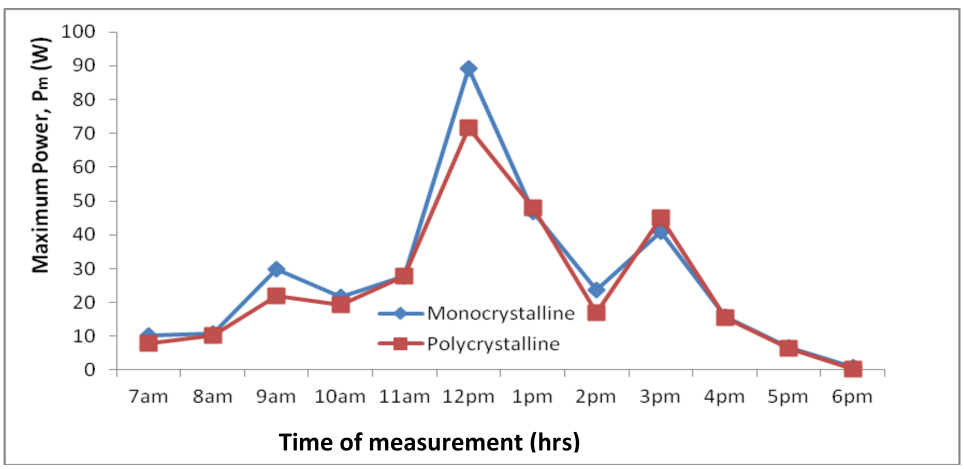


Fig 4.6: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.6 Discussion

Table 4.6 shows experimental results recorded during the 6^{th} day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (1^{st} of July, 2016). Also fig.4.6 (a-c) represent the time history of the measured parameters; Fig.4.6a shows the (V_{OC} - t) plot, fig.4.6b shows the (I_{SC} - t) plot while fig.4.6c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 11am to 3pm but the polycrystalline Si had a higher voltage than the monocrystalline Si within the time frame.

The short circuit current increases gradually from 8am and peaked at 12pm for both solar panels. The monocrystalline Si produced a higher current than the polycrystalline Si from 8am to 2pm and similar trend was observed for both solar panels as shown in figure 4.6.

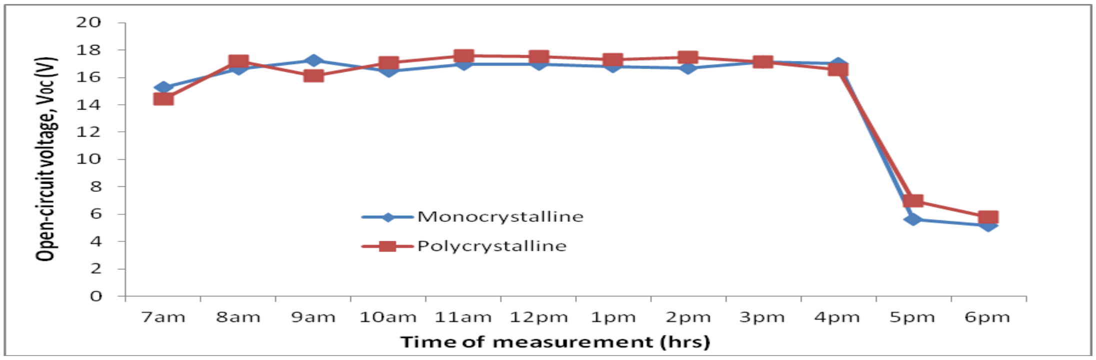
The maximum power, P_M for the monocrystalline Si was 89.31W and that of the polycrystalline Si was 71.56W and this happened at 12pm at the very time the current reached maximum.

For the 6^{th} day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si.

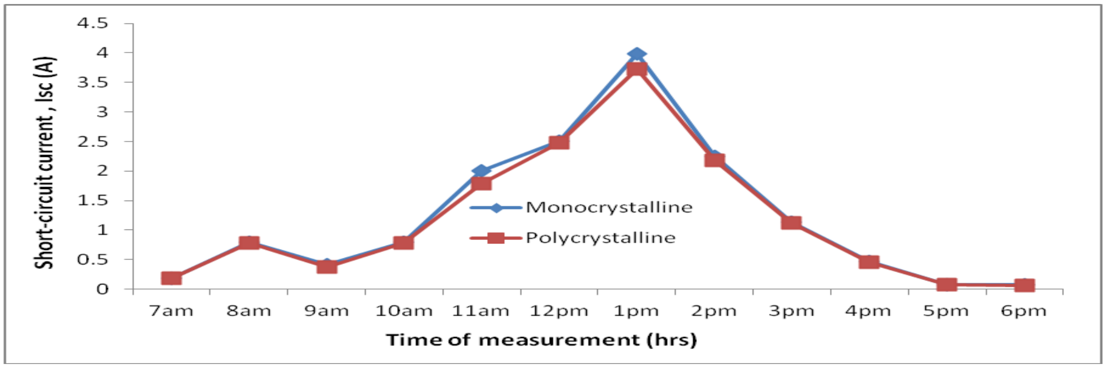
Day 7

Table 4.7: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day seven (2nd July, 2016).

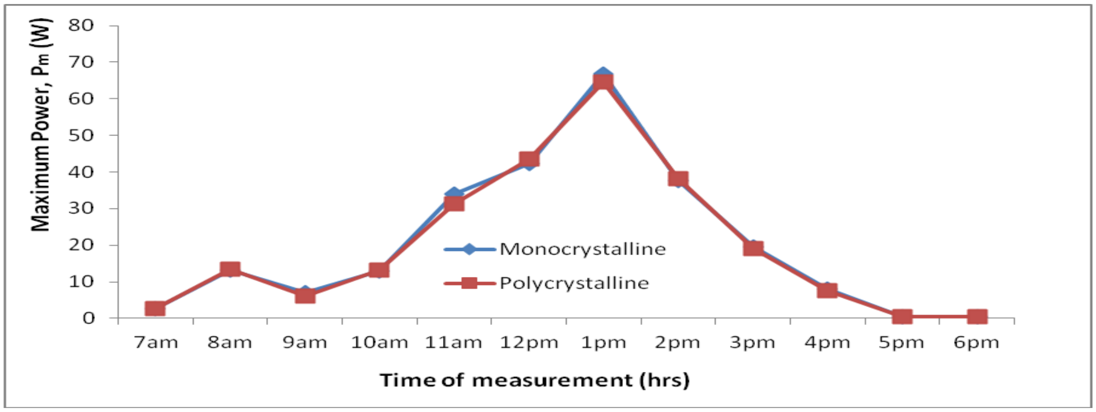
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	15.27	5.15	0.18	0.08	2.75	0.41	14.41	12.26	0.18	0.06	2.59	0.74
8am	16.61	16.44	0.79	0.32	13.12	5.26	17.18	17.02	0.78	0.30	13.40	5.11
9am	17.27	16.06	0.41	0.22	7.08	3.53	16.10	15.72	0.38	0.20	6.12	3.14
10am	16.45	16.35	0.79	0.36	13.00	5.89	17.06	16.92	0.78	0.35	13.31	5.92
11am	16.98	16.64	2.00	0.38	33.96	6.32	17.58	17.42	1.78	0.36	31.29	6.27
12pm	16.94	16.31	2.50	0.37	42.35	6.03	17.55	17.51	2.48	0.35	43.52	6.13
1pm	16.78	16.65	3.98	0.35	66.78	5.83	17.31	17.21	3.73	0.34	64.57	5.85
2pm	16.70	16.56	2.25	0.34	37.58	5.63	17.46	17.38	2.18	0.33	38.06	5.74
3pm	17.14	17.00	1.14	0.32	19.54	5.44	17.11	16.98	1.12	0.32	19.16	5.43
4pm	17.02	12.48	0.47	0.31	8.00	3.87	16.58	16.22	0.45	0.31	7.46	5.03
5pm	5.64	2.96	0.08	0.05	0.45	0.15	06.96	3.94	0.08	0.04	0.56	0.16
6pm	5.15	2.10	0.07	0.03	0.36	0.06	05.80	3.12	0.06	0.02	0.35	0.06



(a)



(b)



(c)

Fig 4.7: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.7 Discussion

Table 4.7 shows experimental results recorded during the 7^{th} day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (2^{nd} of July, 2016). Also fig.4.7 (a-c) represent the time history of the measured parameters; Fig.4.7a shows the (V_{OC} - t) plot, fig.4.7b shows the (I_{SC} - t) plot while fig.4.7c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 10am to 4pm but the polycrystalline Si had a higher voltage than the monocrystalline Si within the time frame and similar trend was observed for both solar panels as shown in figure 4.7.

The short circuit current increases gradually from 9am and peaks at 1pm for both panels. The monocrystalline Si produced a higher current than the polycrystalline Si from 11am to 1pm and similar trend was observed for both solar panels as shown in figure 4.7.

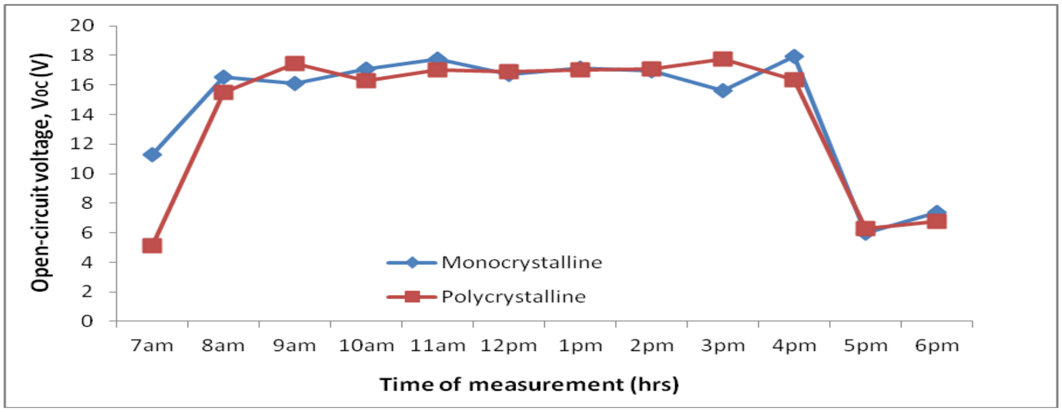
The maximum power, P_M for the monocrystalline Si was 66.78W and that of the polycrystalline Si was 64.57W and this happened at 1pm at the very time the current reached maximum.

For the 7^{th} day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si solar panel.

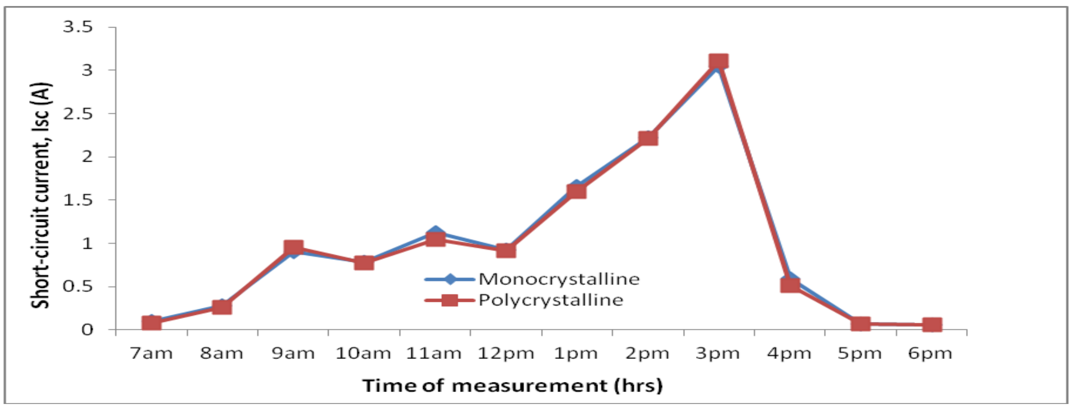
Day 8

Table 4.8: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day eight (3rd July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(V)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	$I_{SC(}$A)	I_L(A)	P_M(W)	P_L(W)
7am	11.26	3.54	0.10	0.06	1.13	0.35	5.15	4.15	0.08	0.04	0.41	0.33
8am	16.52	6.01	0.28	0.12	4.63	0.72	15.52	14.92	0.26	0.10	4.04	1.49
9am	16.10	15.78	0.90	0.30	14.49	4.73	17.43	17.28	0.95	0.29	16.56	5.01
10am	17.05	16.46	0.78	0.29	13.30	4.77	16.29	16.16	0.77	0.27	12.54	4.36
11am	17.75	17.38	1.12	0.35	19.88	6.08	17.02	16.09	1.04	0.34	17.70	5.47
12pm	16.71	16.38	0.92	0.31	15.37	5.08	16.91	16.71	0.91	0.30	15.39	5.01
1pm	17.17	17.02	1.66	0.35	28.50	5.95	17.03	16.95	1.60	0.34	27.25	5.76
2pm	16.93	16.13	2.22	0.37	37.58	5.97	17.07	17.00	2.21	0.36	37.72	6.12
3pm	15.60	15.03	3.05	0.39	47.48	5.86	17.78	17.74	3.11`	0.38	55.30	6.74
4pm	17.96	14.62	0.59	0.26	10.60	3.80	16.34	16.02	0.51	0.25	8.33	4.01
5pm	6.00	3.18	0.07	0.03	0.42	0.22	6.28	3.99	0.07	0.03	0.44	0.12
6pm	7.39	2.85	0.06	0.02	0.44	0.06	6.77	3.05	0.06	0.02	0.41	0.06



(a)



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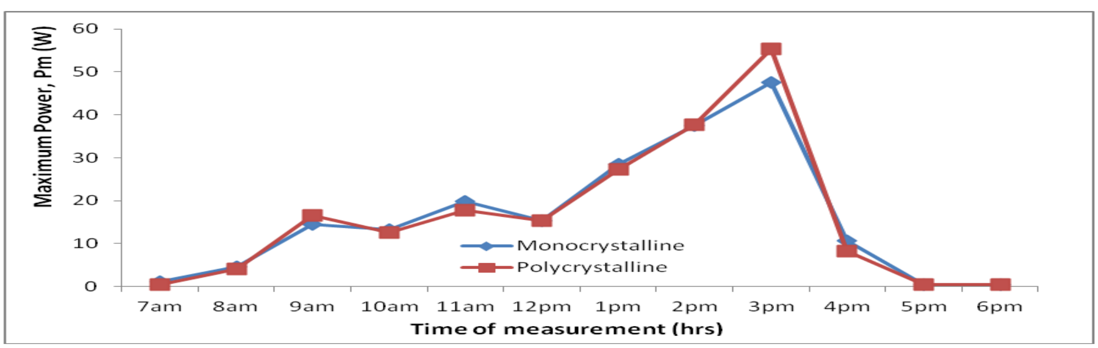


(C)

Fig 4.8: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.8 Discussion

Table 4.8 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (3rd July, 2016). Also fig.4.8 (a-c) represent the time history of the measured parameters; Fig.4.8a shows the (V_{OC} - t) plot, fig.4.8b shows the (I_{SC} - t) plot while fig.4.8c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si was high from 9am and 3pm while the monocrystalline Si was high from 10am to 11am and 4pm. From figure 4.8, the polycrystalline Si was fairly constant from 10am to 3pm while the monocrystalline Si varied from 8am to 4pm.

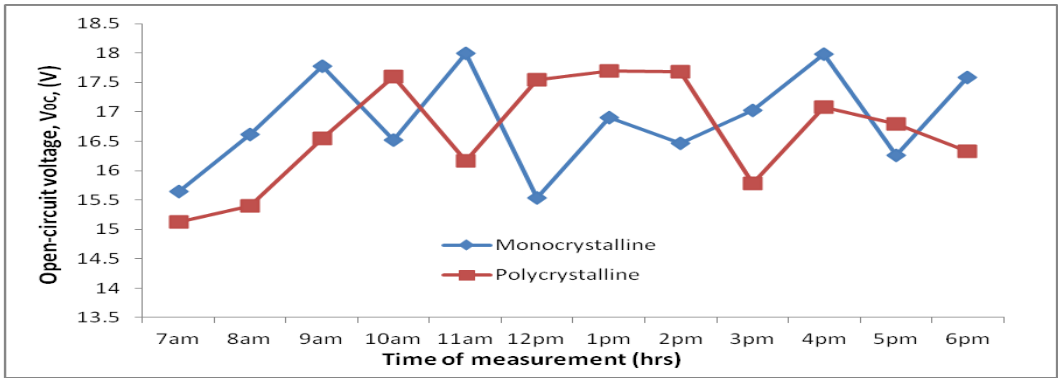
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend from figure 4.8. The short-circuit current for both solar panels varied from 8am and peaked at 3pm before decreasing gradually. The decrease was as a result of cloudy weather condition.

For the 8th day, the maximum power for the monocrystalline Si was 47.58W and that of the polycrystalline Si was 55.30W and this happened at 3pm at the very time the current reached its maximum. Both solar panels show similar trend. The polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

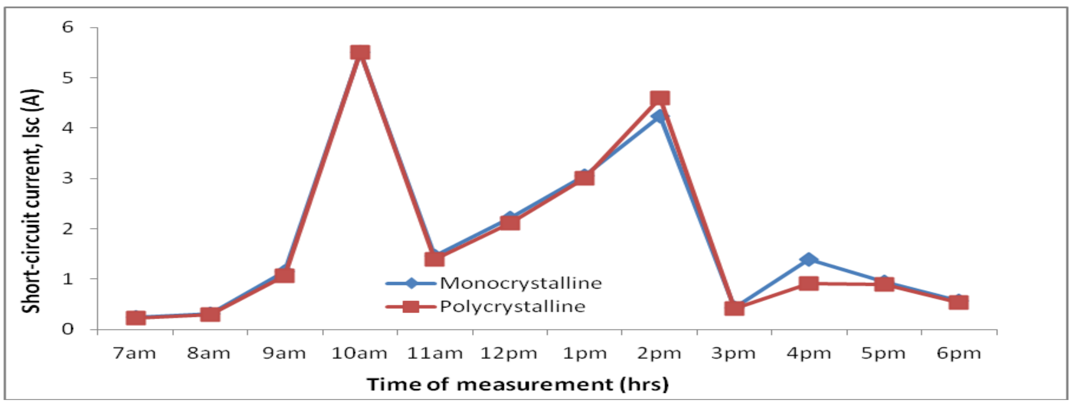
Day 9

Table 4.9: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day nine (4th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	15.64	6.12	0.24	0.15	3.75	0.92	15.12	14.06	0.22	0.14	3.33	1.97
8am	16.62	6.15	0.31	0.20	5.15	1.23	15.40	14.54	0.30	0.17	4.62	2.47
9am	17.78	16.26	1.15	0.30	20.45	4.88	16.55	16.42	1.07	0.25	17.71	4.11
10am	16.52	16.04	5.51	0.43	91.03	6.90	17.60	17.55	5.50	0.40	96.80	7.02
11am	17.99	16.08	1.47	0.35	26.45	5.63	16.17	16.07	1.40	0.31	22.64	4.98
12pm	15.54	15.03	2.22	0.38	34.50	5.71	17.54	17.47	2.11	0.36	37.01	6.29
1pm	16.90	16.15	3.05	0.34	51.55	5.49	17.70	17.25	3.00	0.33	53.10	5.69
2pm	16.46	16.27	4.24	0.39	69.79	6.35	17.68	17.56	4.60	0.37	81.33	6.50
3pm	17.03	11.92	0.44	0.22	7.49	2.62	15.78	15.48	0.41	0.21	6.47	3.25
4pm	17.98	15.29	1.40	0.28	25.17	4.28	17.08	17.53	0.92	0.26	15.71	4.56
5pm	16.26	16.11	0.94	0.24	15.28	3.87	16.79	16.64	0.90	0.24	15.11	3.99
6pm	17.59	14.01	0.57	0.21	10.03	2.94	16.33	16.08	0.54	0.21	8.82	3.38



(a)



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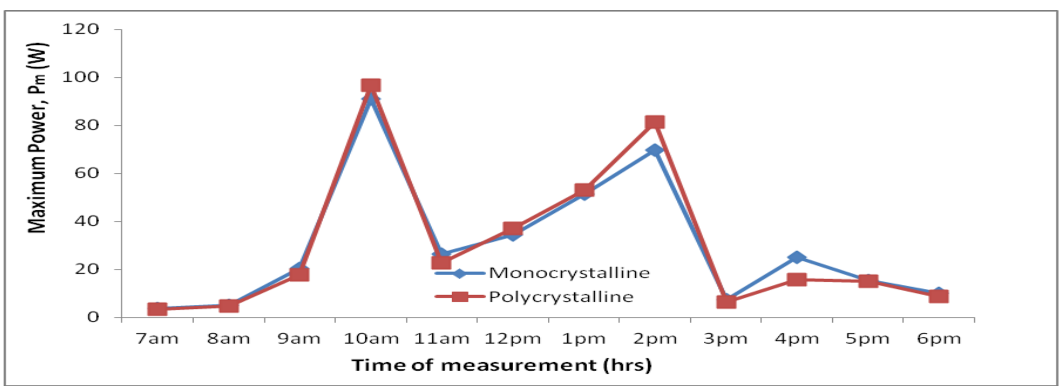


(c)

Fig 4.9: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.9 Discussion

Table 4.9 shows experimental results recorded during the 9th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (4th of July, 2016). Also fig.4.9 (a-c) represent the time history of the measured parameters; Fig.4.9a shows the (V_{OC} - t) plot, fig.4.9b shows the (I_{SC} - t) plot while fig.4.9c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels varied from 9am to 6pm but the monocrystalline Si had a higher voltage than the polycrystalline Si at 9am, 11am and 4pm and similar trend was observed for both solar panels as shown in figure 4.9.

The short circuit current increases gradually from 8am and peaked at 10am for both panels, it decreases between 10am and 11am due to change in weather condition and increased gradually to 2pm before declining due to cloudy weather condition. A similar trend was observed for both solar panels as shown in figure 4.9.

