DETERMINATION OF CLOUD EFFECT ON THE PERFORMANCE OF PHOTOVOLTAIC MODULE

BY

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DECLARATION

I hereby declare that this work is the product of my own research efforts; undertaken under the supervision of (Dr. M.H. Ali) and has not been presented and will not be presented elsewhere for the award of a degree or certificate.

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CERTIFICATION

This is to certify that the research work for this thesis and the succeeding preparation by (Abdulsalam Ibrahim Gaya) with registration number (SPS/13/MPY/00053) were carried out under my supervision.

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APPROVAL PAGE

This dissertation has been examined and approved for the award of masters of science (M. Sc.) in Electronics.

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ACKNOWLEDGMENT

In the name of Allah the Most Beneficent the Most Merciful. Praise is to Allah, Lord of the universe. Blessing and peace be upon our Prophet (S. A.W.), his household, his companions and all those who follow his teaching till the Day of Judgment. I wish to express my sincere gratitude to my parent for all they have been doing for me, May Allah (S. A.W.) reward them with Jannatul Firdaus.

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DEDICATION

This dissertation is dedicated to my parents.

Table of content

CHAPTER TWO

LITERATURE REVIEW

CHAPTER THREE

METHODOLOGY

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

This work investigates the effect of cloud on the performance of solar PV panel. The intensity of solar radiation is reduced in cloud condition, because cloud interrupts beam radiation reaching the earth surface, as a result, this affect the output performance of the PV module. Outdoor experiment and simulations of parameters of the PV module are conducted using MATLAB to investigate this effect. Result shows that, the cloud reduced efficiency of the PV module by blocking some part of the Sun. In the three experimental locations of this work, the reduction in efficiency was found to be from 0.96% to 3.77%.

CHAPTER ONE

INTRODUCTION

1.0 GENERAL INTRODUCTION

The discovery of energy by humans remains one of the greatest things that made our life more and more comfortable (Malviya and Prakash, 2016). Increasing consumption and demand for energy shows that energy will be one of the major problem in the world (Khalil and Zaidi, 2014). An alternative renewable energy source is the answer. The renewable energy resources are becoming essential factor in power electric generation in many countries. There are various renewable sources which are utilized for the production of electric power, such as solar energy, wind energy, and geothermal etc. solar energy is the best choice for electric generation in the countries characterized by an high solar radiation intensity (Bouraiou *et al.,* 2015).

Solar energy is the energy that is available in the sun light or in the heat generated sun light (Farooq and Kumar, 2013). Solar energy can play a remarkable role in reducing the destructive effects of fossil fuel exploitation. Solar energy is considered as one of the greatest renewable energy sources due to its accessibility in the most part of the world (Sabzpooshani and Mohammadi, 2014). The solar energy can be harvested by three approaches; chemical (photosynthesis), thermal (solar heaters) and electrical energy (solar cells) (Malviya and Prakash. 2016).

The research interests in renewable energy, especially the solar energy, are continuously increasing because of the rising price of traditional energy resources and serious environmental pollution. The solar energy can be study in two ways, the experimental study and the numerical simulation study. Simulations are numerical experiment and can give some kind of thermal performance information as can physical experiments (Shen *et* al., 2008).

Over the last 20years. the PV industry showed annual growth rates between 40% and 80%, providing its strength and potential to become a major worldwide power generation source (Makrides *et al.,* 2010). The working of solar PV panel is totally dependent on the solar radiation. It is well known that the energy conversion efficiency of PV modules depends on a number of different external influences (Huld and Amillo, 2015). The design and analysis of PV modules require a tool that can predict the behavior of photovoltaic generators under various weather conditions. Manufacturers usually provide electrical specifications of the PV panels at standard test conditions (STC), namely solar radiation of 1000 W/m^2 and cell temperature of 25 °C. To characterize the performance of a photovoltaic module under varying weather conditions, simulation models of PV modules have been developed (Vengatesh and Rajan, 2011), (Bouraiou *et al.*. 2015), (Bikaneria and Joshi, 2014). However, there is need to experimentally investigate the validity of these models in predicting the performance of photovoltaic module under different climatic conditions.

In this research, we determined the effect of cloud on the performance of photovoltaic module. Although, presence of cloud is statistical, conducting experiment for some days may allow one to have presence of cloud in one or two days, that enables him to identify the quantitative effect of the cloud on the panel function.

1.1 HISTORY OF SOLAR ENERGY

Energy from the sun is by far the largest energy source available on the earth: the amount of solar energy reaching the earth surface of the earth annually ($3.9 \times 10^{24} J$) is about ten thousand times more than the global primary energy demand and more than all available energy source on the earth (Masters. 2004). Furthermore, it is inexhaustible and clean source of energy, which is essential in the globally prevailing circumstances.

The sun is a vast and hot sphere of gas: the temperature in the interior of the sun is approximated to be around 15 million kelvins, its diameter is 1.4 million kilometers and its mass is 2.0×10^{30} kilograms. Comparatively, for the earth these figures are 12800 kilometers and 6.0×10^{24} kilograms, respectively. The sun consists of mainly of helium and hydrogen; by mass approximately 80% is hydrogen and 20% helium. The energy of the sun emerges from fusion reactions where four hydrogen nuclei fuse into one helium nucleus in the interior of the sun (Masters, 2004).

Human was keen to exploit the natural resources which God harness for him. Sun is one of the most important resources which have been exploited. Back to the fifth century BC, Greeks exploited the sun for heating purposes. The effects of photovoltaic cells discovered by Becquerel in 1839 while experimenting with an electrolytic cell but not develop as power source on till 1954. They invent the first PV cell which is capable of converting enough of the suns energy into power to run every day electrical equipment.

1.2 BENEFITS OF CLEAN RENEWABLE ENERGY

There are many advantages resulting from the use of clean energy distributed on fields of environmental, economic and health. The benefits of clean energy include diversity, security improved quality of life, environment and human health. It also improves economic gains through avoiding medical costs and more jobs creation.

1.2.1 Economic Impacts

Technological advancement in the field of renewable energy has become clear in recent years. We noted that while the prices of traditional energy sources constantly rise, the costs of renewable energy decline steadily so the advantages of investment in renewable energy has become increasingly clear, even in areas that traditionally support fossil fuels. The main reasons that make renewable energy technologies offer an economic advantage are labor intensive, so they generally create more jobs invested than conventional electricity generation technologies. They also use primarily indigenous resources, so most of the energy dollars can be kept, where individuals, companies, or communities can reduce their utility bills. For example, schools can cut costs by using wind and electric cooperatives can provide cheaper electricity to members with photovoltaic (Panjeshahi *et al,* 2008).

1.2.2 Health and Environmental Impacts

All energy sources have some impacts on our environment and health which varies between long-term and short-term effects. Fossil fuels are more harmful than renewable energy sources. Thus, we need to improve access to low-emission, renewable, and modern energy technologies both at home at community. They can benefit from long term sustainability. Notably, the inefficient combustion of fossil fuels and biomass for energy purposes is the major cause of climate change. Air pollution, often due to inefficient modes of energy production, distribution, and consumption, is a large and growing cause of environmental health risks (Sawin and Moomaw, 2009), so it is advisable to increase reliance on renewable energy sources, and support clean energy initiatives. This appears through better air quality which enhances local quality of life. Healthier people reduces strain on the health system, using fewer sick days also lower carbon dioxide emissions in the near term may have a large impact on our ability to meet long term climate goals since greenhouse gas accumulate and remain in the atmosphere for decades,, affecting our global climate system and human health for the long-term (Sawin and Moomaw, 2009).

1.3 SOURCES OF RENEWABLE ENERGY

The main sources and components used in renewable energy systems included solar, wind, hydropower, biomass, and geothermal resources. In this section a brief is given for each type of these sources.

