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Electrical Power Engineering

Investigate the Effect of Dust, Air Velocity and Temperature on Photovoltaic Cells Performance.

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Firstly, I would like to thank Allah, for His mercy during all our life, and praise the prophet Mohammad (peace be upon him).We dedicate this work to our father's (Hani Jabari, Mousa Al-Azzeh, Taiseer Khalefeh), our mother's, our brothers and sisters. Furthermore, I greatly appreciate the support which I received from our supervisor Dr.Maher maghalseh, also thanks for everyone who give us any support. I want to declare that this work was supported and funded by Deanship of Graduate Studies and Scientific Research (Palestine Polytechnic University).

Abstract

Nowadays, the energy becoming the main driver of the progress of civilization and a key element in human life, but the depletion of fossil fuel which is the primary source of this energy, which is one of non-renewable sources While the world is suffering from climate change and pollution of its air and the risk of decline in the Ozone layer, has become a challenge that the world faces how to find alternatives to energy-friendly environment.

The main idea of the project to study the effect of natural conditions on the photovoltaic module (temperature, dust and air velocity) through laboratory experiments (indoor experiments), in order to reach the best efficiency is to obtain the highest value of electrical power generated from PV module.

This project investigates the environmental effects (Temperature, Dust and air velocity) on the photovoltaic module (mono-crystalline) performance. The degradation of PV performance due to the increase of temperature, dust density and air velocity has been investigated. A series of experiments were conducted in order to study the effect of these parameters on the PV performance. In the first section, the effect of temperature on the I-V curve, Power, and efficiency was explained. In the second section, the effects of several type of dust were studied. These are red soil, sand and calcium carbonate. The experimental results show that the PV voltage and power is strongly depends on pollutant type and deposition level. also in third section which talking about the effect of air velocity on PV performance, and how the increasing in the air velocity affects the PV efficiency, more heat can removed from the PV module surface and higher air velocity decrease the relative humidity which lead to better PV efficiency.

الملخص

في عصر أصبحت فيه الطاقة بمصادرها المختلفة هي المحرك الاساسي للتقدم الحضاري وعنصرا أساسيا في حياة البشر، وفي ظل تناقص كميات النفط الأحفوري الذي يعتبر المصدر الأساسي لهذه الطاقة والذي يعتبر من المصادر الغير متجددة وفي حين يعاني العالم من التغير المناخي وتلوث هوائه وخطر انحسار طبقة الأوزون وارتفاع معدلات الحرارة، أصبح التحدي الذي يواجه العالم كيفية أيجاد بدائل للطاقة صديقة للبيئة بحيث تحد من استنزاف مصادر الطاقة الغير متجددة وتسعى إلى توصيل الطاقة إلى مختلف أرجاء العالم دون المساس بالبيئة وبأسعار مقبولة.

يوجد هناك العديد من المؤثرات على الخلايا الشمسية الطبيعية منها والصناعية والتي تؤدي الى تقليل من كفاءة الخلايا الشمسية وتعتبر المؤثرات الطبيعية من أهم العوامل التي يلزم مراعاتها عند تصميم مشاريع الطاقة الشمسية . والقصور في مراعاة العوامل المناخية قد يؤدي إلى سوء تشغيل هذه المنظومة وضعف الاستفادة من الطاقة المتاحة منها.

تقوم الفكرة الرئيسة للمشروع على دراسة تأثير الظروف الطبيعية على الخلايا الشمسية (الغبار, الحرارة ,الرياح ,الاشعاع الشمسي) من خلال تجارب مخبرية بهدف التوصل الى افضل كفاءة تتمثل بالحصول على اعلى قيمة للقدرة الكهربائية الناتجة من للخلايا الشمسية بالاضافة للوصل الى نسبة تاثير كل نوع من انواع المؤثرات الطبيعية على القدرة الناتجة والتوصل لمعامل لكل نوع من انواع المؤثرات.

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Abbreviations:

Description	Abbreviation
Photovoltaic Cells	**PV**
Standard Test Condition	**STC**
Infrared emitting diode	**IRED**
Alternating Current	**AC**
Direct Current	**DC**
Fill Factor	**FF**
Open circuit voltage	**Voc**
Short circuit current	**Isc**
Irradiation sensor	**TM206**
Maximum current	**Im**
Maximum voltage	**Vm**
Air Mass	**AM**
Efficiency	**ɳ**
Max Power Point Voltage	**Vmm**
Max Power Point Current	**Imm**
Series Resistance	**Rs**
Shunt Resistance	**Rsh**

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CHAPTER ONE

Introduction

1.1Problem statement.

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1.1 Problem statement

The solar energy is one of the most important renewable energy sources, due to its easy availability, cleanness, and cheap energy resources. Now days a number of solar energy approaches are in progress and solar cells have paid more attention, due to rapidly developing world and society. The solar cell is a device which directly converts electrical energy from the solar radiation which is based on the photovoltaic effect.

The solar panels is affected by many environmental parameters such as light intensity or irradiation, tracking angle, temperature, air velocity and dust. Through the photovoltaic parameters like open circuit voltage, short circuit current, maximum output power, fill factor and efficiency are generally affected by the above environmental parameters [1].

In this project we aims to Investigate the effect of dust, air velocity and temperature on photovoltaic panels performance, by making many experiments focus on these factors and how its affect the PV panels .

1.2 Approach

The approach is briefly talking about some experiments that can be show the effect of temperature, air velocity and dust of a photovoltaic (PV) panels. We also make a simulation by a software Program for the all cases, then compare it by theoretical one, after all of that we can conclude it by numerical relation between experimental and theoretical factor which affected the solar panels.

1.3 Objectives

Studying the effect of Temperature, air velocity and Dust of a Monocrystalline photovoltaic module. In addition simulate the above factors making a numerical relation of the experiments and theoretical study, to show the PV performance of I-V and P-V curves for different above cases.

1.4 Motivation

In all over the world, Especially in Palestine there is a serious problem that facing the solar panels, such as to increase the efficiency of it or to stay it work at maximum efficiency without any effects to decrease. All of that because the solar energy is the most important source nowadays and scientist see that the future is by solar energy. So our aim to experimentally studying the factors that affect solar cell comparing it by Standard test conditions of solar cell, then knowing the percentage of impact of these factor on solar panels.

1.5 Requirements

Hardware requirements include:

- Mono-crystalline silicon solar cell
- Solar Radiation sensor: measures solar energy from the sun or sun simulator.
- Temperature PV sensor: used to detect the change in PV cell temperature.
- Dust intensity sensor: used to detect the dust density on solar cell.
- Fan for air velocity impact test.
- Sun simulator: To concentrate the light on solar cell to get a needed radiation.
- Microcontroller: used to control the system of sensors which control the solar cell.
- Software Program: such as Matlab to simulate our data and analyze it.

1.6 Project Plan:

This part show the distribution tasks on the weeks to complete the project.

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Select the idea	■	■													
Preparing for the project and collecting information			■	■	■	■	■	■	■	■	■	■	■		
Project analysis													■	■	■
Determine the project equipment requirements									■	■					
Design											■	■	■	■	
Report deadline for supervisor												■	■	■	
Report deadline for the electrical engineering department															■

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CHAPTER TWO

Background

2.1 Introduction

In this chapter review of published scientific papers related to the study are summarized. The review is concerned about the photovoltaic cells performance and characteristic and the external influences and parameters that affect the characteristics of photovoltaic cells and performance.

2.2 Photovoltaic Power Generation

A material or device that is capable of converting the energy contained in photons of light into an electrical voltage and current is said to be photovoltaic. A photon with short enough wavelength and high enough energy can cause an electron in a photovoltaic material to break free of the atom that holds it. If a nearby electric field is provided, those electrons can be swept toward a metallic contact where they can emerge as an electric current. The driving force to power photovoltaic comes from the sun, and it is interesting to note that the surface of the earth receives something like 6000 times as much solar energy as our total energy demand. Photovoltaic use semiconductor materials to convert sunlight into electricity. The technology for doing so is very closely related to the solid-state technologies used to make transistors, diodes, and all of the other semiconductor devices that we use so many of these days. The starting point for most of the world's current generation of photovoltaic devices, as well as almost all semiconductors, is pure crystalline silicon [2].

Semiconductor material such as silicon, is composed of a P-type semiconductor and an N-type semiconductor. Solar radiation emitting the photovoltaic cell produces two types of electrons, negatively and positively charged electrons, in the semiconductors. The electric current flows through an external circuit between the two electrodes. Photovoltaic cells are connected electrically in series or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits. A photovoltaic array is the complete power-generating unit, consisting of a number of PV modules, PV module and array are shown in Fig 2.1[3].

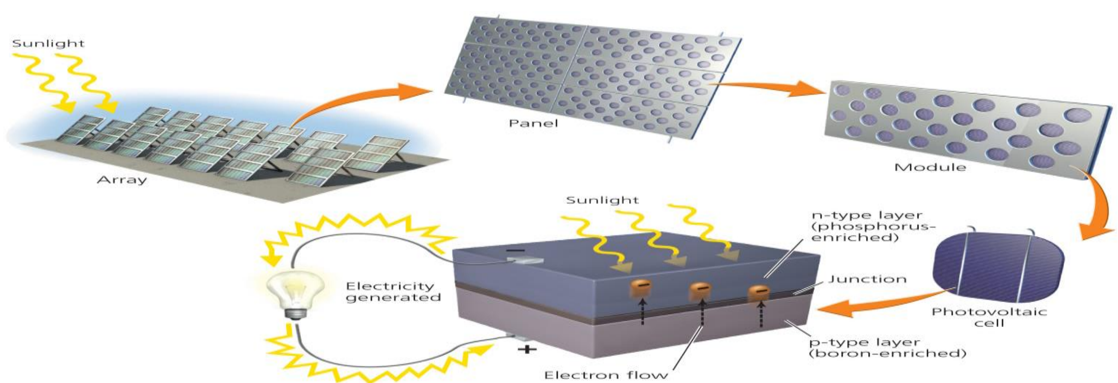

Figure 2.1: Cell, Module to Panel [3].

As photons are absorbed, hole-electron pairs may be formed. The electric field in the depletion region will push the holes into the p-side and push the electrons into the n-side. The p-side accumulates holes and the n-side accumulates electrons, which creates a voltage that can be used to deliver current to a load. If electrical contacts are attached to the top and bottom of the cell, electrons will flow out of the n-side into the connecting wire, through the load and back to the p-side. Since wire cannot conduct holes, it is only the electrons that actually move around the circuit. When they reach the p-side, they recombine with holes completing the circuit. By convention, positive current flows in the direction opposite to electron flow, so the current going from the p-side to the load and back into the n-side, as shown in Fig 2.2 [4].

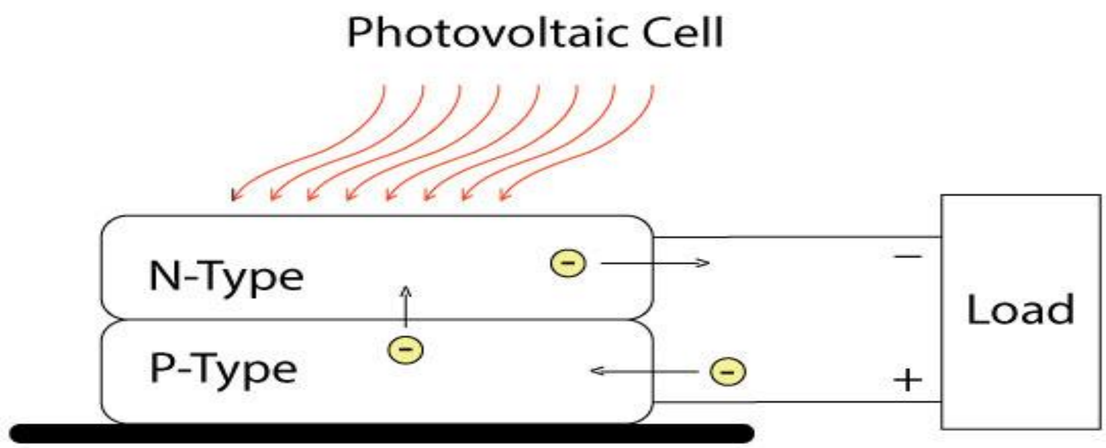

Figure 2.2: The p-n junction with load [4].

2.3 The PV Characteristics and I-V Curve under Standard Test Conditions (STC)

The performance of a photovoltaic module depends on manufacturing technology and operating conditions under Standard Test Condition (STC) which represented as a test of the produce solar cell or module for measure and explain the I-V curve characteristic of a photovoltaic cell for terrestrial solar power modules, to compare the performance of different solar power modules uniform operating data. These conditions define performance at an incident sunlight of 1000 W/m², a cell temperature of 25°C (77°F) and an AM of 1.5 (AM = Air Mass). The air mass determines the radiation impact and the spectral combination of the light arriving on the earth's surface [5].

Also to be familiar of the I-V curve we must identify the electrical Parameters that describe the performances of Photovoltaic cells:

1. Short circuit current (Isc): The value of (Isc) can be obtained by connecting the terminals of a module via an ammeter and measuring the current. The value of Isc changes in function of solar radiation and very little of temperature [6].

2. Open circuit voltage (Voc): It's the voltage of a PV module measured at its terminals at no load [6].

3. Maximum power point (MPP): The maximum power point of a photovoltaic is a unique point on the (I-V) or (P-V) characteristics and the power supplied in this point is maximum, where measured in Watts (W) .its value can be calculated by the product Vmax and Imax [6].

4. Maximum efficiency: is the ratio between the maximum power and the incident light power.

$$\eta = \frac{Pout}{Pin} \qquad (2.1)$$

5. Fill Factor (FF): The ratio of output power at maximum power point to the power computed by multiplying Isc by Voc.The FF is obtained according the following equation:

$$FF = \frac{Vmpp * \ Impp}{Vout * \ Isc} \qquad (2.2)$$

Typically, crystalline silicon photovoltaic FF module is between 0.67 and 0.74. If the I-V curves of two individual PV modules have the same values of Isc and Voc, the array with the higher fill factor (squarer I-V curve) will produce more power. Also, any impairment that reduces the fill factor will reduce the output power [6].

Now we can consider theI –V characteristic curve of the module as well as the P–V characteristic curve of the load, as shown in Fig 2.3.

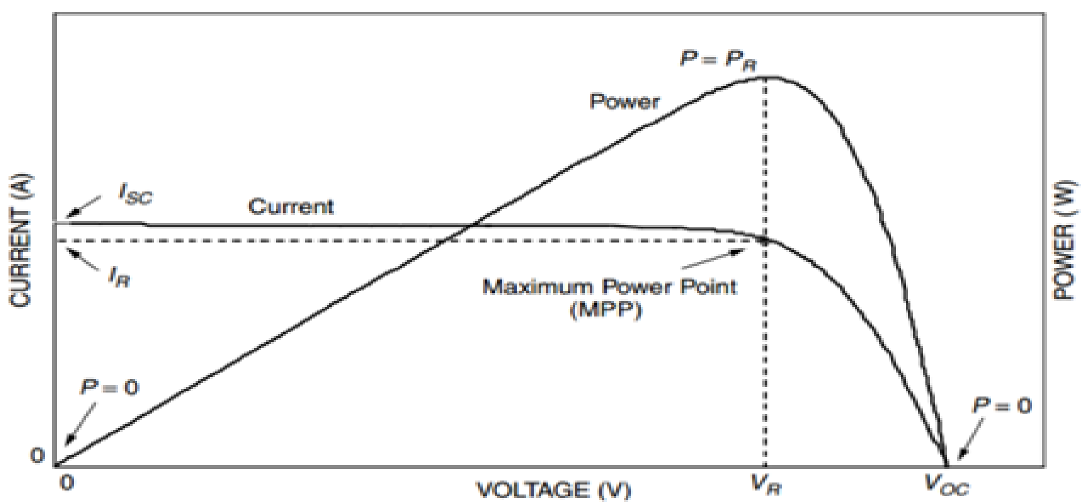

Figure 2.3: The I –V curve and P-V curve for a PV module. At the maximum power point (MPP)

The module delivers the most power that it can under the conditions of sunlight and temperature for which the I –V curve has been drawn [2].

2.3.1 Modeling of Photovoltaic cell

The equivalent electrical circuit of one-diode model consists of a real diode in parallel with a current source. The current source produces the current Iph and the current Id flows through diode. The current Ic which flows to the load is the difference between Iph and Id and it is reduced by the resistances Rs and Rp. [7]Two resistances, Rs and Rp, are included to model the contact resistances and the internal PV cell resistance respectively. The values of these two resistances can be obtained from measurements or by using curve fitting methods based on the I-V characteristic of PV. The equivalent electrical circuit for a PV cell or module is illustrated in Fig 2.4 [8].

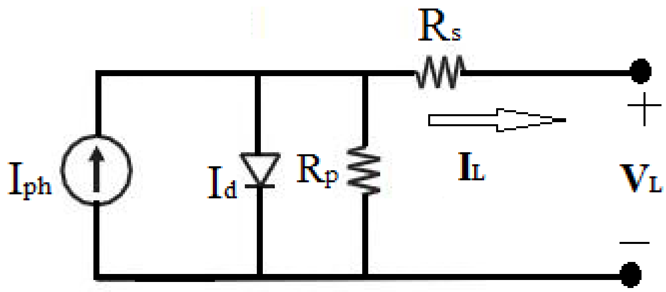

Figure 2.4: Equivalent circuit of PV.

From the fig2.4 shown above:
The current source (Iph) depended on the solar radiation and the ambient temperature. The (I-V) characteristics of photovoltaic cell can be determined by the following equations [9, 10]. The terminal current shown in Fig2.4 (IL) is given by:

$$IL = Iph - Id - Ip \tag{2.3}$$

Where:

Iph: photocurrent from photovoltaic cellin Amper (A).

Id: is the current passing through none linear diode in Amper (A).

Ip: current through shunt resistance in Amper (A).

The photocurrent Iph is a function of solar r radiation and temperature, it is determined by:

$$Iph = Isc + KI(Tc - Tr) * \frac{G}{Gn} \tag{2.4}$$

Where:

Isc: is the short-circuit of the cell at standard test condition (STC: Gn =1000W/m² and Tr =298.15K) in Amper (A).

kI: is the short-circuit current temperature co-efficient of the cell [A/ K].

Tc and Tr: are the working temperatures of the cell and reference temperature respectively.

G and Gn: are the working solar radiation and nominal solar radiation respectively [W/m²].
The diode saturation current Id of the cell varies with the cell temperature, which is expressed in equation (2.3) as:

$$Id = Io[e^{q(Vl+Il*Rs)AKTc} - 1] \quad (2.5)$$

Io: reverse saturation current of the diode.

q: is the electron charge [1.6021× 10−19 C].

VL: output voltage of the photovoltaic cell.

Rs: series resistance of cell (Ω).

A: is the ideality constant of diode depend on the PV technology (1.2-3.3).

K: Boltzmann constant (1.38 × 10−23 J/K).

The shunt current Ip is given by equation (2.6):

$$Ip = \frac{Vl+IlRs}{Rp} \quad (2.6)$$

Where: Rp [Ω] is parallel resistance.

2.3.2 Modeling of Photovoltaic module

A PV module is the result of connecting several PV cells in series in order to increase the output voltage. The characteristic has the same shape except for changes in the magnitude of the open circuit voltage [2], as shown in Fig (2.5) [2,6].

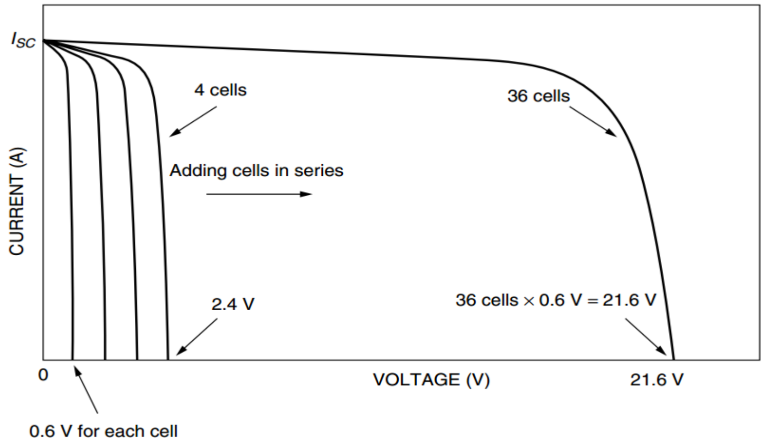

Figure 2. 5: The I-V characteristics of a typical PV module consisting of 36 cells connected in series. The output voltage of a PV module is calculated by:

$$Vmodel = n(Vd - IlRs) \quad (2.7)$$

Where:
n: is the number of PV cells connected in series in the module.
Vd: is the voltage of the diode of the equivalent circuit of the cell (v).

2.3.3 Modeling of Photovoltaic array

The PV Arrays are composed of some combination of series and parallel of PV modules. The modeling of PV arrays is the same as modeling of the PV module from the PV cells. Modules in series, the (I–V) curves are simply added along the voltage axis. The total voltage is just the sum of the individual module voltages.For PV modules connected in parallel the total current is the sum of the currents of the modules whereby the total output voltage is equal to the voltage of one module, as shown in Fig 2.6 [11].

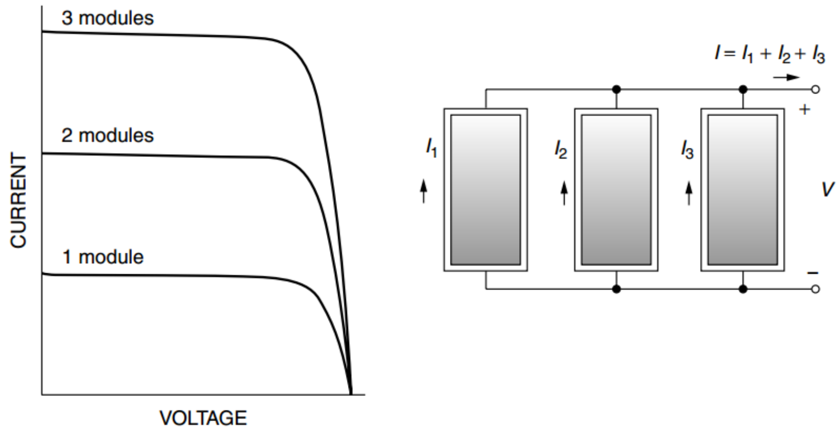

Figure 2.6: The I-V characteristics of 3 PV modules connected in parallel.