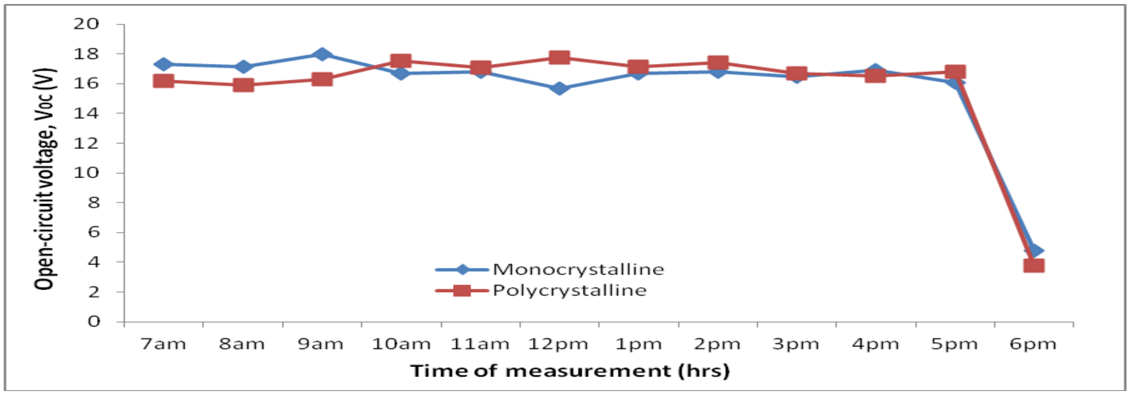
The maximum power, P_M for the monocrystalline Si was 91.03W and that of the polycrystalline Si was 96.80W and this happened at 10am at the very time the current reached maximum.

For the 9th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

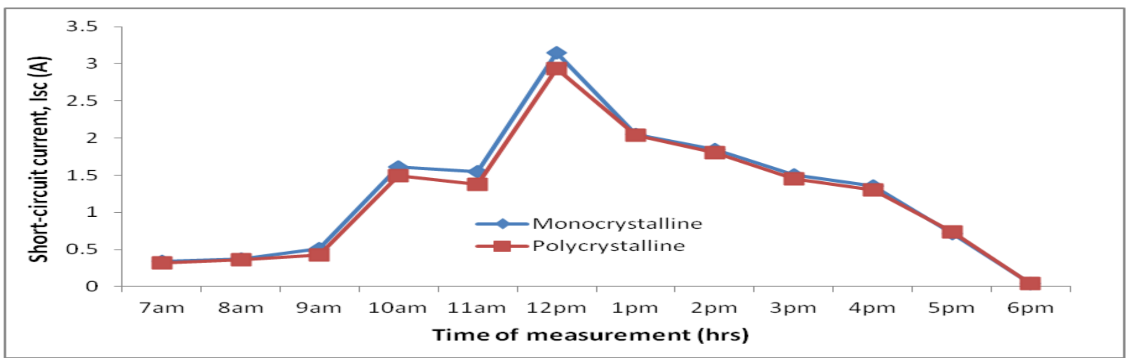
Day 10

Table 4.10: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day ten (5th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	17.32	05.45	0.34	0.16	5.89	0.87	16.16	15.73	0.32	0.14	5.17	2.20
8am	17.14	05.56	0.37	0.20	6.34	1.11	15.92	15.43	0.36	0.18	5.73	2.78
9am	17.97	13.68	0.51	0.32	9.16	4.38	16.31	15.91	0.43	0.30	7.01	4.78
10am	16.68	16.22	1.61	0.35	26.85	5.68	17.51	17.41	1.49	0.34	26.09	5.92
11am	16.78	16.56	1.55	0.38	26.01	6.29	17.09	16.98	1.38	0.37	23.58	6.28
12pm	15.70	15.13	3.15	0.40	49.46	6.05	17.78	17.64	2.94	0.39	52.27	6.88
1pm	16.72	16.08	2.05	0.37	34.28	5.95	17.14	17.03	2.04	0.36	34.97	6.13
2pm	16.83	16.26	1.85	0.36	31.14	5.85	17.45	17.20	1.80	0.35	31.41	6.02
3pm	16.45	16.10	1.50	0.33	24.68	5.31	16.67	16.33	1.45	0.32	24.17	5.26
4pm	16.93	16.21	1.35	0.29	22.86	4.70	16.54	16.40	1.30	0.27	21.50	4.43
5pm	16.09	15.55	0.72	0.26	11.58	4.04	16.78	16.59	0.74	0.25	12.42	4.15
6pm	4.78	2.78	0.04	0.01	0.19	0.03	3.75	3.10	0.04	0.01	0.15	0.03



(a)



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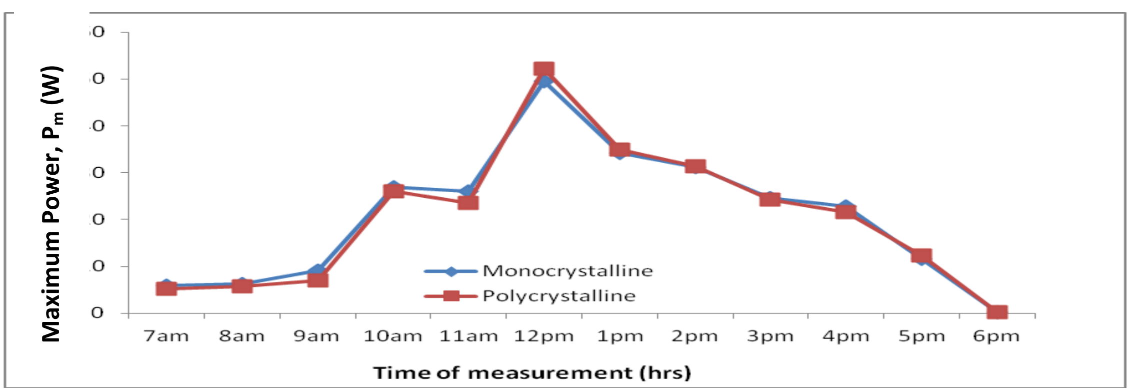


(c)

Fig 4.10: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.10 Discussion

Table 4.10 shows experimental results recorded during the 10th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (5th of July, 2016). Also fig.4.10 (a-c) represent the time history of the measured parameters; Fig.4.10a shows the (V_{OC} - t) plot, fig.4.10b shows the (I_{SC} - t) plot while fig.4.10c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels varied from 10am to 5pm but the polycrystalline Si had a higher voltage than the monocrystalline Si from 10am to 3pm. A similar trend was observed for both solar panels as shown in figure 4.10.

The short circuit current increased gradually from 9am and peaked at 12pm for both solar panels before decreasing gradually due to cloudy weather condition. The monocrystalline Si has a higher current than the polycrystalline Si from 9am to 12pm. A similar trend was observed for both solar panels as shown in figure 4.9.

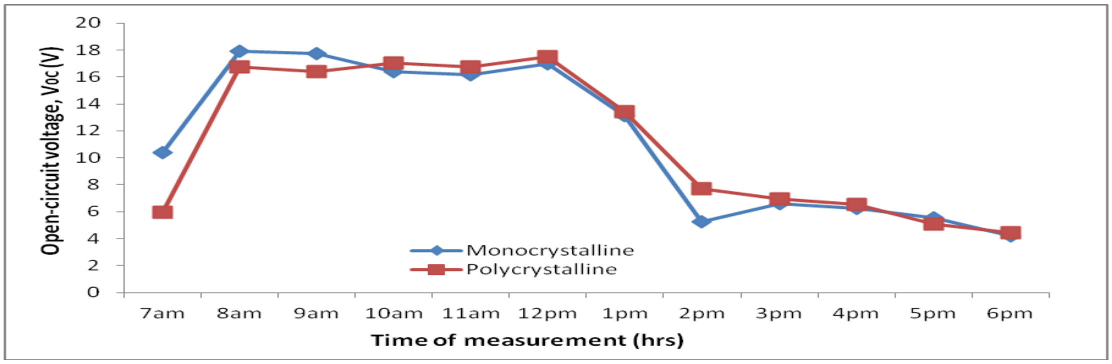
The maximum power, P_M for the monocrystalline Si was 49.46W and that of the polycrystalline Si was 52.27W and this happened at 12pm at the very time the current reached maximum.

For the 10th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

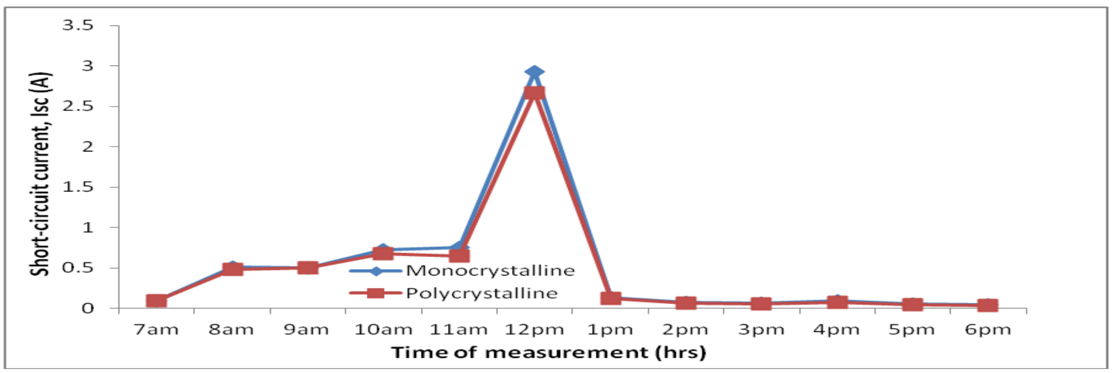
Day 11

Table 4.11: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day eleven (6th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	10.40	2.96	0.09	0.04	0.94	0.12	5.94	4.53	0.09	0.03	0.53	0.14
8am	17.92	13.12	0.51	0.22	9.14	2.89	16.73	16.43	0.48	0.20	8.03	3.29
9am	17.75	13.15	0.50	0.21	8.88	2.76	16.38	16.06	0.50	0.20	8.19	3.21
10am	16.39	16.06	0.73	0.25	11.96	4.02	17.04	16.34	0.68	0.24	11.59	3.92
11am	16.16	15.06	0.75	0.26	12.12	3.92	16.73	16.54	0.65	0.25	10.87	4.14
12pm	16.96	16.90	2.93	0.35	49.69	5.92	17.48	17.40	2.67	0.34	46.67	5.92
1pm	13.11	4.11	0.13	0.06	1.70	0.25	13.42	10.72	0.12	0.06	1.61	0.64
2pm	5.24	3.08	0.08	0.04	0.42	0.12	7.73	3.60	0.07	0.03	0.54	0.11
3pm	6.60	3.73	0.07	0.03	0.46	0.11	6.92	3.24	0.06	0.03	0.42	0.10
4pm	6.24	4.22	0.09	0.04	0.56	0.17	6.55	3.82	0.08	0.04	0.52	0.15
5pm	5.56	3.62	0.06	0.02	0.33	0.07	5.10	4.24	0.05	0.02	0.26	0.08
6pm	4.18	2.12	0.05	0.01	0.21	0.02	4.42	3.56	0.04	0.01	0.18	0.04



(a)



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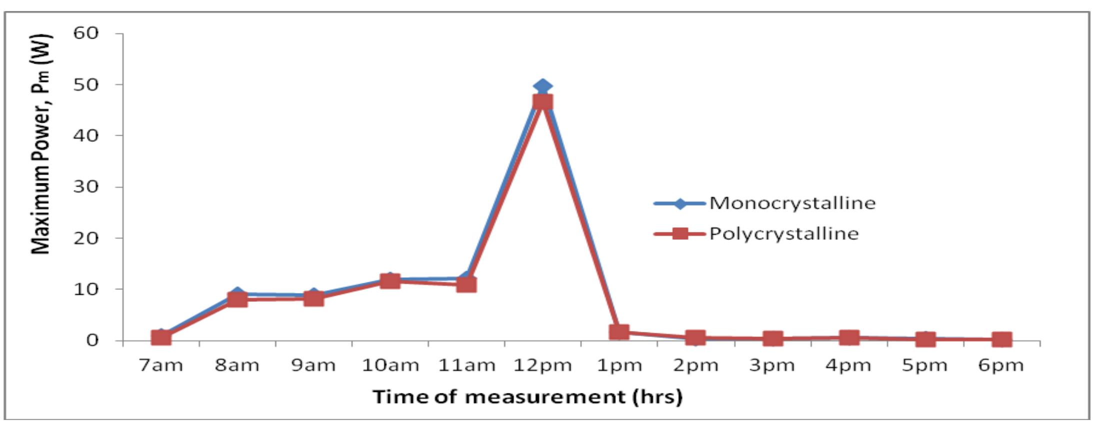


(C)

Fig 4.11: A plot of **(a)** **V_{OC} versus time**

(b) **I_{SC} versus time**

(c) **Pm versus time**

4.11 Discussion

Table 4.11 shows experimental results recorded during the 11th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (6th of July, 2016). Also fig.4.11 (a-c) represent the time history of the measured parameters; Fig.4.11a shows the (V_{OC} - t) plot, fig.4.11b shows the (I_{SC} - t) plot while fig.4.11c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 8am to 12pm but the polycrystalline Si had a higher voltage than the monocrystalline Si from 10am to 12pm. The V_{OC} for both panels decreased from 3pm to 6pm due to rainfall

The short circuit current increases gradually from 7am and peaked at 12pm for both panels before decreasing due to rainfall. The monocrystalline Si had a higher current than the polycrystalline Si at 12pm. Similar trend was observed for both solar panels as shown in figure 4.11.

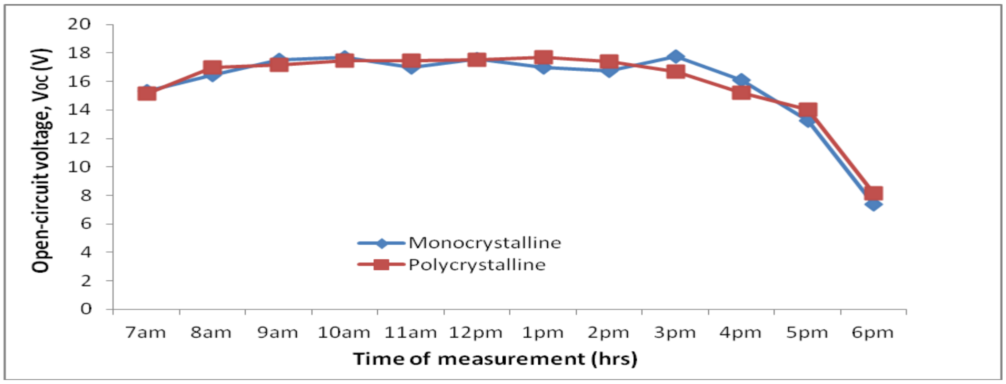
The maximum power, P_M for the monocrystalline Si was 49.69W and that of the polycrystalline Si was 46.67W and this happened at 12pm at the very time the current reached maximum.

For the 11th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si solar panel.

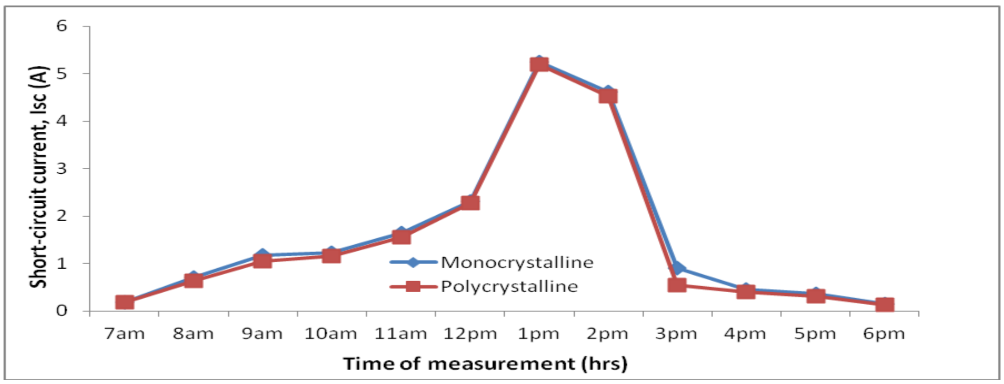
Day 12

Table 4.12: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day twelve (7th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L (V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	15.32	5.08	0.19	0.08	2.91	0.41	15.14	14.30	0.18	0.07	2.73	1.00
8am	16.44	15.97	0.71	0.25	11.67	3.99	16.98	16.70	0.64	0.24	10.87	4.01
9am	17.53	16.78	1.17	0.30	20.51	5.03	17.16	17.08	1.04	0.30	17.85	5.12
10am	17.70	17.62	1.22	0.32	21.59	5.64	17.47	17.36	1.15	0.31	20.09	5.38
11am	16.96	16.07	1.65	0.33	27.98	5.30	17.43	17.35	1.56	0.32	27.19	5.55
12pm	17.55	16.70	2.31	0.35	40.54	5.85	17.54	17.40	2.27	0.34	39.82	5.92
1pm	16.97	16.92	5.25	0.42	89.09	7.11	17.71	17.65	5.20	0.40	92.09	7.06
2pm	16.72	16.54	4.61	0.39	77.08	6.45	17.38	17.34	4.53	0.38	78.73	6.59
3pm	17.75	16.45	0.90	0.28	15.98	4.61	16.69	16.42	0.54	0.26	9.01	4.27
4pm	16.10	15.55	0.45	0.27	7.25	4.20	15.21	15.10	0.40	0.23	6.08	3.47
5pm	13.26	13.00	0.36	0.15	4.77	1.95	14.01	12.25	0.30	0.12	4.20	1.47
6pm	7.36	4.25	0.15	0.05	1.10	0.21	8.15	6.35	0.12	0.03	0.98	0.19



(a)



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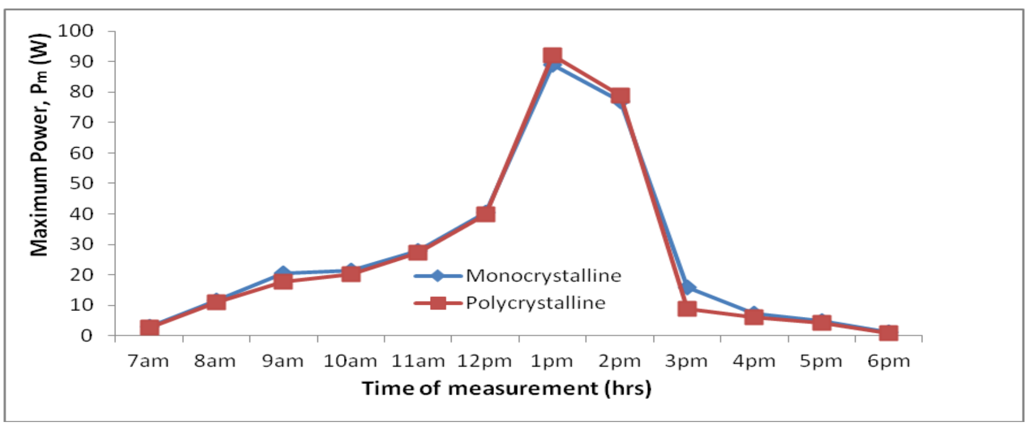


(C)

Fig 4.12: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.12 Discussion

Table 4.12 shows experimental results recorded during the 12th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (7th of July, 2016). Also fig.4.12 (a-c) represent the time history of the measured parameters; Fig.4.12a shows the (V_{OC} - t) plot, fig.4.12b shows the (I_{SC} - t) plot while fig.4.12c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 7am to 2pm but the polycrystalline Si had a higher voltage than the monocrystalline Si from 11am to 2pm.

The short circuit current increased gradually from 7am and peaked at 1pm for both panels before decreasing due to rainfall. Similar trend was observed for both solar panels as shown in figure 4.12.

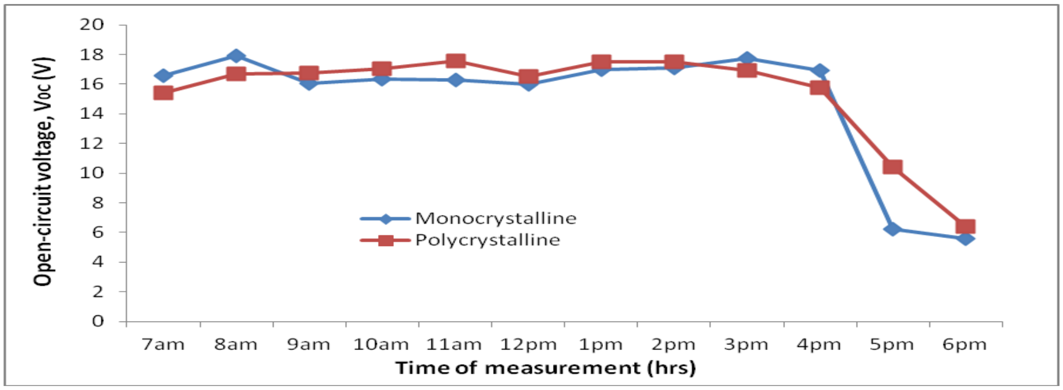
The maximum power, P_M for the monocrystalline Si was 89.09W and that of the polycrystalline Si was 92.09W and this happened at 1pm at the very time the current reached maximum.