1.3.1 Biomass and Biofuels

Bioenergy term sometimes used to cover biomass and biofuels together. Bioenergy resources are widely available worldwide and have the largest share of all renewable energy sources. Biomass resources were the first energy source harnessed by humans (Herzog *et al,* 2001). It comes in many forms. Traditionally, wood, crop residues and, animal waste have been used for heating or cooking, but today biomass is also used in many other ways. Municipal solid waste (MSW) can be used for heat electricity. Landfill gases can be used for heat, electricity or fuels. Biological conversion of MSW using anaerobic digestion can produce electricity, heat or fuel gas. Wood and wood wastes can be used to produce electricity, heat for industrial purposes or domestic space heating.

Recently, the interest in producing liquid fuels from grain and dedicated energy crops are increasing. They are only renewable source of liquid transportation fields, which can be in the form of ethanol or biodiesel. Moreover, the carbon in biomass is obtained from CO_2 in the atmosphere via photosynthesis, and not from fossil sources. When biomass is burnt or digested, the emitted CO_1 is recycled into atmosphere without adding atmospheric CO_2 concentration over the lifetime of the biomass growth (Herzog *et al,* 2001).

1.3.2 Wind Power

The extraction of power from the wind with modern turbines and energy conversion systems is an established industry. Machines are manufactured with a capacity from tens of watts to several megawatts, and diameter of about 1m to more than 100m (Herzog *et al,* 2001). The power output increases rapidly with an increase in available wind velocity.

Small wind speed difference makes a very big difference because the energy contained in the wind increases with the cube of the wind speed. A maximum of about 59% of the energy can be extracted. For this reason, good wind sites are important (Holm and Arch, 2005). We must take into account the wind does not blow equally or evenly everywhere on earth. Over open sea or flat stretches of land the wind is stronger than over towns or woods. Modern turbines have already greatly reduced noise pollution, which is less than traffic noise, efficiencies and availabilities have improved and wind farm concept have become popular in addition to that, wind turbines have become larger, combine with solar (Jimenez and Olson, 1998).

1.3.3 Hydropower

The term hydropower is usually restricted to the generation of shaft power from falling water. The power is then used for direct mechanical purpose or, more frequently, for generating electricity. Other sources of water power are waves and tides (Herzog *et al,* 2001). But the hydroelectric technology is the most mature form of renewable energy and extremely reliable, but it requires very high initial investments, with low maintenance cost. Its design life is more than a century. Natural and pumped storage dams are suitable for peak electricity demand. Hydropower is cheap if calculated in the conventional manner. Worldwide, about 45000 large dams have been built for electricity generation, flood protection, water storage, agricultural irrigation, navigable waterways and recreation. As a result of economies of scale, approximately 97% of hydroelectric plants have a capacity in excess of 10MW (Holm and Arch, 2005). The main disadvantages of hydropower are associated with effects other than the generating equipment, particularly for large systems. These include possible adverse environmental impact, effect on fish, silting of dams, and corrosion of turbines in certain water conditions, social impacts of displacement of people from the reservoir site, loss of potentially productive land (often balanced by the benefits of irrigation on other land) and relatively large capital costs compare with fossil fuel power stations.

1.3.4 Geothermal

Geothermal in the earth's crust derives from the hot core of the earth. Where the inner core of the earth reaches a maximum temperature of about 4000°C. Heat passes out through the solid submarine and land surface mostly by conduction and occasionally by active convective current of molten magma or heated water (Herzog *el al,* 2001).

Examples of geothermal energy are the natural geysers and hot water sources employed for power generation and space heating or using deep hot dry rock as heat exchangers by pumping water through then natural rock fissures to produce steam for power generation.

1.3.5 Photovoltaic

Solar energy can be used in number of ways. For electricity generation, the most common process is through solar photovoltaic where PV panels convert sunlight directly into DC electricity. PV panels, having no moving parts, require little maintenance, are highly reliable, long live where the semiconductor materials are encapsulated and sealed hermetically making lasts for a longer period of more than 25 years. In addition, PV / panels are highly modular. Also it is easy to assemble PV panels into an array that can meet any given sized load. With suitable electronics, PV systems can be grid-connected or stand-alone, where they can also be used for water pumping or other mechanical work. PV arrays do not emit vibrations, noises and pollutants during their operation. This means they can be integrated into new and existing buildings, which then become energy exporters instead of consumers. All above advantages makes this modern technology increasingly attractive (Hersch and Zweibel. 1982).

1.4 STATEMENT OF THE PROBLEM

The overall performance of solar cell varies with varying irradiance and temperature with the change in time of the day the power received from the sun by the PV panel changes. Not only this, both irradiance and temperature affect solar cell efficiency as well as corresponding Fill factor also changes. Low efficiency of photovoltaic is central to the user. This problem is approached from different perspectives; battery efficiency and panel efficiency. Some external influence such as changes in the climatic weather conditions and the amount of incident radiation also contribute to the performance of a given solar panel. Many mathematical models have been developed (Bikaneria *et al,* 2013).

1.5 AIM AND OBJECTIVES

1.5.1 Aim

The aim of this thesis is to investigate the cloud effect on the performance of photovoltaic module.

1.5.2 Objectives

The main objective of this research is

1) To evaluate the performance of photovoltaic module.
2) To determine the cloud effect on the performance of photovoltaic module.
3) To develop a computer code in MATLAB program that will simulate photovoltaic module parameter.
4) To compare the simulated result with the experimental result.

1.6 SCOPE AND LIMITATION

The main focus of this research work is to determine the effect on the performance of photovoltaic module due to solar insolation under cloud condition. To achieve this, experimental and simulation were carried out. The V - I and P - V characteristics were obtained from the experiment. While in the simulation, we develop a MATLAB program code to simulate mathematical equations relating to one diode photovoltaic equivalent circuit.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter the theoretical background of the research and the review of related literature were presented.

2.1 SEMICONDUCTOR PHYSICS

Semiconductors are characterized by their conductivity properties that lie between those of conductors and insulators. The most common semiconductor is silicon, which is a group IV element in the periodic table of elements. This means that it has four electrons in its outermost shell, i.e., it has four valence electrons, which determines its electrical properties. Other common semiconductors are germanium, gallium and arsenic, cadmium and tellurium and copper, indium and selenide are also used to produce semiconductors. Here semiconductor properties are discussed using the example of silicon. In pure silicon crystal, the four valence electrons of a silicon atom are tied with strong covalent bonds to four adjacent silicon atoms. Therefore at zero temperature silicon is perfect insulator: since there are no free electrons to carry currents as in metals, but all the electrons are tied to their nuclei. As the temperature increases, some electrons gain enough energy to escape from the potential field of their nuclei and thus the conductivity of silicon increases as the temperature rises. Semiconductors are very sensitive to impurities. This property can be exploited in changing their conductivity in a more favorable direction by adding suitable impurities, which is called doping. Semiconductors can be doped so that there is excess or shortage of electrons, to make N or P-type semiconductors, respectively. When P and N-type materials are brought into contact a P-N junction is formed. This junction has many favorable properties and is used widely in electronics, including photovoltaic solar cells (Masters, 2004).

2.2 PRINCIPLE OF OPERATION OF PHOTOVOLTAIC (PV) CELL

Ninety-nine percent of today's solar cells are made of silicon (Si) the second most abundant material on earth. However, scarce indium and tellurium are used in some cells (Masters, 2004). PV cells are basically made up of a PN junction fabricated in a thin wafer or layer of a semiconductor, figure 2.1 shows the photocurrent generation principle of PV cells. In fact when sunlight hits the cell, the photons are absorbed by the semiconductor atoms, freeing electrons from the negative layer. These free electrons find its path towards the positive layer through an external circuit resulting in an electric current from the positive layer to the negative layer. Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology, this voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, many of PV cells (involving 36 to 72 cells) are connected in series to form a PV module. The photoelectric conversion in the PN junction, P-N junction (diode) is a boundary between two differently doped semiconductor layers; one is a P-type layer (excess holes), and the second one is an N-type (excess electrons). At the boundary between the P and N area, there is a spontaneous electric field, which affects the generated electrons and holes and determines the direction of the current. To obtain the energy by the photoelectric effect, there shall be a directed motion of photoelectrons, i.e. electricity. All charge particles, photoelectrons also, move in a directed motion under the influence of electric field. The electric field in the material itself is located in semiconductors, precisely in the impoverished area of P-N junction (diode). It was pointed out for the semiconductors along with the free electrons in them; there are cavities as charge carriers, which are a sort of byproduct in the emergence of free electrons. Cavities (holes) occurs whenever the valence electrons turns into free electron, and this process is called the generation, while the reverse process, when the free electron fills the holes, is called recombination. If the electrons hole pairs occur away from the impoverished area areas it is possible to recombine before they are separated by the electric field. Photoelectrons and holes in semiconductor are accumulated at opposite ends, thereby creating an electromotive force. If a consuming device is connected to such a system, the current will flow and we will get electricity (Masters, 2004).