Practically the PV array will consist of a combination of series and parallel modules depending on the needed output power of the system is needed, such as shown in Fig2.7.

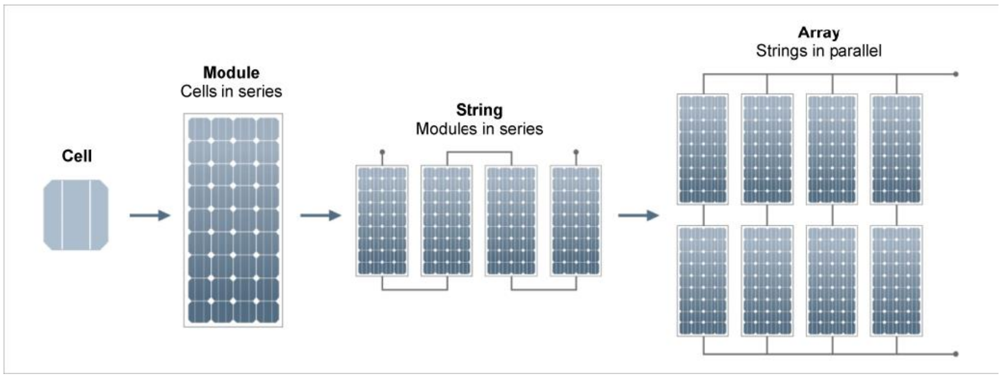

Figure 2.7: Array of PV combination of series and parallel cells.

2.4 Factor Affecting on Photovoltaic Cell:

1- Solar Irradiance:

Irradiance is the measure of the power density of sunlight received at a location on earth. Due to changes in environmental conditions, temperature change and hence irradiance level changes and is measured in watt per meter square. As the solar isolation keeps on changing throughout the day thus I-V and P-V characteristics varies [12].

With the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies. The PV cell current is strongly dependent on the solar radiation. However, the voltage has a small change with increasing solar irradiation. The effect of irradiation on short circuit current (Isc) is proportionally increasing with increasing irradiation. But the change on open circuit voltage (Voc) is very small with increasing irradiation [13].

2- Temperature:

Temperature play major factor in determining the solar cell efficiency. As cell temperature increase, the open-circuit voltage decrease substantially while the short-circuit current increases only slightly.

Photovoltaic perform better on cold, clear days than hot ones. When cells heat up the MPP slides slightly with decrease in maximum power. Thus it should be quite apparent that temperature needs to be included in any estimate of module performance [14].

Cells vary in temperature not only because ambient temperatures change, but also because insolation on the cells changes. Since only a small fraction of the insolation hitting a module is converted to electricity and carried away, most of that incident energy is absorbed and converted to heat [14].

3- Orientation and Tilt Angle:

The performance of photovoltaic (PV) modules and systems is affected by the orientation and tilt angle. As these parameters determine the amount of solar radiation received by the surface of a PV module in a particular region. Normally the region that lies in the northern hemisphere the panel installed on these building should be facing south or facing the equator and for southern hemisphere facing the north tilt from horizontal at an angle approximately equal to the site latitude. So that maximum irradiance captured Panel will collect solar radiation more efficiently where the sun rays are perpendicular to the panel surface [15].

4- Series and Parallel Resistor:

The main impact of series resistance is to reduce the fill factor, although excessively high values may also reduce the short-circuit current [16].

Series resistance does not affect the solar cell at open-circuit voltage since the overall current flow through the solar cell, and therefore through the series resistance, is zero. However, near the open-circuit voltage, the IV curve is strongly affected by the series resistance.

The main impact of the shunt resistance is to increase power losses due to manufacturing defects, rather than poor solar cell design. Low shunt resistance causes power loss in solar cells by providing an alternate current path for the light-generated current. Such a diversion reduces the amount of current flowing through the solar cell junction and reduces the voltage from the solar cell. The effect of a shunt resistance is particularly severe at low light levels, since there will be less light-generated current. The loss of this current to the shunt therefore has a larger impact. In addition, at lower voltages where the effective resistor of the solar cell is high, the impact of resistors in parallel is large [16].

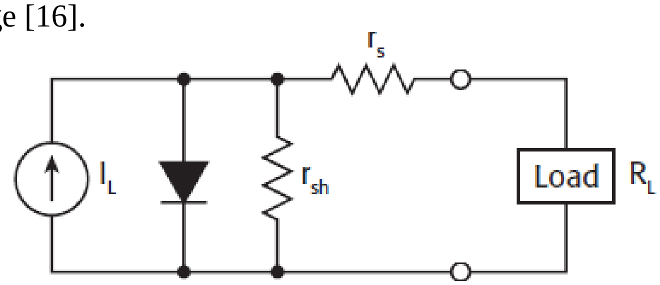

Figure2.7: show equivalent circuit of PV cell with Rs and Rsh [12].

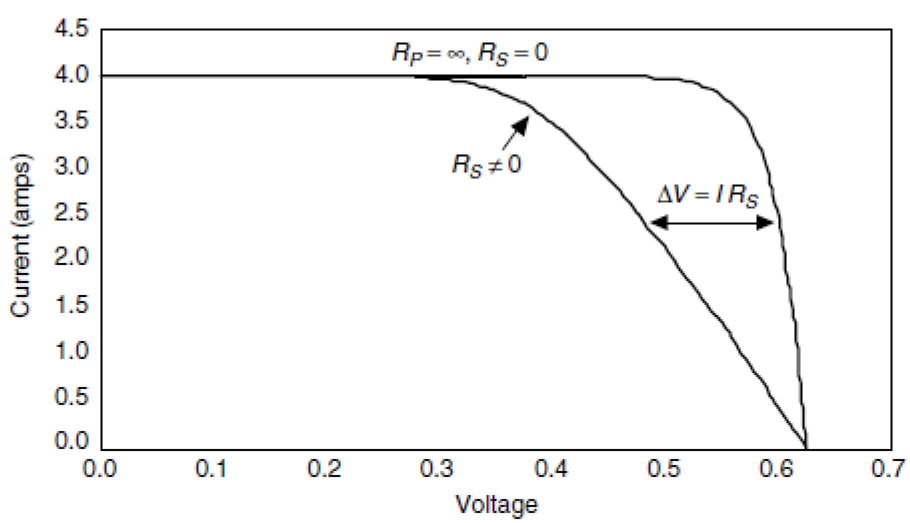

Figure 2.8: The impact of series resistance on I-V curve of PV cell [13]

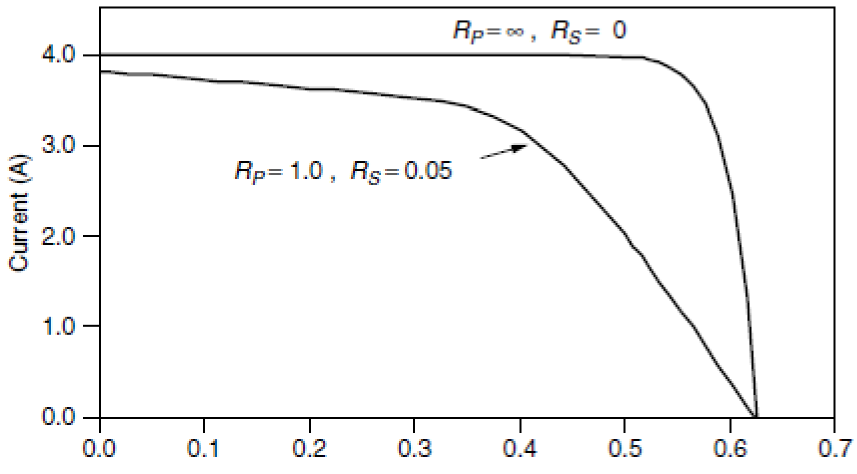

Figure 2.9: The I-V curve of PV cell with Rs and Rsh [13]

4- Shading:

When selecting the roof area for the photovoltaic array, efforts should always be made to avoid shading or areas known for accumulation of substances that will result in cell shading. Shading is another very important factor that drastically affects the performance of PV module. Solar PV array often subjected to partial shading and rapid fluctuation of the shading. Rapid fluctuation in shading pattern makes maximum power point tracking difficult. There will exist multiple local MPP and their values will change as rapidly as does the illumination. The shading of the PV module may be by the trees, large buildings construction structure surrounding it. These may cause partial or full shading. The effect of shading is more in the conventional configuration (PV module connected in series) than parallel. Highly parallel-configured PV system that operates effectively in rapidly varying shaded conditions [17].

5- Dust:

As we know any shadow made on a solar collector can affect many parameters of the operating performance. In order to take electricity from a PV module we have the need of the main source which is the sun. The irradiation of the sun absorbed from each PV cell and conversed to electricity due to the photovoltaic phenomenon. If a shadowing effect take place on our PV module we have a performance decrease, due to the decreased irradiation absorption.

Dust is defined as the minute solid particles less than 500 **µ**m in diameter. Dust deposition is a function of various environmental and weather conditions [18].

Dust settlement mainly relies on the dust properties (chemical properties, size, shape, weight, etc.) as well as on the environmental conditions (site-specific factors, environmental features and weather conditions).

The performance of solar radiation collectors is affected by the presence of dust on the surface. The effect of dust on efficiency of collectors is difficult to generalize because it depends on factors such as material and size of dust particles, orientation of the surface with respect to the dominant wind direction, wind speed, humidity, distribution of dust on the surface (g/m2) and the tilt of the collector from the horizontal [18,19,20].

The efficiency of a solar collector drops progressively as dust is accumulated on its surface. The rate of decrease in the efficiency depends mainly on the rate of dust deposition. The latter is a strong function of the dust concentration in the atmosphere. Therefore, the investigation of the effect of dust on the efficiency of a solar collector necessitates the monitoring of dust concentration in the atmosphere around the collector and its variation with time [20].

6- Humidity:

Humidity describes the quantity of water vapor in gas like air, the temperature is important factor for humidity, so the warmer air has greater capacity for holding water vapor than cooler air. Relative humidity defined as the ratio of water vapor actually in the air to the maximum water vapor the air can hold at given temperature.

When the relative humidity increase the current, voltage, power and efficiency decrease. When the light consisting of energy strikes the water layer, refraction appears which results in decreasing of intensity of the light and then decreasing the efficiency of the PV.

Humidity changes the irradiance non-linearly and irradiance itself cause little variation in Voc and large variation in Isc linearly [21].

7 - Wind speed:

The PV cell performance is sharply sensitive to cell temperature. PV cell temperature is a function of different parameters such as weather variables (ambient temperature, wind velocity, etc.), solar irradiance, cell material and system dependent properties (glazing cover transmittance, plate absorption, etc.)

By increased wind velocity more heat can be removed from the PV cell surface. In the same vein, higher air velocity lowers the relative humidity of the atmospheric air in the surroundings which in turn leads to better efficiency. On the contrary, wind lifts dust and scatters it in the environment resulting in shading and poor performance of PV cells [22].

2.5 Types of Photovoltaic Solar Cell

The majority of solar cell today made up by silicon, so we will consider most of the famous and efficient types of it.

1- Monocrystalline Silicon Solar Cells:

Solar cells made of monocrystalline silicon (mono-Si), also called single-crystalline silicon (single-crystal-Si), are quite easily recognizable by an external even coloring and uniform look, indicating high-purity silicon, as shown in Fig2.10

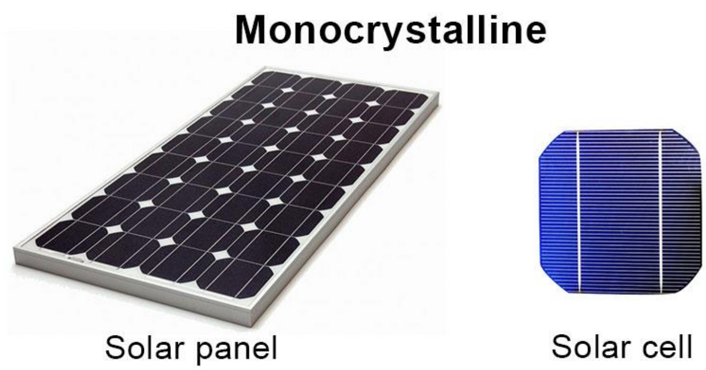

Figure2.10: Monocrystalline Solar Cell [23].

Monocrystalline solar cells are made out of silicon ingots, which are cylindrical in shape. To optimize performance and lower costs of a single monocrystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers, which is what gives monocrystalline solar panels their characteristic look [23].

2- Polycrystalline Silicon Solar Cells:

The first solar panels based on polycrystalline silicon, which also is known as polysilicon (p-Si) and multi-crystalline silicon (mc-Si), were introduced to the market in 1981. Unlike

Figure2.11: Polycristalline solar Panel.

monocrystalline-based solar panels. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers [23].

3-Thin Film Solar Cell (TFSC):

Depositing one or several thin layers of photovoltaic material onto a substrate is the basic gist of how thin-film solar cells are manufactured. They are also known as thin-film photovoltaic cells (TFPV). Depending on the technology, thin-film module prototypes have reached efficiencies between 7–13% and production modules operate at about 9%. Future module efficiencies are expected to climb close to the about 10–16% [23].

Figure2.12: Thin Film solar Panel.

2.6 Literature Review and Related Work

This section discusses the background of this project, methods that have been proposed by other researchers and the technique to implement the overall system. Several scientific papers were published in different journals related to investigate many environment effects on the photovoltaic cells some of these articles is:

Darwish and A Kazem, et al [24] this paper investigates Impact of Dust on Sola Photovoltaic and dust accumulation on the surface of solar module, Dust particles differ in phase, sort, chemical and physical properties by used two identical pairs of PV panels, the first panel being clean and the second being artificially polluted with three different type of air pollutants namely red soil, limestone and carbonaceous fly-ash particles. According to the results obtained, it was found that the decreasing magnitude depending on the type of pollutant (i.e. composition, color) the important of this study came due to the transfer of large scale PV technology to the desert area in Arab countries.

El-shobokshy and Hussein et al [25] studied the investigation of the physical properties and deposition density on the performance of PV panel's .The artificial duct which included limestone, cement and carbon particles were used. They used halogen lamps to represent the source of radiation energy. It was showed in the study that the cement particles at (73 g/ m3) would result most significant drop in the PV short circuit voltage by 80%. In their study they had found that for fixed deposition density, the smaller particle size lead to great reduction in solar intensity received by solar PV panels and this is due to that fine particles have a greater ability than large particles to minimize inter-particle gaps and thus dimness the light path that receive on the PV panel.

Sulaiman et al [26] made a study to investigate the effect of duct accumulation on PV panels. The study was made by using experiment which consist of solar panel (50w) under constant light radiation represented by two spotlight each spotlight gives 500 w. An artificial duct was used in two form (dried mud, talcum powder) instead of real duct. A plastic sheet used to put the duct on it. To measure the duct accumulation on the plastic sheet, the Scanning Electron Microscope (SEM) was used. The power of the solar panel was measured for four conditions: no plastic sheet, clear plastic sheet, mud on plastic sheet and talcum on plastic sheet and the result showed that the highest peak power occur when the panel is not covered by layer of duct or plastic sheet, if the dust accumulate on plastic sheet, the reduction on power generated can be up to 18 %. Thus the clean plastic and solar PV panel without plastic gives the highest efficiency due to absent of duct on its surface. Conversely if the duct appear
On the surface of Photovoltaic solar panel can reduce the system efficiency by up to 50%.

Effect of wind velocity on PV cell performance .The solar cell is very sensitive to cell temperature, the PV cell temperature affected by different factors such ambient temperature, wind velocity, and solar irradiance ...act.
Mekhilef et al, [27] present the effect of dust, humidity and air velocity on PV cell efficiency .The study show that when increased wind velocity more heat can be removed from PV cell surface and higher air velocity decrease the relative humidity which lead to better PV efficiency, but wind causing shading and low PV efficiency resulting from wind lifts duct on PV.

Seferlis and Etier et al [28] this paper examined the performance of PV modules whose PV cells operate under different temperatures since the fluid flowing through the pipes has a temperature gradient from the inlet toward the outlet. Therefore, this study introduced a more accurate evaluation of the PV modules performance. Implementing cooling pipes underneath each PV string improves the performance of the PV cells since they will not heat much in comparison with using one pipe for the entire PV module. Applying a cooling pipe for each string enhances much more the electrical efficiencies of the PV cells. The best design is the one which keeps the operating temperature of the PV cells as minimum and uniform as possible, resulting in a maximum energy yield of the PV cells. So they talk about a hybrid system between thermal and PV cells, to study the effect of temperature on the PV's.

Chander and Purohit et al [29] in this study, the effect of cell temperature on the photovoltaic parameters of monocrystalline silicon solar cell undertaken. The experiment was carried out employing solar cell simulator with varying temperature in the range of 25-60 C at constant light intensities 215-515 W/m2.
The results show that cell temperature has a significant effect on the photo voltaic parameters and it controls the quality and performance of the solar cells .The open circuit voltage of solar cell is highly sensitive to the cell temperature. The open circuit voltage ,Fill factor and maximum output power decreases with temperature while short circuit current increases with temperature ,therefore temperature coefficient of the open circuit voltage, fill factor and maximum output is negative as well as positive for the short circuit current. The relative change study of photovoltaic parameters with temperature is also undertaken.

Dubey and Sarvaiya et al [30] in this paper there is a brief discussion is presented regarding the operating temperature of one-sun commercial grade silicon based solar cells/modules and its effect upon the electrical performance of photovoltaic installations. Generally, the performance ratio decreases with latitude because of temperature. However, regions with high altitude have higher performance ratios due to low temperature, like, southern Andes, Himalaya region, and Antarctica. PV modules with less sensitivity to temperature are preferable for the high temperature regions and more responsive to temperature will be more effective in the low temperature regions. The geographical distribution of photovoltaic energy potential considering the effect of irradiation and ambient temperature on PV system performance is considered.

3

CHAPTER THREE

Block Diagram Description and Equipment’s

3.1 Introduction.

3.3 Block diagram.

3.3 Required equipment’s.

3.1 Introduction

In this chapter will describe the block diagram for the project as well as discuss the experiment procedure and tools.

3.2 Block diagram

The figure 3.1: below demonstrates the block diagram of the system that will be used in applied experiments and research in this project.

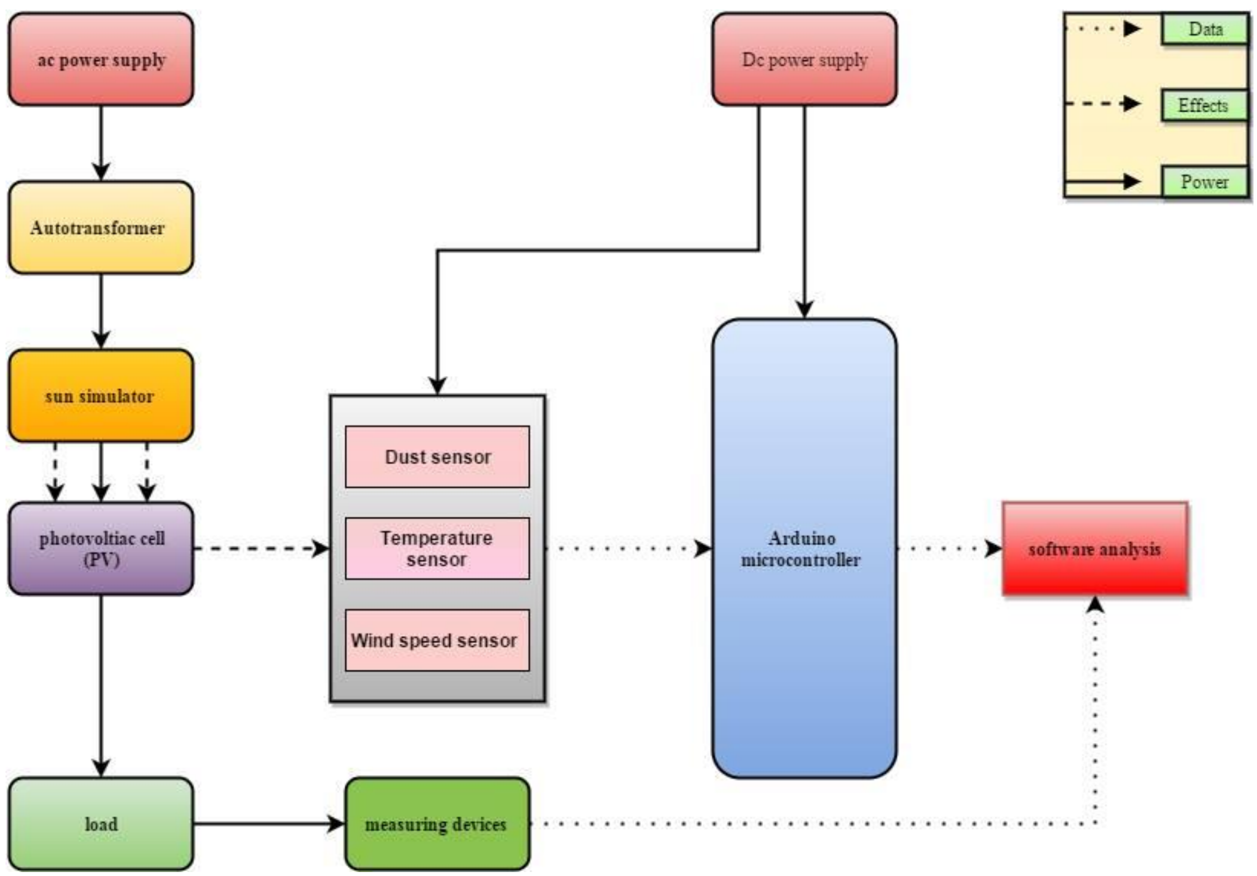

Figure 3.1: Block Diagram Parameters

3.3 Required equipment's

1- **Solar Cell**

Mono-crystalline silicon solar cell was used to investigate the performance. Mono crystalline solar cell is slices cut form pure drawn crystalline silicon bars. The entire cell is aligned in one direction , which means that when the sun is shining brightly on it at correct angle , it is extremely efficient .So this solar panel work best in bright sunshine with the sun shining directly on it .It has a uniform blacker color because they are absorbing most of the light. Mono crystalline solar cell is the most efficient of other solar cell types and efficient have been at upwards of 20%, the mono-crystalline solar cell shown in Fig3.2.