For the 12th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

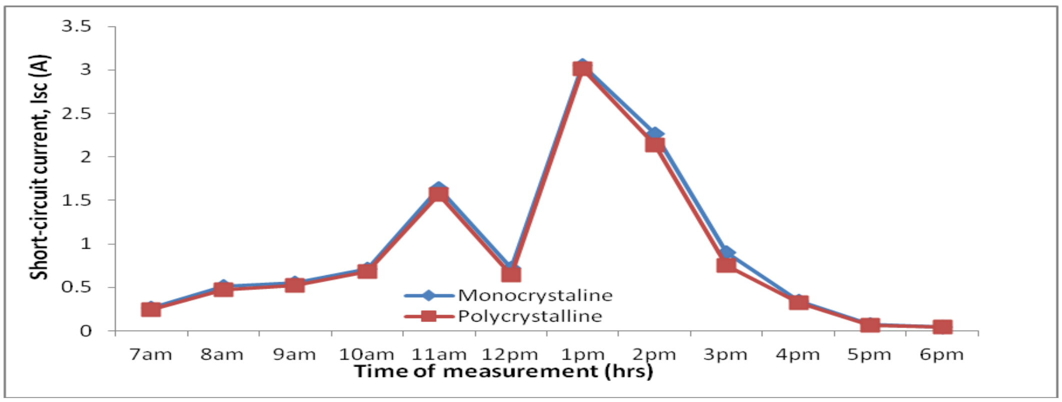
Day 13

Table 13: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day thirteen (8th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	16.55	7.79	0.26	0.11	4.30	0.86	15.42	14.49	0.24	0.10	3.70	1.45
8am	17.93	12.99	0.51	0.20	9.14	2.59	16.68	16.35	0.47	0.18	7.84	2.94
9am	16.05	14.23	0.55	0.21	8.83	2.99	16.73	16.43	0.52	0.20	8.70	3.29
10am	16.32	15.50	0.71	0.25	11.59	3.88	17.03	16.04	0.68	0.24	11.58	3.85
11am	16.29	16.16	1.64	0.30	26.72	4.85	17.57	17.47	1.57	0.28	27.58	4.89
12pm	16.02	15.98	0.72	0.26	11.53	4.15	16.52	16.35	0.64	0.24	10.57	3.92
1pm	16.96	16.16	3.05	0.38	51.73	6.14	17.48	17.40	3.01	0.36	52.61	6.26
2pm	17.09	16.70	2.27	0.33	38.79	5.51	17.53	17.45	2.14	0.32	37.51	5.58
3pm	17.75	16.45	0.90	0.28	15.98	4.61	16.92	16.77	0.75	0.27	12.69	4.53
4pm	16.90	5.65	0.34	0.13	5.75	0.73	15.75	15.26	0.32	0.12	5.04	1.83
5pm	6.23	4.25	0.07	0.03	0.44	0.13	10.42	6.15	0.06	0.03	0.63	0.18
6pm	5.60	2.15	0.04	0.01	0.22	0.02	6.42	3.15	0.04	0.01	0.26	0.03



(a)



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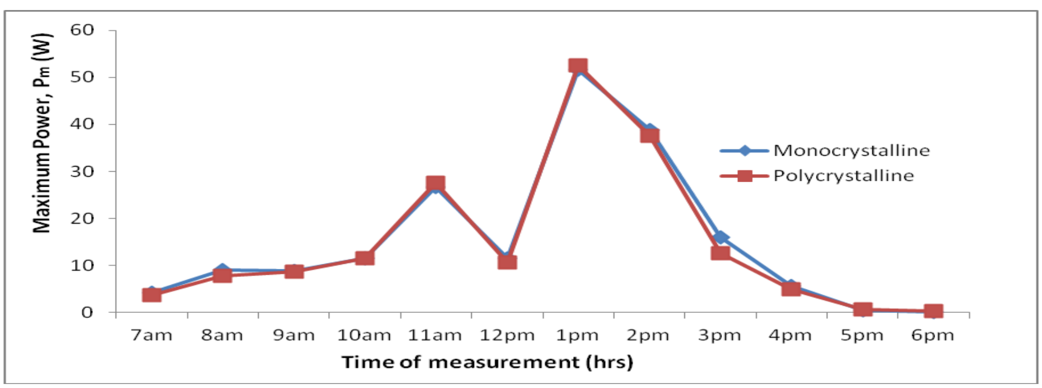


(c)

Fig 4.13: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus time

4.13 Discussion

Table 4.13 shows experimental results recorded during the 13th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (8th of July, 2016). Also fig.4.13 (a-c) represent the time history of the measured parameters; Fig.4.13a shows the (V_{OC} - t) plot, fig.4.13b shows the (I_{SC} - t) plot while fig.4.13c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 9am to 3pm but the polycrystalline Si had a higher voltage than the monocrystalline Si from 9am to 2pm.

The short circuit current increased gradually from 7am and peaked at 1pm for solar both panels before decreasing due to rainfall. Similar trend was observed for both solar panels as shown in figure 4.13.

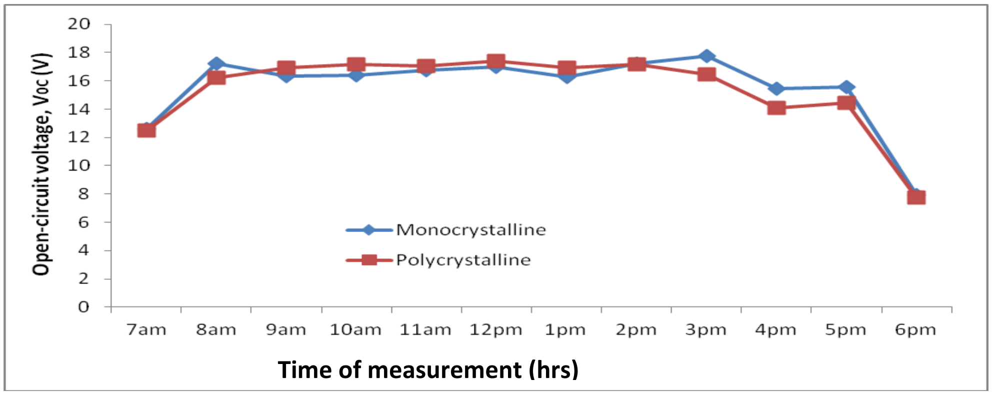
The maximum power, P_M for the monocrystalline Si was 51.73W and that of the polycrystalline Si was 52.61W and this happened at 1pm at the very time the current reached maximum.

For the 13th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

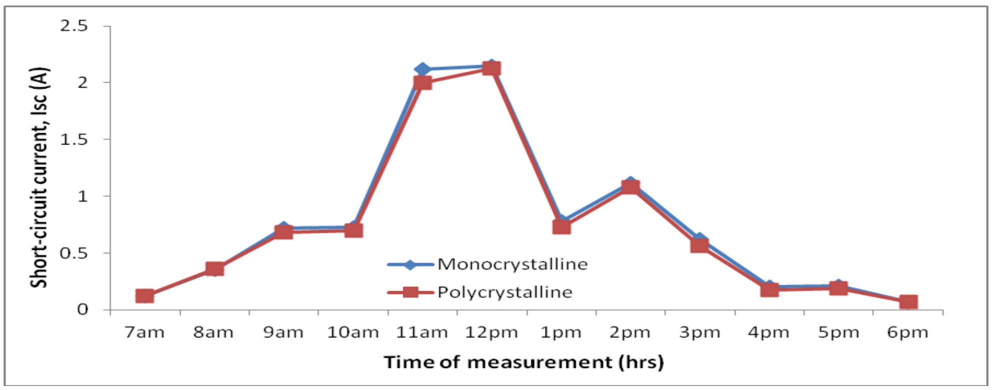
Day 14

Table 4.14: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) and short-circuit current (I_{SC}) of monocrystalline and polycrystalline Si solar panels for day fourteen (9th July, 2016).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	12.62	3.18	0.12	0.08	1.51	0.25	12.48	06.44	0.12	0.08	1.50	0.52
8am	17.25	05.93	0.35	0.16	6.04	0.95	16.20	15.70	0.36	0.16	5.83	2.51
9am	16.33	15.91	0.72	0.24	11.76	3.82	16.95	16.76	0.68	0.23	11.53	3.85
10am	16.42	16.25	0.73	0.24	11.99	3.90	17.15	16.99	0.70	0.24	12.01	4.08
11am	16.76	16.32	2.12	0.35	35.53	5.71	17.02	16.98	2.00	0.34	34.04	5.77
12pm	16.98	16.18	2.15	0.36	36.51	5.82	17.38	17.31	2.13	0.35	37.02	6.06
1pm	16.28	16.08	0.78	0.25	12.70	4.02	16.04	16.77	0.73	0.24	12.37	4.02
2pm	17.25	17.15	1.12	0.30	19.32	5.15	17.15	17.04	1.08	0.29	18.52	4.94
3pm	17.75	14.55	0.62	0.23	11.01	3.35	16.45	16.22	0.58	0.21	9.54	3.58
4pm	15.47	7.17	0.20	0.11	3.09	0.79	14.08	11.95	9.17	0.10	2.39	1.20
5pm	15.58	6.28	0.21	0.10	3.27	0.63	14.46	12.75	0.19	0.08	2.75	1.02
6pm	7.93	2.95	0.07	0.03	0.56	0.09	7.76	3.76	0.07	0.03	0.54	0.11



(a)



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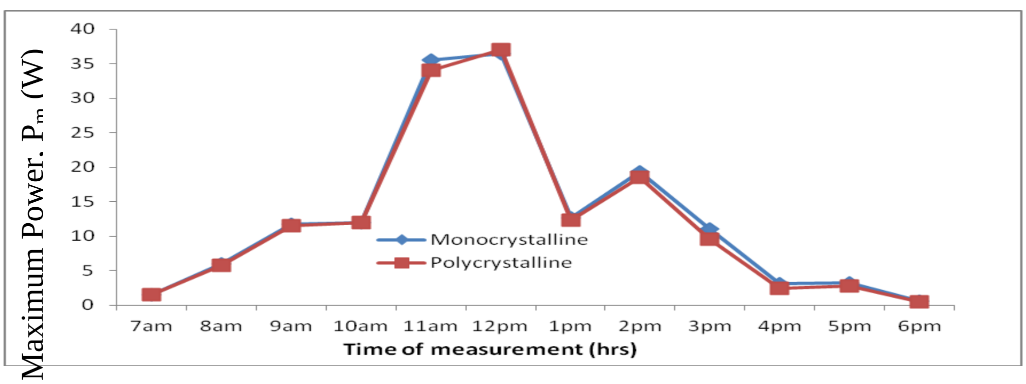


(c)

Fig 4.14: A plot of (a) V_{OC} versus time

(b) I_{SC} versus time

(c) Pm versus tim

4.14 Discussion

Table 4.14 shows experimental results recorded during the 14th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (9th of July, 2016). Also fig.4.14 (a-c) represent the time history of the measured parameters; Fig.4.14a shows the (V_{OC} - t) plot, fig.4.14b shows the (I_{SC} - t) plot while fig.4.14c shows the (P_M - t) curve.

For the open-circuit voltage, the monocrystalline Si varied from 8am to 5pm while the polycrystalline Si was fairly constant from 9am to 2pm but the polycrystalline Si had a higher voltage than the monocrystalline Si from 9am to 2pm.

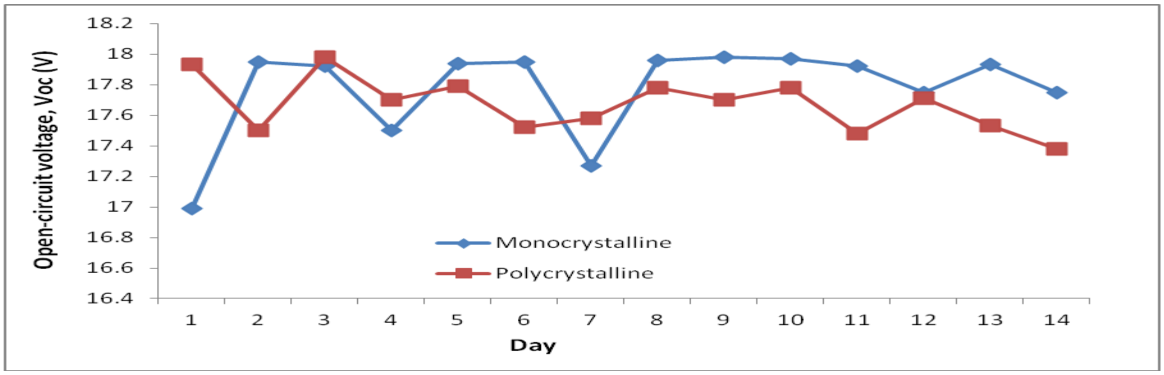
The short circuit current increased gradually from 7am and peaked at 12pm for both solar panels before varying and finally declined from 4pm to 6pm due to rainfall. Similar trend was observed for both solar panels as shown in figure 4.14.

The maximum power, P_M for the monocrystalline Si was 36.51W and that of the polycrystalline Si was 37.02W and this happened at 12pm at the very time the current reached maximum.

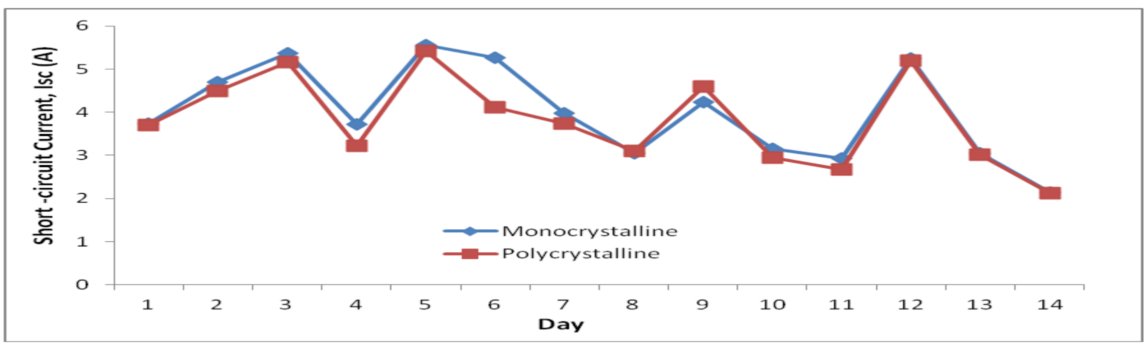
For the 14th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

Table 4.15: Experimental results of maximum open-circuit voltage (V_{OC}), maximum short-circuit current (I_{SC}) and maximum power output of monocrystalline and polycrystalline Si solar panels for the fourteen days of the rainy season.

	Monocrystalline Si			Polycrystalline Si		
Day	V_{OC}(V)	I_{SC}(A)	P_M(W)	V_{OC}(V)	I_{SC}(A)	P_M(W)
1	16.99	3.73	59.31	17.93	3.70	66.34
2	17.95	4.70	78.16	17.50	4.50	77.18
3	17.92	5.36	83.78	17.98	5.16	92.36
4	17.50	3.72	62.87	17.70	3.32	56.37
5	17.94	5.56	94.24	17.79	5.42	93.06
6	17.95	5.26	89.31	17.52	4.12	71.56
7	17.27	3.98	66.78	17.58	3.73	64.57
8	17.96	3.05	47.48	17.78	3.11	55.30
9	17.99	5.51	91.03	17.70	5.50	96.80
10	17.97	3.15	49.46	17.78	2.94	52.27
11	17.92	2.93	49.69	17.48	2.67	46.67
12	17.75	5.25	89.09	17.71	5.20	92.09
13	17.93	3.05	51.73	17.57	3.01	52.61
14	17.75	2.15	36.51	17.38	2.13	37.02



(a)



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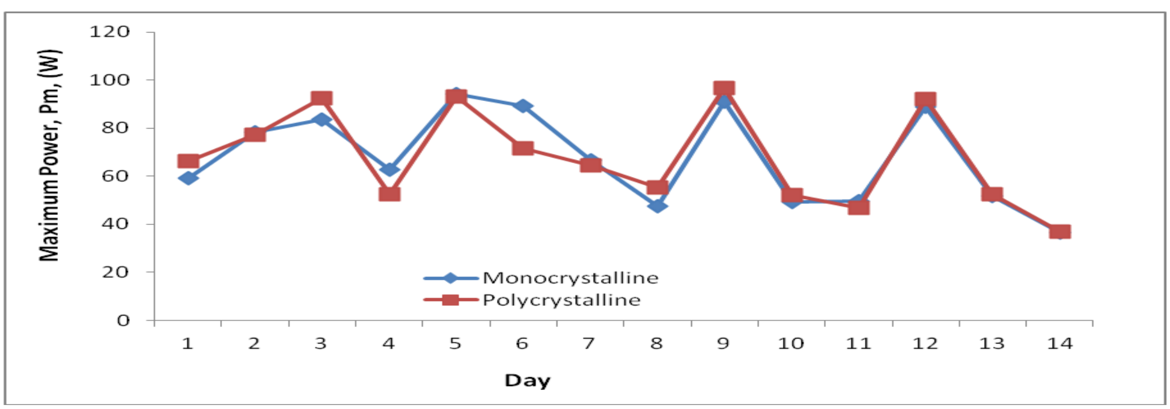


(c)

Fig 4.15: A plot of (a) $V_{OC\ max}$ versus number of days.
(b) $I_{SC\ max}$ versus number of days.
(c) Pm_{max} versus number of days.

4.15: Comparison of the maximum open-circuit voltage (V_{OC}), maximum short- circuit current (I_{SC}) and maximum power output (P_M) for the fourteen days for both the monocrystalline Si and polycrystalline Si solar panels.

Fig 4.15 shows the maximum open –circuit voltage V_{OC}, maximum short-circuit current I_{SC} and highest maximum power (P_M) recorded for the fourteen days for both the monocrystalline Si and polycrystalline Si solar panels.

For the open-circuit voltage, both solar panels varied from day one to the fourteenth day but the monocrystalline Si solar panel was fairly constant from the 8^{th} day to the 12^{th} day while the polycrystalline Si solar panel varied from the 8^{th} day to the 12^{th} day. The monocrystalline Si had a slightly higher voltage than the polycrystalline from the 8^{th} day to 14^{th} day.

The short-circuit current for both solar panels showed similar trend from the 1^{st} day to the 14^{th} day with the monocrystalline Si having a high current compared to the polycrystalline Si solar panel.

The maximum power output for both solar panels showed similar trend. The polycrystalline Si produced the highest maximum power output on the 9^{th} day compared to the monocrystalline Si solar panel. The maximum power for both solar panels varied from the 1^{st} day to the 14^{th} day. This is as a result of variance in the open-circuit voltage for both solar panels.

Based on the outdoor testing of the monocrystalline Si and polycrystalline Si solar panels carried out for fourteen days, the following conclusions were drawn:

(a) Open-circuit voltage for monocrystalline is high during the early hours of the day and toward the evening hours while the polycrystalline Si is high during midday and fairly constant between 10am and 3pm for most of the days. The open-circuit voltage for the monocrystalline Si varies compared to the polycrystalline Si solar panel.

(b) The monocrystalline Si produces high short-circuit current compared to the polycrystalline Si solar panel. The short-circuit current gradually increases during the early hours of the day and is dependent on the amount of insolation that are incident on both solar panels. Low short-circuit current is produced when there is cloudy weather for both solar panels.

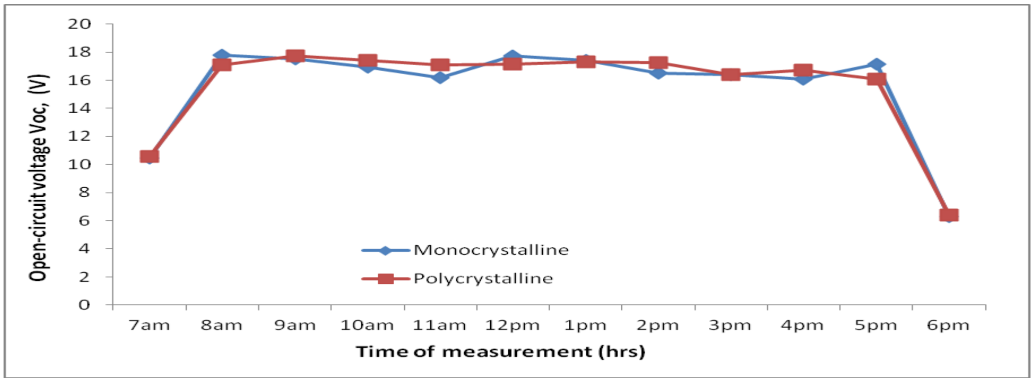
(c) The maximum power output is dependent on the amount of short-circuit current produced. Due to variation in the open-circuit voltage of the monocrystalline Si solar panel, the maximum power output is affected. The polycrystalline Si solar panel produced the highest maximum power output than the monocrystalline Si solar panel. This is because the polycrystalline Si had a high open-circuit voltage at that particular time of the day while the monocrystalline Si solar panel had a lower open-circuit voltage.