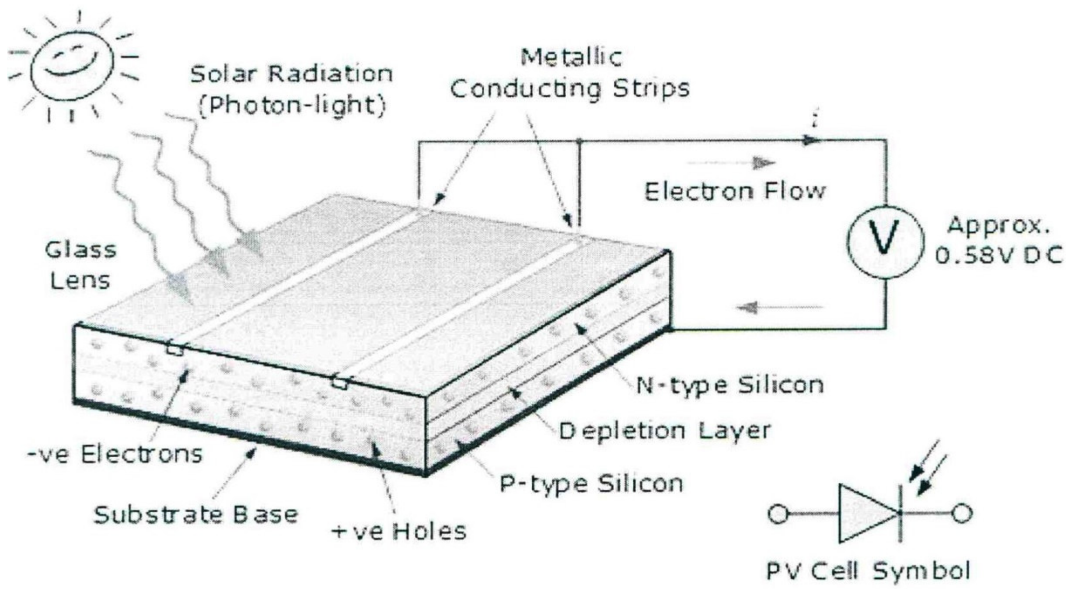


Figure 2.1: Photocurrent generation principle

2.3 THE CHARACTERISTICS OF PV CELL PERFORMANCE FACTORS

The factors must be taken into account are the sunlight intensity and PV cell temperature where the output power of PV module is dependent on these two parameters. Solar irradiance has direct relation and temperature has reverse relation with output power of PV module. It means increasing the sunlight intensity; the output power rises up. Increasing the temperature; the power comes down (Rekioua and Mategne. 2012). Photovoltaic module is affected by many factors during conversion; these factors are occurred mainly by climatic conditions, which affect the effective incident radiation, and also from the fabrication and electrical specification of the PV modules.

2.3.1 Irradiation Effect

Photovoltaic output power is affected by incident irradiation. PV module short circuit current (Isc) linearly proportional to the irradiation, while open circuit voltage (V_{oc}) increases exponentially to the maximum value with increasing incident irradiation, and varies slightly with the light intensity (Rekioua and Mategne. 2012). Figure 2.2 describes the relation between photovoltaic voltage and current with the incident irradiation.

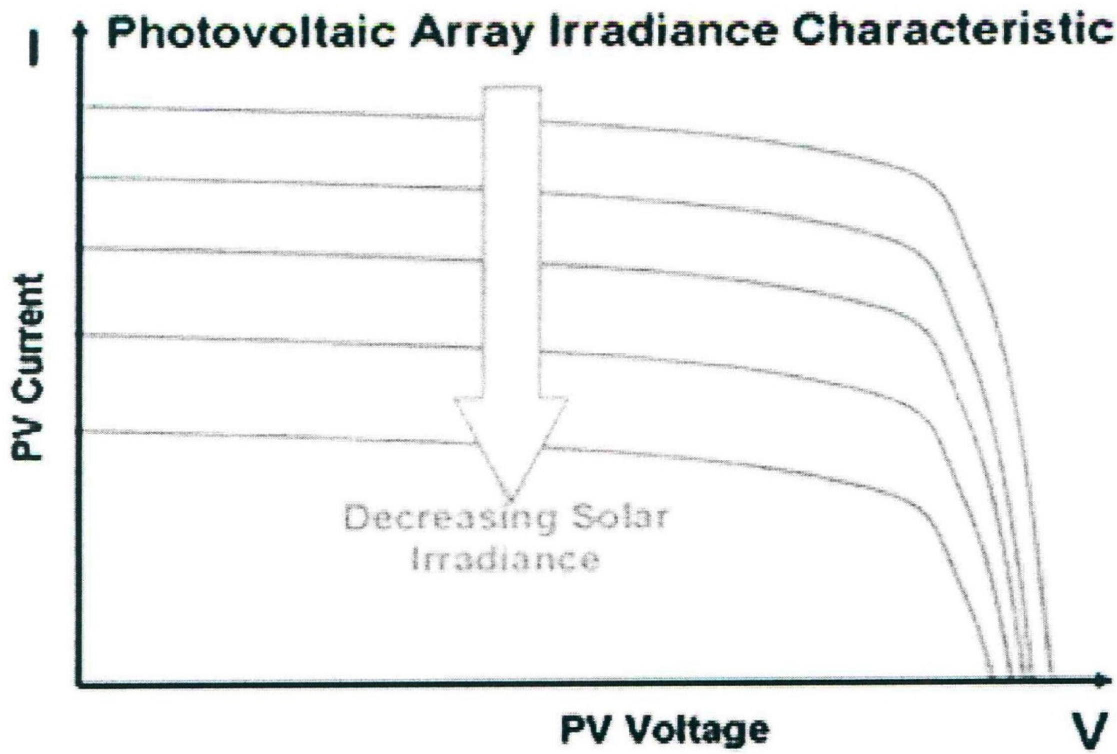


Figure 2.2: Effects of the incident irradiation on module voltage and current.

2.3.2 Temperature Effect

Module temperature is highly affected by ambient temperature. Short circuit current increases slightly when the PV module temperature increases more than the standard Test Condition (STC) temperature, which is 25°C. In other words the increasing current is proportionally lower than the decreasing voltage. Therefore, the output power of the PV module is reduced (Masters, 2004). Figure 2.3 explains the relation between module temperature with voltage and current.

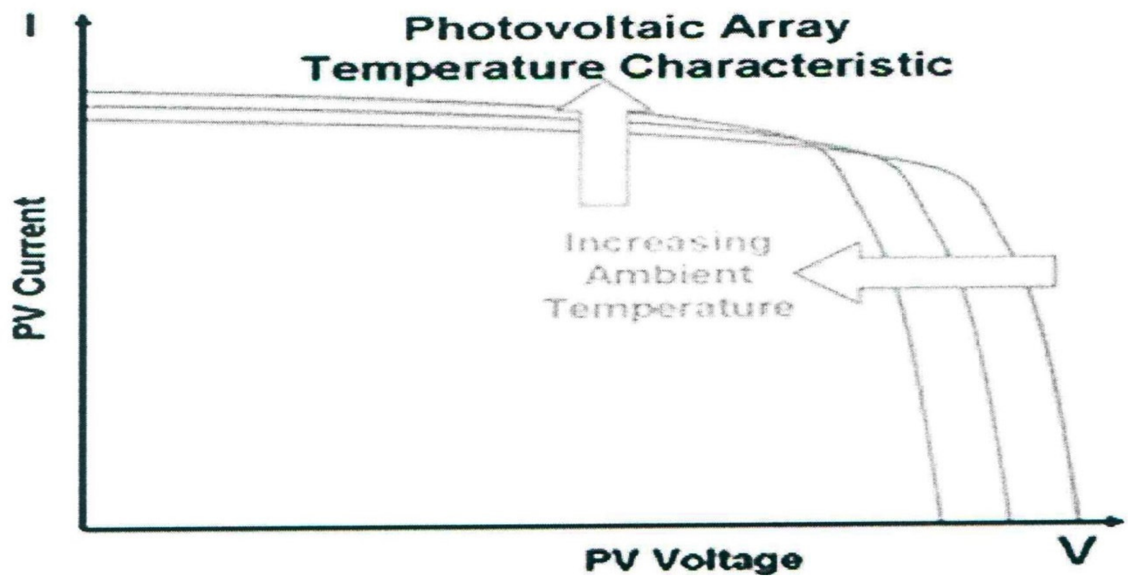


Figure 2.3: Effect of ambient temperature on module voltage and current.