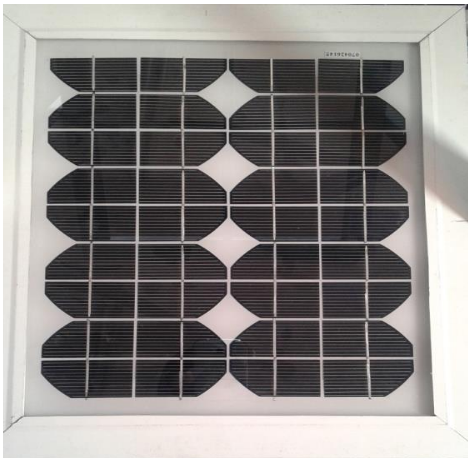

Figure 3.2: The mono-crystalline solar cell used in experiments.

In our experiments mono-crystalline solar cell will be used due to shown characteristics. The parameter of cell is show below. Mono crystalline cell parameters are shown in Table 3.1 and Table 3.2.

Series Specifications	**Model No.**	**SP10-36A**
	Power Warranty	12 Years of 90% Output Power.
Electrical Characteristics		
Maximum output power	10	Watt
Maximum power voltage	18.4	Volt
Maximum power current	0.54	Ampere
Open circuit voltage	22.08	Volt
Short circuit current	0.6	Ampere
Panel Efficiency	10 %	
Power Tolerance(Positive)	+ 3 %	
Power Tolerance(Negative)	-3%	

Table 3.1: Shows electrical characteristic for monocrystalline solar panel.

These parameters taken from the data sheet of cell under STC condition (1000w/m2, A.M 1.5, 25 C) [31].

MECHANICAL CHARACTERISTICS		
Size	Height	291 mm
	Width	342 mm
	Thickens	18 mm
Weight	Net	1.2 Kg
Cells	Type	Monocrystalline
	Size	125 x 125 mm
	Cell number	36
Frame	Type	Aluminum Alloy

Table 3.2: The mechanical characteristics for mono crystalline solar panel.

2- Lamps "sun simulator"

A halogen floodlight 500w was used as a source of irradiation instead of suns ray's beams. The lamps are connected on solar panel vertically. In these experiments four lamp each with 500w will be used. The four lamps are connected in parallel to obtain constant voltage, sun simulator as shown in Fig3.3.

Figure 3.3: 500W halogen floodlight.

3-Power Supply

We will used it to supply:

a- AC Power Supply: for the load and autotransformer by 220V
b- DC Power Supply: for the microcontroller by 5V.

4- Autotransformer

A transformer is a static machine used for transforming power from one circuit to another without changing frequency Autotransformer is kind of electrical transformer where primary and secondary shares same common single winding [32].

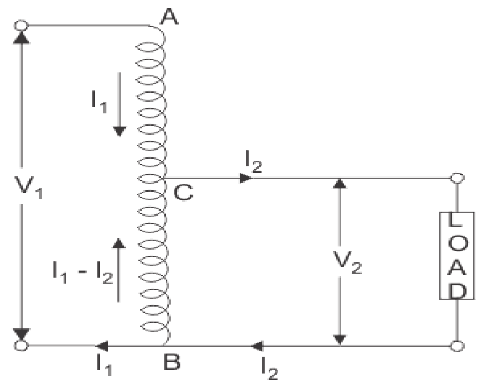

Figure 3.4: The electrical circuit of autotransformer [33].

Two 0 -260 V one phase transformer will be used to change the amount of irradiation coming from Lamps to obtain I-V and P-V curves with different irradiation. Each transformer are connected to two lamps.

Figure 3.5: 0/260 V I phase autotransformer.

5-Fan

It will be used as a cooler system for the solar cell, in order to remain the cell temperature constant in some case and it can used to make a wind on surface in order to investigate the effect of wind speed on PV cell and plot I-V and P-V characteristic. The speed will be change and control by using microcontroller.

Figure3.6: Fan used in experiments.

5- Load

A 1-10KΩ variable resistor with power 10W, will be used as a load in the experiments in order to present the I-V and P-V characteristics.

6-Microcontroller

A controller is used to control some process. At one time, controllers were built exclusively from logic components, and were usually large, heavy boxes. The Arduino microcontroller will be used in experiments in order to process the data coming from sensors that shown in block diagram.

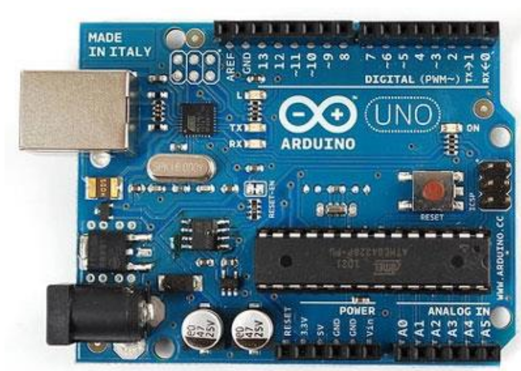

Figure3.7: Arduino microcontroller

7-Software Analysis

It used for analyzing the data which we will accumulate from our experiments, also we can use it for numerical comparing results from which we study by standards conditions and curves. Due to that we will use Matlab and Excel software to meet our goals.

3.3.1 Measurement Instruments

1- Irradiation Sensor

Is a device used to measure solar irradiance on panel surface. In the experiments TM-206 Solar power meter will be used to measure incident irradiation from the lamps on solar cell.

TM-206 Solar Power meter is ideal for the measurement of the solar radiation that is emitted by the sun. The units of measure are Watts per square meter [34].

Figure3.8: TM-206 Solar Power meter.

2- Temperature Sensor "LM35"

LM35 is a precision IC temperature sensor with its output proportional to the temperature (in oC). In experiments it will be used to measure the temperature of the Solar cell in order to present the effect of the temperature on I-V and P-V solar cell characteristics.

Figure3.9: The temperature sensor that used in experiments.

3- Digital Multimeter

The Digital Multimeter is an electronic measuring instrument that combines several measurement functions in one unit. A typical Digital Multimeter may include features such as the ability to measure AC and DC voltage, current and resistance. In this experiment two Multimeters will be used. One used to measure the cell's current while the second used to measure the cell voltage.

Figure3.10: Digital Multimeter device.

4- Dust Sensor

GP2Y1010AU0F It is a device used to measure the accumulation of dust on surface of solar panel is an optical air quality sensor, designed to sensing dust particles. An infrared emitting diode and a phototransistor are diagonally arranged into this device, to allow it to detect the reflected light of dust in air. It is especially effective in detecting very fine particles, and is commonly used in air purifier systems. The sensor has a very low current consumption (20mA max, 11mA typical), and can be powered with up to 7VDC. The output of the sensor is an analog voltage proportional to the measured dust density, with a sensitivity of 0.5V/0.1mg/m3.

Figure3.11: The Dust sensor device

Principle of work:

The working principle of this device depends on a system of sending infrared emitting diode (IRED) and receiver system an phototransistor In addition to the entrance to allow the passage of air through it when the dust laden air enters through the doorway that works to deflect light emitted from the infrared emitting diode causes decreasing the amount of light receiving from phototransistor Accordingly, amplifier circuit the Senses of the existence of the particles Based on the change in the value of the voltage from the outside of phototransistor[35].

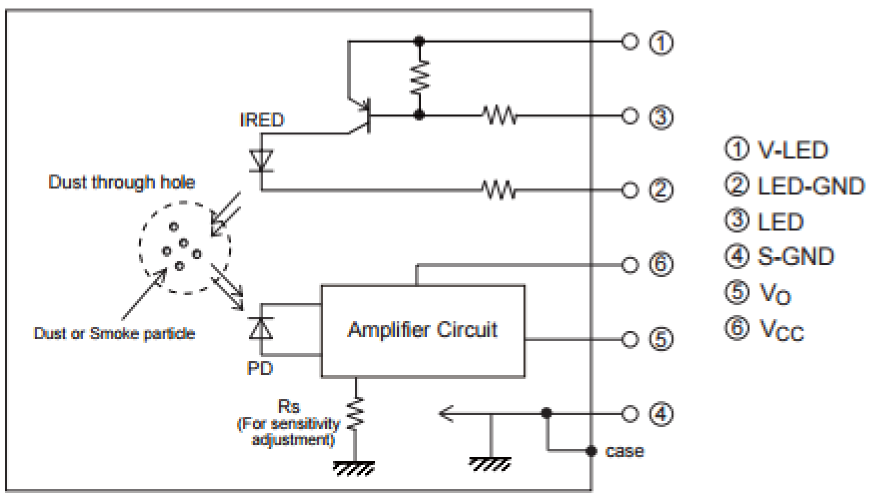

Figure3.12: Internal schematic for dust sensor [35].

5- Wind Speed Sensor "Anemometer"

Is an instrument that measures wind speed and wind pressure .Anemometer has 3 or 4 cups attached to horizontal arm, the arms are attached to a vertical rod .As the wind blows the cups rotate making the rods spin. The stronger the wind blows, the faster the rod spin.

Figure3.13: Anemometer used for measuring wind speed.

4

CHAPTER FOUR

Simulation

4.1 Introduction.

4.2 Aim of the experiments.

4.3 Prototype.

4.4 The experimental procedure.

4.5 The Simulation.

4.1 Introduction

The environmental and economic merits of converting solar energy into electricity via photovoltaic cells have caused an ever increasing interest among developed and developing countries to allocate more budget on photovoltaic systems in order to boost up their efficiency in recent years. Besides the material and design parameters, there are several omnipresent factors such as dust, temperature and air velocity that can influence the PV cell's performance. There have been a handful of studies conducted on the effect of various influential parameters on the efficiency and performance of photovoltaic cells; however none has taken all these three parameters into account simultaneously. In this study the impact of dust accumulation, temperature level and the air velocity will be elaborated separately and finally the impact of each on the other will be clarified. It is shown that each of these three factors affect the other [36].

4.2 Aim of the experiments

- Learn the properties of a photovoltaic (PV) panel including its equivalent circuit.
- Determine the optimal conditions for operating a PV panel in a circuit with a known load and understand MPPT (maximum power point tracking).
- Investigate the effects of dust, solar insolation, temperature, and wind speed on a solar panel through the I-V curve characteristic measurement.
- Used of numerical analysis to get the coefficient of for each case of effects (dust, temperature, wind speed).
- To plot the I-V curve of a solar cell in Matlab and Excel, and to identify the maximum power point, the short circuit current, and the open circuit voltage at the all effects.

4.3 Prototype

we assume that the Experimental set up such as Fig 4.1drawing by a Catia Software,so we can see the sun simulator which control the irradiation by autotransformer and the monocrystalline solar cell under it ,all of that carrying by an aluminum stand which we can control the distance between the sun simulator and the solar cell .

The dimension of Prototype:

It is as the dimension of the solar cell which we take from the datasheet

By that prototype we will do many experiments to show the effect of different factor on the solar cell and its efficiency.

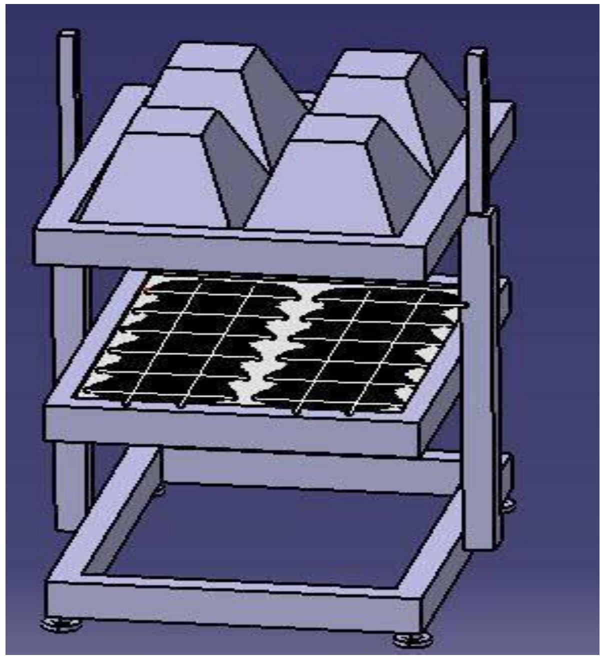

Figure 4.1: Prototype of experimental setup for determining the characteristics curve of the solar cell.

4.4 The experimental procedure

We want to make four different experiments for four different stages or factors that affect the solar cell and its characteristics.

4.4.1 The performance of solar cell at standard test condition (STC) without any effects

This is the first stage of the experiment to illustrate the I-V, P-V curves and characteristics of the mono crystalline solar cell. The procedure for this stage is as the following:

- The value of the standard test condition (STC) for the solar cell, the open circuit voltage, and the short circuit current were measure and the results were compared with the data sheet of a monocrystalline cell. Illustrates the connection to measure the STC of solar cell.

- To obtain the short circuit current (Isc) and open circuit voltage (Voc) under STC, firstly the sun simulator will be adjusted to 1000 W/m2 by using the autotransformers.

- The taps of autotransformer will be change until the irradiation sensor (TM206) show the irradiation intensity 1000W/m2.
- The temperature of cell will be adjusted to 25 C by using thermometer and the fan will be operate when temperature increase above 25 C by using Arduino microcontroller.
- Two digital multimeter will be used, one set to voltmeter to measure the voltage and other use as ammeter to measure the current.
- The variable load (0-10KΩ_10W) and measurement device are connect as shown in Fig 4.2.

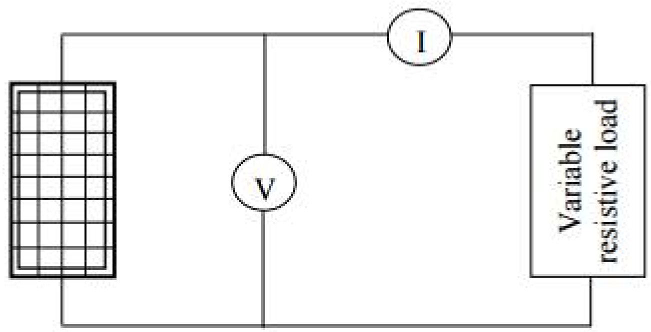

Figure4.2: The connection of measurements devices to PV panel.

- To measure short circuit current (Isc), the variable resistor set to minimum value (0Ω) and the short circuit current will be read by the Ammeter.
- To measure open circuit voltage (Voc), the variable resistor set to maximum value (10KΩ_10W) and then Voc will obtain by Voltmeter.
- The variable resistor will be changed from minimum to maximum value, and for each resistor value the current and voltage will be measured by measurement devices.
- The values of current and voltage will be management by Matlab and Excel software then the I-V curve, P-V curve are plot by Matlab.
- The maxim current (Im) and maximum voltage (Vm) will be found from the measuring value of current and voltage and then the max Power will be obtained by using an equation(4.1):

$$Pmax = Im * Vm \tag{4.1}$$

Where: Im: is the maximum measured value of current when load varying.
Vm: is the maximum measured value of voltage when load varying.

- The fill factor will be calculated by using the an equation (4.2)

$$FF = \frac{Im\,Vm}{Isc\,Voc} \tag{4.2}$$

- The maximum efficiency of PV panel will be obtain by equation(4.3) :

$$\eta(maximumefficiency) = \frac{Pmax\ (maximum\ output\ power)}{E(indicent\ irradiation\ flux) * Ac(area\ of\ collector)} \quad (4.3)$$

- The result of this case will be taken as reference in order to compare the result from other cases to it.

4.4.2 The performance of solar cell at different value of the dust density and different type of dust.

The second stage is to be investigated the effects of dust density on the solar cell performances also by using different type of dust which we will illustrate in this section.

In addition, Dust is particles that come from the environment such as soil and pollution. Dust has become one of the major issues with regards to the performance of a solar panel. One of the contributing factors on decreasing solar performance is accumulated dust on the surface of solar panel which comes from the pollution and industrial area and the nature of the surrounding environment. In this stage, we investigate the effects dust materials on the surface of a solar panel (PV) performance during the experiment [37] [38].

Type of dust

Dust is a general name for minute solid particles with diameters less than (500 micrometers). Consists of particles in the atmosphere that come from various sources such as soil, dust lifted up by wind, show in Fig4.3. Dust have many different properties including texture, structure or architecture There in Palestine many types of soil, but there are three types of soil most widely, a red soil and chalk soil, sandy soil where there are three types of dust depends on the soil type found in the region. Through this project we will study all affected by this kind of species on the efficiency of photovoltaic cells and in the following explanation in all type [39].

Figure 4.3: dust lifted up by wind [38].

1. **Red dust**

Red soil. It is formed by break down of igneous rock and metamorphic rock. Red soil in Palestine is largely It is located in flat areas of mountain peaks areas and valleys red soil is also found in several other regions in west bank as show in Fig 4.4 [39].

Fig4.4: Red dust.

2. **White dust**

A form of limestone composed of the mineral calcite. Calcite is white dust or $CaCO3$. Chalk has greater resistance to weathering and slumping than the clays with which it is usually associated Chalk soil in Palestine is largely found in it is located in Hills in the West Bank and the “Nitzana Chalk curves" situated at Western Negev as shown in Figure 4.5 [39].

Fig4.5: White dust.

3. Sand dust

Sand particles are mainly fragments of quartz and some feldspars and mica. They have little surface area exposed (0.1 m2 g−1 specific area). Sand particles are visible to the naked eye, gritty in feeling, having little or no capacity to hold water or nutrients, and bind other particles. They are loose when wet, very loose when dry. Sand does not absorb water and does not exhibit swelling and shrinkages, stickiness and plasticity. Sandy soil in Palestine is largely found in It is located in Coastal plains and the Negev desert show in Figure 4.6 [40].

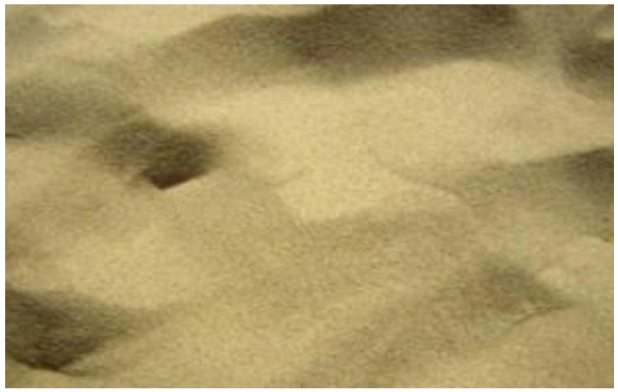

Fig4.6: Sand dust.

The procedure s for this stage have been illustrated below:

- Preparation all tools (solar panel, measurement device, sun simulator, autotransformer, dust sensor, microcontroller, sieve, fan, variable resistor module).
- We required Preparation 3 types of soil materials (Red dust, White dust, Sand dust).
- All materials must adapt to a specific size. This made with a sieve as shown in Fig4.7 (Screen openings 0.075mm).

Fig4.7: sieve.

- Use microcontroller (Arduino) for programmable dust sensor and connection with computer.
- Used two dust Sensor **GP2Y1010AU0F** for to sensing the existence of dust at atmosphere and display the value on the screen.
- Connection the lamp on the two autotransformer.
- The sun simulator will be adjusted to 1000 W/m2 by using the autotransformers.
- The temperature of cell will be adjusted to 25 C by using thermometer and the fan will be operate when temperature increase above 25 C by using Arduino microcontroller.
- Set the digital multimeter device at the voltage scale and select the correct range and connected with solar module.
- Set the digital multimeter device at the Amper scale and select the correct range and connected with solar panel.
- Connection the variable resistor module on the solar module output.
- Used the fan for strewing each type of dust on surface solar module.
- Turn on all devices and changing the value of variable resistor module
- Take the value of dust sensor during the computer display.
- Take the results from the measurement device current and voltage values and plot then the I-V curve, P-V curve by Matlab and Excel.
- Repeat the previous step several time but changing the value of dust in the air.
- Using another type of dust and repeated all previous steps.

4.4.3 The performance of PV panel with different temperature and constant irradiation

To investigate the effect of temperature on performance of PV panel we will change the temperature cell to different value (55-25) C under constant intensity of irradiation. The results of this case will be compared to case1.

♦ **For temperature above 25 C:**

1. In the beginning we will adjust the irradiation intensity to 800 W/m2 by using autotransformer that control the sun simulator intensity.
2. At temperature 30 C, the variable resistor changes and the value of current, voltage will be measured by measurement devices.
3. By using Matlab Software, I-V, P-V curves will be plotted. The fill factor (FF) and efficiency (η) will be calculated as illustrated in previous cases.
4. The same procedure will be used when temperature changes to 35 C and 40 C.

4.4.4 The Performance of PV panel with effect of wind speed

To investigate the effect of wind speed on PV cell, the I-V and P-V curves will be plotted under specified values of wind speed. The results of this stage will be compared to results in reference stage1 and we will show what parameter affecting by wind speed.

- As illustrated in previous cases, the irradiation, temperature adjusted to 800 W/m^2, 25C repressively.
- The fan will be used to make a wind and the value of wind speed will be adjusted by using Arduino microcontroller.
- For specified wind speed value, the current and voltage will be measuring for each value of resistor. The I-V, P-V characteristic of PV will be plotted and the fill factor (FF), efficiency will be calculated as mentioned in previous cases.
- These steps will be repeated for different wind speed value.

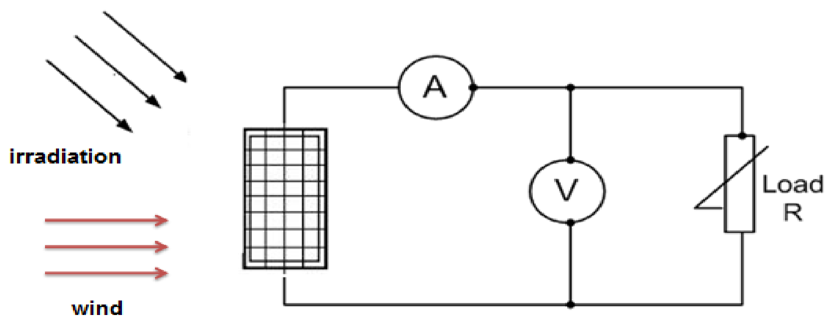

Figure4.8: The schematic diagram of the circuit connection with wind effect.