The following results were obtained for each day during the outdoor testing of the solar panels for the dry season

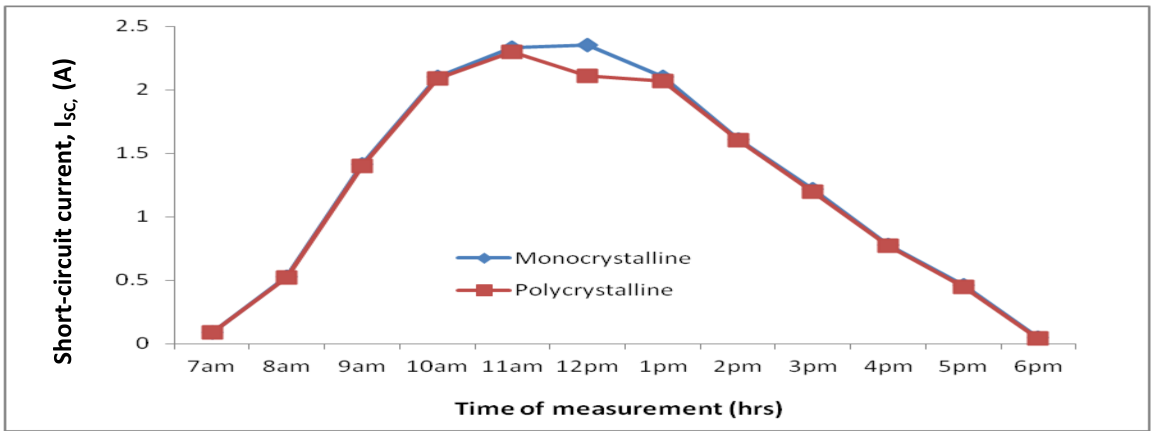
Day 1

Table 4.16: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) , short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day one (6th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(v)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(w)
7am	10.47	2.54	0.09	0.04	0.94	0.10	10.58	3.74	0.09	0.03	0.95	0.11
8am	17.78	6.02	0.53	0.33	9.42	1.99	17.12	15.34	0.52	0.33	8.90	5.06
9am	17.53	15.06	1.41	0.40	24.72	6.02	17.74	16.53	1.40	0.37	24.83	6.11
10am	16.93	16.27	2.10	0.44	35.55	7.16	17.39	15.42	2.09	0.43	36.34	6.63
11am	16.17	16.10	2.33	0.42	37.68	6.76	17.12	16.14	2.30	0.40	39.38	6.46
12pm	17.72	16.58	2.35	0.40	41.64	6.63	17.15	16.24	2.11	0.39	36.19	6.33
1pm	17.39	16.49	2.10	0.38	36.52	6.27	17.30	16.07	2.07	0.37	35.81	5.94
2pm	16.53	16.31	1.61	0.37	26.61	6.03	17.23	16.75	1.60	0.36	27.57	6.03
3pm	16.38	14.76	1.22	0.36	19.98	5.31	16.38	16.34	1.20	0.35	19.66	5.72
4pm	16.09	11.34	0.78	0.24	12.55	2.72	16.73	15.04	0.77	0.22	12.88	3.31
5pm	17.15	7.32	0.46	0.20	7.89	1.46	16.07	13.37	0.45	0.19	7.23	2.54
6pm	6.32	1.95	0.05	0.02	0.32	0.04	6.42	3.56	0.04	0.01	0.26	0.14



(a)



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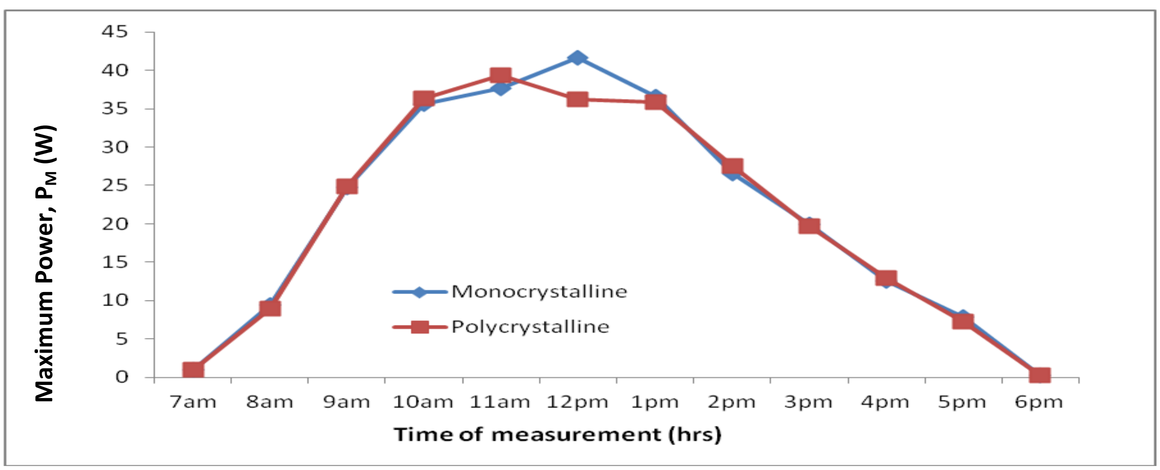


(c)

Fig 4.16: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.16 Discussion

Table 4.16 shows experimental results that were recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panel for Day 1(6th January, 2017). Also fig.4.16 (a-c) represent the time history of the measured parameters; Fig.4.16a shows the (V_{OC} - t) plot, fig.4.16b shows the (I_{SC} - t) plot while fig.4.16c shows the (P_M - t) curve.

The open-circuit voltage V_{OC} for the polycrystalline Si was fairly constant from 9am to 2pm while V_{OC} for monocrystalline Si varied.

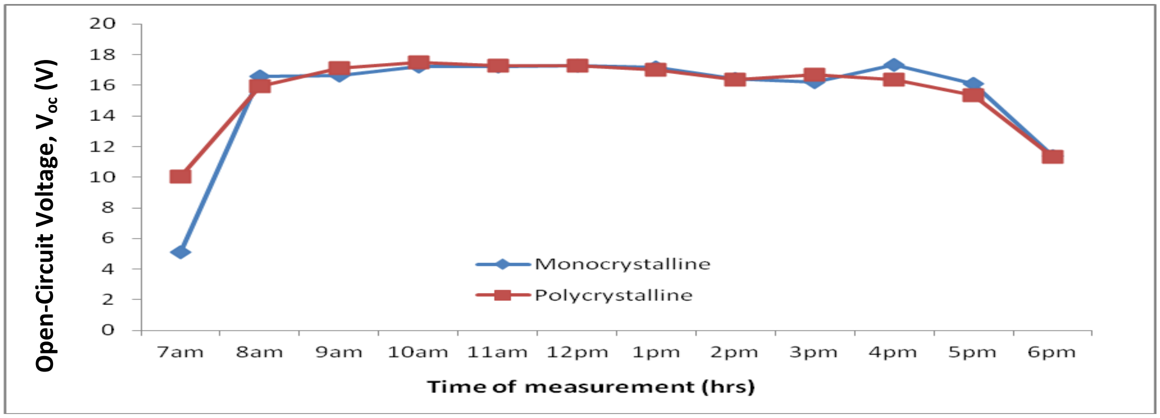
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend. It increased from 7am and peaks at 12pm before decreasing gradually.

The maximum power, P_M is dependent on the current. For this particular day, the maximum power for the monocrystalline Si was 41.64W and that of the polycrystalline Si was 39.38W and this happened at 12pm for the monocrystalline Si and 11am for the polycrystalline Si. Both solar panels also showed similar trend. The monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si for the first day.

Day 2

Table 4.17: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day two (7th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	5.10	2.28	0.09	0.06	0.46	0.14	10.03	03.74	0.09	0.05	0.90	0.19
8am	16.56	4.74	0.32	0.22	5.30	1.04	15.93	10.41	0.31	0.18	4.94	1.87
9am	16.62	15.75	0.97	0.32	16.12	5.04	17.12	16.34	0.95	0.30	16.26	4.90
10am	17.21	14.30	1.44	0.35	24.78	5.01	17.51	16.04	1.42	0.34	24.86	5.45
11am	17.24	15.20	2.31	0.38	39.82	5.78	17.29	16.07	2.25	0.37	38.90	5.95
12pm	17.27	15.17	2.34	0.40	40.41	6.07	17.28	16.08	2.11	0.39	36.46	6.27
1pm	17.15	16.74	1.73	0.37	29.67	6.19	17.01	16.59	1.64	0.36	27.90	5.97
2pm	16.39	16.34	1.54	0.36	25.24	5.88	16.35	16.12	1.52	0.35	24.85	5.64
3pm	16.22	13.23	1.04	0.33	16.87	4.37	16.66	15.15	1.01	0.32	16.83	4.85
4pm	17.35	14.78	0.64	0.26	11.10	3.84	16.36	14.36	0.63	0.24	10.31	3.45
5pm	16.08	9.16	0.31	0.20	4.98	1.83	15.33	10.15	0.29	0.19	4.45	1.83
6pm	11.38	2.58	0.10	0.08	1.14	0.21	11.31	03.61	0.08	0.06	0.90	0.22



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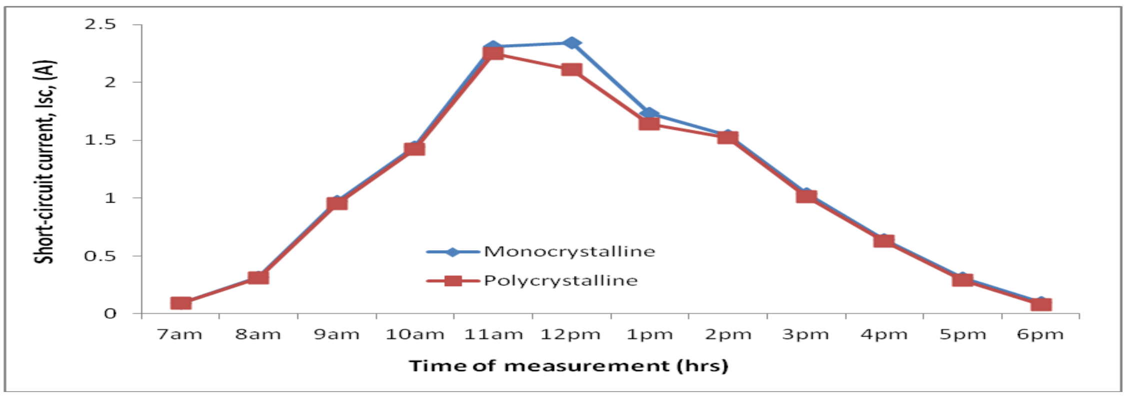

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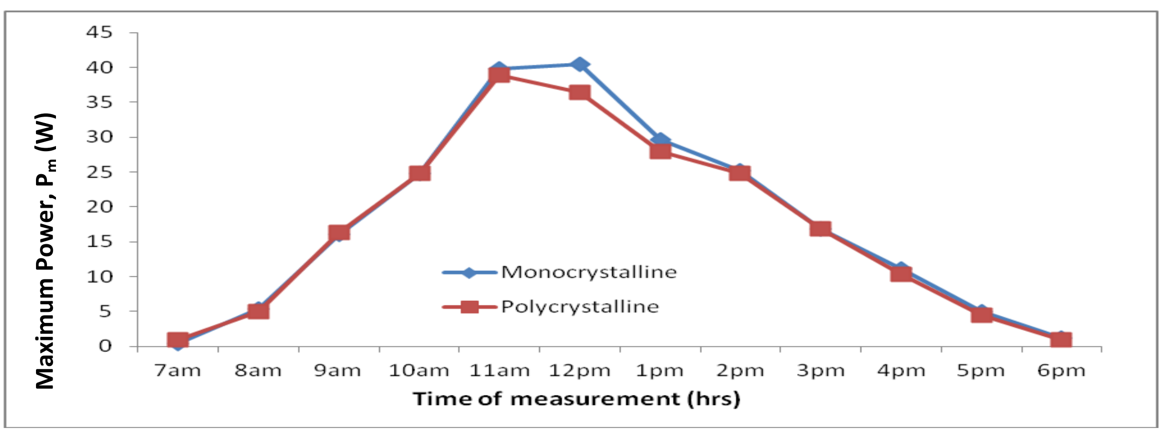


(c)

Fig 4.17: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.17 Discussion

Table 4.17 shows experimental results that were recorded during the 2nd day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (7th January, 2017). Also fig.4.17 (a-c) represent the time history of the measured parameters; Fig.4.17a shows the (V_{OC} - t) plot, fig.4.17b shows the (I_{SC} - t) plot while fig.4.17c shows the (P_M - t) curve.

For the monocrystalline Si, the open-circuit voltage fluctuated from 8am to 3pm compared to the polycrystalline Si. The open-circuit voltage for the polycrystalline Si was fairly constant from 9am to 4pm.

The short circuit current increased gradually from 7am and peaked at 12pm for the monocrystalline Si and 11am for the polycrystalline Si solar panel. Similar trend was observed for both solar panels as shown in figure 4.17.

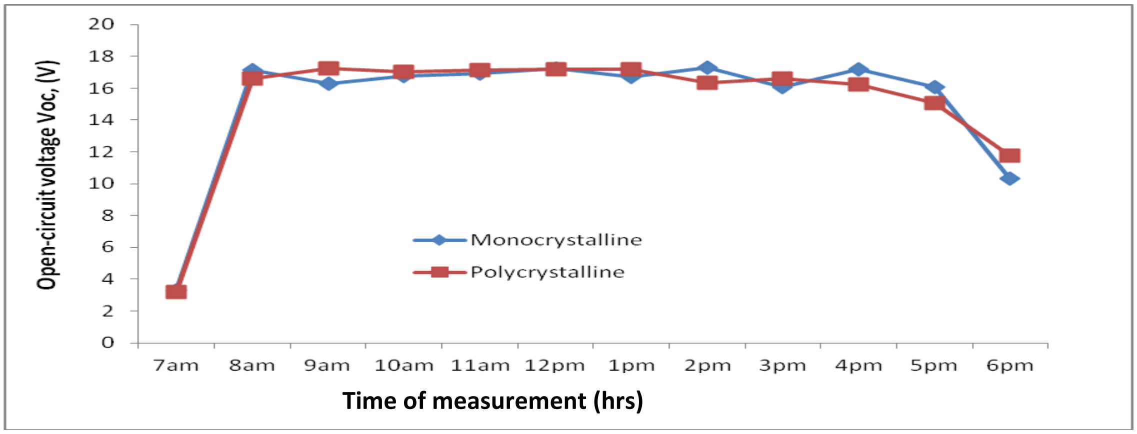
The maximum power, P_M for the monocrystalline Si was 40.41W and that of the polycrystalline Si was 38.90W and this happened at 12pm for the monocrystalline Si and 11am for the polycrystalline Si. Similar trend was observed for maximum power (P_M) for both solar panels.

For the 2nd day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si.

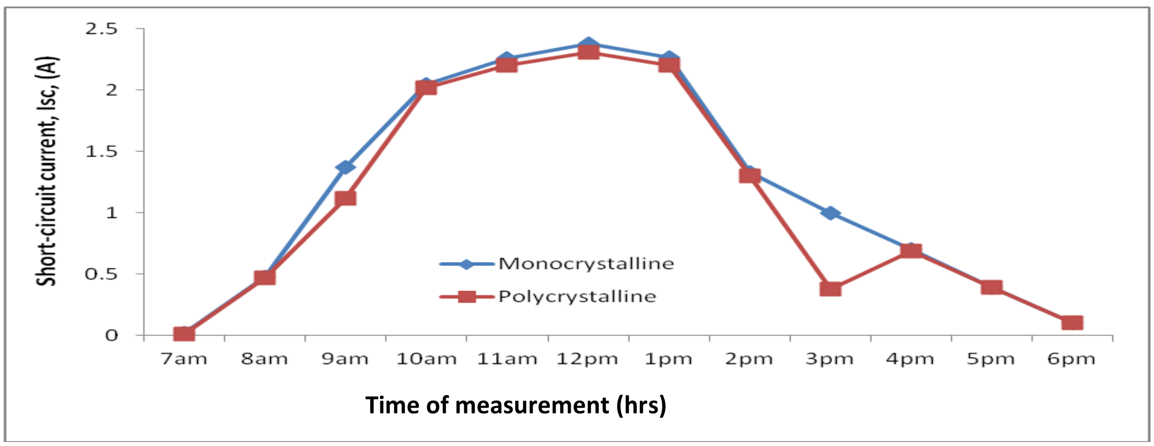
Day 3

Table 4.18: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day three (8th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	3.28	1.18	0.02	0.01	0.07	0.11	3.18	2.23	0.01	0.01	0.03	0.22
8am	17.16	7.10	0.48	0.24	8.24	1.70	16.62	14.12	0.47	0.23	7.81	3.25
9am	16.29	15.18	1.37	0.35	22.32	5.31	17.22	16.39	1.12	0.34	19.29	5.57
10am	16.75	16.31	2.05	0.38	34.34	6.20	17.01	16.50	2.02	0.35	34.36	5.78
11am	16.95	16.42	2.26	0.39	38.31	6.40	17.12	16.14	2.20	0.38	37.66	6.13
12pm	17.25	16.58	2.38	0.42	41.06	6.96	17.19	16.01	2.31	0.40	39.71	6.40
1pm	16.70	16.11	2.27	0.40	37.91	6.44	17.21	17.03	2.20	0.39	37.86	6.64
2pm	17.32	15.26	1.33	0.36	23.04	5.49	16.36	16.10	1.30	0.33	21.27	5.31
3pm	16.05	12.56	1.00	0.34	16.05	4.27	16.62	15.07	0.38	0.32	6.32	4.82
4pm	17.19	14.77	0.70	0.29	12.03	4.28	16.22	14.19	0.69	0.28	11.19	3.97
5pm	16.07	10.12	0.39	0.20	6.27	2.02	15.05	13.01	0.39	0.20	5.87	2.60
6pm	10.35	2.18	0.10	0.05	1.04	0.11	11.77	3.63	0.10	0.05	1.18	0.18



(a)



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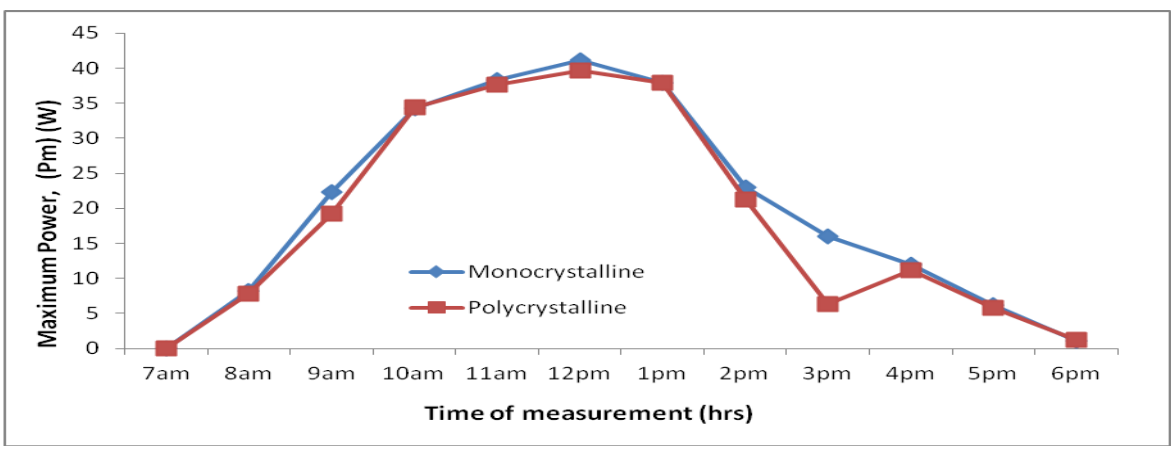


(c)

Fig 4.18: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.18 Discussion

Table 4.18 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (8th January, 2017). Also fig.4.18 (a-c) represent the time history of the measured parameters; Fig.4.18a shows the (V_{OC} - t) plot, fig.4.18b shows the (I_{SC} - t) plot while fig.4.18c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si had a higher V_{OC} from 9am to 1pm while the monocrystalline Si was high at 2pm and from 4pm to 5pm. From figure 4.18, both solar panels were fairly constant from 9am to 1pm and varied after then.

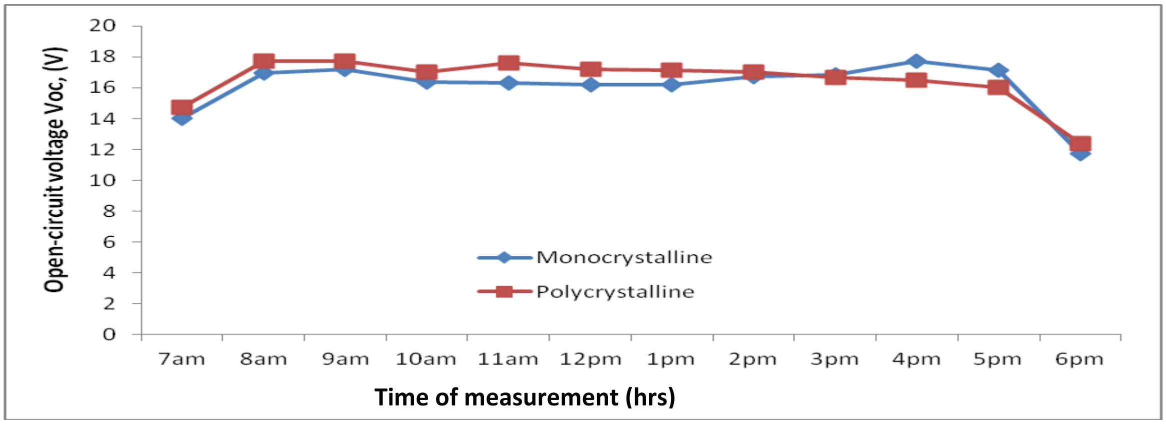
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend. The short-circuit current for monocrystalline Si was higher than that of the polycrystalline Si. The short-circuit current for both solar panels increased from 7am and peaked at 12pm then decreased gradually.

The maximum power, P_M is dependent on the current. For the 3rd day, the maximum power for the monocrystalline Si was 41.06W and that of the polycrystalline Si was 39.71W and this happened at 12pm at the very time the current reached its maximum. The monocrystalline Si solar panel produced the high maximum power output for the 3rd day.

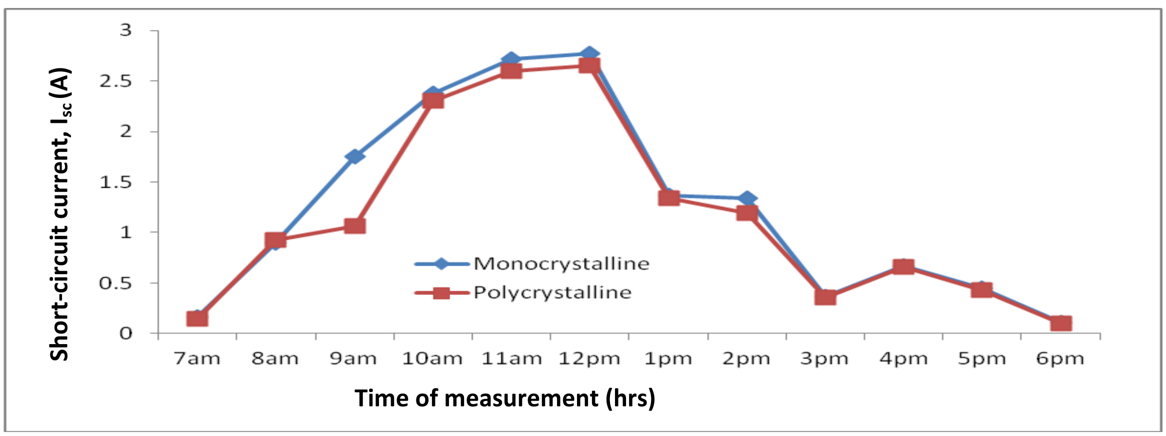
Day 4

Table 4.19: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day four (9th January, 2017).