2.3.3 Thermal Effect

Thermal response of the PV module is the main factor which affects the electrical power output. The PV module receives the incident irradiation; a portion of it is converted to electricity in proportional with the module efficiency. The rest of the incident irradiation heats the PV module and increases its operating temperature in relation to the PV material heat capacity. In the same time, a portion of the absorbed heat is dissipated into surrounding; this occurred through conduction, convection and the radiation exchange heat transfer between the module and the surrounding.

2.4 CURRENT VOLTAGE (I-V) AND POWER VOLTAGE (P-V) CHARACTERISTICS OF SOLAR CELL

PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature. The typical I-V and P-V characteristics of solar cell are shown in figure 2.4. The fundamental parameters related to solar cell characteristics are Short circuit current (I_{SC}), and Open circuit voltage *(V_{oc}),* Maximum power point (MPP) and Fill factor (Islam *et al.,* 2014).

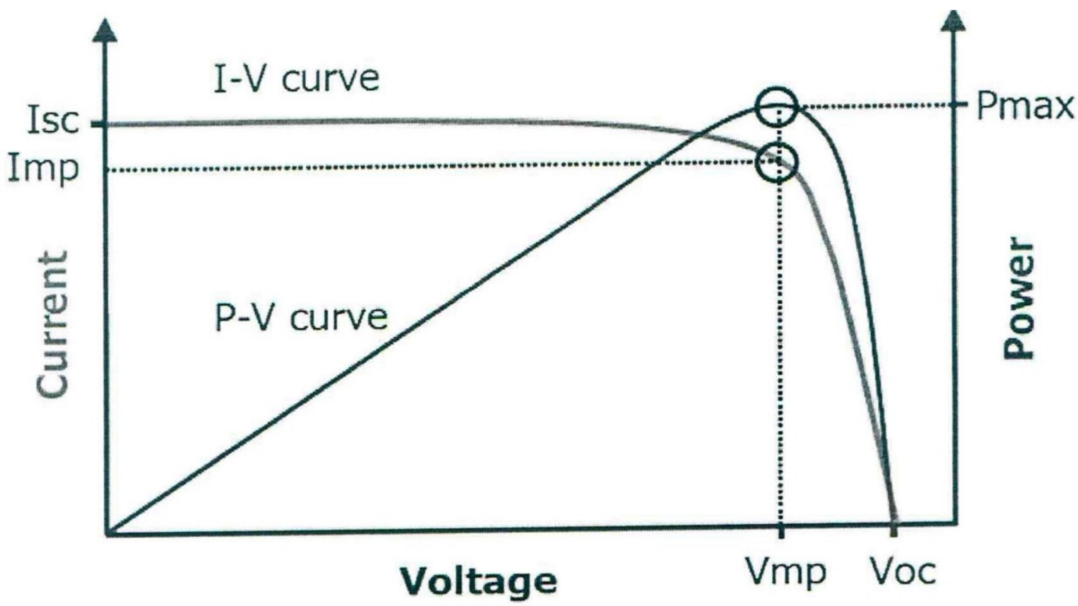


Figure 2.4: Typical I-V and P-V Characteristics of solar cell.

2.4.1 Maximum Power Point (P_{MPP})

Maximum electrical power of the PV module is equal to the current at maximum power point (MPP) multiplied by the voltage at maximum power point (VMP), which is the maximum possible power at Standard Test Condition (STC). Referring to figure 2.4, the "knee" of the I-V curve represents the maximum power point (PMPP) of the PV module/system. At this point the maximum electrical power is generated at STC. The usable electrical output power depends on the PV module efficiency which is related to the module technology and manufacture.

2.4.2 Fill Factor (FF)

The PV cell/module or arrays are often characterized by a parameter known as fill factor (FF). FF actually measures the quality of the PV array. It is the ratio of the power at the maximum power point (actual) to the product of Isc and VQC (theoretical), FF can be expressed as:

$$F \frac{I_{MP} * V_{MP}}{I_{sc} * V_{oc}} \qquad (2.0)$$

and it can be interpreted graphically as the ratio of the rectangular areas defined by the I-V curve as illustrated in figure: 2.5 (Chen, 2011).

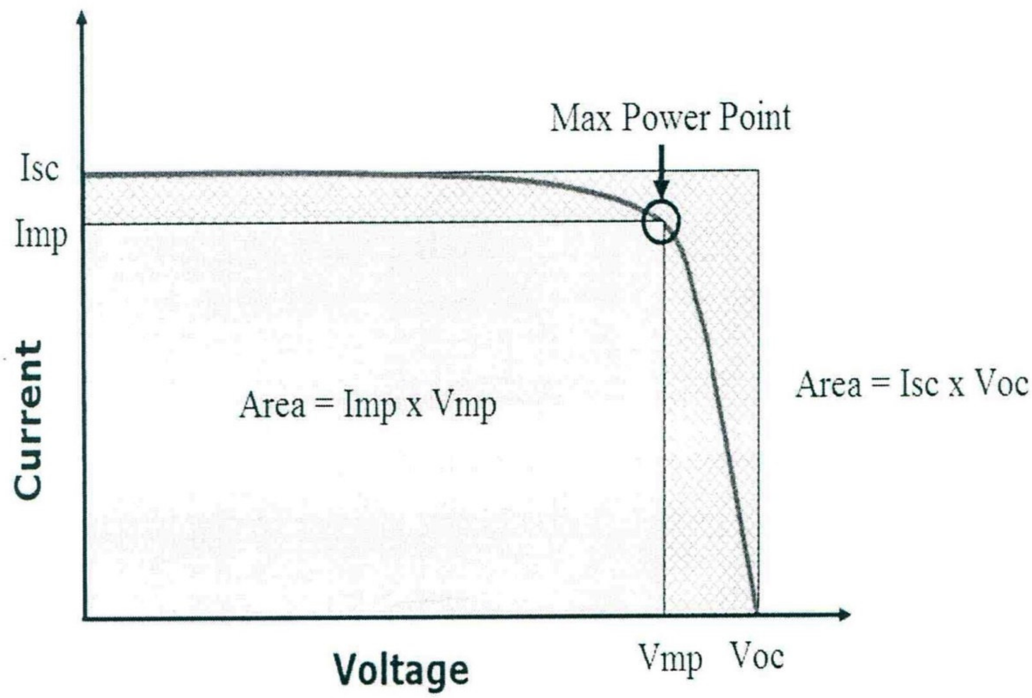
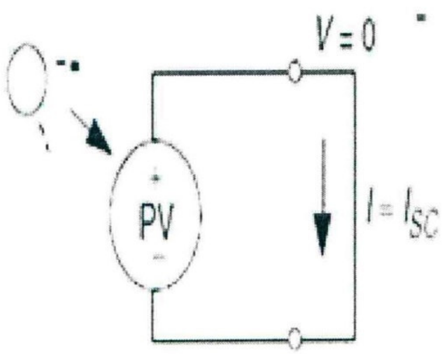


Figure 2.5: Fill Factor

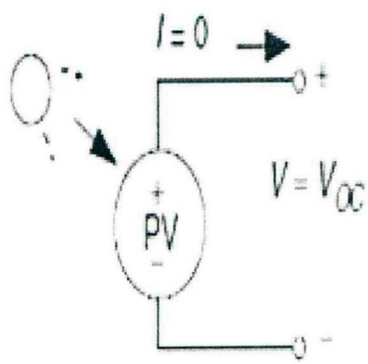
High performance cells are designed with a low series resistance values and high parallel resistance values, to reach ideal situation where the current held right up to the short circuit value, then reduced suddenly to zero at the MPP and have a FF of unity. Needless to say, practical cells do not achieve this value where they depend on PV arrays types. The importance of FF is to indicate the power achieved. The array with higher FF will produce more power; e.g., in case of two individual PV modules having the same values of Isc and V_{OC} Also, any impairment that reduces the FF will reduce the output power. The ideal FF value is 1 which means that the two rectangles are identical (Chen, 2011).