4.5 The Simulation

Concerning performance studies on PV systems digital simulations, while compared to measurements, are considered faster, low cost and appropriate for sensitivity analysis on different design parameters [41].

Knowledge of the characteristic of photovoltaic panel is a prerequisite for designing and dimensioning a PV power supply. This is the reason for the development of PV panel models useful for electrical applications .Four factor that effect on photovoltaic panel was proposed in this project as a simple method of modeling and simulation of photovoltaic module using Matlab Simulink.

Matlab Simulink method is used to determine the characteristic of PV panel and to obtain I-V and P-V curves of PV panel under different scenarios of influence of different values of irradiation, temperature, wind speed and dust accumulation. The results that produced using Matlab Simulink will be matches and compared with results that will be produced using experiments under the same conditions.

4.5.1Modeling PV Solar Panel using Matlab Simulink

A 10 W PV Solar Panel is taken as the reference module for simulation and the data sheet details are given in Table3.1.Referring to the chapter 2 , the equations (2.3,2.4,2.5) were used to modeling the mathematical model of PV cell .
These models are developed to include the effect of irradiation, temperature, wind speed and dust accumulation on PV cell as shown in Fig 4.9. The final representation of PV solar panel with environmental effect is shown below in Fig 4.10.

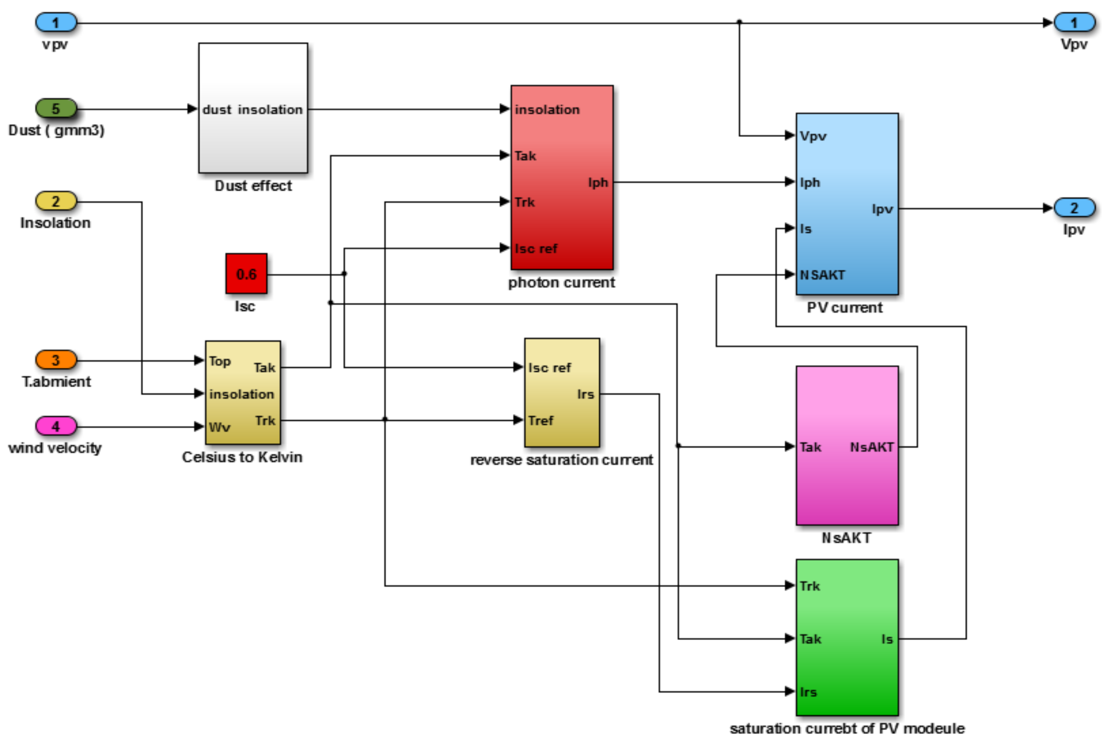

Figure 4.9: The interconnection of all subsystem used to modeling PV solar Panel [42]

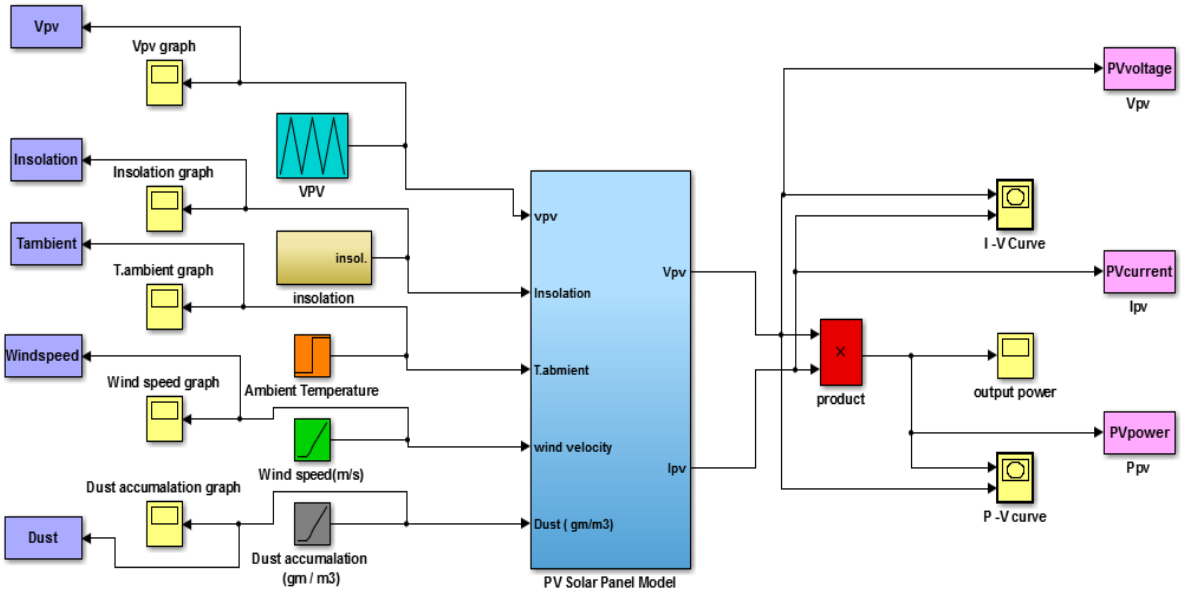

Figure 4.10: PV Solar Panel modeling in Matlab Simulink [42].

4.5.2 Simulation Results and Discussion

Study of four variables variations model will be consider in this section , the study consist of extracting the Matlab–Simulink results for the variation of Solar Insulation, PV module Temperature, wind speed and dust accumulation. The I-V and P–V curves producing for each effect will be described an analysis. The simulation was divided to five different stages as explain below.

4.5.2.1 The performance of solar cell under standard test condition (STC)

Simulink is used in this case to demonstrate behavior of PV solar panel under STC (1000 W/m^2, 25 o C, A.m 1.5). The I-V and P-V characteristic of PV solar panel is shown below in Fig 4.11 and Fig 4.12. The open circuit voltage (Voc), and the short circuit current (Isc) and maximum power (P max) that result from simulation will compare to parameters in datasheet.

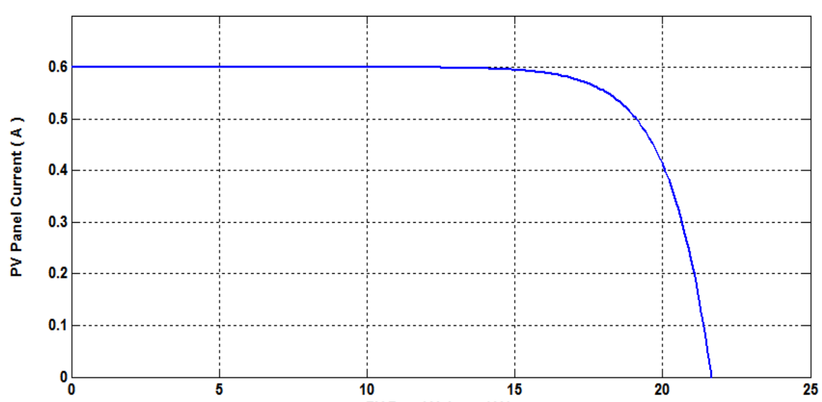

Figure 4.11: Show I – V Curve of PV solar panel under STC.

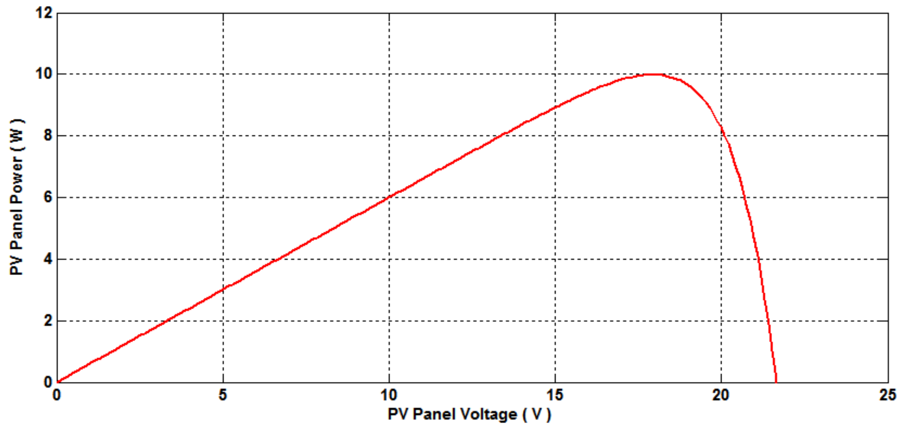

Figure 4.12: Show P – V Curve of PV solar panel under STC.

4.5.2.2The Performance of PV panel with different irradiation and constant temperature cell.

Simulink is used in this case to demonstrate behavior of PV module under varying solar .To investigate the effect of irradiation on PV performance ,in this case we will change the irradiation intensity to (800,600,400) W/m^2 , and the temperature will be kept constant (25℃). The I-V and P-V characteristic of PV solar panel for this case are shown below in figure 4.13and figure 4.14.

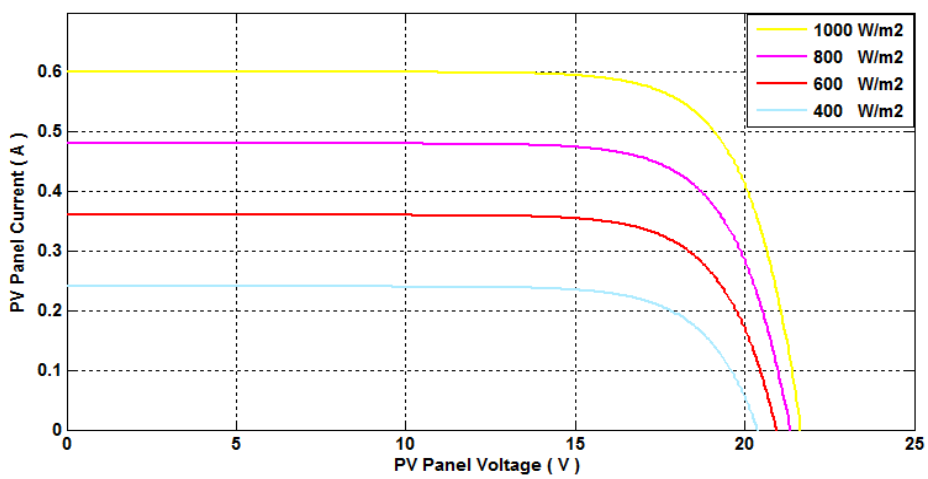

Figure 4.13: The I-V curves of PV panel at different irradiation and constant cell temperature(25℃) .

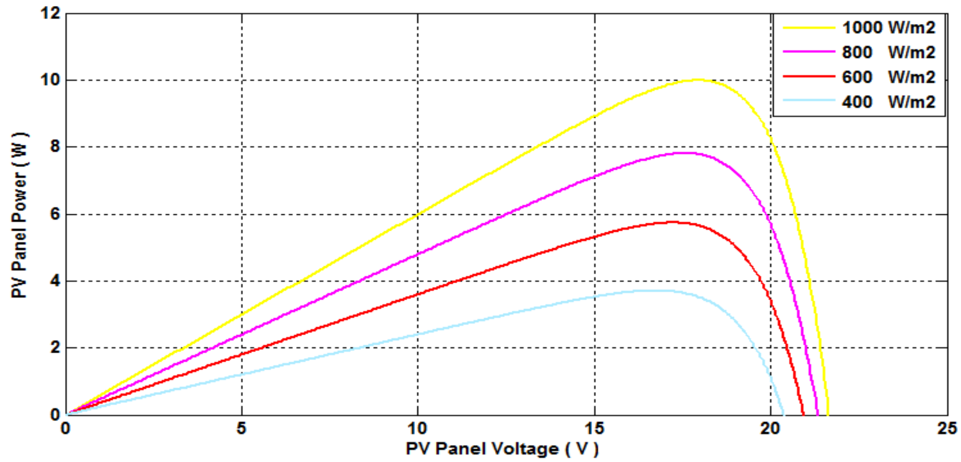

Figure 4.14: The P-V curves of PV panel at different irradiation and constant cell temperature(25 ℃) .

Refer to Fig 4.13 we can observe that when irradiation change, large change in short circuit current (Isc) and small change result on open circuit voltage (Voc) .And for Fig 4.14 the maximum output power of PV panel was decrease as the irradiation decrease and this cause drop in the efficiency of PV panel.

4.5.2.3The performance of PV panel with different temperature and constant irradiation

I-V and P-V characteristics are studied at different temperatures (30, 35, and 40) 25℃ at constant Irradiation (1000 W/m2). The I-V and P-V characteristic of PV solar panel for this case are shown below in Fig 4.15 and Fig 4.16.

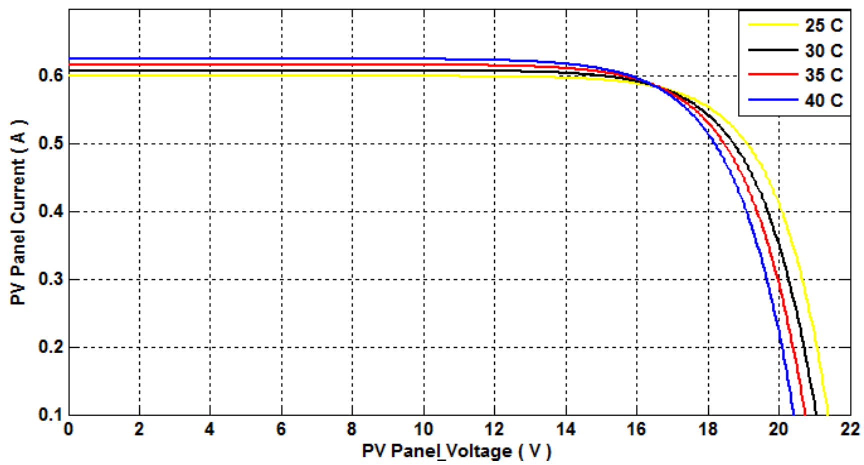

Figure 4.15: The I-V Curve of PV panel at different ambient temperature (25, 30, 35, and 40) ℃ and constant irradiation intensity (1000 W/m2).

The result of figure 4.16 show that when temperature increase, slightly increase was accrue for short circuit current (Isc) but clear increase for open circuit voltage (Voc).

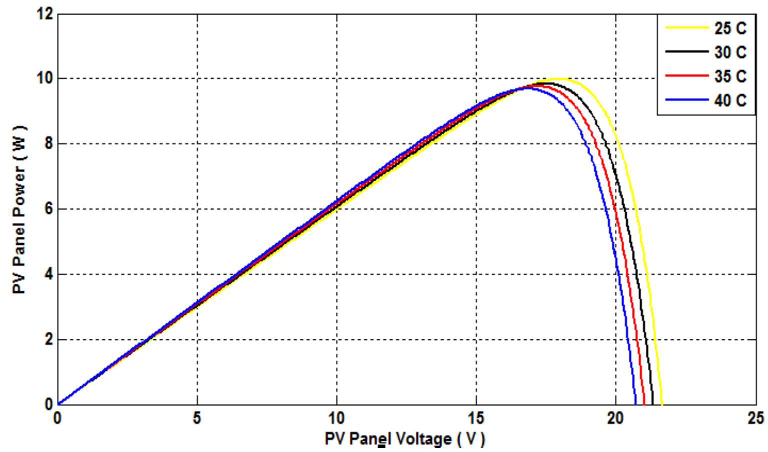

Figure 4.16: The P-V Curve of PV panel at different ambient temperature (25, 30, 35, 40)℃ and constant irradiation intensity (1000 W/m^2).

The result of Fig4.16 show that when temperature increase, the maximum output power of PV panel and fill factor (FF) was decrease and this lead to drop in performance of PV solar panel.

4.5.2.4The Performance of PV panel with effect of wind speed

To investigate the effect of wind speed variation on PV performance, Simulink used to demonstrate the I- V and P- V curves of PV panel at different value of wind speed.

The simulation result for I-V and P-V curve is illustrated in Fig 4.17 and Fig 4.18.

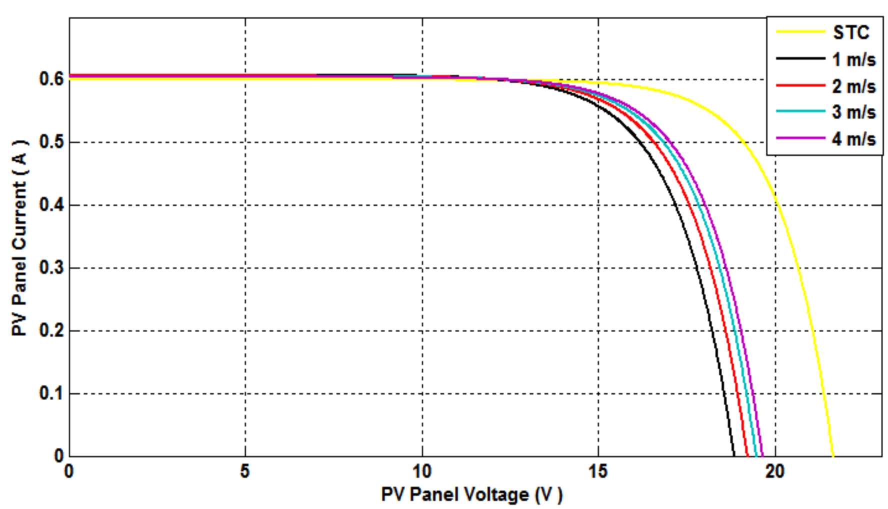

Figure 4.17: Show I-V curve of PV panel at different value of wind speed (1, 2, 3, 4) m/s.

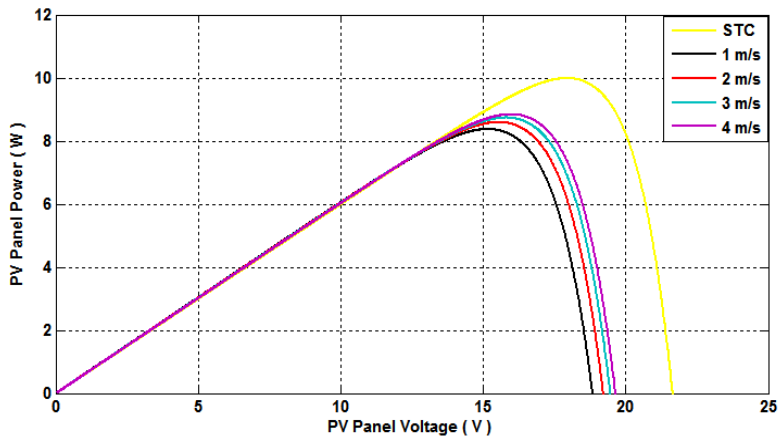

Figure 4.18: The P-V curve of PV Panel at different value of wind speed (1, 2, 3, and 4) m/s.

Fig4.17 and Fig4.18 indicate that increase the value of wind speed causing increase in open circuit voltage (Voc), maximum power of PV panel and this lead to improve the fill factor (FF) and performance of PV Panel.

The simulation results demonstrate that the wind speed is in inverse proportion to the PV module operating temperature due to the fact that it increases the heat transfer process in the PV solar panel as shown in figure 4.19.

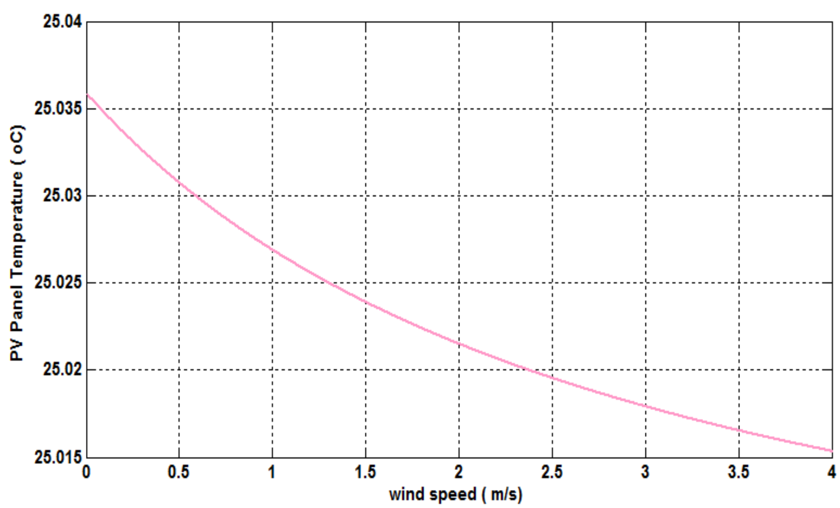

Figure 4.19: The relationship between wind speed and PV temperature at irradiation of

1000 W/m2 and ambient temperature at 25°C.

When irradiation intensity changes to (800W/m^2, 600W/m^2, 400W/m^2), the simulation result obtain in figure 4.20.