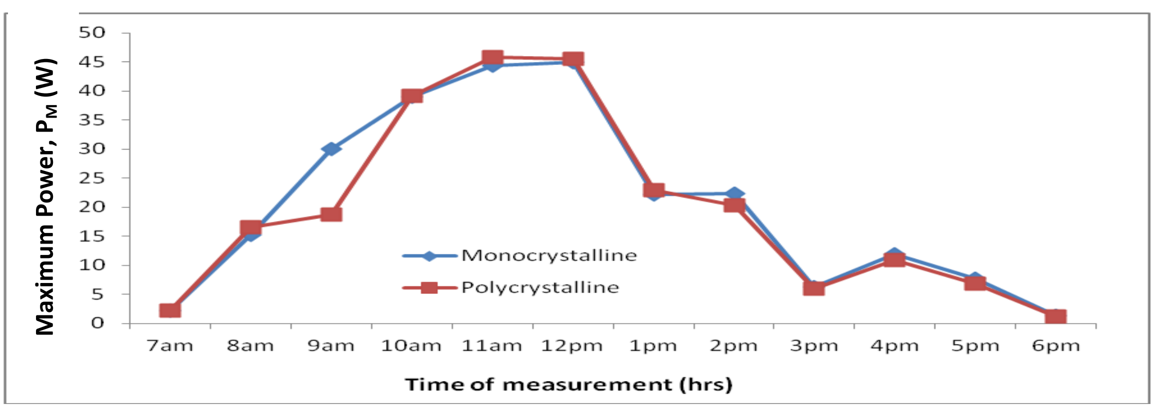
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	14.05	3.03	0.16	0.08	2.25	0.24	14.73	6.00	0.15	0.06	2.21	0.36
8am	16.93	11.73	0.90	0.31	15.24	3.64	17.71	16.03	0.93	0.31	16.47	4.97
9am	17.18	17.02	1.75	0.33	30.07	5.62	17.72	17.24	1.06	0.32	18.78	5.52
10am	16.39	16.12	2.38	0.35	39.00	5.64	17.04	17.16	2.30	0.34	39.19	5.83
11am	16.30	16.25	2.72	0.37	44.34	6.01	17.60	17.14	2.60	0.36	45.76	6.17
12pm	16.22	16.16	2.77	0.39	44.93	6.30	17.19	17.13	2.65	0.38	45.55	6.51
1pm	16.19	16.02	1.37	0.36	22.18	5.77	17.15	16.72	1.34	0.35	22.98	5.85
2pm	16.71	16.45	1.34	0.36	22.39	5.92	17.04	16.31	1.19	0.35	20.28	5.71
3pm	16.86	16.53	0.37	0.25	6.24	4.13	16.68	15.33	0.36	0.24	6.00	3.68
4pm	17.70	16.95	0.67	0.30	11.86	5.09	16.47	15.13	0.66	0.30	10.87	4.54
5pm	17.15	16.75	0.45	0.28	7.72	4.69	16.04	13.95	0.43	0.27	6.90	3.77
6pm	11.74	3.62	0.11	0.06	1.29	0.22	12.37	3.70	0.10	0.05	1.24	0.19



(a)



(b)



(c)

Fig 4.19: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.19 Discussion

Table 4.19 shows experimental results recorded during the 4th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (9th of January, 2017). Also fig.4.19 (a-c) represent the time history of the measured parameters; Fig.4.19a shows the (V_{OC} - t) plot, fig.4.19b shows the (I_{SC} - t) plot while fig.4.19c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels are fairly constant from 10am to 3pm. The polycrystalline Si has a higher voltage than the monocrystalline Si from 7am to 2pm.

The short circuit current increased gradually from 8am and peaked at 12pm then varied thereafter for both panels. The monocrystalline Si produced a higher current than the polycrystalline Si from 8am to 12pm. A similar trend was observed for both solar panels for I_{SC} as shown in figure 4.19.

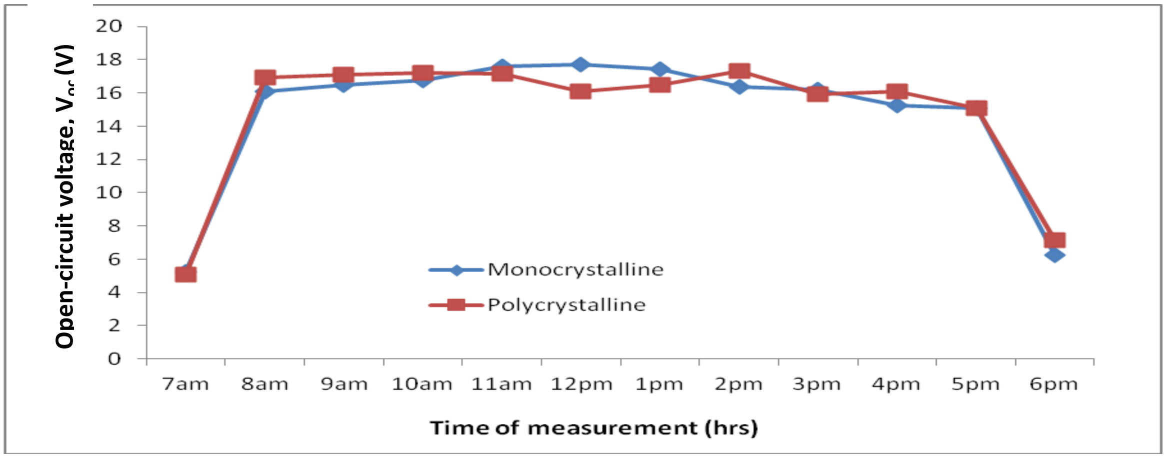
The maximum power, P_M for the monocrystalline Si was 44.93W and that of the polycrystalline Si was 45.76W and this happened at 12pm for the monocrystalline Si and 11am for the polycrystalline Si.

For the 4th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si.

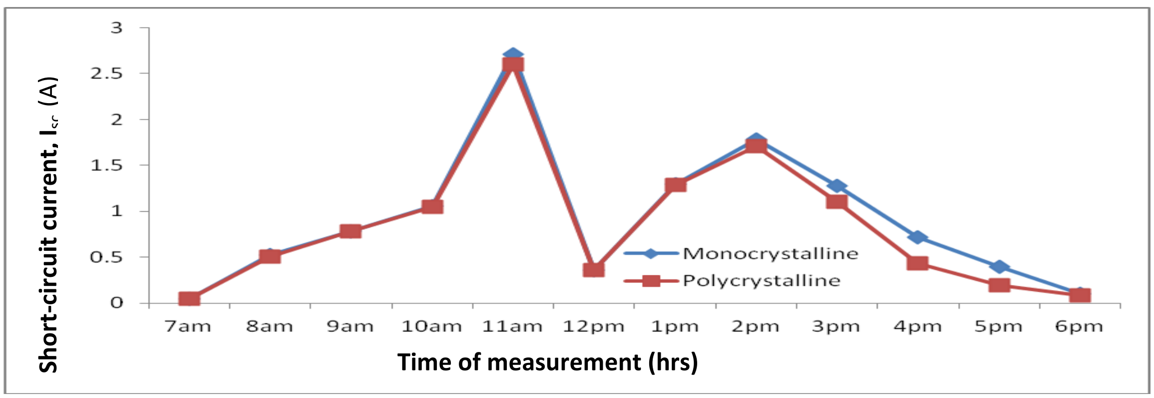
Day 5

Table 4.20: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L) , short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day five (10th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	5.24	3.81	0.05	0.02	0.26	0.08	5.05	3.76	0.05	0.02	0.25	0.08
8am	16.08	15.62	0.53	0.29	8.52	4.53	16.93	15.15	0.51	0.28	8.63	4.24
9am	16.48	16.25	0.78	0.30	12.85	4.88	17.10	16.30	0.78	0.30	13.34	4.89
10am	16.78	16.41	1.06	0.32	17.79	5.25	17.19	16.57	1.05	0.31	18.05	5.14
11am	17.59	17.20	2.71	0.39	47.67	6.71	17.14	17.04	2.60	0.38	44.56	6.48
12pm	17.74	17.53	0.36	0.25	6.39	4.38	16.10	15.68	0.36	0.25	5.80	3.92
1pm	17.42	16.95	1.30	0.32	22.65	5.42	16.50	15.82	1.29	0.31	21.29	4.90
2pm	16.35	16.13	1.78	0.34	29.10	5.48	17.30	16.01	1.71	0.33	29.58	5.28
3pm	16.18	15.82	1.28	0.32	20.71	5.06	15.90	15.49	1.10	0.30	17.49	4.65
4pm	15.24	15.03	0.72	0.18	10.97	2.71	16.10	15.88	0.43	0.14	6.92	2.22
5pm	15.10	11.93	0.40	0.15	6.04	1.79	15.08	8.22	0.20	0.12	3.02	0.99
6pm	6.25	3.96	0.10	0.05	0.63	0.20	7.15	3.56	0.09	0.03	0.64	0.11



(a)



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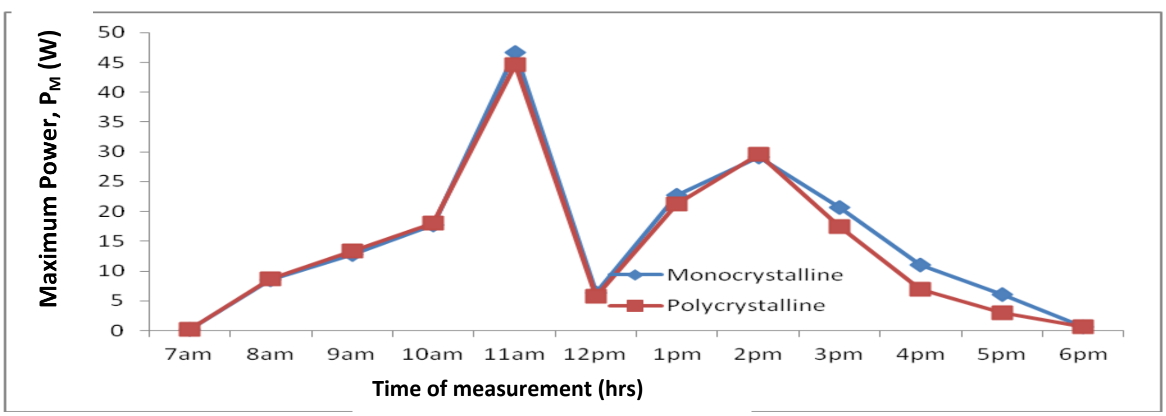


(c)

Fig 4.20: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.20 Discussion

Table 4.20 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (10th January, 2017). Also fig.4.20 (a-c) represent the time history of the measured parameters; Fig.4.20a shows the (V_{OC} - t) plot, fig.4.20b shows the (I_{SC} - t) plot while fig.4.20c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels varied from 10am to 4pm and decreased thereafter.

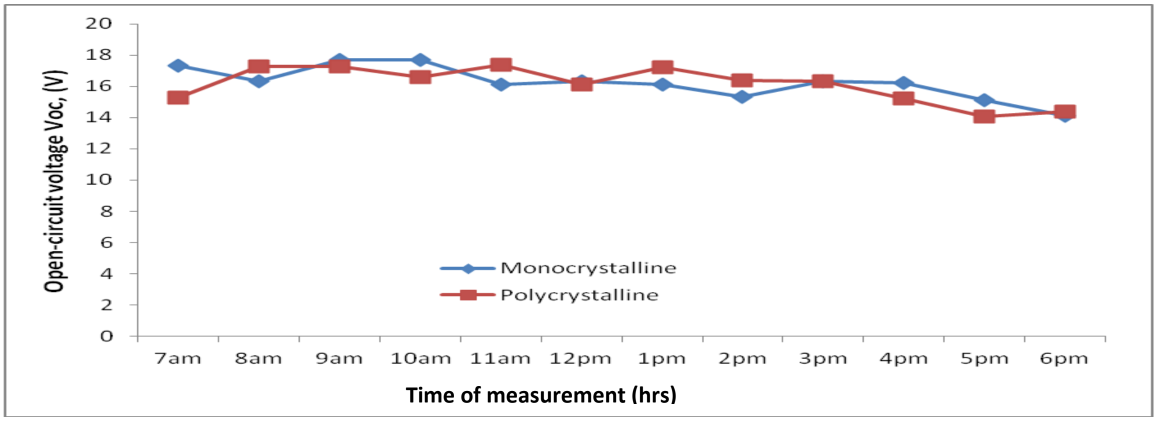
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend. The short-circuit current for both panels increased from 7am and peaked at 11am then varied before decreasing gradually. The decrease was as a result of the harmattan season as low sunlight was observed.

For the 5th day, the maximum power for the monocrystalline Si was 47.67W and that of the polycrystalline Si was 44.56W and this happened at 11am .The monocrystalline Si solar panel produced a high maximum power than the polycrystalline Si.

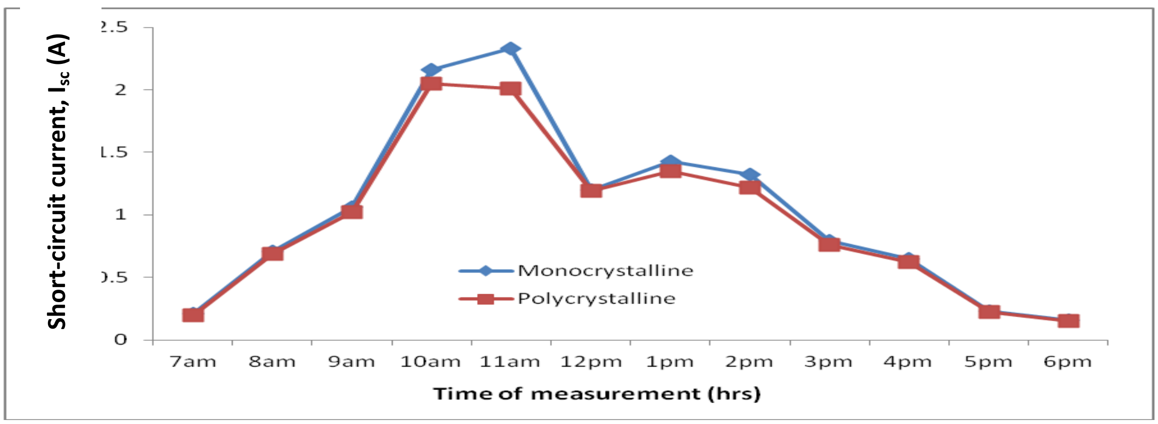
Day 6

Table 4.21: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day six (11th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	17.31	10.15	0.21	0.15	3.64	1.52	15.29	7.01	0.20	0.14	3.04	0.98
8am	16.35	16.10	0.71	0.30	11.61	4.83	17.26	16.04	0.69	0.29	11.91	4.65
9am	17.71	16.52	1.06	0.33	18.77	5.45	17.25	15.33	1.02	0.32	17.60	4.91
10am	17.70	16.65	2.16	0.39	38.23	6.49	16.60	15.90	2.05	0.38	34.03	6.04
11am	16.13	16.05	2.33	0.38	37.58	6.10	17.39	17.22	2.01	0.37	34.95	6.37
12pm	16.32	16.21	1.20	0.34	19.58	5.51	16.10	15.79	1.19	0.34	19.16	5.37
1pm	16.10	15.95	1.43	0.36	23.02	5.74	17.20	16.10	1.35	0.35	23.22	5.64
2pm	15.34	15.15	1.32	0.35	20.25	5.30	16.40	16.26	1.22	0.34	20.00	5.53
3pm	16.35	16.21	0.79	0.31	12.92	5.03	16.32	15.11	0.76	0.30	12.40	4.53
4pm	16.20	8.10	0.65	0.29	10.53	3.23	15.20	15.08	0.62	0.28	9.42	4.22
5pm	15.13	6.39	0.23	0.16	3.48	1.02	14.05	6.24	0.22	0.12	3.09	0.75
6pm	14.12	5.37	0.16	0.07	2.26	0.38	14.36	6.78	0.15	0.06	2.15	0.41



(a)



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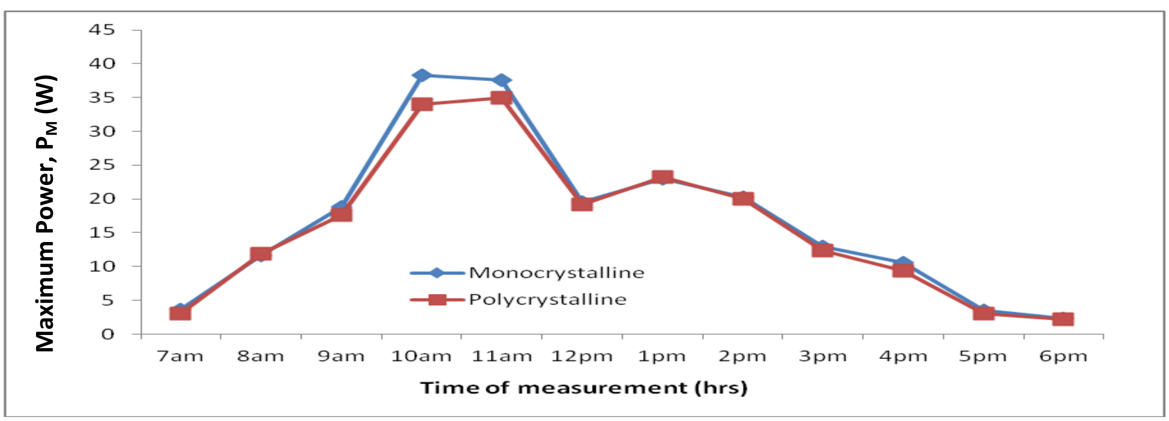


(c)

Fig 4.21: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.21 Discussion

Table 4.21 shows experimental results recorded during the 6th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (11th of January, 2017). Also fig.4.21 (a-c) represent the time history of the measured parameters; Fig.4.21a shows the (V_{OC} - t) plot, fig.4.21b shows the (I_{SC} - t) plot while fig.4.21c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels varied from 7am to 3pm and decreased thereafter.

The short circuit current increased gradually from 8am and peaks at 11am for both panels. The monocrystalline Si produced a higher current than the polycrystalline Si from 9am to 2pm. A similar trend was observed in the I_{SC} for both solar panels as shown in figure 4.21.

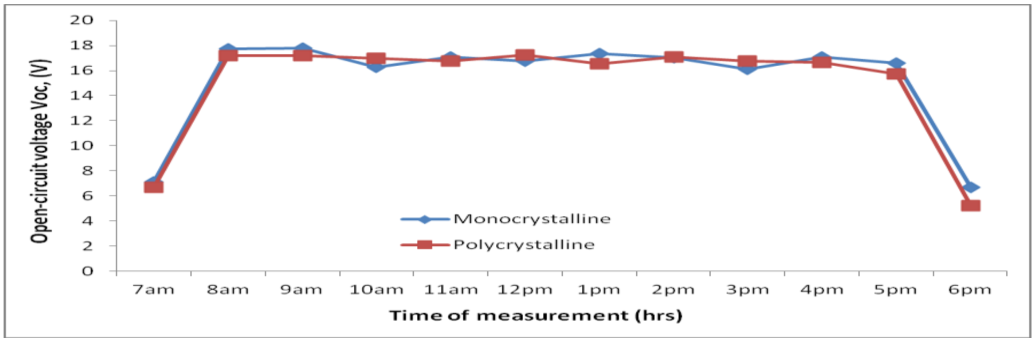
The maximum power, P_M for the monocrystalline Si was 38.23W and that of the polycrystalline Si was 34.95W and this happened at 10am for the monocrystalline Si and 11am for the polycrystalline Si.

For the 6th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si.

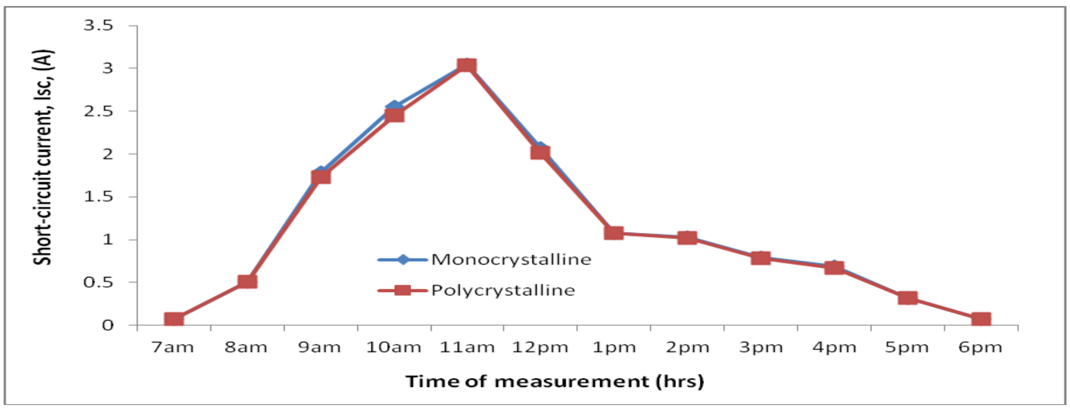
Day 7

Table 4.22: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day seven (12th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	7.15	2.25	0.07	0.02	0.50	0.05	6.69	3.65	0.07	0.01	0.47	0.04
8am	17.74	15.04	0.51	0.22	9.05	3.31	17.20	16.01	0.51	0.20	8.77	3.20
9am	17.77	17.01	1.79	0.28	31.81	4.76	17.17	16.54	1.73	0.25	29.70	4.14
10am	16.29	16.02	2.55	0.32	41.54	5.13	16.99	16.42	2.45	0.30	41.63	4.93
11am	17.07	16.30	3.05	0.36	52.06	5.89	16.76	16.20	3.04	0.35	50.95	5.67
12pm	16.77	16.31	2.07	0.38	34.71	6.20	17.24	16.06	2.01	0.36	34.65	5.78
1pm	17.35	16.38	1.08	0.36	18.74	5.89	16.53	15.07	1.08	0.34	17.85	5.12
2pm	17.02	16.58	1.03	0.30	17.53	4.97	17.07	16.38	1.02	0.29	17.41	4.75
3pm	16.12	16.07	0.79	0.31	12.73	4.98	16.74	15.08	0.78	0.30	13.06	4.52
4pm	17.07	16.18	0.69	0.33	11.78	5.34	16.64	15.11	0.67	0.32	11.15	4.84
5pm	16.60	11.38	0.32	0.25	5.31	2.85	15.73	11.64	0.32	0.24	5.03	2.79
6pm	6.68	3.54	0.07	0.03	0.47	0.11	5.24	3.55	0.07	0.02	0.37	0.07



(a)



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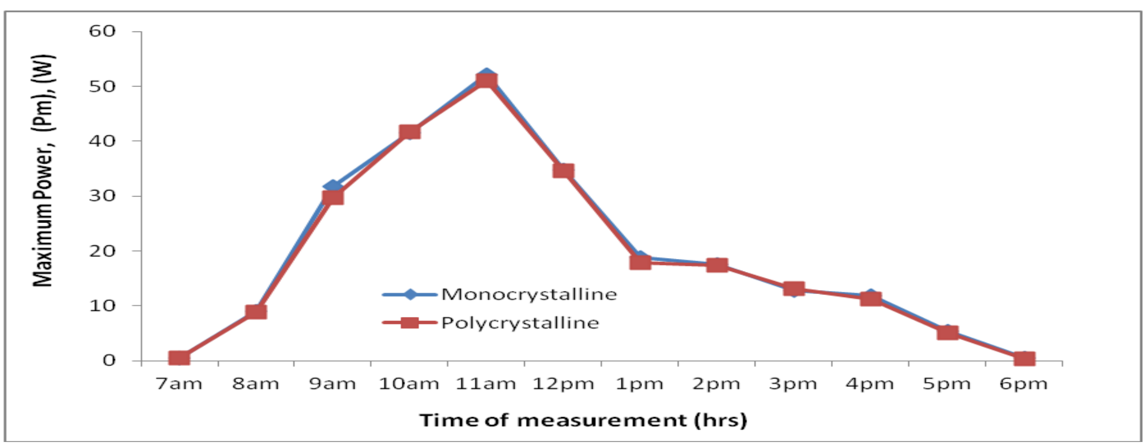


(c)

Fig 4.22: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.22 Discussion

Table 4.22 shows experimental results recorded during the 7th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (12th of January, 2017). Also fig.4.22 (a-c) represent the time history of the measured parameters; Fig.4.22a shows the (V_{OC} - t) plot, fig.4.22b shows the (I_{SC} - t) plot while fig.4.22c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si was fairly constant from 8am to 11am and varied thereafter while the monocrystalline Si varied from 9am to 4pm.