2.4.3 The Short-Circuit Current (I_{SC}) and the Open Circuit Voltage (V_{OC})

There are two conditions of particular interest for the actual PV cell and for its equivalent circuit. As shown figure 2.6, the current that flows when the terminals are shorted together which is called the short circuit current Isc and the voltage across the terminals when the leads are left open which is called the open circuit voltage V_{OC}. When the leads of the equivalent circuit for the PV cell are shorted together, no current flows in the (real) diode since $V_d = 0$, so all of the current from the ideal source flows throw the shorted leads. The shunt resistance R_{SH} is neglected in both cases, since power is the product current and voltage, no power is delivered by the module and no power is received by the load (Masters, 2004).



(a) Short-Circuit current



(b) Open-Circuit voltage

Figure 2.6: The short circuit current I_{SC} and the open-circuit voltage V_{OC}.

2.4.4 Efficiency

The PV cell/module efficiency is the ability to convert sunlight to electricity. The electricity of a solar cell is defined as the ratio of the output electric power over the input solar radiation power under standard illumination conditions at the maximum power point (Chen, 2011). The maximum efficiency of the PV module is given by:

$$\eta = \frac{P_{out}}{G * A} * 100\% \tag{2.1}$$

Where G is global radiation and considered to be l000W/m^2 at (STC) and *A* is the Area of the PV module (input power of the solar panel P_{in}).

2.5 CLEAR SKY DIRECT-BEAM RADIATION

Clear flux striking a collector Ic, will be a combination of *direct - beam* radiation I_{BC}, that passes in a straight line through the atmosphere to the receiver, *diffuse* radiation I_{DC}, that has been scattered by molecules and aerosols in the atmosphere, and *reflected* I_{RC}, that has bounced off the ground or other surface in front of the collector.

The clear sky insolation reaching the earth's surface (normal to the rays), is given by (Masters, 2004);

$$I_B = Ae^{-km} \tag{2.2}$$

$$A = 1160 + 75 \sin\left[\frac{360}{365}(n - 275)\right]\left(\frac{w}{m^2}\right) \tag{2.3}$$

$$k = 0.174 + 0.035 \sin\left[\frac{260}{265}(n - 100)\right] \tag{2.4}$$

$$m = {}^{1}/_{\beta} \tag{2.5}$$

where A is the apparent extraterrestrial solar insolation, k is the atmospheric optical depth, m is the air mass ratio, β is the solar altitude angle and, n is the day number.

2.6 TOTAL CLEAR SKY INSOLATION ON A COLLECTING SURFACE

Reasonably accurate estimates of the clear sky, direct beam insolation are easy enough to work out and the geometry needed to determine how much of that will strike a collector surface is straightforward. It is not easy to account for the diffuse and reflected insolation but since that energy bonus is relatively small fraction of the total, even crude models are usually acceptable (Masters, 2004).

2.6.1 Direct-Beam Radiation

The direct beam radiation I_B (normal to the rays) into beam insolation striking a collector face I_B is a simple function of the angle of incidence θ between a line drawn normal to the collector face and the incoming radiation, is given by (Masters, 2004);

$$I_{BC}=I_B\ COS\ \theta \tag{2.6}$$

The incident angle is given by (Masters, 2004);

$$COS\ \theta = COS\ \beta\ COS\ (\phi_s - \phi_c)\ \sin\Sigma + \sin\beta\ \mathrm{Cos}\ \Sigma \tag{2.7}$$

Where ϕ_s is the solar azimuth angle, ϕ_c is the collector tilt angle and, Σ is the collector of the tilt angle.

2.6.2 Diffuse Radiation

The diffuse radiation on a collector (I_{DC}) is much more difficult to estimate accurately than it is for the beam. The radiation can be scattered by atmospheric particles and moisture or reflected from clouds. Some is reflected from the surface back into the sky and scattered again back to the ground. The simplest model of diffuse radiation assumes it arrives at a site with equal intensity from all direction; that is, the sky is considered to be isotropic (Masters, 2004).

$$I_{DC}=CI_B\left(\frac{1+COS\Sigma}{2}\right) \tag{2.8}$$

$$C=0.095 + 0.04\ \sin\left[\frac{360}{365}\ (n-100)\right] \tag{2.9}$$

where C is the sky diffuse factor.

2.6.3 Reflected Radiation

The final components of insolation striking a collector results from radiation that is reflected by surfaces in front of the panel (I_{RC}).This reflection can provide a considerable boost in performance. The assumption needed to model reflected radiations are considerable, and the resulting estimates are very rough indeed. The simplest model assumes a large horizontal area in front of the collector, with a reflectance ρ that is diffuse, and it bounces the reflected radiation in equal intensity in all directions (Masters, 2004).

$$IRC = \rho I_B\,(\sin\beta + C)\frac{1 = cos\Sigma}{2} \tag{2.10}$$

where ρ is the ground reflectance.

Combining the equations for the three components of radiation, direct beam, diffuse and reflected gives the following for total rate at which radiation strikes a collector on a clear day (Masters, 2004);

$$I_C = I_{BC} + I_{DC} + I_{RC} \tag{2.11}$$

$$I_C = Ae^{-km}\left[\cos\beta\cos(\Phi_s - \Phi_c)\sin\Sigma + \sin\beta\ cos\Sigma + C\left(\frac{1+cos\Sigma}{2}\right) + \rho(sin\beta + C)\left(\frac{1-cos\Sigma}{2}\right)\right] \tag{2.12}$$

2.6.4 Solar Declination

The angle formed between the plane of the equator and a line drawn from the center of the sun to the center of the earth is called solar declination angle (δ). It varies between the extremes of ±23.45°, and a simple sinusoidal relationship that assumes a 365-day year and which puts the spring equinox on day n = 284 provides good approximation (Masters, 2004).

$$\delta = 23.45\sin\left[\frac{360(284+n)}{365}\right] \tag{2.13}$$

2.6.5 Solar Position at Any Time of Day

The location of the sun at any time of day can be describes in terms of its latitude angle β and its azimuth angle ϕ_s. The subscript s in the azimuth angle helps us remember that this is the azimuth angle of the sun. By convention, the azimuth angle is positive in the morning with the sun in the east and negative in the afternoon with the sun in the west (Masters, 2004).

2.6.6 Equations of Solar Angle:

$$\beta_N = 90 - L + \delta \tag{2.14}$$

$$\sin\beta = \cos L \ \mathrm{cost}\ H + \sin\delta \tag{2.15}$$

$$H = \frac{15^0}{hour} \ or\ H = \frac{15^0}{hour} \tag{2.16}$$

Where β_N = altitude angle at solar noon. L = latitude and, H is the hour angle (Masters, 2004).

2.7 ONE DIODE PV MODEL CIRCUIT

The simplest model of PV cell is shown as an equivalent circuit below that consists of ideal current source in parallel with an ideal diode (Bikaneria and Joshi, 2013).