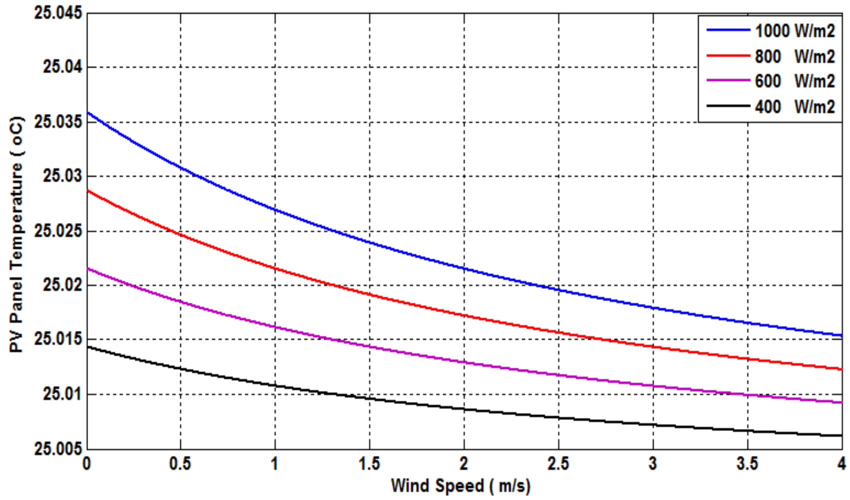

Figure 4.20: The behavior of PV cell temperature at different value of wind speed and different irradiation intensity.

4.5.2.5 The performance of solar cell at different value of the dust density and different type of dust.

To investigate the effect of dust accumulation on performance of PV panel, I-V and P-V curve was obtain at different accumulation of dust by Matlab – Simulink. The I-V and P-V curves simulations was illustrate below in Fig 4.21 and Fig 4.22.

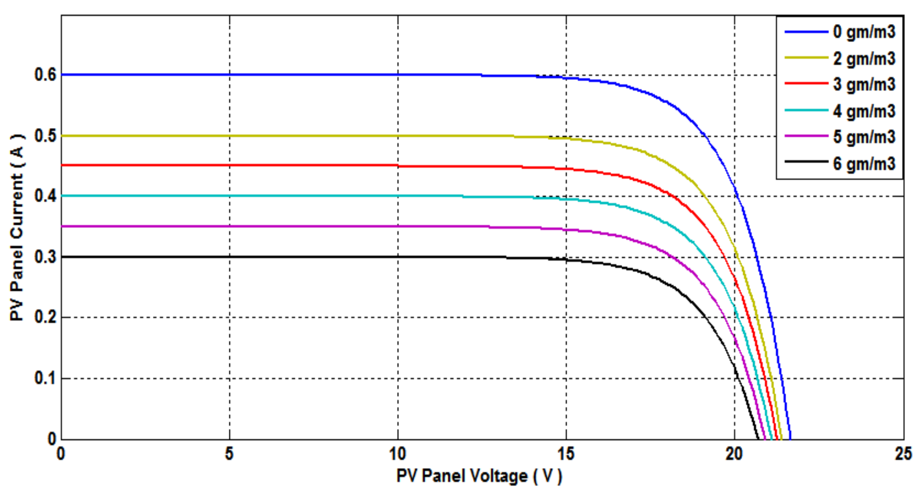

Figure 4.21: The I- V curve of PV panel at different dust accumulation.

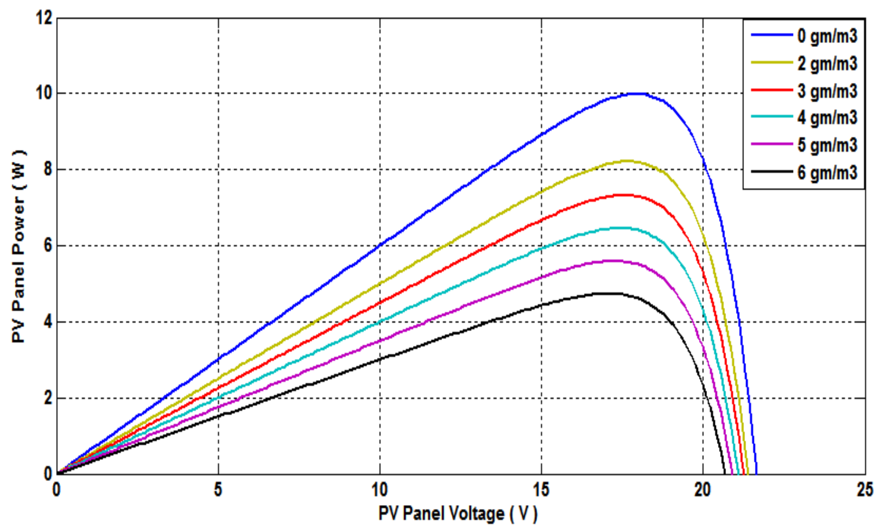

Figure 4.22: The P-V curve of PV panel at different dust accumulation.

As shown in Figures above , the accumulation of dust on the surface of PV panel causing clear decreasing on short circuit current (Isc) and decreasing in open circuit voltage (Voc), so the maximum output power and fill factor (FF) will drop due to accumulation of dust , thus the efficiency of solar panel will decrease.

Decreasing on short circuit current (Isc) was produced due to decreasing in the irradiation intensity that receiving to the solar panel due to accumulation of dust on surface panel this result is illustrated below in figure 4.23.

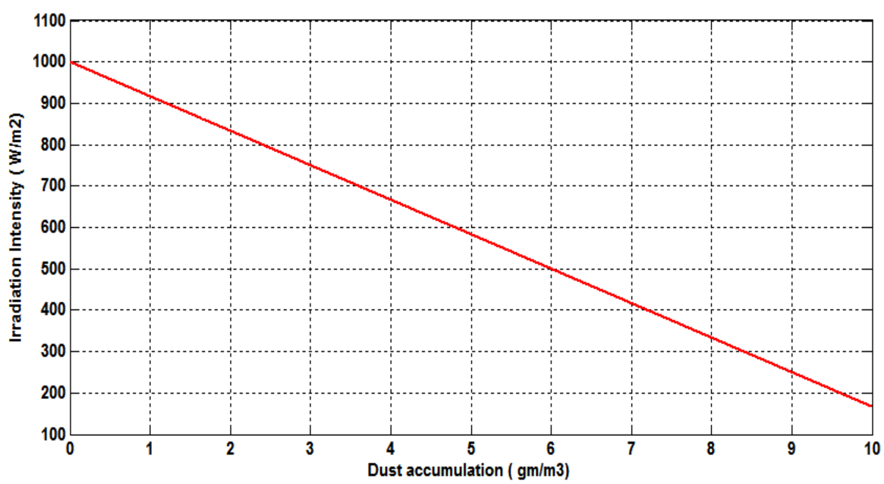

Figure 4.23: The relationship between irradiation intensity and dust accumulation on PV panel surface

5

CHAPTER FIVE

Experimental Prototype

5.1 Introduction

5.2 Temperature experiment

5.3 Dust experiment

5.4 Wind speed experiment

5.1 Introduction

This chapter gives a detail description of all electrical circuits and sensors, codes that has been used in practical experiments. In addition to a set of some images for each experiment In order to give expectation for the mechanism of experience application.

5.2 Temperature experiments

For this experiment, we used three temperature sensor type of LM35 and distributed on the solar module surface regularly for cover all the solar module area and connected all these sensors with microcontroller (Arduino) at analog ports, then the microcontroller (Arduino) will send the value of average of temperature to computer to display it on a screen .

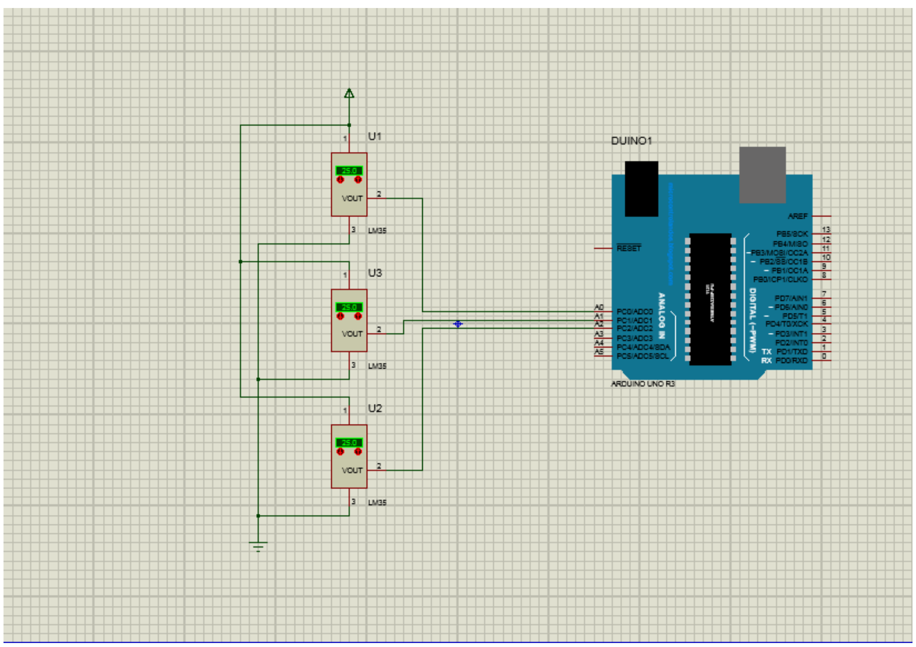

Figure 5.1: Connection three temperature sensors with Arduino.

Code for connection temperature sensors with Arduino:" see the source code of the temperature sensors in appendix A".

5.2.1 Some images for this experiment.

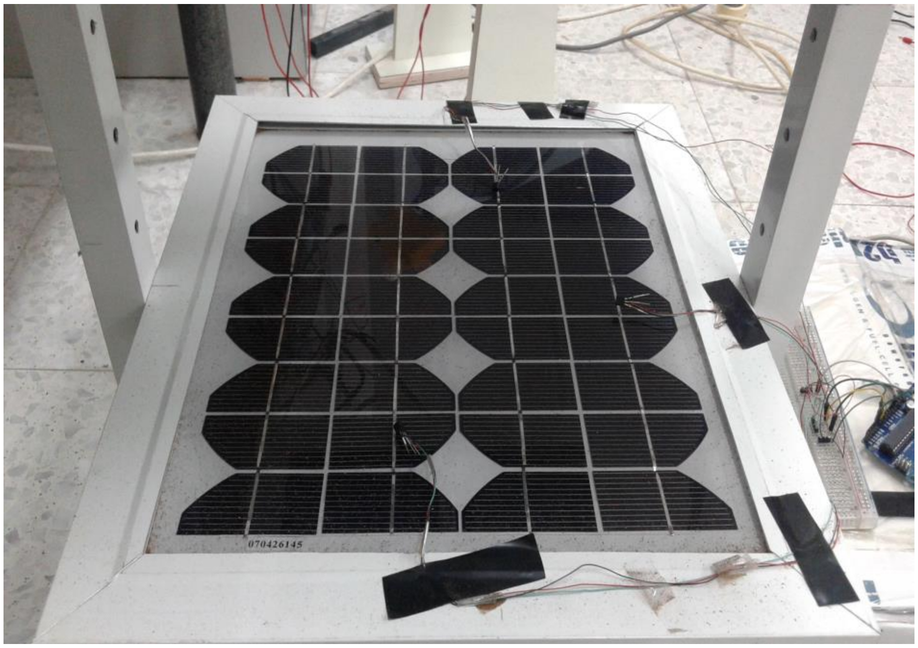

Figure 5.2: Three sensors distributed on the surface solar module.

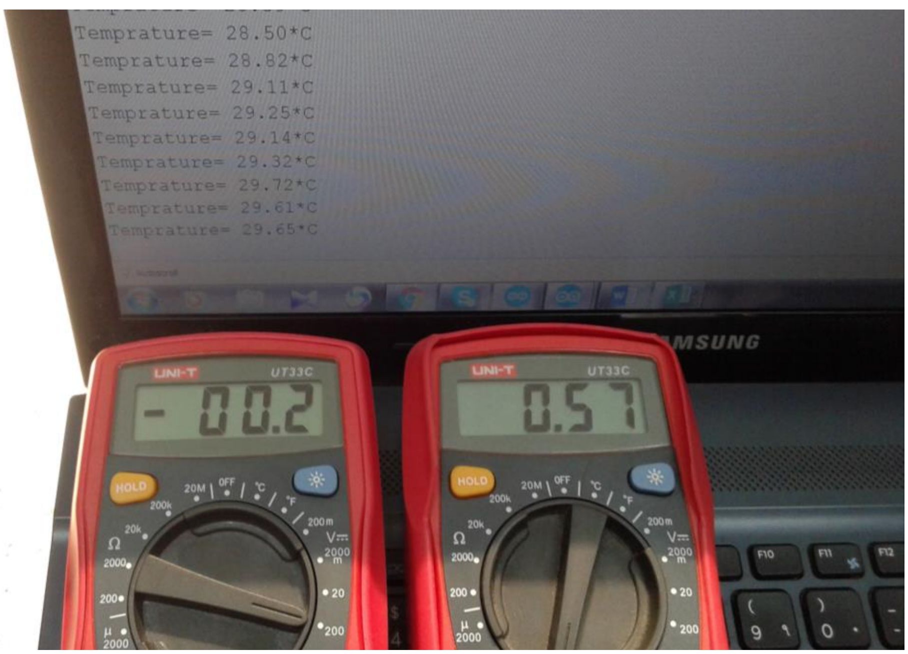

Figure 5.3: Result of temperature on computer screen.

5.3 Dust experiments

In this experiment we used a dust sensor type of **GP2Y1010AU0F** It is a device used to measure the dust density of the air ambient of the solar module is an optical air quality sensor we connection this sensor with Arduino at analog port and sending of dust density value to the computer and used fan to be distributed Dust regularly.

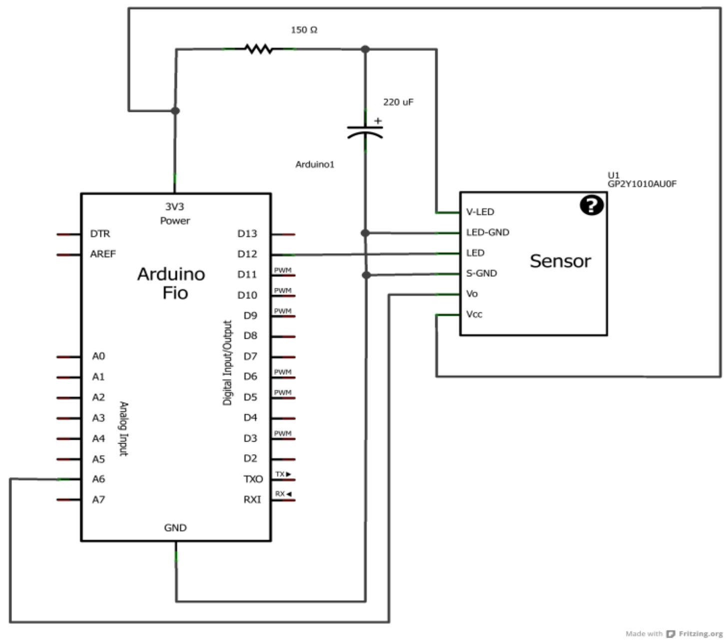

Figure 5.4: Connection dust sensor GP2Y1010AU0F with Arduino

Code of connection dust sensors with Arduino:" see the source code of the dust sensor in the appendix A".

5.3.1 Some images for this experiment

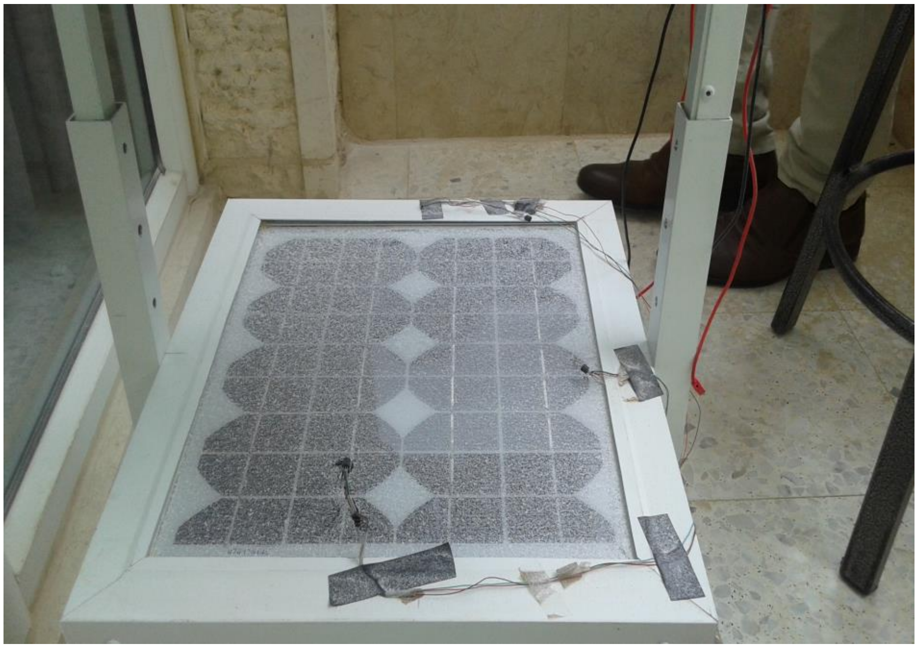

Figure 5.5: White dust dust distributed on the solar module surface.

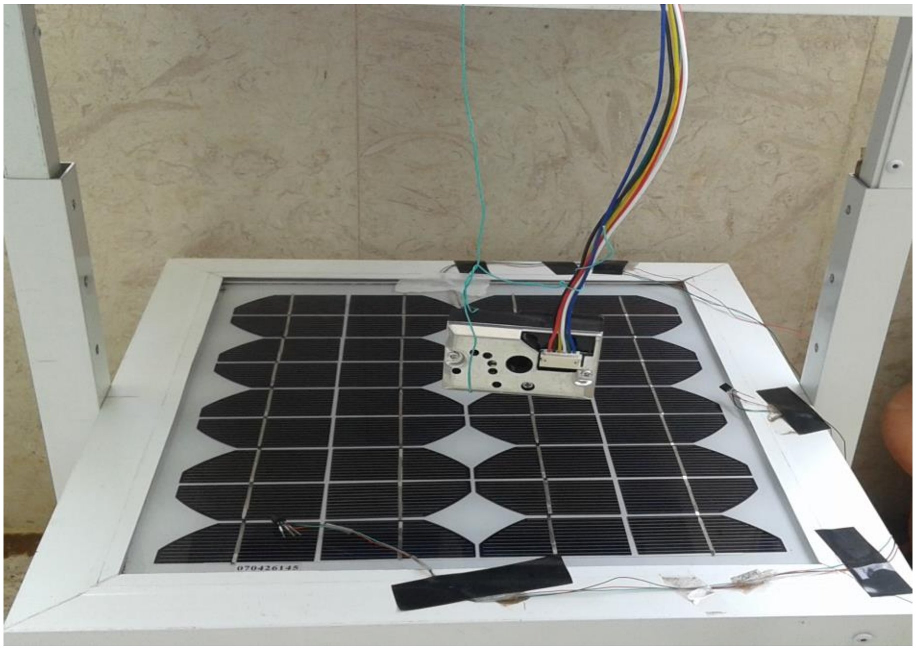

Figure 5.6: Dust sensor device on PV module.

5.4 Wind speed experiment

In this experiment, we used wind speed sensor (**Anemometer**) .it used to measuring the effect of wind speed on the solar module. We connect this sensor with result analysis unit, so display the result on its special screen and we used change speeds fan to reach the different speeds

Figure 5.7: Using change speed fan in experiment.

Figure 5.8: Wind speed unit analysis.

6

CHAPTER SIX

Results and Analysis

6.1 Introduction

6.2 Photovoltaic module at standard test conditions.

6.3 The effect of change temperature on PV module

6.4 The effects of dust density on PV module

6.5 Effect of wind speed on PV module

6.6 Errors affects the experiments

6.1 Introduction

In this chapter, we will describe the results that obtained from practical experiments for the effect of temperature, dust and wind speed on PV module. Also the changes in the PV module parameter (P, η, Isc, and Voc) will be shown in this chapter.

6.2 Photovoltaic module at standard test conditions.

Fig 6.1and Fig 6.2 illustrate the I-V and P-V curves when the PV cell was tested under STC (1000W/m2, 25 °C, A.M 1.5). From this figures, the short circuit current (Isc) is 0.6 A and open circuit voltage is 20.7 V. Under STC the maximum power can obtain from PV module is 9.352 W and the efficiency is 9.396 %.

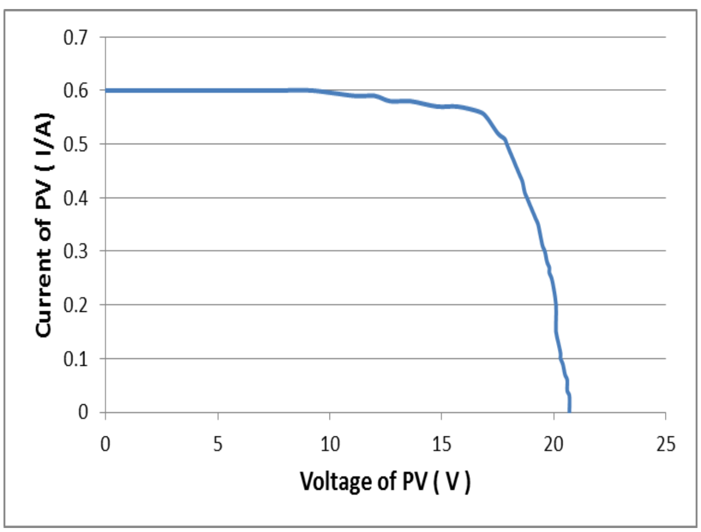

Figure 6.1: I-V curve of PV module at STC.