The short circuit current increased gradually from 7am and peaked at 11am for both solar panels. Similar trend was observed in the I_{SC} for both solar panels as shown in figure 4.22.

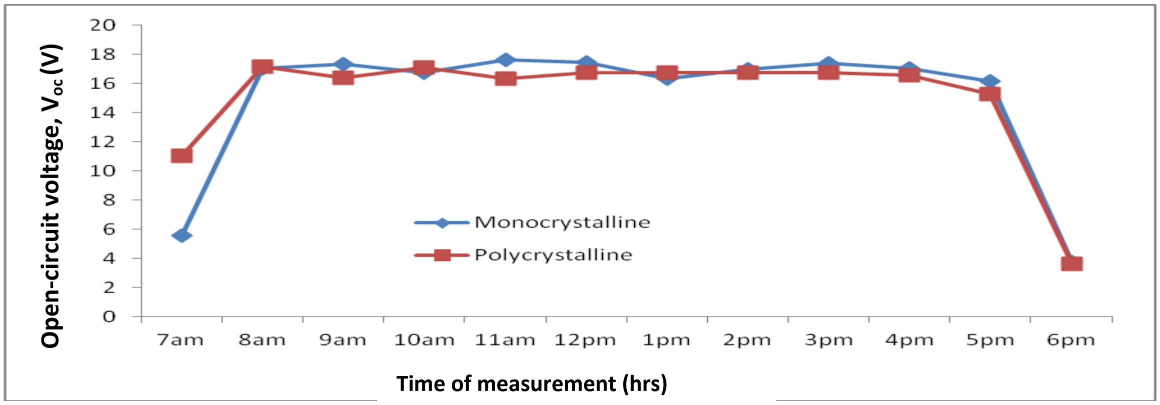
The maximum power, P_M for the monocrystalline Si was 41.54W and that of the polycrystalline Si was 41.63W and this happened at 11am at the very time the current reached maximum.

For the 7th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

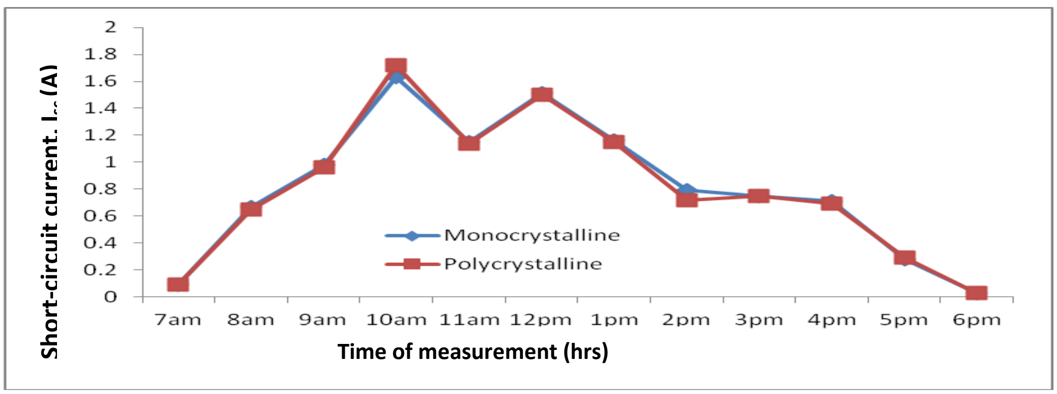
Day 8

Table 4.23: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day eight (13th January, 2017).

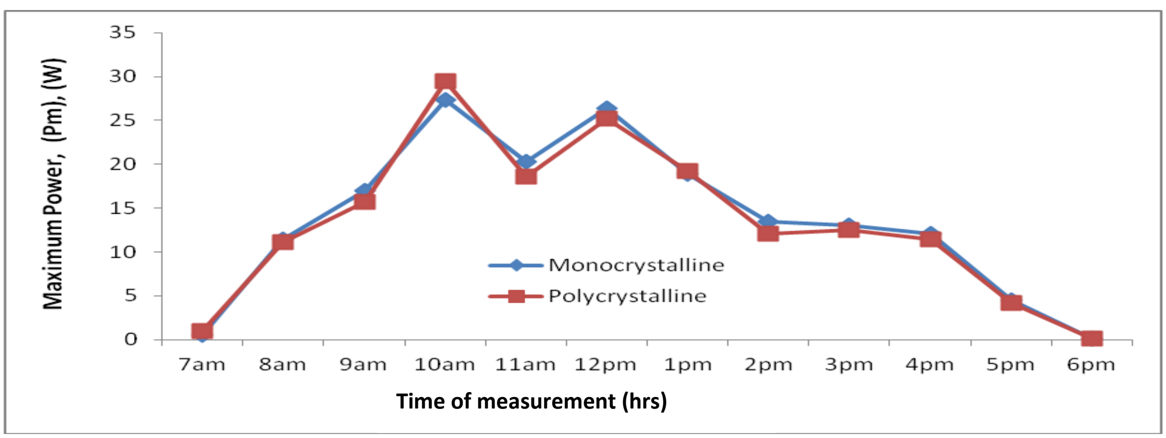
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	5.54	3.31	0.09	0.06	0.50	0.20	11.05	03.65	0.09	0.05	0.99	0.18
8am	17.07	17.00	0.67	0.36	11.44	6.12	17.16	16.18	0.65	0.35	11.15	5.66
9am	17.35	17.26	0.98	0.45	17.00	7.77	16.38	16.26	0.96	0.43	15.72	7.00
10am	16.74	16.24	1.63	0.40	27.29	6.50	17.12	16.74	1.72	0.39	29.45	6.53
11am	17.65	17.01	1.15	0.36	20.30	6.12	16.31	16.14	1.14	0.35	18.59	5.65
12pm	17.47	16.18	1.51	0.38	26.38	6.15	16.77	16.25	1.50	0.36	25.16	5.85
1pm	16.31	15.31	1.16	0.35	18.92	5.36	16.76	16.13	1.15	0.33	19.27	5.32
2pm	17.00	16.38	0.79	0.33	13.43	5.41	16.74	15.18	0.72	0.32	12.05	4.86
3pm	17.38	16.64	0.75	0.30	13.04	4.99	16.72	15.73	0.75	0.29	12.54	4.56
4pm	17.04	16.04	0.71	0.29	12.10	4.65	16.57	15.14	0.69	0.28	11.43	4.24
5pm	16.16	10.39	0.28	0.20	4.52	2.08	15.27	5.74	0.27	0.19	4.12	1.09
6pm	3.71	3.11	0.03	0.01	0.11	0.03	3.65	3.13	0.03	0.01	0.11	0.03



(a)



(b)



(c)

Fig 4.23: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.23 Discussion

Table 4.23 shows experimental results recorded during the outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (13th January, 2017). Also fig.4.23 (a-c) represent the time history of the measured parameters; Fig.4.23a shows the (V_{OC} - t) plot, fig.4.23b shows the (I_{SC} - t) plot while fig.4.23c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels varied from 8am to 1pm with the monocrystalline Si having a high voltage than the polycrystalline Si. From figure 4.23, both panels were fairly constant from 1pm to 5pm before decreasing.

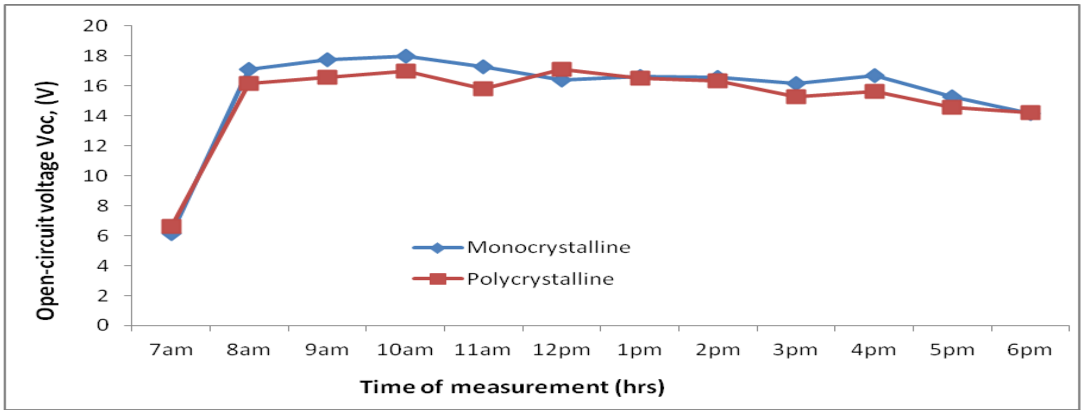
The short-circuit current I_{SC} for both the monocrystalline Si and polycrystalline Si showed similar trend from figure 4.23. The short-circuit current for both panels increased from 7am and peaked at 10am and varied thereafter. The variation was as a result of the harmattan as low sunlight was observed intermittently.

For the 8th day, the maximum power for the monocrystalline Si was 27.29W and that of the polycrystalline Si was 29.45W and this happened at 10am at the very time the current reached its maximum. The polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

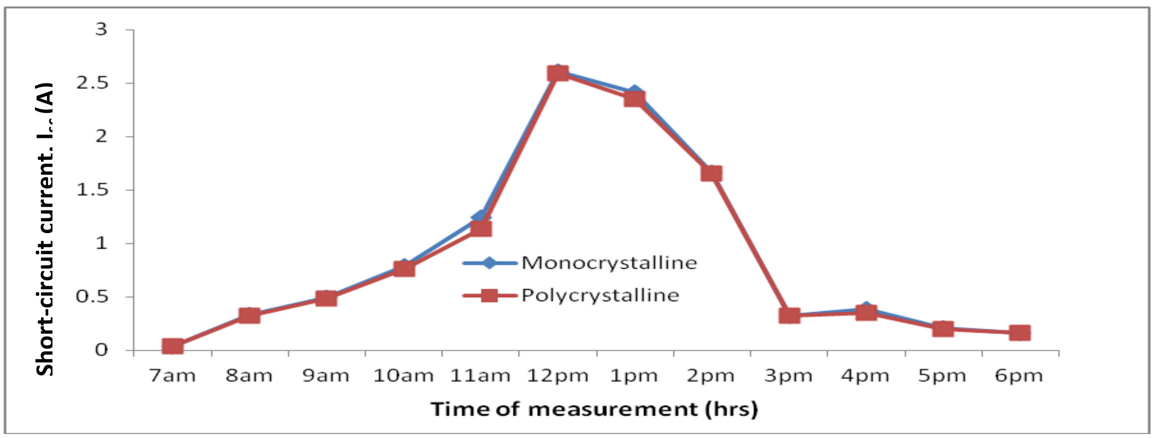
Day 9

Table 4.24: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day nine (14th January, 2017).

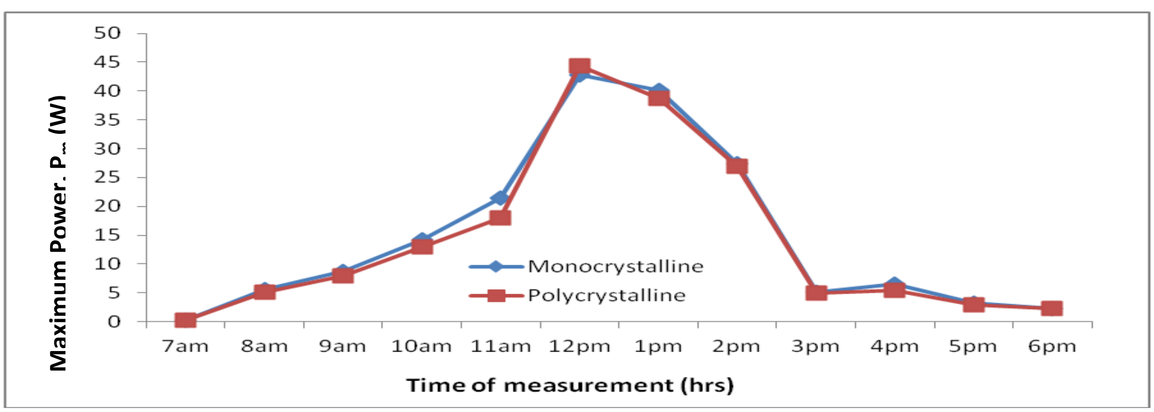
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	6.12	3.53	0.04	0.01	0.24	0.04	6.60	3.98	0.04	0.01	0.26	0.04
8am	17.07	11.74	0.33	0.28	5.63	3.29	16.15	12.15	0.32	0.26	5.17	3.16
9am	17.73	15.49	0.49	0.40	8.69	6.20	16.56	14.72	0.48	0.38	7.95	5.59
10am	17.95	16.98	0.79	0.37	14.18	6.28	16.98	16.07	0.76	0.36	12.90	5.79
11am	17.24	16.70	1.24	0.39	21.38	6.51	15.79	15.30	1.14	0.37	18.00	5.66
12pm	16.38	16.15	2.61	0.35	42.75	5.65	17.10	16.72	2.59	0.34	44.29	5.68
1pm	16.65	16.45	2.41	0.38	40.13	6.25	16.50	16.25	2.35	0.35	38.76	5.69
2pm	16.55	16.25	1.66	0.36	27.47	5.85	16.33	16.14	1.65	0.34	26.94	5.49
3pm	16.15	12.53	0.32	0.28	05.17	3.51	15.28	12.12	0.32	0.25	4.89	3.03
4pm	16.68	13.25	0.39	0.22	6.51	2.91	15.65	12.71	0.35	0.20	5.48	2.54
5pm	15.27	5.18	0.21	0.15	3.21	0.78	14.57	7.69	0.20	0.10	2.91	0.77
6pm	14.14	6.72	0.16	0.08	2.26	0.54	14.18	6.32	0.16	0.05	2.27	0.32



(a)



(b)



(c)

Fig 4.24: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.24 Discussion

Table 4.24 shows experimental results recorded during the 9th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (14th of January, 2017). Also fig.4.24 (a-c) represent the time history of the measured parameters; Fig.4.24a shows the (V_{OC} - t) plot, fig.4.24b shows the (I_{SC} - t) plot while fig.4.24c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si varied from 10am to 4pm while the monocrystalline Si was fairly constant from 12pm to 4pm.

The short circuit current increased gradually from 7am and peaked at 12pm for both solar panels before declining due to low sunlight. Similar trend was observed in the I_{SC} for both solar panels as shown in figure 4.24.

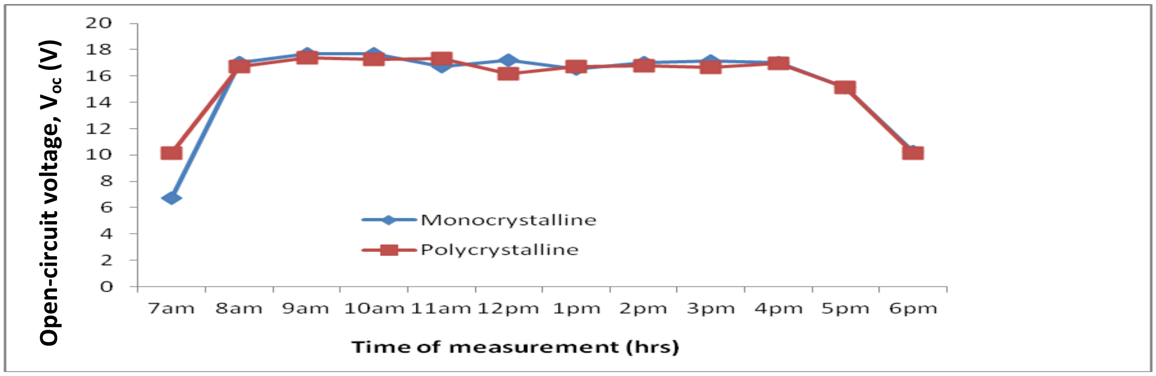
The maximum power, P_M for the monocrystalline Si was 42.75W and that of the polycrystalline Si was 44.29W and this happened at 12pm at the very time the current reached maximum.

For the 9th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

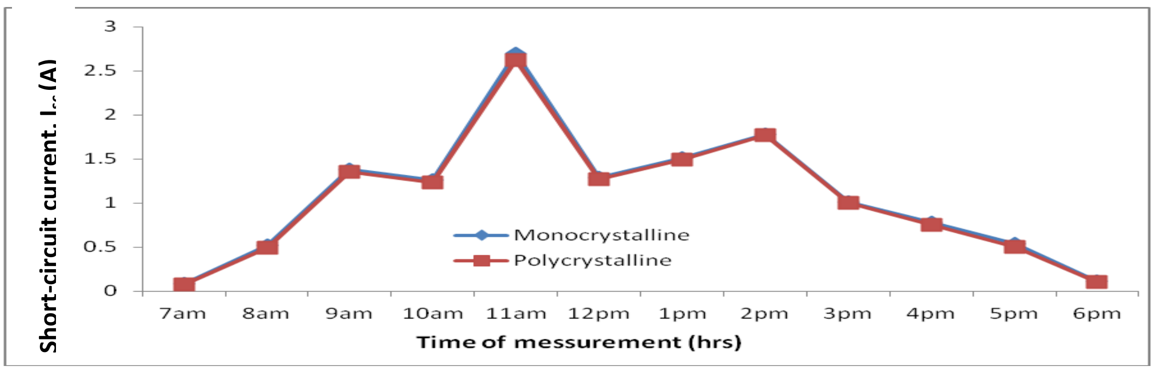
Day 10

Table 4.25: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day ten (15th January, 2017).

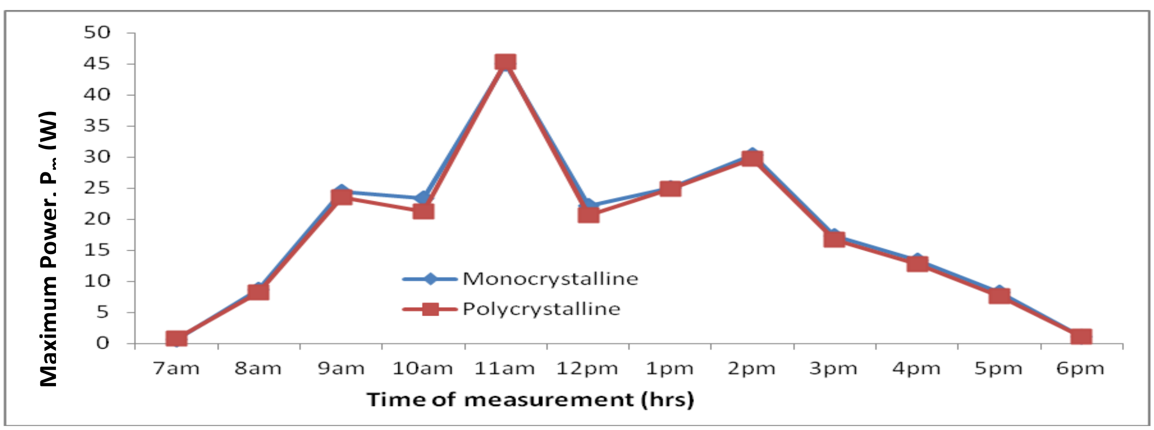
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	6.74	3.74	0.09	0.06	0.61	0.22	10.17	3.75	0.08	0.04	0.81	0.15
8am	17.02	14.65	0.52	0.28	8.85	4.10	16.70	14.66	0.49	0.26	8.18	3.81
9am	17.71	17.17	1.38	0.33	24.44	5.67	17.37	16.35	1.35	0.30	23.45	4.91
10am	17.72	17.32	1.26	0.35	23.33	6.06	17.25	16.64	1.23	0.34	21.22	5.66
11am	16.70	15.22	2.70	0.39	45.09	5.94	17.32	17.02	2.62	0.38	45.38	6.47
12pm	17.19	17.08	1.29	0.34	22.18	5.81	16.19	15.67	1.27	0.33	20.56	5.17
1pm	16.56	16.22	1.51	0.36	25.01	5.84	16.72	16.45	1.49	0.36	24.91	5.92
2pm	17.05	16.66	1.78	0.37	30.35	6.16	16.78	16.14	1.77	0.37	29.70	5.97
3pm	17.15	16.16	1.01	0.32	17.32	5.17	16.68	15.15	1.00	0.31	16.68	4.70
4pm	17.02	16.09	0.78	0.29	13.28	4.67	16.95	16.53	0.75	0.28	12.71	4.63
5pm	15.13	15.06	0.54	0.27	8.17	4.07	15.11	14.72	0.50	0.25	7.56	3.68
6pm	10.24	6.15	0.11	0.06	1.13	0.37	10.13	7.54	0.10	0.05	1.01	0.38



(a)



(b)



(c)

Fig 4.25: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.25 Discussion

Table 4.25 shows experimental results recorded during the 10th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (15th of January, 2017). Also fig.4.25 (a-c) represent the time history of the measured parameters; Fig.4.25a shows the (V_{OC} - t) plot, fig.4.25b shows the (I_{SC} - t) plot while fig.4.25c shows the (P_M - t) curve.