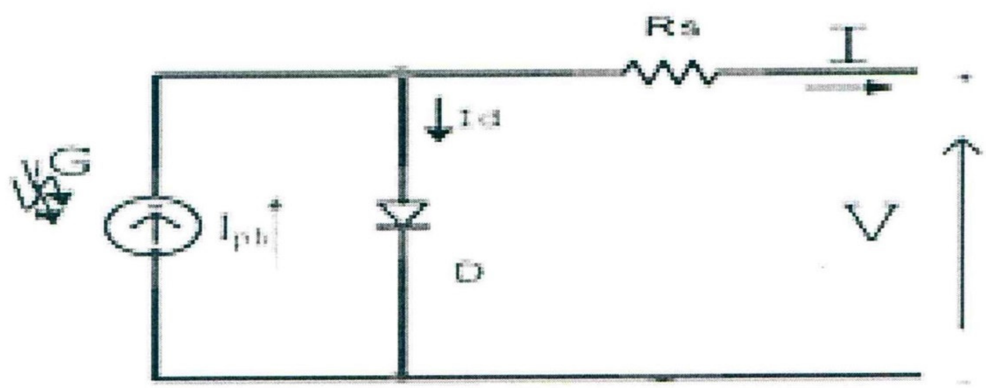


Figure 2.7: A one diode equivalent circuit PV Cell (El-Basit, 2013).

Where I_{ph} is the photocurrent generator, D is a single parallel-connected diode, R_S is a series resistor, I_d is the normal diode current and I is the output current. From figure 2.3, it can be seen that (Vengatesh and Rajan, 2011).

$$I = I_{ph} - I_d \tag{2.17}$$

and the normal diode current I_d is

$$I_d = I_S \left[e \frac{q(V+IR_S)}{kAT_C} - 1 \right] \tag{2.18}$$

Substituting Equation (2.2) into Equation (2.16)

$$I_d = I_{ph} - I_S \left[e \frac{q(V+IR_S)}{kAT_C} - 1 \right] \tag{2.19}$$

where I_S is the cell saturation dark current, q (= 1.6×10^{-19} C) is an electronic charge, k (= 1.38x 10^{23}J/K) is a Boltzmann's constant. T_C is the cell's working temperature, A is the ideality factor. The photocurrent I_{ph} mainly depends on the solar insolation and cell's working temperature, which is described as (Kachhiya *et al.,* 2011).

$$I_{ph} = [I_{SC} + K_I\,(T_C - T_{Ref})]N \tag{2.20}$$

where I_{SC} the cell's short-circuit current at 25°C and l00W/m^2, K_I is the short-circuit temperature coefficient. T_{Ref} is the cell's reference temperature, N is the solar insolation in W/m^2. Since normally $I_{ph} >> I_s$ and ignoring the small diode current I_d and ground-leakage current under zero-terminal voltage, the short-circuit current is approximately equal to the photocurrent I_{ph} (Kachhiya *et al.,* 2011).

$$I_{Ph} = I_{SC} \tag{2.21}$$

Therefore the short-circuit current I_{SC} can be obtained as;

$$I_{SC} = I = I_{Ph} = - I_S \left[e \frac{q(V+IR_S)}{kAT_C} - 1 \right] \tag{2.22}$$

On the other hand the cell's or diode saturation current varies with the cell temperature, which is described as;

$$I_S = I_{RS} \left(\frac{T_C}{T_{Ref}} \right)^3 \; e \frac{qE_G}{Ak} \left(\frac{1}{T_{Ref}} - \frac{1}{T_C} \right) \tag{2.23}$$

where I_{RS}, is the cell's reverse saturation current at a reference temperature of a solar radiation, E_G is the band-gap energy of the semiconductor used in the cell. The reverse saturation current at reference temperature can be approximately obtained as (Vajpai and khyani, 2013).

$$I_{RS} = \frac{I_{SC}}{\left[e\left(\frac{qV_{SC}}{N_S T C^{KA}}\right)-1\right]} \tag{2.24}$$

where V_{oc} is an open circuit voltage obtained when the diode is not conducting. V_{oc} is found to be given as (Rodrigues *et al.,* 2011).

$$V_{OC} = \frac{AKT}{q} in \left(1 + \frac{I_{SC}}{I_S}\right) \tag{2.25}$$

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series and parallel configurations on a given module to produce enough high power (Seifi *et al.,* 2013). A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The terminal equation for the current and voltage of the array becomes as follows (Vajpai & Khyani, 2013), (Rizi & Abadi, 2016).

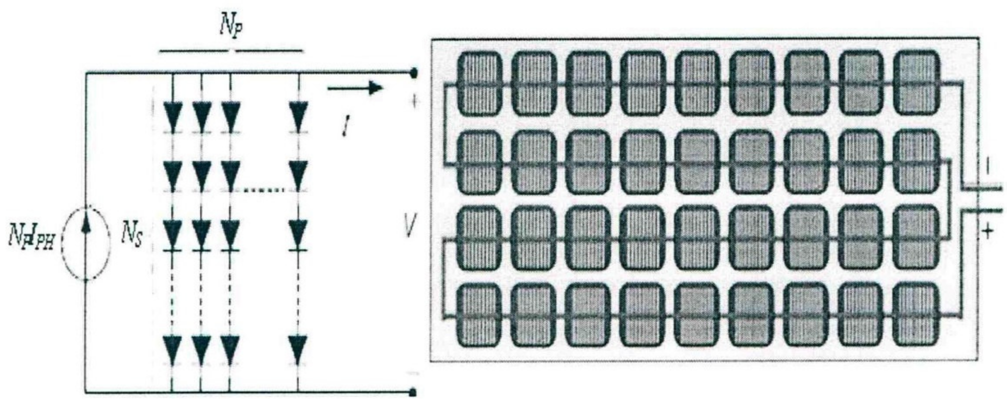


Figure 2.8: Ideal model of PV module and typical PV Module connected in series

$$I = N_P I_{Ph} - N_P I_S \left[e \frac{q}{KAT_C}\left(\frac{V+IR_S}{N_S}\right) - 1\right] \tag{2.26}$$

The output power can be obtained by:

$$P = V\left[N_P I_{Ph} - N_P I_S \left[e \frac{q}{KAT_C}\left(\frac{V+IR_S}{N_S}\right) - 1\right]\right] \tag{2.27}$$

CHAPTER THREE

METHODOLOGY

3.0 INTRODUCTION

In this chapter the methods and the detail of the procedure that lead to the successful execution of this work is presented. The study was carried out in two ways; Experimental and Simulation.

3.1 EXPERIMENTAL METHOD

In this method, the experiment was conducted in three locations at Bayero University Kano Old Campus; A: Central Mosque (latitude: 11.976801N, longitude: 8.480831E), B: Nana Hall (latitude: 11.98295N, longitude: 8.47756E), C: PG Common Room (latitude: 11.98136N, longitude: 8.4768IE). The data were obtained using the following procedure;

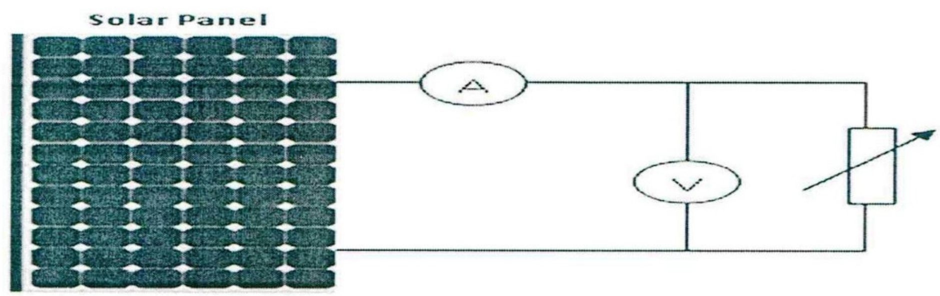


Fig. 3.0 : Experimental set up (Vengatesh and Rajan, 2011)

The instruments used are Solar panel (YL30P - 17b), Intelligent Digital Multimeter with PC Interface (MAS-345), Rheostat (SR 451) and some connecting wires. The local latitude values for the three locations were used as the PV module tilt angle. The sun azimuth angle of the experimental time was also considered and made equal to the azimuth angle of the panel. The V-I characteristics of the panel was obtained by varying the rheostat in steps. The open circuit and short circuit values were obtained by actually opening and shortening the terminals (Vengatesh and Rajan, 2011).