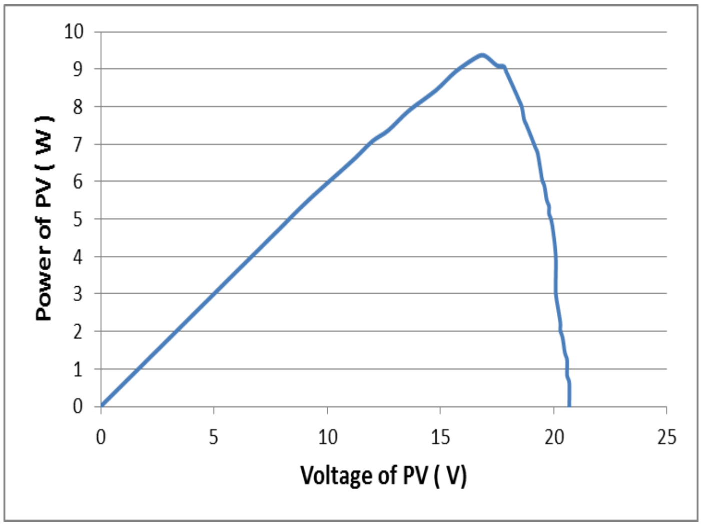

Figure 6.2: P-V curve of PV module at STC.

6.3 The effect of change temperature on PV module.

In This section, the performance of the PV module at different temperature level has been investigated. The analysis deal with the effect of temperature on the open circuit voltage (Vo.c), short circuit current (Isc), maximum power and efficiency of PV module.

Figures 6.3and Figures 6.4 illustrated I-V and P-V curves at different temperature of PV. It can be seen that when the temperature of PV increased to 30,35,40,45,50 and 55°C , the open circuit voltage (Voc) decreased to 20,18.9,18,17.4,16.4 and16.1 V respectively. While short circuit current (Isc) was slightly increased to 0.61, 0.62, 0.64, 0.65, 0.66 and 0.67A respectively. In other word Voc was decreased by 3.89% per 5 °C above 25°C and Isc was increased by 2% per 5°C above 25°C.

The P-V curves of PV mentioned that maximum power(Pmax) can generated from PV was decreased to 9.263 ,8.584,8.208,7.611,7.02 and 6.786 W ,when the temperature of PV raised to 30,35,40,45,50and 55 °C .Also the efficiency of PV was decreased to 9.263%,8.584%,8.208%,7.611%,7.02% and 6.786% respectively. From this result we conclude that Pmax and (η) was decreased by 5% per 5°C above 25 °C.

In case of the temperature of PV below 25°C, Voc increased to 21 V and Isc was decreased to 0.56 A. The maximum output power (Pmax) and the efficiency (η) generated from PV was decreased to 8.823W and 8.86%, respectively.

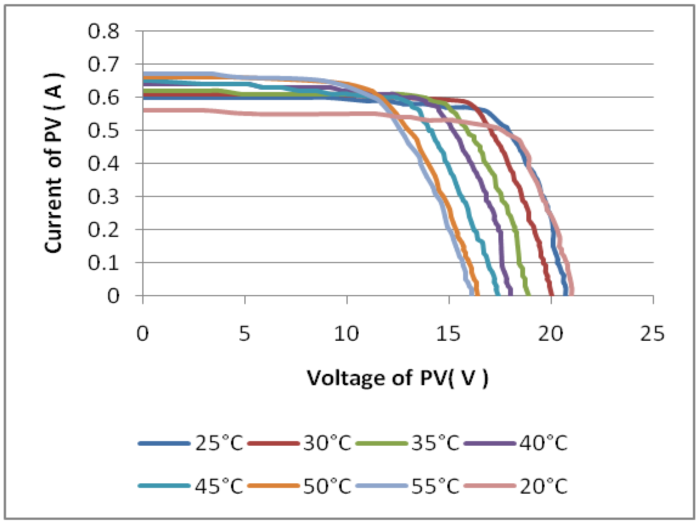

Figure 6.3: I-V curves of PV module at different temperature.

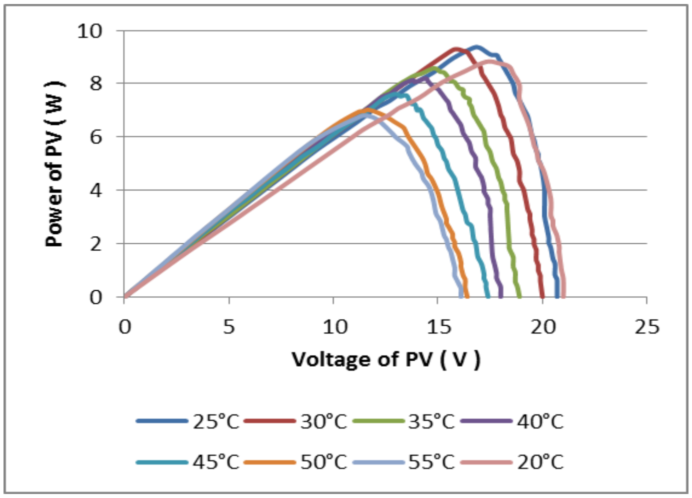

Figure 6.4: P-V curves of PV module at different temperature.

The effect of change temperature on maximum output power of PV module is developed in figure 6.5.

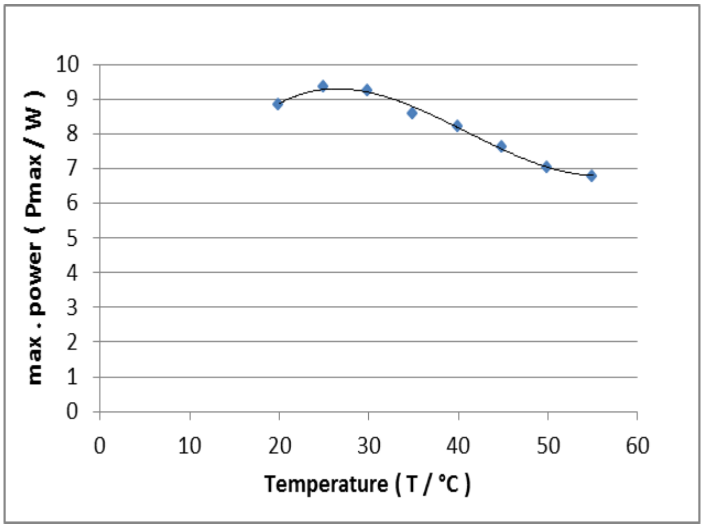

Figure 6.5: The maximum output power of PV module at different temperature.

From the figure above we can obtain a mathematical expression that describe the relation between Pmax and temperature of PV (T).

The Pmax of PV as a function of temperature is shown below:

- In case of $T \geq 25$ °C

$$Pmax(T) = -0.09398\,T + 11.88$$

- In case of $T \leq 25$ °C

$$Pmax(T) = 0.092\,T + 7.029$$

Where: Pmax: The maximum output power can generated from PV module (W)

T: The temperature of PV module (°C)

Figure 6.6 below show how the efficiency of PV module changed when the temperature of PV was increased.

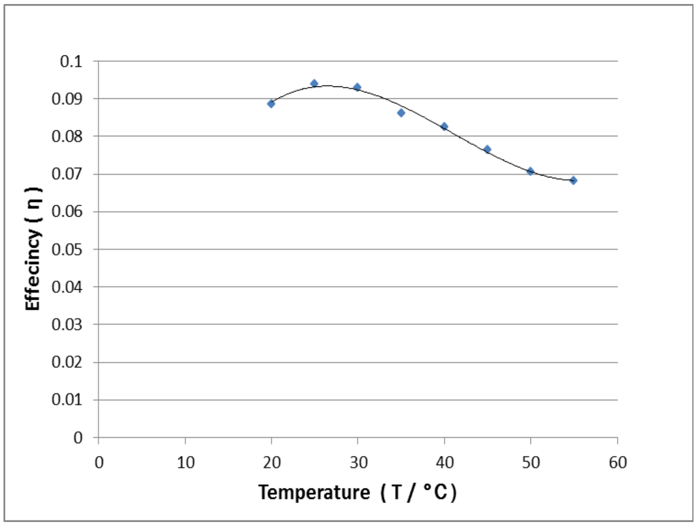

Figure 6.6: The efficiency of PV module at different temperature.

All data that obtained from temperature experiments that include the measuring parameter (I, V, P) is founded in appendix B.

6.4 The effects of dust density on PV module

In this section, the effect of several types of dust on the PV performance was investigated. Three types of the dust have been used in the experiment. These are red, Sand, white) soil. It was found that the short circuit current (Isc) was strongly decreased as the dust density increased. Also maximum output power and efficiency was decreased significantly as the dust density increase. However, at different dust type with varying dust density, the open circuit voltage (Voc) was slightly increased.

All data that obtained from dust experiments for each type (red , sand ,white) soil that include the measuring parameter (I ,V ,P, and dust density) is founded in appendix C, D , E and G for red , white, sand dust ,and irradiation data respectively .

6.4.1 Effect of red soil dust on PV module

Figures 7-10 show the effect of red dust on the I-V curve, power, and efficiency of PV module. The results show that the short circuit current (Isc) was decreased from 0.61 to 0.56, 0.64 and 0.48 A for red dust density 25, 30 and 35mg/m3, respectively. While the open circuit voltage (Voc) was slightly increased to 20.1and 20.3 V for red dust density 30and 35mg/m3. In other words, Isc was decreased by 2.4% and Voc increased by 0.15% per 5mg/m3 of red dust density.

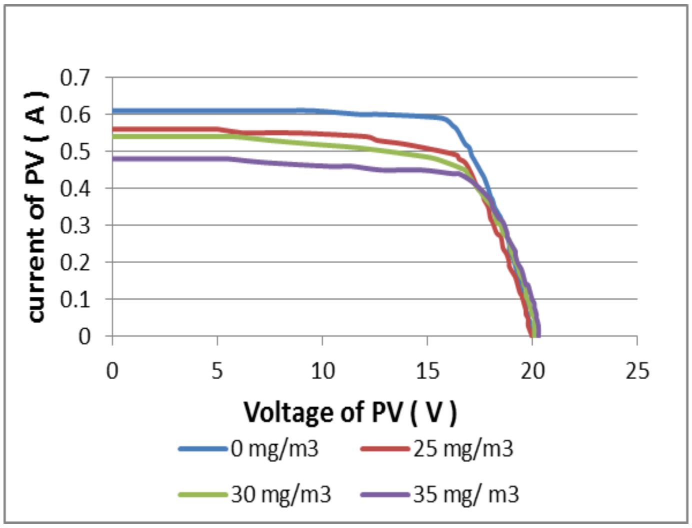

Figure 6.7: I-V curves at 30°C and different red soil dust density.

The maximum output power and efficiency of PV module at different red dust density shown in Figure 6.8 , 6.9and 6.10 .From these figures it can be seen that without any dust on PV module , the maximum power is 9.263W but in case of red dust density was 25 ,30 ,35 mg/m3 ,the maximum power decreased to 8.036 , 7.56 ,7.26 W respectively. It can be concluded that the maximum power and efficiency of the PV is decreased by 13.24%, 18.38%, and 21.62% for the cases of 25, 30, 35 mg/m3, respectively .In other words The maximum power and efficiency of PV was decreased by 3% per 5mg/m3 of red dust .

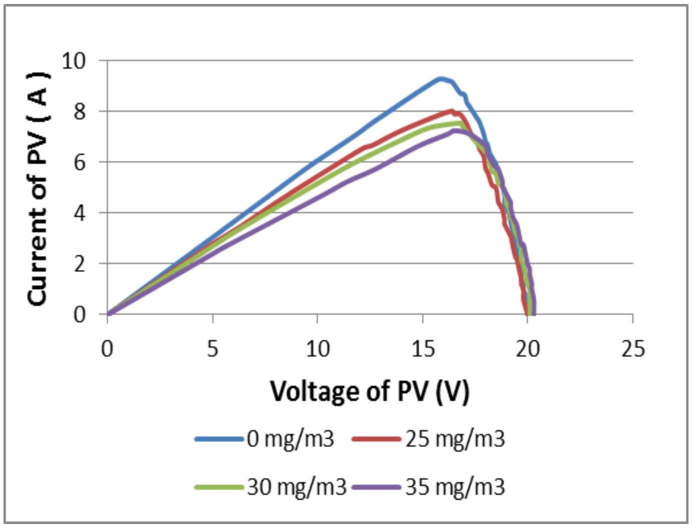

Figure 6.8: P-V curves at 30°C and different red soil dust density.

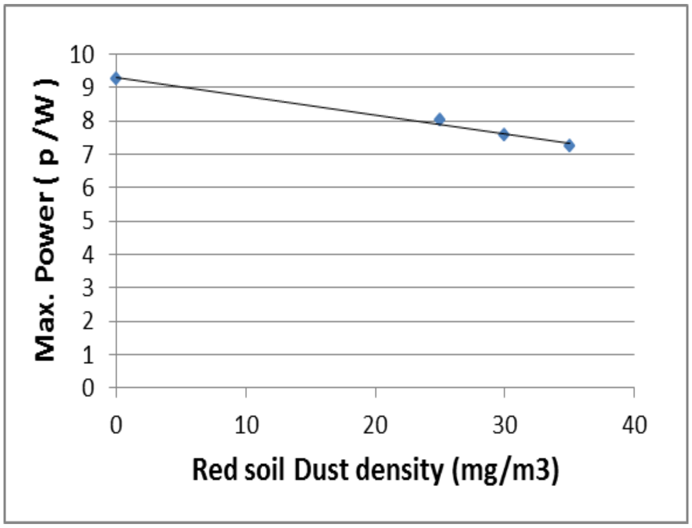

Figure 6.9: The effect of different red soil dust density on max output power of PV.

According to figure above we can expressed the relationship between dust density and the maximum power can obtain from PV module as follow:

$$Pmax\ (D) = -0.05638\ D + 9.298$$

Where: Pmax: the maximum output power of PV module. (W)

D: Red soil dust density. (mg/m3).

Figure 6.10 describe the effect of applied different red soil dust density on PV module on the efficiency. From this figure we show the decreasing in efficiency of PV when the dust density increased.

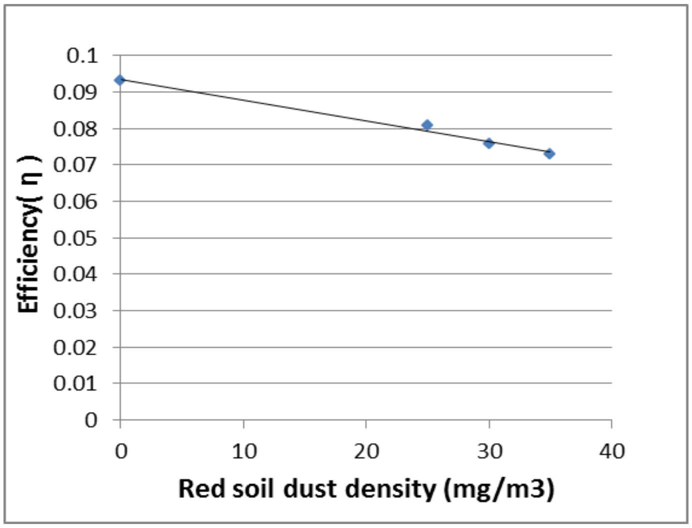

Figure 6.10: The efficiency of PV module at different red soil dust density.

6.4.2 Effect of Sand dust on PV module

Figures 11-14 show the effect of red dust on the I-V curve, power, and efficiency of PV module. The experimental results show that without any dust on PV ,the short circuit current (Isc) and open circuit voltage (Voc) was 0.61 A ,20 V respectively .But when PV subjected to sand dust with density 25, 30, 35 , the short circuit current (Isc) was decreased to 0.59 ,0.58,and 0.55, respectively . But the Voc increased to 20.5 V and 20.5V for sand density 30, 35 mg/m3, respectively. Which mean that Isc decreased by 3.27%, 4.91%, 9.83% for the cases of 25, 30, 35 mg/m3. And for 30 and 35 mg/m3, Voc increased by 2.5%, 4% sequentially. In general, Voc was increased by 0.5% / (5mg/m3) but Isc was decreased by 1.02% / (5mg/m3).

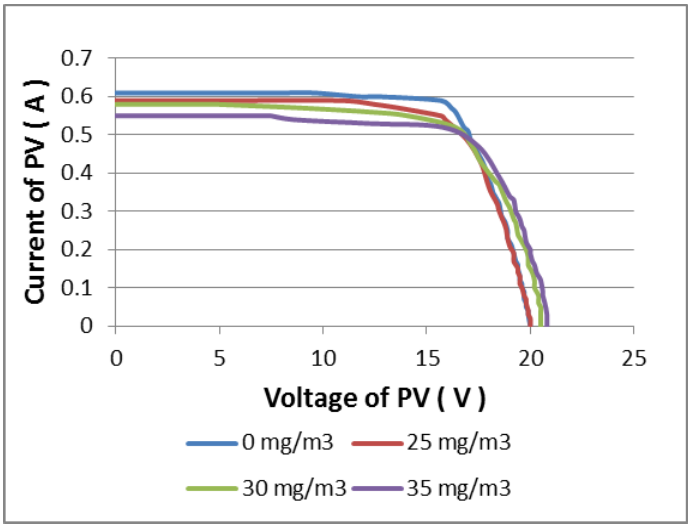

Figure 6.11: I-V curves of PV module at different sand dust density.

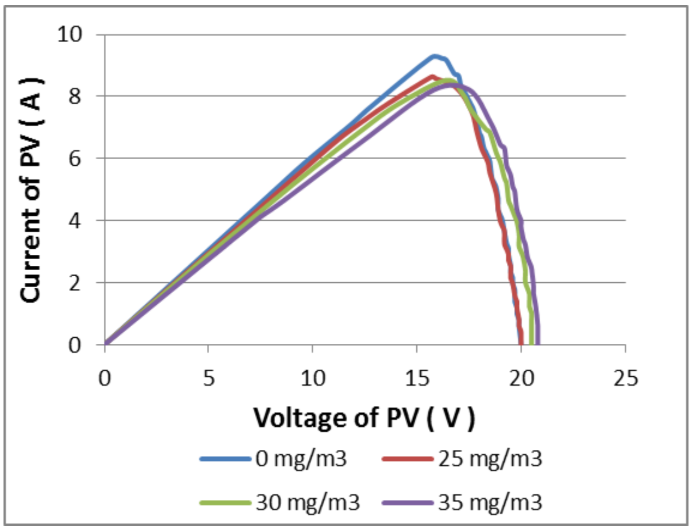

Figure 6.12: P-V curves of PV module at different sand dust density.

The maximum output power obtained from PV module at different sand density is obtained. It can be seen from Figure 6.13 that the maximum power when the PV clean was 9.263W .But when we spread sand dust on PV with density 25,30and 35 mg/m3 , the maximum power was decreased to 8.635 ,8.528 and 8.225 W that means maximum power was decreased by 6.77%,7.93% and 11.2% Sequentially .beside this, for 5mg/m3 of sand dust , the maximum power of PV module decreased by 1.5 %.Also the efficiency of PV at different dust was decreased by the same percentage as maximum power decreased.

The following equation illustrate the relation between max. Power of PV and different sand density:

$$Pmax\ (D) = -0.02767\ D + 9.285$$

Where: Pmax: maximum output power of PV module (W)

D: Sand density (mg/m3).

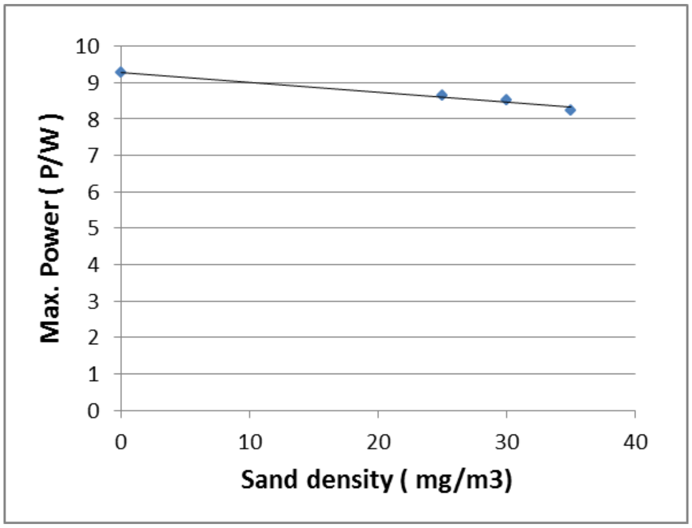

Figure 6.13: Effect of sand density on maximum output power of PV.

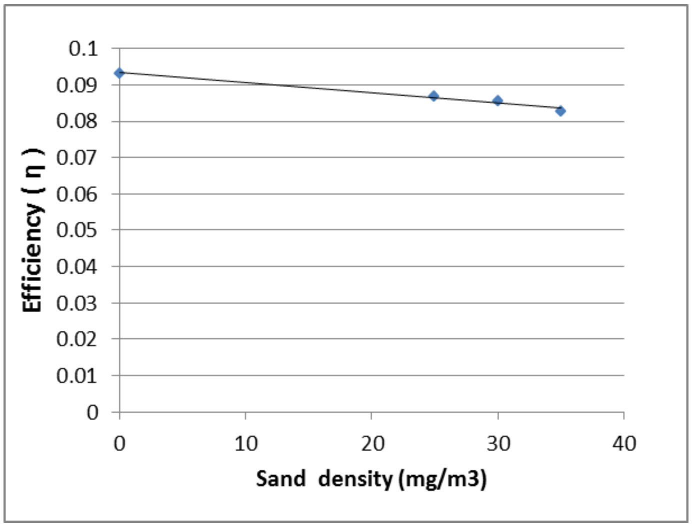

Figure 6.14: The efficiency of PV at different sand density.

6.4.3 Effect of White soil dust on PV module

Figures 15-18 shows the effect of white dust dust density on PV module. It can be seen that the white dust has a significant effect on the short circuit current (Isc). However, in case of clean PV module (without any dust), the short circuit current is 0.61A and open circuit voltage (Voc) was 20 V. While when PV covered with white dust, the short circuit current (Isc) was decreased to 0.53, 0.51and 0.43A for dust density 20,30and 40 mg/m3 respectively. Conversely the open circuit voltage (Voc) was increased to 20.7, 20.8 and 20.9 for 20,30and 40 mg/m3 dust density. For 20,30and 40 mg/m3 of dust density ,it can conclude that the short circuit current (Isc) was decreased by 13.11%, 16.39%and 29.5% , respectively .but open circuit voltage (Voc) was increased by 3.5%,4%and 4.5% respectively. However, it was found that Voc increased by 0.54% per 5mg/m3 and Isc decreased by 3.4% per 5mg/m3 of white soil dust.