For the open-circuit voltage, both panels were fairly constant from 1pm to 4pm before declining. Similar trend was observed in the V_{OC} for both solar panels as shown in figure 4.25.

The short circuit current varied from 9am to 3pm for both panels before decreasing.

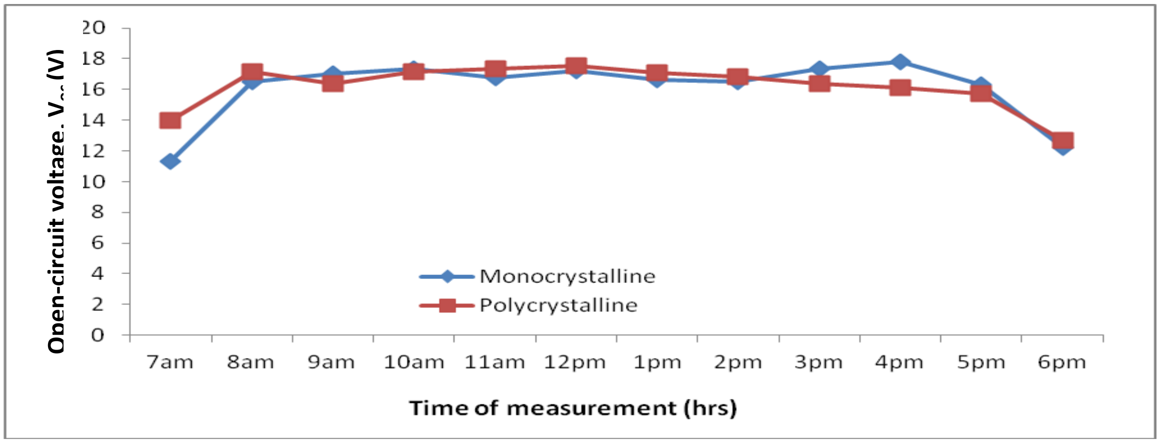
The maximum power, P_M for the monocrystalline Si was 45.09W and that of the polycrystalline Si was 45.38W and this happened at 11am at the very time the current reached maximum.

For the 10th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

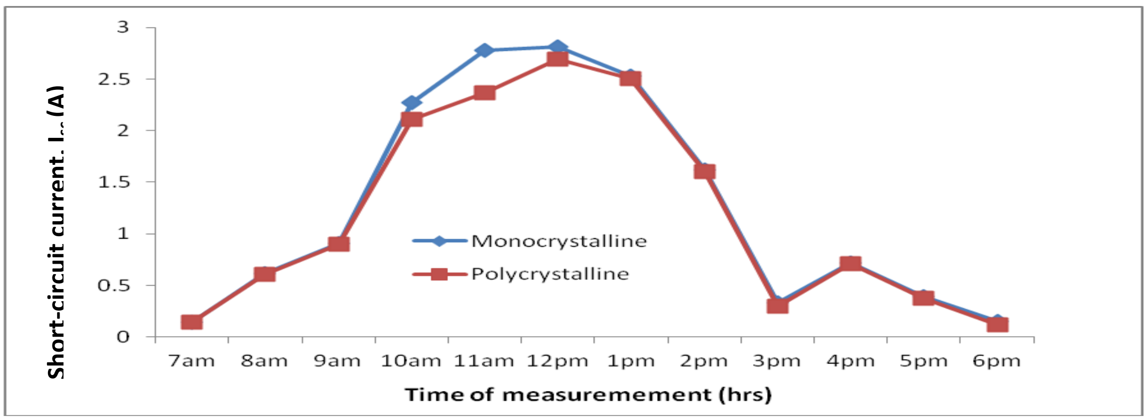
Day 11

Table 4.26: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day eleven (16th January, 2017).

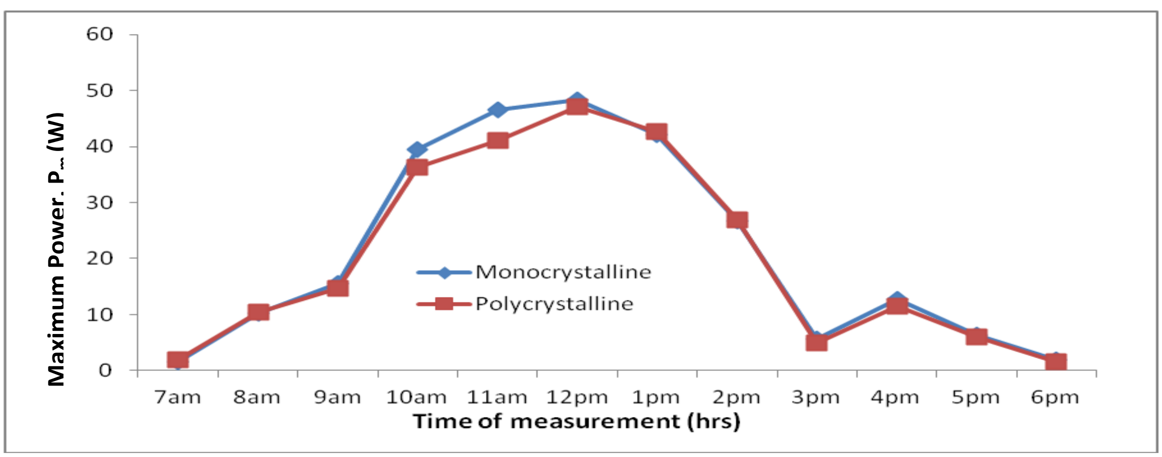
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	11.31	5.66	0.14	0.09	1.58	0.51	14.00	5.58	0.14	0.06	1.96	0.33
8am	16.50	16.32	0.62	0.29	10.23	4.73	17.14	15.05	0.61	0.28	10.46	4.21
9am	17.01	16.28	0.91	0.32	15.48	5.21	16.35	16.14	0.90	0.32	14.72	5.16
10am	17.37	16.76	2.27	0.35	39.43	5.87	17.17	17.09	2.11	0.35	36.23	5.98
11am	16.76	15.24	2.78	0.38	46.59	5.79	17.36	17.01	2.37	0.36	41.14	6.12
12pm	17.20	16.44	2.81	0.39	48.33	6.41	17.52	16.48	2.69	0.38	47.13	6.26
1pm	16.67	16.24	2.53	0.37	42.18	6.01	17.10	16.93	2.50	0.36	42.75	6.09
2pm	16.54	16.15	1.62	0.34	26.79	5.49	16.82	16.27	1.60	0.34	26.91	5.53
3pm	17.34	16.03	0.33	0.25	5.72	4.01	16.36	15.78	0.30	0.23	4.91	4.73
4pm	17.78	16.34	0.72	0.31	12.80	5.07	16.15	15.38	0.71	0.30	11.47	4.61
5pm	16.31	13.29	0.39	0.28	6.36	3.72	15.75	12.73	0.38	0.26	5.99	3.31
6pm	12.25	7.29	0.15	0.10	1.84	0.73	12.67	6.58	0.12	0.08	1.52	0.53



(a)



(b)



(c)

Fig 4.26: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.26 Discussion

Table 4.26 shows experimental results recorded during the 11th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (16th of January, 2017). Also fig.4.26 (a-c) represent the time history of the measured parameters; Fig.4.26a shows the (V_{OC} - t) plot, fig.4.26b shows the (I_{SC} - t) plot while fig.4.26c shows the (P_M - t) curve.

For the open-circuit voltage, the polycrystalline Si was fairly constant from 9am to 2pm and the monocrystalline Si was fairly constant from 11am to 2pm.

The short circuit current increased gradually from 7am and peaked at 12pm for both panels before decreasing due to low sunlight. The monocrystalline Si had a higher current than the polycrystalline Si from 10am to 12pm. A similar trend was observed in the I_{SC} for both solar panels as shown in figure 4.26.

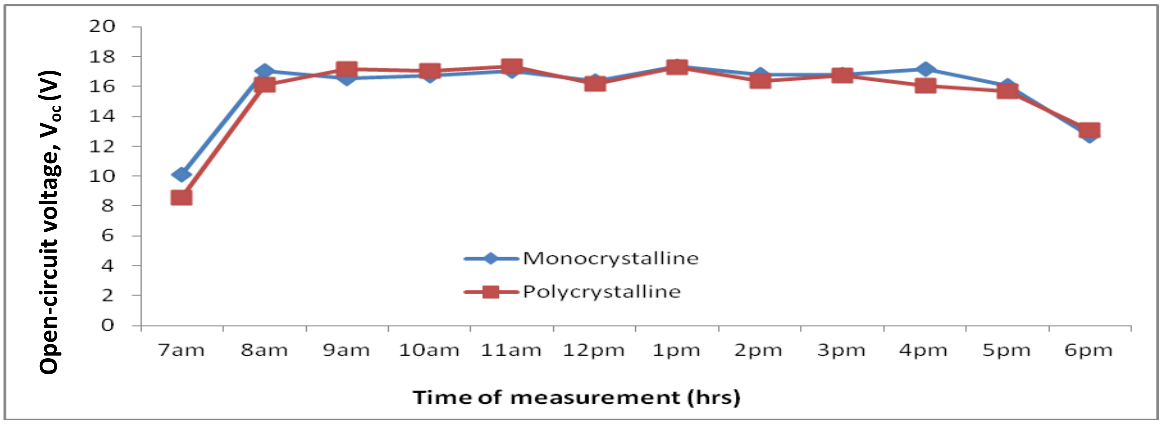
The maximum power, P_M for the monocrystalline Si was 48.33W and that of the polycrystalline Si was 47.13W and this happened at 12pm at the very time the current reached maximum.

For the 11th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si solar panel.

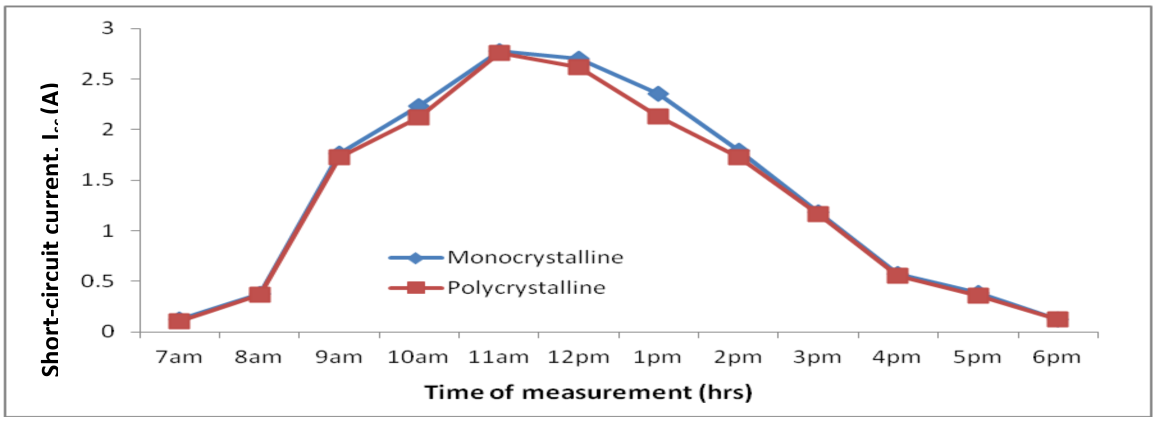
Day 12

Table 4.27: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day twelve (17th January, 2017).

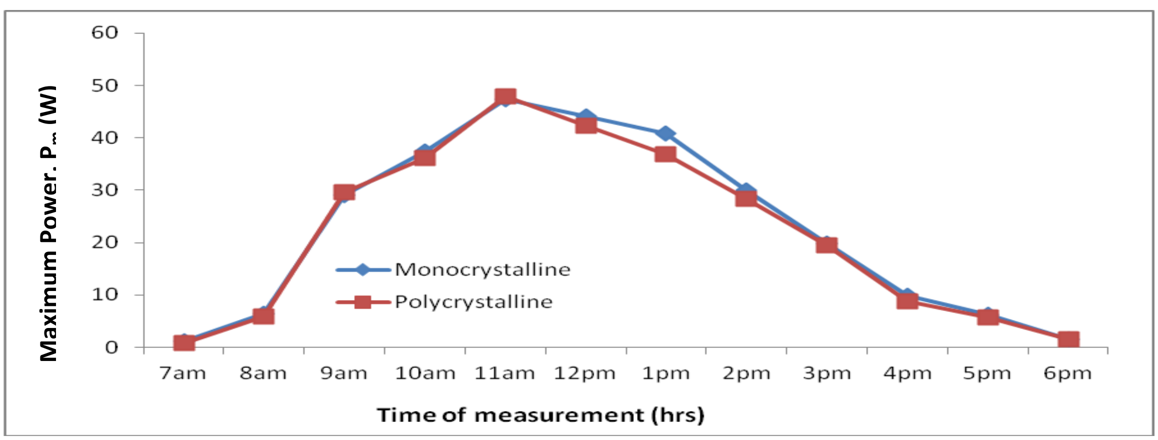
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	10.12	5.34	0.12	0.08	1.21	0.43	8.56	6.23	0.10	0.05	0.86	0.31
8am	17.02	12.29	0.38	0.32	6.47	3.93	16.08	12.57	0.37	0.30	05.95	3.77
9am	16.56	15.30	1.76	0.34	29.15	5.20	17.17	17.07	1.73	0.33	29.70	5.63
10am	16.75	16.07	2.23	0.36	37.35	5.79	17.02	16.54	2.12	0.35	36.80	5.79
11am	17.02	15.23	2.78	0.38	47.32	5.79	17.33	16.37	2.76	0.36	47.83	5.89
12pm	16.35	16.14	2.70	0.37	44.15	5.97	16.15	15.62	2.62	0.35	42.31	5.47
1pm	17.37	16.12	2.35	0.35	40.82	5.64	17.29	16.31	2.13	0.34	36.83	5.55
2pm	16.79	16.12	1.79	0.34	30.05	5.48	16.34	16.30	1.73	0.33	28.27	5.37
3pm	16.76	16.52	1.18	0.32	19.78	5.29	16.72	16.12	1.16	0.32	19.40	5.16
4pm	17.19	14.02	0.57	0.31	9.80	4.35	16.07	14.62	0.55	0.31	8.84	4.53
5pm	16.04	13.25	0.39	0.30	6.26	3.98	15.70	12.30	0.36	0.28	5.65	3.44
6pm	12.72	4.16	0.12	0.07	1.53	0.29	13.10	5.10	0.12	0.06	1.57	0.31



(a)



(b)



(c)

Fig 4.27: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.27 Discussion

Table 4.27 shows experimental results recorded during the 12th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (17th of January, 2017). Also fig.4.27 (a-c) represent the time history of the measured parameters; Fig.4.27a shows the (V_{OC} - t) plot, fig.4.27b shows the (I_{SC} - t) plot while fig.4.27c shows the (P_M - t) curve.

For the open-circuit voltage, both panels varied from 11am to 3pm before decreasing.

The short circuit current increased gradually from 7am and peaks at 11am for both panels before decreasing due to low sunlight.

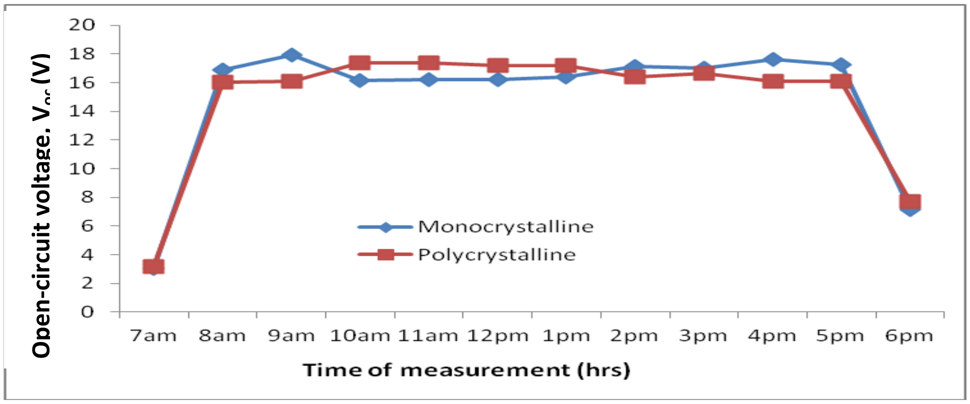
The maximum power, P_M for the monocrystalline Si was 47.32W and that of the polycrystalline Si was 47.83W and this happened at 11am at the very time the current reached maximum.

For the 12th day, the polycrystalline Si solar panel produced a high maximum power output than the monocrystalline Si solar panel.

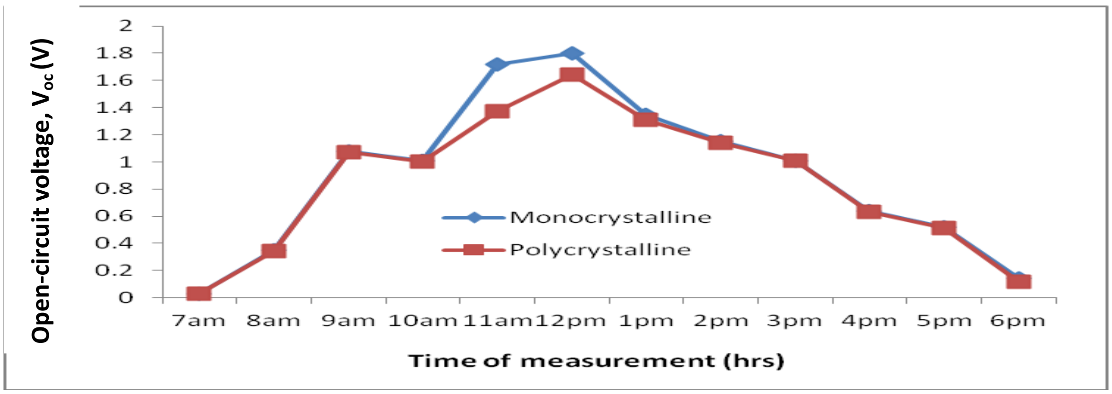
Day 13

Table 4.28: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day thirteen (18th January, 2017).

	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	3.07	2.76	0.03	0.01	0.09	0.03	3.16	2.09	0.03	0.01	0.09	0.03
8am	16.90	11.76	0.35	0.20	5.92	2.35	16.06	12.04	0.34	0.17	5.46	2.05
9am	17.95	16.63	1.08	0.30	19.39	4.99	16.10	15.93	1.07	0.25	17.23	3.98
10am	16.16	15.28	1.01	0.33	16.32	5.04	17.37	16.05	1.00	0.30	17.37	4.81
11am	16.19	15.06	1.72	0.35	27.85	5.27	17.35	16.08	1.37	0.31	23.77	4.99
12pm	16.20	16.08	1.80	0.38	29.16	6.11	17.20	17.10	1.64	0.36	28.21	6.16
1pm	16.39	16.25	1.31	0.34	22.13	5.53	17.21	16.77	1.31	0.33	22.55	5.53
2pm	17.12	16.36	1.04	0.29	19.69	4.74	16.38	16.17	1.14	0.26	18.67	4.20
3pm	17.02	16.08	1.01	0.26	17.19	4.18	16.65	15.34	1.01	0.23	16.82	3.53
4pm	17.62	15.63	0.64	0.24	11.28	3.75	16.10	15.02	0.63	0.22	10.14	3.30
5pm	17.27	14.05	0.52	0.21	8.98	2.95	16.07	14.14	0.51	0.19	8.20	2.69
6pm	7.14	3.36	0.14	0.09	1.00	0.29	7.68	3.58	0.12	0.07	0.92	0.32



(a)



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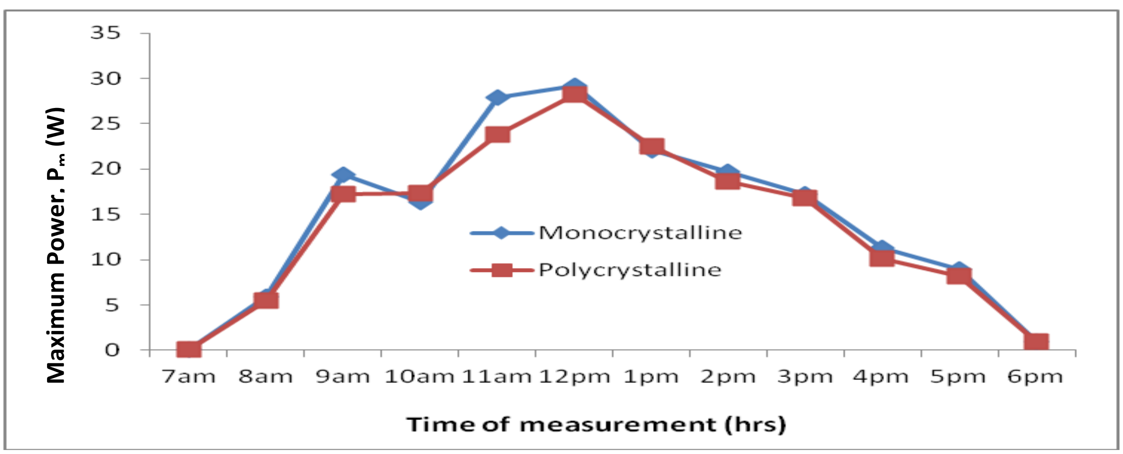


(c)

Fig 4.28: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.28 Discussion

Table 4.28 shows experimental results recorded during the 13th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (18th of January, 2016). Also fig.4.28 (a-c) represent the time history of the measured parameters; Fig.4.28a shows the (V_{OC} - t) plot, fig.4.28b shows the (I_{SC} - t) plot while fig.4.28c shows the (P_M - t) curve.

For the open-circuit voltage, both solar panels were fairly constant from 10am to 1pm with the polycrystalline Si having a higher voltage than the monocrystalline Si at the time frame.

The short circuit current increased gradually from 7am and peaked at 12pm for both solar panels with the monocrystalline Si having a high current from 10am to 12pm.