3.2 SIMULATION METHOD

In the simulation procedure. Rs PV module single diode model was used and simulated in MATLAB environment. Both the experimental and simulation procedures were carried out for each of the three locations of this research

CHAPTER FOUR

RESULTS AND DISCUSSION

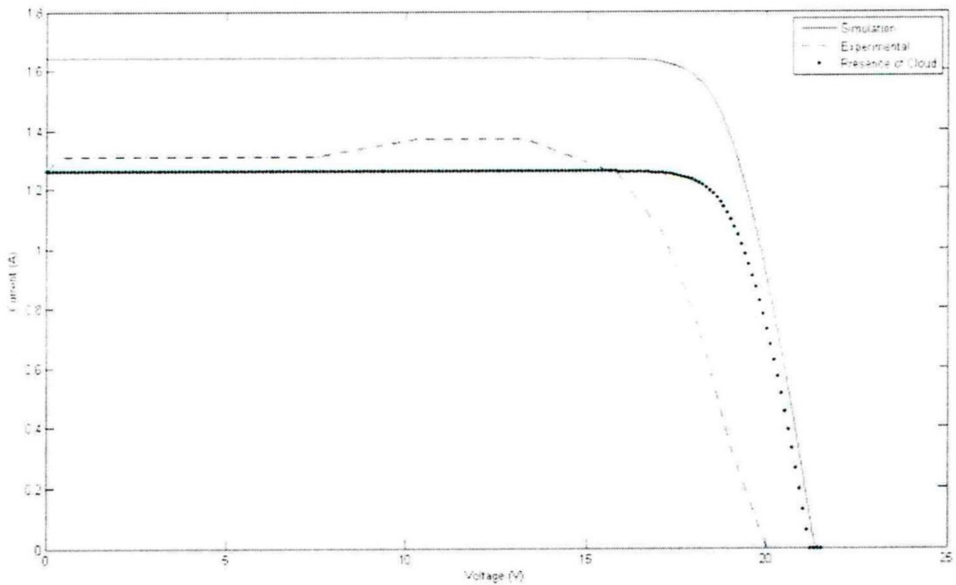
4.0 INTRODUCTION

This chapter presents the results and discussion of the experimental and simulation work.

3.1 GENERAL RESULTS AND DISCUSSION

The measured PV currents and voltages at each experimental locations are plotted. On each plot the simulated values of these parameters are also plotted. Based on the latitude, the day and time of the experiment, the corresponding clear day V-I characteristics of the PV panel was also plotted together. The corresponding P-V curves are also plotted on a separate figure.

A



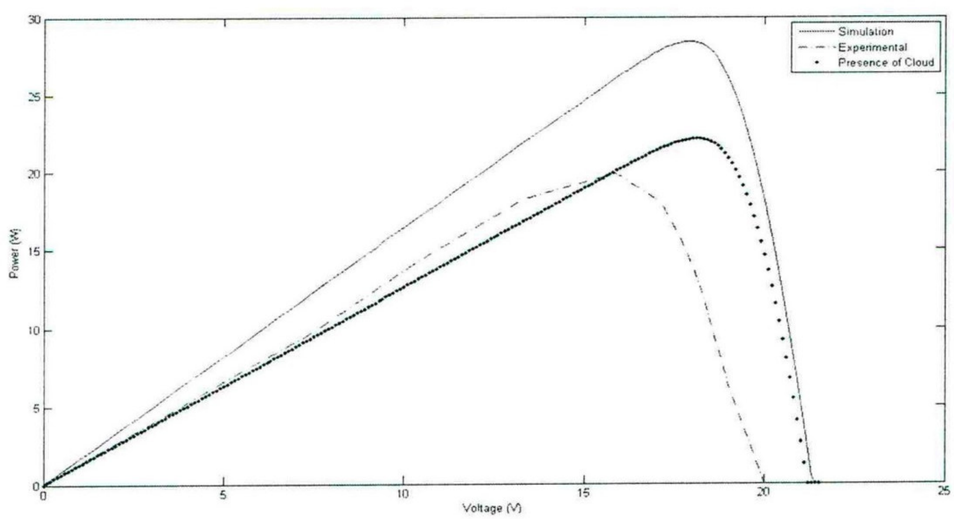
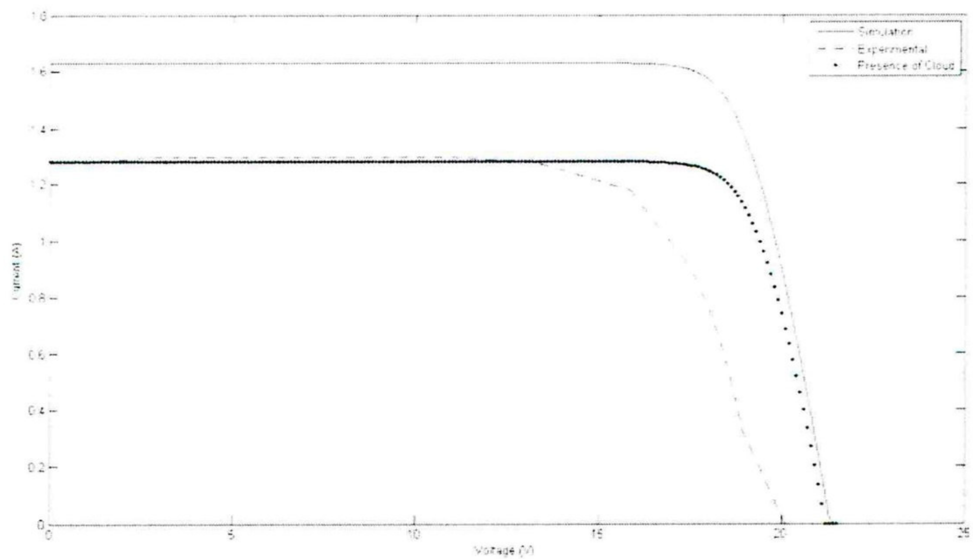


Fig. 4.0 : V-I, P-V characteristics obtained from simulation and experimental study on the day of 9 September 2015 at 9.00am, latitude = 11.98 , tilt angle = 12 , temperature =28°.

B.



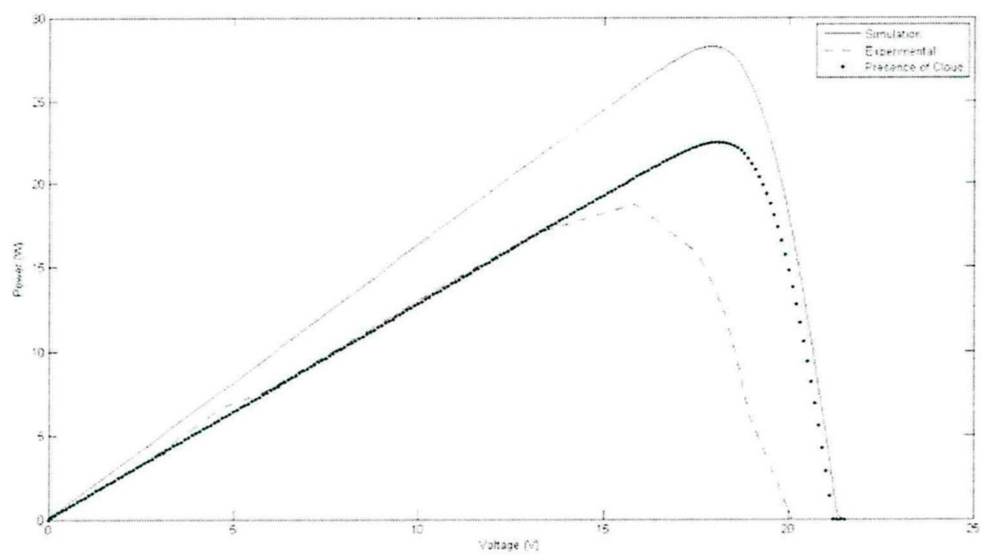


Fig. 4.1: V-I. P-V characteristics obtained from simulation and experimental study on the day of 4th September 2015 at 9.00am, latitude = 11.98°, tilt angle = 12°, temperature =28°.

C.