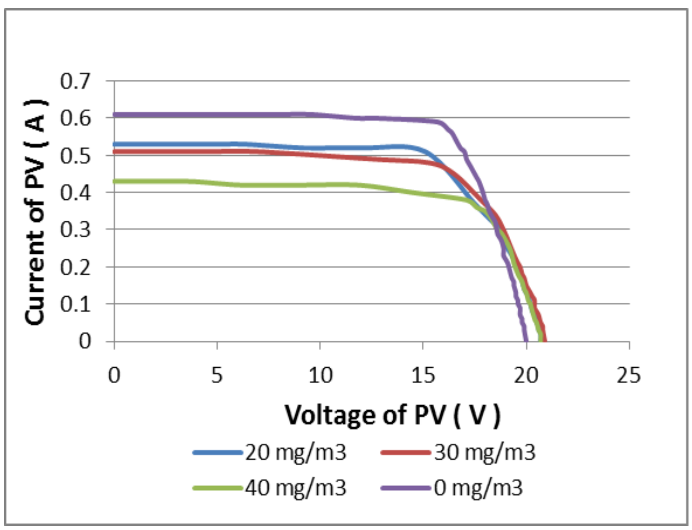

Figure 6.15: I-V curves of PV module at different white dust density.

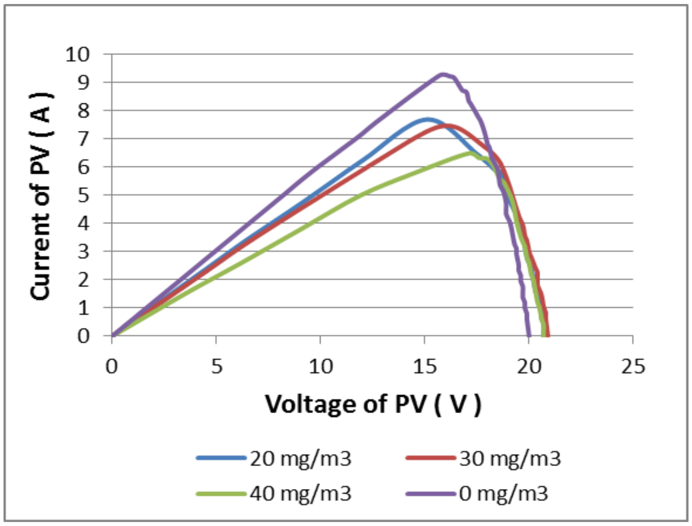

Figure 6.16: P-V curves of PV panel at different white dust density.

Figure 6.17and 6.18 shows the effect of white dust on the PV maximum power and PV efficiency. It can be seen that the maximum power for the case of PV without any dust was 9.263W, and it is decreased to 7.701, 7.425, and 6.498 W for the cases of 20, 30, and 40 mg/m^3 of dust density, respectively. It can be concluded that the maximum power and the efficiency of the PV is decreased by 16.86%, 19.84%, and 29.84% for the cases of 20, 30, 40 mg/m3, respectively. However, it was found that the maximum power and PV efficiency was decreased by 3.6% per 5mg/m3 of white dust (3.6 %/(5mg/m3)).

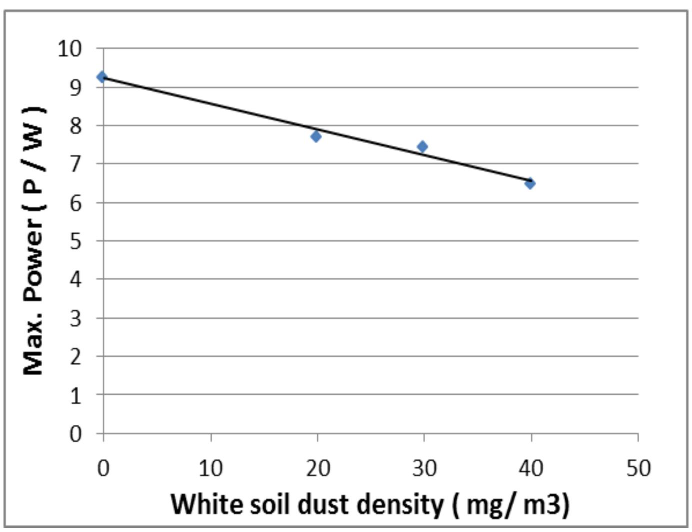

Figure 6.17: The effect of white dust density on maximum power of PV.

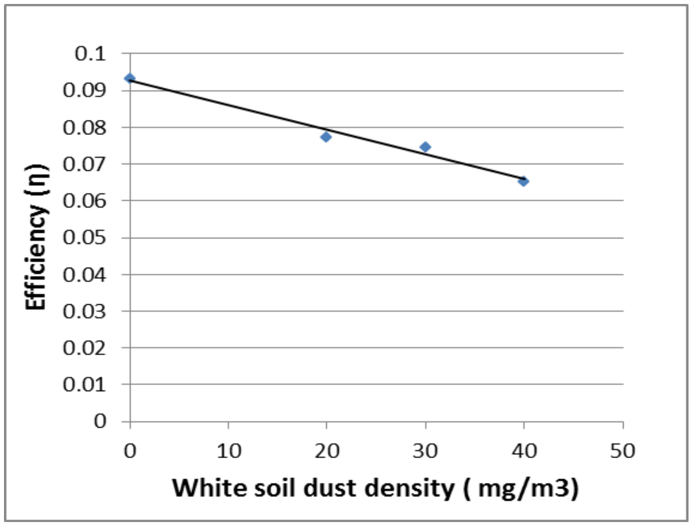

Figure 6.18: The efficiency of PV module at different white dust density.

The following equation describe the relation between density of white dust and the max. Power can generated from PV module:

$Pmax\ (D) = -0.06659\ D + 9.22$

Where: Pmax: The maximum power of PV module (W).

D : White soil dust density (mg/m3)

6.4.4 Effect dust density on irradiation intensity.

In this section, the changing in irradiation intensity due to dust density was obtained by using matlab software.

In general, the intensity of irradiation that received on PV module was decreased, when the dust density increased. Figures from 6.19 to 6.21 mentioned how irradiation intensity decreased, when the dust density increased for each type of dust (red soil, sand, white dust)

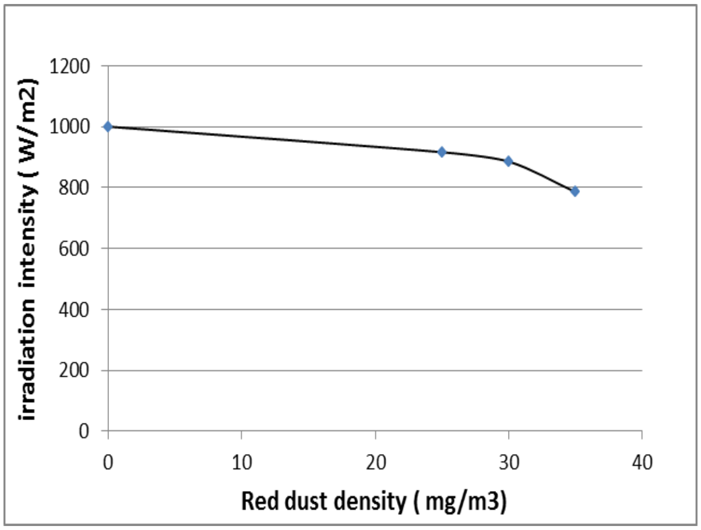

Figure 6.19: Relationship between red dust density and irradiation intensity

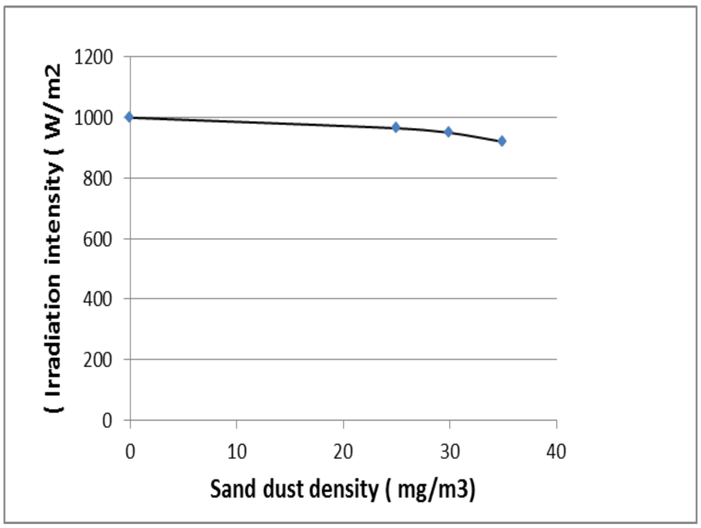

Figure 6.20: Relation between sand density and irradiation intensity.

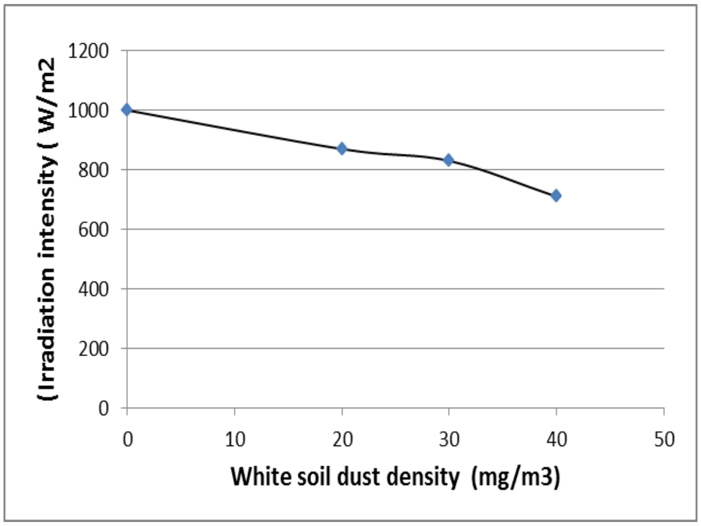

Figure 6.21: Relation between white dust density and irradiation intensity.

The following equations are express the relation between dust density and irradiation intensity:

● For red soil dust.

$$G(D) = -0.000769e^{(0.3376\,D)} + 1000e^{(-0.003354\,D)}$$

●For sand dust.

$$G(D) = -1000e^{(-0.001615\,D)}$$

●For white soil dust.

$$G(D) = -1.796x10^{-14}e^{(0.8949\,D)} + 997.6e^{(-0.006367\,D)}$$

Where: G: irradiation intensity that received on PV panel (W/m2).

D: Dust density (mg/m3).

6.5 Effect of wind speed on PV module

In this section, we study the effect of wind speed on PV performance by varying the speed of fan and we take the PV data at 1 m/s as a reference. Figure6.22 and 6.23 show effect of wind speed on maximum power and PV efficiency .At 1m/s of wind speed , the maximum power of PV was 6.656

W .In case of increasing wind speed to 2,3,4and 5 m/s , the maximum power was increasing to 6.902 ,7.182, 7.535 and 8.064 W, respectively .In other words, the maximum power and efficiency was increased by3.6%,7.9%,13.2%and 21.1% for case of 2,3,4 and 5 m/s sequentially. Also it can be conclude that the maximum power and efficiency of PV was decreased by 5% per 1 m/s increasing of wind speed.

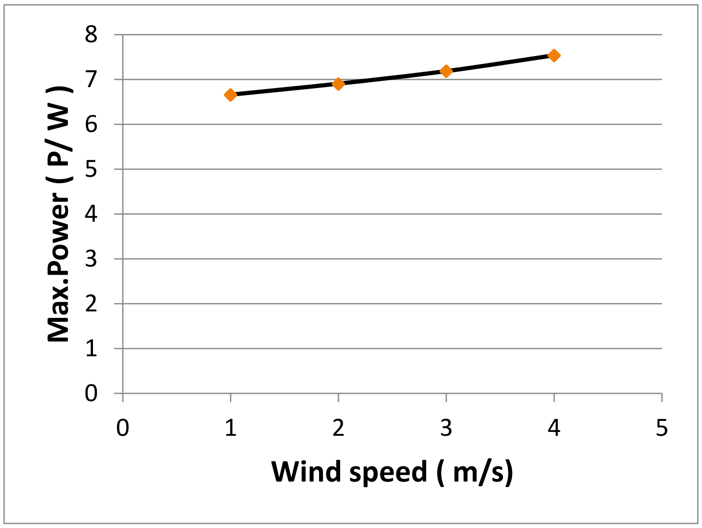

Figure 6.22: The effect of Wind speed on maximum power of PV.

According to figure 6.22, the changing in maximum power of PV module due to increasing of wind speed can express as the following equation:

$$Pmax\ (W) = 6.281e^{(0.04785\ W)}$$

Where Pmax: maximum output power of PV.

W: Wind speed (m/s).

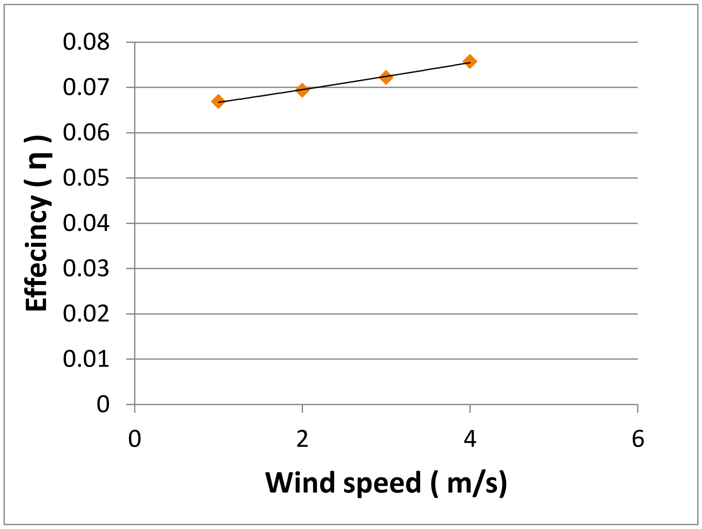

Figure 6.23: The effect of Wind speed on efficiency of PV.

On the other hand, at 1m/s of wind speed , the short circuit current (Isc) and open circuit voltage was 0.6 A and 17 V , respectively .while we changed the speed of fan to 2 ,3,4 and 5m/s , the short circuit current changed to 0.6 ,0.59,0.59 and 0.56 A , respectively. Conversely open circuit voltage (Voc) was increased to 17.3, 17.8, 18.5 and 20.2 V respectively. From this data we can conclude that, Isc slightly decreased by 1.48 % / (1m/s) while Voc was increased by 2.02 % / (1m/s). The I-V and P-V curves at different wind speed is shown in figure 6.24 and 6.25.

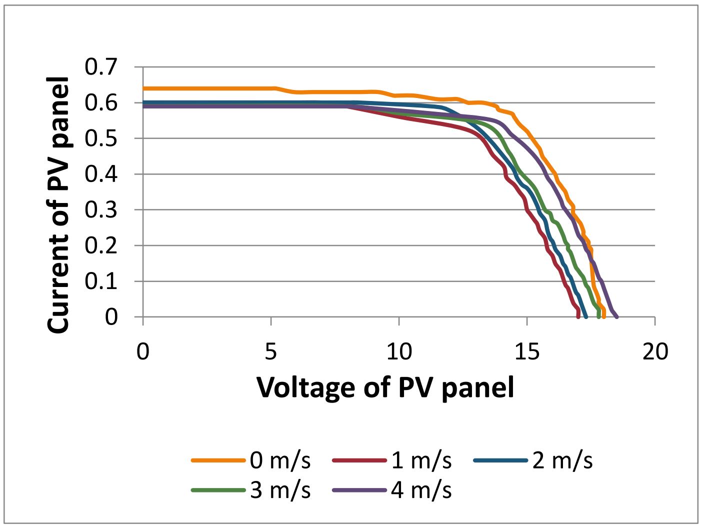

Figure 6.24: I-V curves of PV panel at different Wind speed.

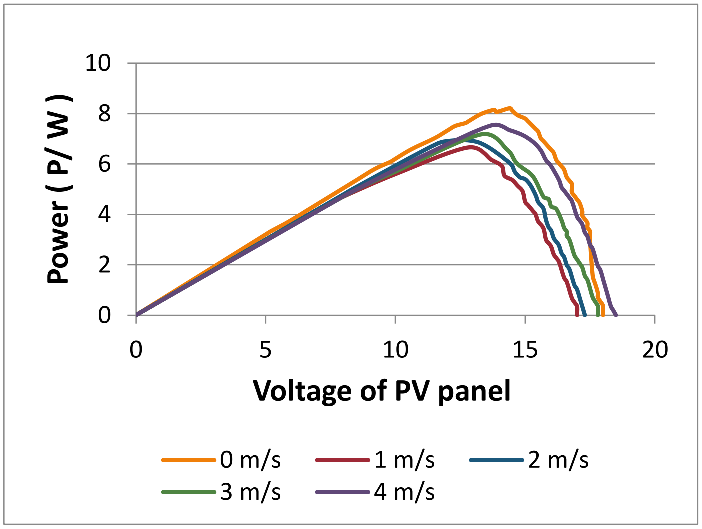

Figure 6.25: P-V curves of PV panel at different Wind speed.

The temperature of PV panel was been effected when value of wind speed varied and this can be shown in figure6.26. When the wind speed increased, the temperature of PV was decreased. So we can express the temperature of PV as a function of wind speed as follow:

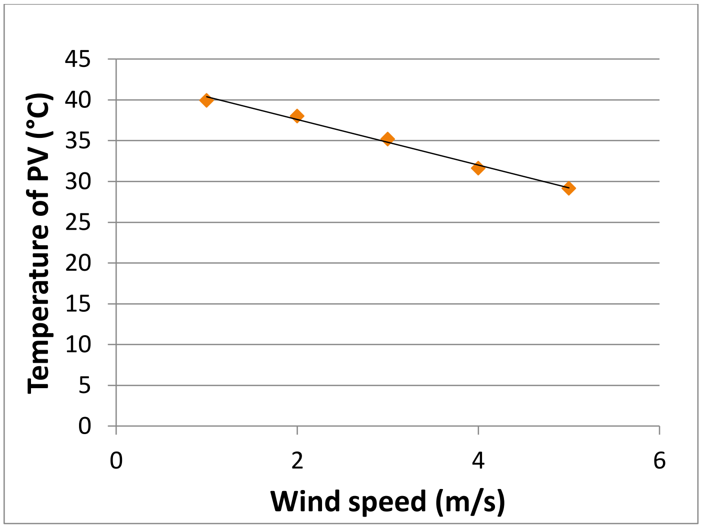

Figure 6.26: The effect of Wind speed on temperature of PV module

$$T(W) = -2.791\,W + 43.18$$

Where T: The temperature of PV module (°C).

W: Wind speed (m/s).

All data that obtained from wind speed experiments include the measuring parameters (I, V, P) is founded in appendix F.

6.6 Errors affects the experiments

Experimental error is always with us, it is in the nature of scientific measurement that uncertainty is associated with every quantitative result. So no experiment can be conducted with perfect certainty of the measured parameters. Errors might exist in any procedure and this may be due to inherent limitations in the measuring equipment, or of the measuring techniques, or perhaps the experience and skill of the experimenter.

There are some common errors which take place during the experiment:

1. **Human error** (a mistake) occurs when the experimenters make mistakes. These happened during the procedure of the experiment. When we set up the experiment incorrectly in the first stage of the experiment during the wiring process by connect a multimeter with the wrong terminal of solar cell. Hence the multimeter gives wrong data. Other mistake occurs when connecting the wires of dust sensor in wrong position this give a wrong data of dust density.

2. **Systematic error**, other common errors in experiments are errors in equipment's. Equipment can never be 100% accurate. However, it should come very close. It is important to test the equipment's margin of error and utilize this in the analysis of the data which is done by testing the multimeter with known resistance. Furthermore there are some factors affect the performances of the PV cell and efficiency such as the losses from the wire, the resistors in the multimeter, dust sensor and thermometer.

7

CHAPTER SEVEN

Conclusion and Recommendation

7.1 Conclusion

7.2 Recommendation

7.1 Conclusion

The effects of dust, air velocity and temperature on mono-crystalline PV module were investigated at constant radiation (G=1000W/m2). A series of experiments were conducted in order to investigate the effect of these parameters on the PV performance. Firstly, the PV model was tested under the Standard Test Condition (STC). The case was used for the comparison purpose. The PV characteristics, the I-V and P-V curves were evaluated. It was found that the short circuit current (Isc) is 0.6A and the open circuit voltage is 20.7 V. Under STC the maximum power can obtain from PV module is 9.352 W and the efficiency is 9.396 %. Secondly, the performance of the PV module at different temperature level has been investigated. The analysis deal with the effect of temperature on the open circuit voltage (Vo.c), short circuit current (Isc), maximum power and efficiency of PV module. It was found that, when the temperature of PV increased to 30,35,40,45,50 and 55°C , the open circuit voltage (Voc) decreased to 20,18.9,18,17.4,16.4 and16.1 V respectively. While short circuit current (Isc) was slightly increased to 0.61, 0.62, 0.64, 0.65, 0.66 and 0.67A respectively. In other word Voc was decreased by 3.89% per 5 °C above 25°C and Isc was increased by 2% per 5°C above 25°C. Furthermore, maximum power(Pmax) can generated from PV was decreased to 9.263 ,8.584,8.208,7.611,7.02 and 6.786 W ,when the temperature of PV raised to 30,35,40,45,50and 55 °C .Also the efficiency of PV was decreased to 9.263%,8.584%,8.208%,7.611%,7.02% and 6.786% respectively. From this result we conclude that Pmax and (η) was decreased by 5% per 5°C above 25 °C.

Thirdly, the effect of several types of dust on the PV performance was investigated. Three types of the dust have been used in the experiment. These are red, Sand, white) soil. It was found that the short circuit current (Isc) was strongly decreased as the dust density increased. Also maximum output power and efficiency was decreased significantly as the dust density increase. However, at different dust type with varying dust density, the open circuit voltage (Voc) was slightly increased. The results show that the short circuit current (Isc) was decreased from 0.61 to 0.56, 0.64 and 0.48 A for red dust density 25, 30 and 35mg/m3, respectively. While the open circuit voltage (Voc) was slightly increased to 20.1and 20.3 V for red dust density 30and 35mg/m3. In other words, Isc was decreased by 2.4% and Voc increased by 0.15% per 5mg/m3 of red dust density. Further, the maximum power decreased to 8.036, 7.56, 7.26 W respectively. It can be concluded that the maximum power and efficiency of the PV is decreased by 13.24%, 18.38%, and 21.62% for the cases of 25, 30, 35 mg/m3, respectively .In other words The maximum power and efficiency of PV was decreased by 3% per 5mg/m3 of red dust .