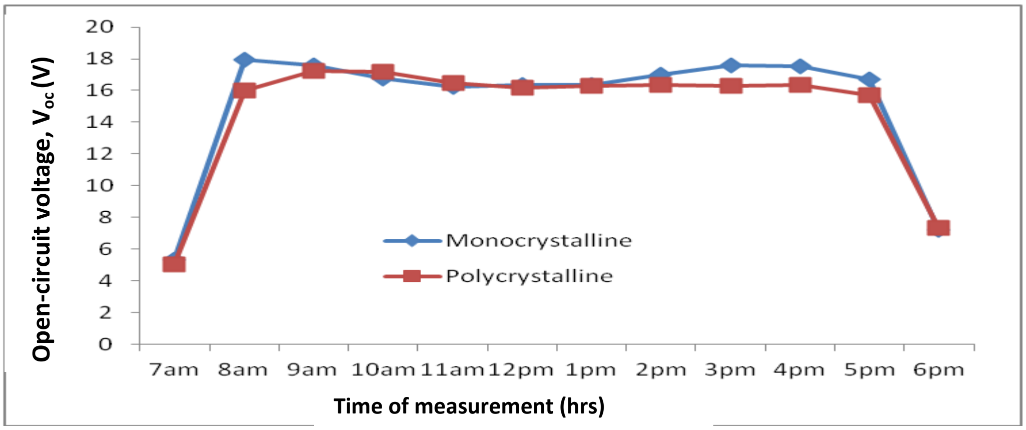
The maximum power, P_M for the monocrystalline Si was 29.16W and that of the polycrystalline Si was 28.21W and this happened at 1pm at the very time the current reached maximum.

For the 13th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si solar panel.

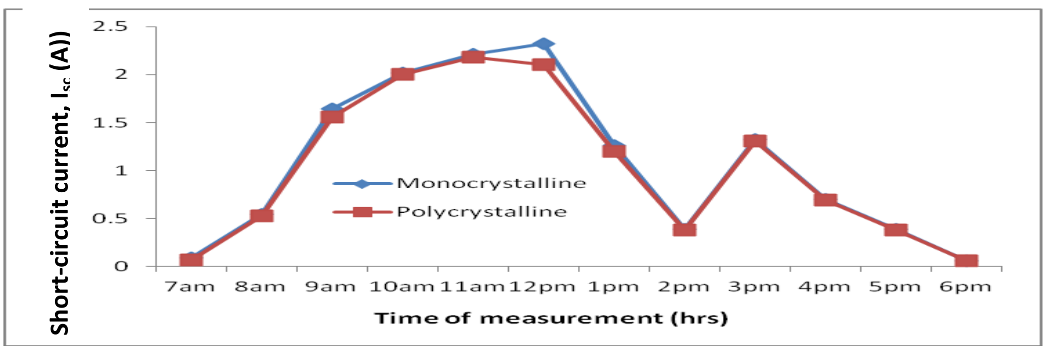
Day 14

Table 4.29: Experimental results of open-circuit voltage (V_{OC}), load voltage (V_L), short-circuit current (I_{SC}) and load current (I_L) of monocrystalline and polycrystalline Si solar panels for day fourteen (19th January, 2017).

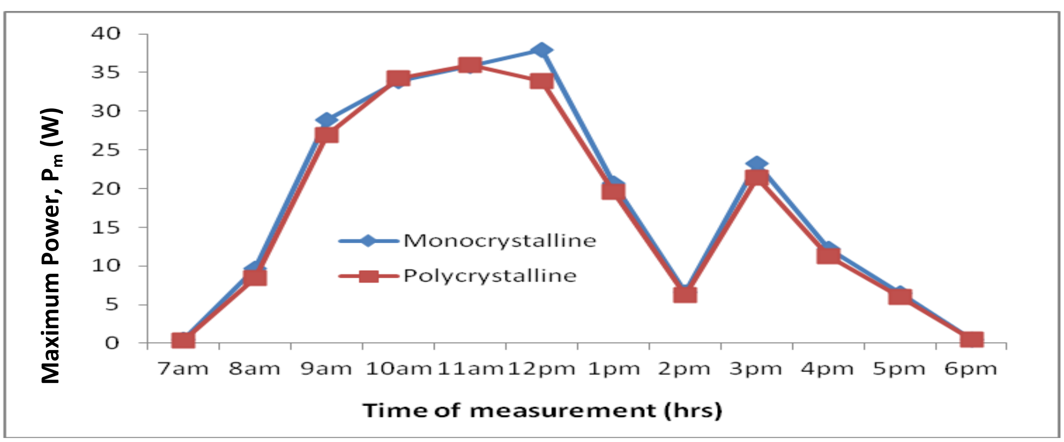
	Monocrystalline Si						Polycrystalline Si					
Time	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)	V_{OC}(V)	V_L(V)	I_{SC}(A)	I_L(A)	P_M(W)	P_L(W)
7am	5.36	3.97	0.09	0.04	0.48	0.16	5.03	4.07	0.07	0.03	0.35	0.12
8am	17.95	15.65	0.54	0.32	9.69	5.01	16.02	15.31	0.53	0.30	8.49	4.59
9am	17.60	16.35	1.64	0.38	28.86	6.21	17.23	16.75	1.56	0.36	26.88	6.03
10am	16.75	16.03	2.02	0.39	33.84	6.25	17.16	16.35	2.00	0.38	34.32	6.21
11am	16.21	16.14	2.21	0.36	35.82	5.81	16.50	16.41	2.18	0.35	35.97	5.74
12pm	16.33	16.12	2.32	0.37	37.89	5.96	16.15	16.09	2.10	0.36	33.92	5.79
1pm	16.38	16.29	1.26	0.34	20.64	5.54	16.30	15.35	1.20	0.32	19.56	4.91
2pm	17.03	16.79	0.39	0.32	6.64	5.37	16.37	15.69	0.38	0.31	6.22	4.86
3pm	17.62	16.52	1.32	0.37	23.26	6.11	16.32	16.08	1.31	0.35	21.38	5.63
4pm	17.52	16.20	0.70	0.32	12.26	5.18	16.36	15.39	0.69	0.31	11.29	4.77
5pm	16.73	12.60	0.39	0.25	6.52	3.15	15.70	12.37	0.38	0.24	6.00	2.97
6pm	7.22	3.11	0.06	0.04	0.43	0.12	7.34	3.79	0.06	0.04	0.44	0.15



(a)



(b)



(c)

Fig 4.29: A plot of (a) V_{OC} versus time
(b) I_{SC} versus time
(c) P_M versus time

4.29 Discussion

Table 4.29 shows experimental results recorded during the 14th day outdoor testing of both the monocrystalline Si solar panel and polycrystalline Si solar panels. (19th of January, 2017). Also fig.4.29 (a-c) represent the time history of the measured parameters; Fig.4.29a shows the (V_{OC} - t) plot, fig.4.29b shows the (I_{SC} - t) plot while fig.4.29c shows the (P_M - t) curve.

For the open-circuit voltage, the monocrystalline Si was fairly constant from 9am to 1pm and the polycrystalline Si was fairly constant from 11am to 5pm before declining.

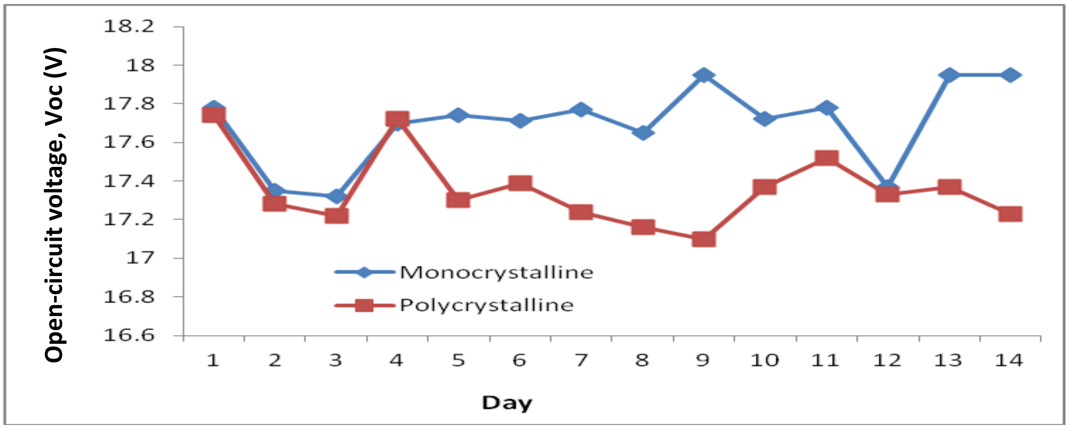
The short circuit current increased gradually from 7am and peaked at 12pm for both solar panels with the monocrystalline Si producing a high current at 12pm. A similar trend was observed in the I_{SC} for both solar panels as shown in figure 4.29.

The maximum power, P_M for the monocrystalline Si was 37.89W and that of the polycrystalline Si was 35.97W and this happened at 12pm for the monocrystalline Si and 11am for the polycrystalline Si.

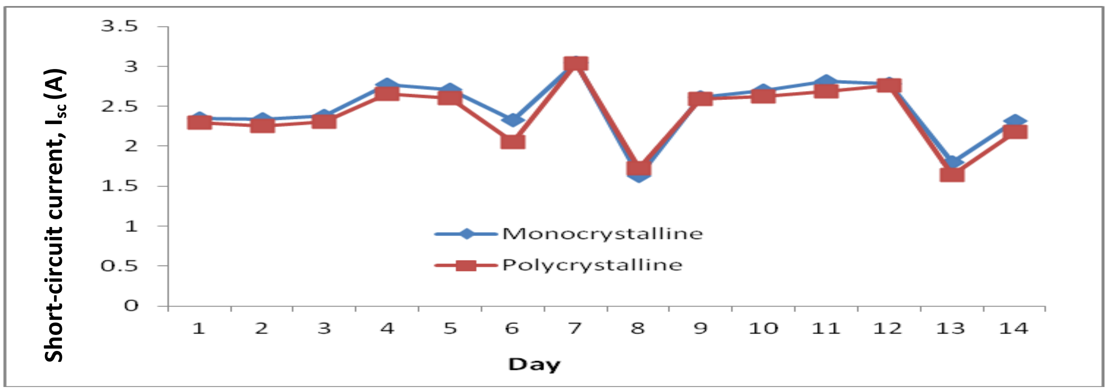
For the 14th day, the monocrystalline Si solar panel produced a high maximum power output than the polycrystalline Si solar panel.

Table 4.30: Experimental results of maximum open-circuit voltage (V_{OC}), maximum short-circuit current (I_{SC}) and maximum power output of monocrystalline and polycrystalline Si solar panels for the fourteen days of dry season.

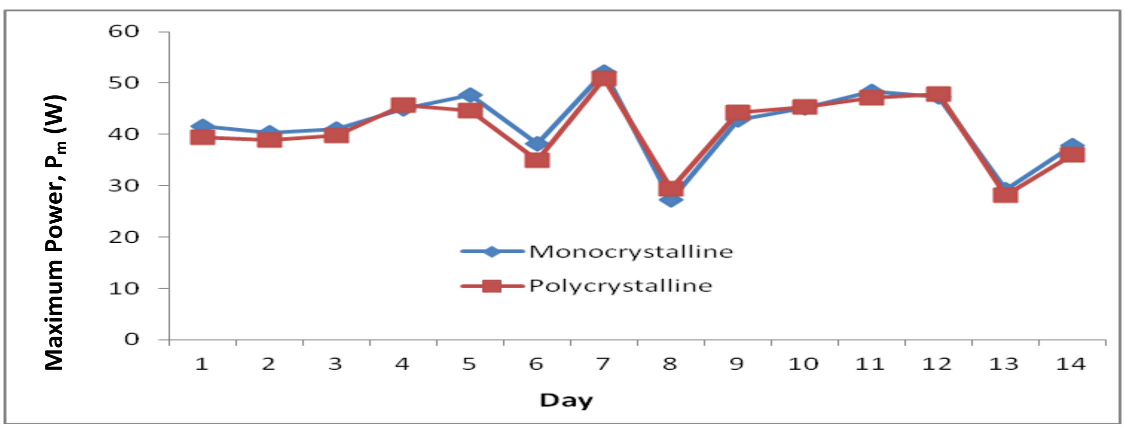
	Monocrystalline Si			Polycrystalline Si		
Day	V_{OC}(V)	I_{SC}(A)	P_M(W)	V_{OC}(V)	I_{SC}(A)	P_M(W)
1	17.78	2.35	41.64	17.74	2.30	39.38
2	17.35	2.34	40.41	17.78	2.25	38.90
3	17.32	2.38	41.06	17.22	2.31	39.71
4	17.70	2.77	44.93	17.72	2.65	45.76
5	17.74	2.71	47.67	17.30	2.60	44.56
6	17.71	2.33	38.23	17.39	2.05	34.95
7	17.77	3.05	52.06	17.24	3.04	50.95
8	17.65	1.63	27.26	17.16	1.72	29.45
9	17.95	2.61	42.75	17.10	2.59	44.29
10	17.72	2.70	45.09	17.37	2.62	45.38
11	17.78	2.81	48.33	17.52	2.69	47.13
12	17.37	2.78	47.32	17.33	2.76	47.83
13	17.95	1.08	29.16	17.37	1.64	28.21
14	17.95	2.32	37.89	17.23	2.18	35.97



(a)



(b)



(c)

Fig 4.30: A plot of (a) $V_{OC\ max}$ versus number of days.

(d) $I_{SC\ max}$ versus number of days.

(e) Pm_{max} versus number of days.

4.30: Comparison of the maximum open-circuit voltage (V_{OC}), maximum short- circuit current (I_{SC}) and maximum power output (P_M) for the fourteen days for both the monocrystalline Si and polycrystalline Si solar panels.

Fig 4.30 shows the plot of maximum open –circuit voltage V_{OC}, maximum short-circuit current I_{SC} and highest maximum power (P_M) against time recorded for the fourteen days for both the monocrystalline Si and polycrystalline Si solar panels during the dry season..

For the open-circuit voltage, both solar panels varied from day one to the fourteenth day but the monocrystalline Si solar panel had a higher voltage from the 5th day to the 14th day than the polycrystalline Si.

The short-circuit current for both solar panels showed similar trend from the 1st day to the 14th day with the monocrystalline Si having a high current compared to the polycrystalline Si solar panel.

The maximum power output for both panels showed similar trend. The monocrystalline Si produced the highest maximum power output on the seventh day compared to the polycrystalline Si solar panel. The maximum power for both solar panels varied from the 4th day to the 14th day. This is as a result of variance in the open-circuit voltage for both solar panels.

Based on the outdoor testing of the monocrystalline Si and polycrystalline Si solar panels carried out for fourteen days, the following conclusions were drawn:

(d) Open-circuit voltage for monocrystalline is high during the early hours of the day and toward the evening hours while the polycrystalline Si is high during midday and fairly constant between 10am and 3pm for most of the days. The open-circuit voltage for the monocrystalline Si varies compared to the polycrystalline Si solar panel.

(e) The monocrystalline Si produces high short-circuit current compared to the polycrystalline Si solar panel. The short-circuit current gradually increases during the early hours of the day and is dependent on the amount of insolation that are incident on both solar panels. Low short-circuit current was recorded during the dry season as a result of low sunlight in the harmattan period.

(f) The maximum power output is dependent on the amount of short-circuit current produced. The maximum power output recorded was low and this is as a result of low short circuit current. Low sunlight was observed during the period of the experiment and this is as a result of the harmattan season.

Table 4.31: Experimental results of maximum open-circuit voltage (V_{OC}), maximum short-circuit current (I_{SC}) and maximum power output of monocrystalline and polycrystalline Si solar panels for the fourteen days for both the rainy and dry season.

	Rainy season						Dry season					
	Monocrystalline Si			Polycrystalline Si			Monocrystalline Si			Polycrystalline Si		
Day	V_{OC}(V)	I_{SC}(A)	P_M(W)	V_{OC}(V)	I_{SC}(A)	P_M(W)	V_{OC}(V)	I_{SC}(A)	P_M(W)	V_{OC}(V)	I_{SC}(A)	P_M(W)
1	16.99	3.73	59.31	17.93	3.70	66.34	17.78	2.35	41.64	17.74	2.30	39.38
2	17.95	4.70	78.16	17.50	4.50	77.18	17.35	2.34	40.41	17.78	2.25	38.90
3	17.92	5.36	83.78	17.98	5.16	92.36	17.32	2.38	41.06	17.22	2.31	39.71
4	17.50	3.72	62.87	17.70	3.32	56.37	17.70	2.77	44.93	17.72	2.65	45.76
5	17.94	5.56	94.24	17.79	5.42	93.06	17..74	2.71	47.67	17.30	2.60	44.56
6	17.95	5.26	89.31	17.52	4.12	71.56	17.71	2.33	38.23	17.39	2.05	34.95
7	17.27	3.98	66.78	17.58	3.73	64.57	17.77	3.05	52.06	17.24	3.04	50.95
8	17.96	3.05	47.48	17.78	3.11	55.30	17.65	1.63	27.26	17.16	1.72	29.45
9	17.99	5.51	9`.03	17.70	5.50	96.80	17.95	2.61	42.75	17.10	2.59	44.29
10	17.97	3.15	49.46	17.78	2.94	52.27	17.72	2.70	45.09	17.37	2.62	45.38
11	17.92	2.93	49.69	17.48	2.67	46.67	17.78	2.81	48.33	17.52	2.69	47.13
12	17.75	5.25	89.09	17.71	5.20	92.09	17.37	2.78	47.32	17.33	2.76	47.83
13	17.93	3.05	51.73	17.57	3.01	52.61	17.95	1.80	29.16	17.37	1.64	28.21
14	17.75	2.15	36.51	17.38	2.13	37.02	17.95	2.32	37.89	17.23	2.18	35.97

4.31: Comparison of the maximum open-circuit voltage (V_{OC}), maximum short- circuit current (I_{SC}) and maximum power output (P_M) for the fourteen days of both the monocrystalline Si and polycrystalline Si solar panels for the rainy and dry season.

Table 4.31 shows the experimental results of maximum V_{OC}, maximum I_{SC} and maximum P_M for the fourteen days of both the monocrystalline Si and polycrystalline Si solar panels. It was observed that both solar panels produced high V_{OC} in both seasons.

For the I_{SC}, the monocrystalline Si produced a higher I_{SC} during the rainy season compared to the dry season. Dusty weather condition was observed in the dry season which is probably due to the harmattan.

The maximum power output is dependent on the current produced by the solar panels. High maximum power was recorded during the rainy season and it was produced by the polycrystalline Si while low maximum power was recorded during the dry season.

4.31.1 Comparison of results obtained with that of the literature review

It was observed from the outdoor testing that the open-circuit for the monocrystalline Si solar panel varied prominently. This corroborates with the findings of Maluta (2011). He carried out an outdoor testing of crystalline silicon panels and amorphous solar panels thereby comparing the performance of the two solar panels. He found out that open-circuit voltage for the crystalline module varies prominently compared to that of the amorphous module.

It has been observed that both solar panels exhibit similar current characteristics. This is in line with the results of Abdelkader *et al*. (2010). They carried out a research on the comparative analysis of the performance of monocrystalline Si and multicrystalline Si PV cells in semi arid climate conditions, the case of Jordan. They observed that both solar panels show similar current characteristics.

It has been observed that the polycrystalline Si produced the highest maximum power output compared with the monocrystalline Si solar panel. This is in line with the results of Kalu *et al.* (2016). They carried out a work on comparative study of three different photovoltaic technologies. They used a simulation approach for the comparative analysis. Three different photovoltaic technologies which are the monocrystalline silicon, polycrystalline silicon and thin film PV were used. They found out that array efficiency of the polycrystalline Si was higher than that of the monocrystalline Si while the thin film PV has lower array efficiency. They preferred the polycrystalline Si because it has very high array efficiency.

CHAPTER FIVE

5.1 SUMMARY

The performance assessment of two solar panel types was carried out in Owerri, Eastern area of Nigeria. 100W monocrystalline and 100W polycrystalline solar panels produced by Flames Company were used for the outdoor testing. The experiments were carried out for fourteen days each for the rainy and dry season to identify the solar panel that has a better performance. It was observed during the experiments that both solar panels exhibited similar voltage and current characteristics. The performance of the solar panel was rated based on the maximum power produced by each panel. It was also observed that the $V_{OC,}$ $V_{L,}$ I_{SC} and I_L are dependent on the amount of sunlight incident on the panel. This means that the higher the insolation, the higher the current and vice versa. Cloudy weather condition affected the performance of the solar panels as the short-circuit current dropped drastically anytime it is about to rain thus making the solar panel not to work efficiently within that particular period of time. Low sunlight was observed during the dry season as a result of dusty weather condition during the harmattan. High solar intensity was observed between 10am and 3pm, as it varied for some of the days during the rainy season. The highest maximum power recorded during the experiment was 96.80W for the polycrystalline silicon solar panel while 94.24W was recorded for the monocrystalline silicon solar panel, and is close to the rating by the solar panel manufacturers (100W). This occurred during the rainy season while low maximum power was recorded during the dry season as a result of low short-circuit current produced by the solar panels.

5.2 Conclusion

Based on the results presented, I would recommend that the polycrystalline Si solar panel would work perfectly in Owerri even though the monocrytsalline Si solar panel is highly in use from the responses of the questionnaire administered. Most users of solar panels lack information on the operation of the solar panels. This research will help to guide would-be-users on the type of solar panel to purchase. The polycrystalline Si solar panel has a fairly constant voltage than the monocrystalline Si solar panel as that of the monocrystalline Si solar panel varies considerably. The difference in the current between the monocrystalline Si and polycrystalline Si is relatively small. In this case, the polycrystalline Si solar panel can give the expected result in terms of performance. Also, the polycrystalline Si solar panel is cost effective as the monocrystalline Si solar panel is very costly.

5.3 Recommendation/Future Work

To continue the performance assessment of the solar panel, outdoor testing should be carried out over all the months of the year to understand the month for best performance of the solar panels. When completed over the year, the results will provide a database for proper advice to Government, individuals and corporate organization on the best types of solar panel to use.

Available solar panels such as the amorphous silicon should be included in the outdoor testing to ascertain the performance.

Irradiance should be measured in subsequent outdoor testing so as to know how it affects the performance of solar panels.

5.4 Contribution to knowledge

The outcome of this study has shown that the polycrystalline silicon solar panel has a better performance than the monocrystalline silicon solar panel. Most users of solar panels lack information on the operation of these panels. The study is an eye opener to solar panel users

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