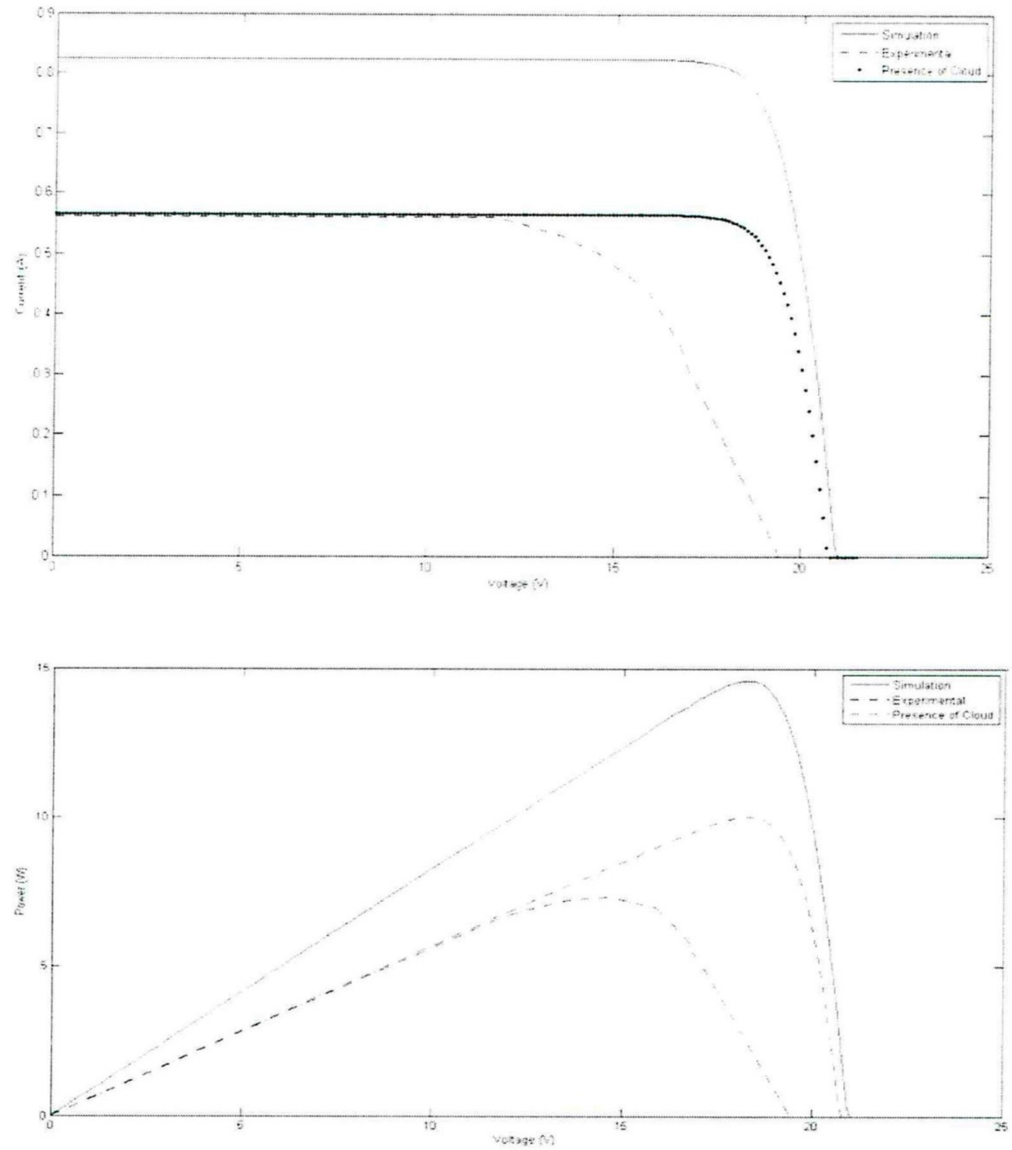


Fig. 4.2: V-I, P-V characteristics obtained from simulation and experimental study on the day of 8th September 2015 at 12.15pm. latitude = 11.98°, tilt angle = 12°, temperature =33°.

The graphs above (Figure 1 - 6) are the results of the study obtained from different days and time that were chosen from different locations in the Bayero University Kano old campus, in which the experiment was conducted. Each graph presents three curves; simulation (clear day), experimental, and the simulated cloud day. The graphs clearly show that the simulation strongly agrees with the experimental data. This further validates the relationship of computing cloudless irradiance being used in this research. The irregularities in the experimental curves are due to the presence of cloud in the atmosphere, and the intensity of irradiance is affected by their blockage.

It can observe that the cloudless solar radiation curve is at higher Isc compared to the experimental curve. This shows that presence of cloud in the atmosphere reduces the short circuit current as well as the maximum power of the PV module, which is in agreement with this work.

Table: 4.0 Values obtained from experiment for the three locations.

S/N	LOCATION	LATITUDE	IRRADIANCE (W/m^2)	EFFICIENCY (%)
1	A	11.976801	662.9	9.97
2	B	11.98295	673.6	9.25
3	C	11.98136	294.8	8.25

Table: 4.1 Values obtained from simulation for the three locations.

S/N	LOCATION	LATITUDE	IRRADIANCE (W/m^2)	EFFICIENCY (%)
1	A	11.976801	862.4258	10.93
2	B	11.98295	856.4575	10.93
3	C	11.98136	862.4254	12.02

Thus, the latitude was the local latitude value for the experimental locations and the irradiance (W/m^2) is the calculated value of solar isolation from the experiment while the efficiency (%) was obtained using the relation;

$$\aleph = \frac{P_{out}}{G*A} * 100\%$$

Where; $P_{out} = I_{out} * V_{out}$

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.0 SUMMARY

Renewable energy is an energy that is environmentally friendly if manage in a proper way it can fulfill the high demand of the energy of the world. Solar radiation distribution at a particular geographical location is of vital importance for the developments of many solar devices. Photovoltaic (PV) modules are devices that convert solar irradiance into electricity. We conducted an experiment and simulated PV parameters to access the performance of the module under cloudy condition. We found that cloud reduced the short circuit current and maximum power of the PV module.

5.1 CONCLUSION

We have found that, cloud reduced the short circuit current (Isc) and maximum power output (P_{max}) as well as the efficiency of the PV module. In this work, the reduction in efficiency at Central Mosque is 0.96%; Nana Hall is 1.68%; PG Common Room is 3.77%. The result from simulation and the experiment are in good agreement. Thus, the effect of cloud on the performance of PV module has been determined.

5.2 RECOMMENDATIONS

- In order to improve the performance of a large scale power plant, the climate and weather condition of that location must be taken into consideration so that maximum output can be taken from it.
- The study to serve as the basic model to carry out the further studies infield of PV modeling.

Major Contributions of the Dissertation

- We validate one diode photovoltaic (PV) module model
- We are able to establish that the performance of solar cell increases with increase in irradiance.
- We are able to establish that cloud reduce the output current and power of a PV module.

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APPENDIX

MATLAB CODE

```
Function [u P V] = pv_module(T,G)

i=[];Tc=25+273;u=[];v=[];P=[]; T=T+273;

Isc=1.87; %Isc and mu: the Temperature coefficient of the short circuit current;

mu=0.06;%in datasheet;

DT=T-Tc;

Iph=0.001 *G*(Isc+mu*DT);

%lo expression

Voc=21.20;

Rs=0.10;

Ns=36;

K=1.38*exp(-23);

eg=1.12*1.6*exp(-19);

A=1.5;

q= 1.6*exp(-19);

a=0.026*A*Ns;

Io=Isc*(exp(-Voc/a)).*(T/Tc).A3.*exp((q*eg/A*K).*((T-Tc)/(T*Tc)));

%lnitialize I

1=0;

forV=0:0.1:Voc

        I=Iph-Io*(exp((V+I*Rs)/a)-l);

u=[u I];
```

```
p=V*I;

P=[Pp];

v=[v V];

end

u(u<=0)=0;

P(P<=0)=0;

u=u';

P=P';

v=v';

plot(v,P)

d=horzcat(u,v,P)

end
```