In the case of sand dust with density 25, 30, 35. The short circuit current (Isc) was decreased to 0.59 ,0.58,and 0.55, respectively . But the Voc increased to 20.5 V and 20.5V for sand density 30, 35 mg/m3, respectively. Which mean that Isc decreased by 3.27%, 4.91%, 9.83% for the cases of 25, 30, 35 mg/m3. And for 30 and 35 mg/m3, Voc increased by 2.5%, 4% sequentially. In general, Voc was increased by 0.5% / (5mg/m3) but Isc was decreased by 1.02% / (5mg/m3). Further, that the maximum power when the PV clean was 9.263W .But when we spread sand dust on PV with density 25,30and 35 mg/m3, the maximum power was decreased to 8.635, 8.528 and 8.225 W that means maximum power was decreased by 6.77%, 7.93% and 11.2% Sequentially .beside this, for 5mg/m3 of sand dust, the maximum power of PV module decreased by 1.5 %.Also the efficiency of PV at different dust was decreased by the same percentage as maximum power decreased.

In the case of white dust, the short circuit current (Isc) was decreased to 0.53, 0.51and 0.43A for dust density 20,30and 40 mg/m3 respectively. Conversely the open circuit voltage (Voc) was increased to 20.7, 20.8 and 20.9 for 20,30and 40 mg/m3 dust density. For 20,30and 40 mg/m3 of dust density ,it can conclude that the short circuit current (Isc) was decreased by 13.11%, 16.39%and 29.5% , respectively .but open circuit voltage (Voc) was increased by 3.5%,4%and 4.5% respectively. However, it was found that Voc increased by 0.54% per 5mg/m3 and Isc decreased by 3.4% per 5mg/m3 of white soil dust. Further, the maximum power for the case of PV without any dust was 9.263W, and it is decreased to 7.701, 7.425, and 6.498 W for the cases of 20, 30, and 40 mg/m^3 of dust density, respectively. It can be concluded that the maximum power and the efficiency of the PV is decreased by 16.86%, 19.84%, and 29.84% for the cases of 20, 30, 40 mg/m3, respectively. However, it was found that the maximum power and PV efficiency was decreased by 3.6% per 5mg/m3 of white dust (3.6 %/(5mg/m3)).

Finaly, the effect of wind speed in the PV performance was also investigated. It was found that the maximum power of PV was 6.656 W, at 1m/s of wind speed. In case of increasing wind speed to 2, 3, 4 and 5 m/s , the maximum power was increasing to 6.902 ,7.182, 7.535 and 8.064 W, respectively .In other words, the maximum power and efficiency was increased by3.6%,7.9%,13.2%and 21.1% for case of 2,3,4 and 5 m/s sequentially. Also it can be conclude that the maximum power and efficiency of PV was decreased by 5% per 1 m/s increasing of wind speed. Further, the short circuit current (Isc) was decreased to 0.6, 0.59, 0.59 and 0.56A. On the other hand, open circuit voltage (Voc) was increased to 17.3, 17.8, 18.5 and 20.2 V respectively. From this data we can conclude that, Isc slightly decreased by 1.48 % / (1m/s) while Voc was increased by 2.02 % / (1m/s). The I-V and P-V curves at different wind speed is shown in figure 6.21 and 6.22.

7.2 Recommendation

The result of this study indicates that the dust, temperature and wind velocity have a significant effects on the PV performance. However, we recommend the following:

- Concentrate the study of environmental effects, especially the effect of dust by making more experiments with high levels of dust density.
- Design a cooling system for the PV module to avoid raising of PV temperature.
- Design cleaning system for the PV module to prevent dust deposition on PV surface which is keeping the PV module with maximum efficiency.
- Select the Appropriate place for putting on the PV module, and avoiding the Place that may reduce the efficiency of PV.
- Making an economical study that shows how much they will loss when the changing of temperature and dust accumulation affect on the production of PV module.

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Appendix A

A.1 Code of connection temperature sensors with Arduino.

```
Float tempC, tempC0, tempC1, tempC2;
int reading0,reading1,reading2;
int tempPin0 = 0;
int tempPin1=1;
int tempPin2=2;

Void setup ()
{
analogReference(INTERNAL);
 Serial.Begin (9600);
}
Void loop ()
{
  reading0 = analogRead (tempPin0);
  reading1 = analogRead (tempPin1);
reading2 = analogRead (tempPin2);
  tempC0 = reading0 / 9.31;
tempC1 = reading1 / 9.31;
tempC2 = reading2 / 9.31;
tempC = (tempC0+tempC1+tempC2)/3 ;
  Serial.Print ("Temperature= ");
  Serial.Print (tempC);
  Serial.Print ("*C");
  Serial.println ();
  Delay (1000);
```

A.2 Code of connection dust sensors with Arduino

```
int measurePin = 6;
int ledPower = 12;

int samplingTime = 400;
int deltaTime = 40;
int sleepTime = 9680;

float voMeasured = 0;
float calcVoltage = 0;
float dustDensity = 0;
Void setup ()
{
  Serial.begin(9600);
  pinMode(ledPower,OUTPUT);
}
Void loop ()
{
  digitalWrite(ledPower,LOW); // power on the LED
  delayMicroseconds(samplingTime);
  voMeasured = analogRead(measurePin); // read the dust value

  delayMicroseconds(deltaTime);
  digitalWrite(ledPower,HIGH); // turn the LED off
  delayMicroseconds(sleepTime);

  // 0 - 3.3V mapped to 0 - 1023 integer values
  // recover voltage
```

```
  calcVoltage = voMeasured * (5.0 / 1024.0);
  // linear eqaution taken from http://www.howmuchsnow.com/arduino/airquality/
  // Chris Nafis (c) 2012
  dustDensity = 0.17 * calcVoltage - 0.1;
  Serial.print("Raw Signal Value (0-1023): ");
  Serial.print(voMeasured);
  Serial.print(" - Voltage: ");
  Serial.print(calcVoltage);
  Serial.print(" - Dust Density: ");
  Serial.println(dustDensity);
  Delay (1000);
}
```

Appendix B

Data of effects temperature on PV module

Temperature 20 °C			Temperature 25 °C			Temperature 30 °C		
V	I	P	V	I	P	V	I	P
0	0.56	0	0	0.6	0	0	0.61	0
0.2	0.56	0.112	0.3	0.6	0.18	0.2	0.61	0.122
3	0.56	1.68	2.9	0.6	1.74	0.3	0.61	0.183
5.3	0.55	2.915	4.8	0.6	2.88	0.4	0.61	0.244
10.3	0.55	5.665	6.4	0.6	3.84	2.9	0.61	1.769
11.4	0.55	6.27	7.4	0.6	4.44	4	0.61	2.44
12.6	0.54	6.804	7.7	0.6	4.62	5	0.61	3.05
12.9	0.54	6.966	7.9	0.6	4.74	6.4	0.61	3.904
13	0.54	7.02	9.2	0.6	5.52	7.6	0.61	4.636
13.1	0.54	7.074	11.1	0.59	6.549	8.1	0.61	4.941
14.1	0.53	7.473	12	0.59	7.08	9.6	0.61	5.856
15.2	0.53	8.056	12.7	0.58	7.366	11.8	0.6	7.08
16.3	0.52	8.476	13.6	0.58	7.888	12.8	0.6	7.68
17.3	0.51	8.823	14.8	0.57	8.436	15.7	0.59	9.263
17.9	0.49	8.771	15.7	0.57	8.949	16.2	0.57	9.234
18.4	0.47	8.648	16.7	0.56	9.352	16.4	0.56	9.184
18.6	0.45	8.37	17	0.55	9.35	16.6	0.54	8.964
18.9	0.42	7.938	17.5	0.52	9.1	16.8	0.52	8.736
18.9	0.39	7.371	17.8	0.51	9.078	17	0.51	8.67
19.3	0.34	6.562	17.9	0.5	8.95	17.1	0.49	8.379
19.5	0.31	6.045	18	0.49	8.82	17.2	0.48	8.256
19.6	0.29	5.684	18.2	0.47	8.554	17.3	0.47	8.131
19.7	0.28	5.516	18.3	0.46	8.418	17.4	0.46	8.004
19.8	0.26	5.148	18.4	0.45	8.28	17.5	0.45	7.875
19.9	0.25	4.975	18.5	0.44	8.14	17.6	0.44	7.744
20.1	0.23	4.623	18.6	0.43	7.998	17.7	0.43	7.611
20.4	0.18	3.672	18.7	0.41	7.667	17.9	0.4	7.16
20.4	0.15	3.06	18.8	0.4	7.52	18	0.38	6.84
20.5	0.14	2.87	18.9	0.39	7.371	18.1	0.37	6.697
20.5	0.13	2.665	19	0.38	7.22	18.2	0.35	6.37
20.6	0.12	2.472	19.1	0.37	7.067	18.3	0.34	6.222
20.7	0.11	2.277	19.2	0.36	6.912	18.4	0.33	6.072
20.8	0.09	1.872	19.3	0.35	6.755	18.5	0.32	5.92
20.8	0.08	1.664	19.4	0.33	6.402	18.6	0.29	5.394
20.9	0.05	1.045	19.5	0.31	6.045	18.7	0.28	5.236
21	0.03	0.63	19.6	0.3	5.88	18.8	0.27	5.076
21	0	0	19.7	0.28	5.516	18.9	0.25	4.725
			19.8	0.27	5.346	18.9	0.24	4.536
			19.8	0.26	5.148	18.9	0.23	4.347
			19.9	0.25	4.975	19	0.22	4.18
			20	0.23	4.6	19.1	0.21	4.011

20.1	0.2	4.02	19.2	0.19	3.648
20.1	0.17	3.417	19.3	0.17	3.281
20.1	0.15	3.015	19.4	0.16	3.104
20.2	0.13	2.626	19.4	0.15	2.91
20.3	0.11	2.233	19.5	0.13	2.535
20.3	0.1	2.03	19.5	0.12	2.34
20.4	0.09	1.836	19.6	0.11	2.156
20.5	0.07	1.435	19.6	0.1	1.96
20.6	0.06	1.236	19.7	0.09	1.773
20.6	0.04	0.824	19.7	0.08	1.576
20.7	0.03	0.621	19.7	0.07	1.379
20.7	0	0	19.8	0.06	1.188
			19.8	0.05	0.99
			19.9	0.04	0.796
			19.9	0.03	0.597
			20	0	0

Temperature 35 °C			Temperature 40 °C			Temperature 45 °C		
V	**I**	**P**	**V**	**I**	**P**	**V**	**I**	**P**
0	0.62	0	0	0.64	0	0	0.65	0
0.2	0.62	0.124	0.4	0.64	0.256	0.3	0.65	0.195
0.7	0.62	0.434	3.2	0.64	2.048	0.4	0.65	0.26
2.9	0.62	1.798	3.9	0.64	2.496	3.1	0.64	1.984
3.8	0.62	2.356	5	0.64	3.2	4	0.64	2.56
4.9	0.61	2.989	5.2	0.64	3.328	5.1	0.64	3.264
5.7	0.61	3.477	5.9	0.63	3.717	5.9	0.63	3.717
6.4	0.61	3.904	6.6	0.63	4.158	6.7	0.63	4.221
7.8	0.61	4.758	6.7	0.63	4.221	6.8	0.63	4.284
8.3	0.61	5.063	6.8	0.63	4.284	7.7	0.62	4.774
9.7	0.61	5.917	7.5	0.63	4.725	8.3	0.62	5.146
11.6	0.61	7.076	7.8	0.63	4.914	8.5	0.62	5.27
12.7	0.61	7.747	8.4	0.63	5.292	9.3	0.61	5.673
13.8	0.6	8.28	8.5	0.63	5.355	10	0.61	6.1
14.2	0.59	8.378	9.2	0.63	5.796	11.7	0.6	7.02
14.8	0.58	8.584	9.8	0.62	6.076	12.4	0.6	7.44
15.1	0.56	8.456	9.9	0.62	6.138	12.9	0.59	7.611
15.3	0.55	8.415	10.6	0.62	6.572	13.1	0.58	7.598
15.5	0.53	8.215	11.5	0.61	7.015	13.2	0.57	7.524
15.6	0.52	8.112	12	0.61	7.32	13.5	0.56	7.56
15.8	0.51	8.058	12.3	0.61	7.503	13.7	0.53	7.261
16	0.49	7.84	12.7	0.6	7.62	13.9	0.52	7.228
16.2	0.48	7.776	12.8	0.6	7.68	14	0.5	7
16.2	0.47	7.614	13.3	0.6	7.98	14.1	0.5	7.05
16.3	0.46	7.498	13.8	0.59	8.142	14.2	0.49	6.958
16.5	0.45	7.425	13.9	0.58	8.062	14.3	0.47	6.721
16.5	0.44	7.26	14.4	0.57	8.208	14.4	0.46	6.624
16.6	0.43	7.138	14.5	0.56	8.12	14.5	0.45	6.525
16.7	0.41	6.847	14.7	0.54	7.938	14.6	0.44	6.424
16.8	0.4	6.72	15	0.52	7.8	14.7	0.43	6.321
16.9	0.39	6.591	15.1	0.51	7.701	14.8	0.41	6.068
17	0.38	6.46	15.2	0.5	7.6	14.9	0.4	5.96
17.1	0.37	6.327	15.4	0.48	7.392	15	0.38	5.7
17.2	0.36	6.192	15.5	0.47	7.285	15.1	0.37	5.587
17.3	0.33	5.709	15.6	0.45	7.02	15.2	0.36	5.472
17.4	0.32	5.568	15.7	0.44	6.908	15.3	0.34	5.202
17.5	0.31	5.425	15.8	0.43	6.794	15.4	0.33	5.082
17.6	0.29	5.104	15.9	0.42	6.678	15.5	0.31	4.805
17.7	0.28	4.956	16	0.41	6.56	15.6	0.3	4.68
17.8	0.27	4.806	16.1	0.4	6.44	15.7	0.29	4.553
17.9	0.25	4.475	16.2	0.38	6.156	15.8	0.28	4.424
18	0.24	4.32	16.3	0.37	6.031	15.9	0.26	4.134
18.1	0.22	3.982	16.4	0.36	5.904	16	0.24	3.84

18.2	0.21	3.822	16.5	0.35	5.775	16.1	0.22	3.542
18.2	0.2	3.64	16.6	0.33	5.478	16.2	0.2	3.24
18.3	0.19	3.477	16.7	0.32	5.344	16.3	0.19	3.097
18.3	0.18	3.294	16.8	0.31	5.208	16.4	0.17	2.788
18.4	0.11	2.024	16.8	0.3	5.04	16.6	0.16	2.656
18.4	0.1	1.84	16.8	0.29	4.872	16.7	0.13	2.171
18.5	0.09	1.665	16.9	0.28	4.732	16.8	0.12	2.016
18.6	0.08	1.488	17	0.27	4.59	16.9	0.09	1.521
18.6	0.07	1.302	17.1	0.26	4.446	17	0.08	1.36
18.6	0.06	1.116	17.2	0.24	4.128	17.1	0.07	1.197
18.7	0.05	0.935	17.2	0.23	3.956	17.2	0.05	0.86
18.7	0.04	0.748	17.3	0.22	3.806	17.2	0.04	0.688
18.7	0.03	0.561	17.4	0.21	3.654	17.3	0.03	0.519
18.8	0.02	0.376	17.4	0.2	3.48	17.3	0.02	0.346
18.9	0	0	17.5	0.19	3.325	17.4	0	0
			17.5	0.18	3.15			
			17.5	0.17	2.975			
			17.6	0.09	1.584			
			17.7	0.07	1.239			
			17.8	0.05	0.89			
			17.8	0.04	0.712			
			17.9	0.03	0.537			
			18	0.02	0.36			
			18	0	0			

Temperature 50 °C			Temperature 55 °C		
V	**I**	**P**	**V**	**I**	**P**
0	0.66	0	0	0.67	0
2.7	0.66	1.782	2.8	0.67	1.876
2.8	0.66	1.848	2.9	0.67	1.943
2.9	0.66	1.914	3.1	0.67	2.077
3	0.66	1.98	3.2	0.67	2.144
4.4	0.66	2.904	3.4	0.67	2.278
8.3	0.65	5.395	4.7	0.66	3.102
10	0.64	6.4	8.8	0.65	5.72
11.2	0.62	6.944	11.3	0.6	6.78
11.4	0.61	6.954	11.7	0.58	6.786
11.7	0.6	7.02	12.1	0.55	6.655
12.4	0.55	6.82	12.5	0.51	6.375
12.9	0.51	6.579	12.8	0.48	6.144
13.3	0.48	6.384	13	0.46	5.98
13.4	0.47	6.298	13.5	0.42	5.67
13.6	0.44	5.984	13.6	0.4	5.44
14.3	0.36	5.148	13.9	0.36	5.004
14.5	0.32	4.64	14.2	0.33	4.686
14.7	0.3	4.41	14.3	0.31	4.433
15	0.26	3.9	14.6	0.28	4.088
15.1	0.24	3.624	14.8	0.24	3.552
15.2	0.22	3.344	14.9	0.21	3.129
15.4	0.19	2.926	15.1	0.19	2.869
15.4	0.18	2.772	15.2	0.17	2.584
15.5	0.17	2.635	15.3	0.15	2.295
15.6	0.16	2.496	15.4	0.14	2.156
15.7	0.15	2.355	15.5	0.12	1.86
15.7	0.14	2.198	15.6	0.11	1.716
15.8	0.13	2.054	15.7	0.09	1.413
15.8	0.12	1.896	15.8	0.07	1.106
15.9	0.11	1.749	15.8	0.06	0.948
16	0.1	1.6	15.8	0.05	0.79
16.1	0.08	1.288	15.9	0.04	0.636
16.1	0.07	1.127	16	0.03	0.48
16.2	0.05	0.81	16.1	0.02	0.322
16.3	0.04	0.652	16.1	0.01	0.161
16.3	0.03	0.489	16.1	0	0
16.3	0.02	0.326			
16.4	0	0			

width (m)	0.342
length (m)	0.291
G(w/m2)	1000

T (° C)	20	25	30	35	40	45	50	55
Voc(V)	21	20.7	20	18.9	18	17.4	16.4	16.1
Isc (A)	0.56	0.6	0.61	0.62	0.64	0.65	0.66	0.67
Pmax (W)	8.823	9.352	9.263	8.584	8.208	7.611	7.02	6.786
FF	0.750255	0.752979	0.7592623	0.732548	0.7125	0.672944	0.648559	0.629091
η	0.08865	0.0939	0.09307	0.08625	0.08247	0.0764	0.0705	0.0681

Appendix C

Data of effects red dust on PV module

Temperature 30°C / Dust density 25 mg/m3			Temperature 30°C / Dust density 30 mg/m3		
V	**I**	**P**	**V**	**I**	**P**
0	0.56	0	0	0.54	0
4.9	0.56	2.744	4.5	0.54	2.43
5	0.56	2.8	5.8	0.54	3.132
6.2	0.55	3.41	7.5	0.53	3.975
6.6	0.55	3.63	9.5	0.52	4.94
8.8	0.55	4.84	11.7	0.51	5.967
12.1	0.54	6.534	14.4	0.49	7.056
12.6	0.53	6.678	15.4	0.48	7.392
13.9	0.52	7.228	16.8	0.45	7.56
15.7	0.5	7.85	16.9	0.44	7.436
16.4	0.49	8.036	17.4	0.4	6.96
16.5	0.48	7.92	17.8	0.37	6.586
16.8	0.47	7.896	18.1	0.35	6.335
17.1	0.44	7.524	18.2	0.33	6.006
17.4	0.4	6.96	18.3	0.31	5.673
17.6	0.39	6.864	18.5	0.3	5.55
17.7	0.37	6.549	18.6	0.28	5.208
17.9	0.35	6.265	18.8	0.27	5.076
18	0.32	5.76	18.9	0.26	4.914
18.1	0.31	5.611	19	0.23	4.37
18.3	0.28	5.124	19.1	0.22	4.202
18.5	0.27	4.995	19.2	0.2	3.84
18.6	0.24	4.464	19.3	0.19	3.667
18.7	0.23	4.301	19.4	0.17	3.298
18.8	0.22	4.136	19.5	0.16	3.12
18.9	0.2	3.78	19.6	0.15	2.94
18.9	0.19	3.591	19.6	0.14	2.744
19.1	0.17	3.247	19.7	0.13	2.561
19.2	0.16	3.072	19.7	0.11	2.167
19.3	0.14	2.702	19.8	0.1	1.98
19.4	0.12	2.328	19.9	0.08	1.592
19.5	0.11	2.145	20	0.06	1.2
19.6	0.09	1.764	20.1	0.05	1.005
19.7	0.07	1.379	20.1	0.04	0.804
19.7	0.06	1.182	20.1	0.03	0.603
19.8	0.05	0.99	20.1	0.01	0.201
19.8	0.04	0.792	20.1	0	0
19.8	0.03	0.594			
20	0	0			

Temperature 30°C / Dust density 35 mg/m3		
V	**I**	**P**
0	0.48	0
4	0.48	1.92
5	0.48	2.4
5.5	0.48	2.64
7.3	0.47	3.431
10.3	0.46	4.738
11.4	0.46	5.244
12.8	0.45	5.76
14.7	0.45	6.615
16.2	0.44	7.128
16.5	0.44	7.26
17.1	0.42	7.182
17.5	0.4	7
18	0.37	6.66
18.1	0.35	6.335
18.3	0.33	6.039
18.4	0.32	5.888
18.6	0.31	5.766
18.8	0.28	5.264
18.8	0.27	5.076
18.9	0.26	4.914
19.1	0.24	4.584
19.2	0.23	4.416
19.2	0.22	4.224
19.3	0.2	3.86
19.4	0.19	3.686
19.5	0.18	3.51
19.6	0.16	3.136
19.7	0.14	2.758
19.8	0.14	2.772
19.9	0.12	2.388
20	0.1	2
20.1	0.09	1.809
20.1	0.08	1.608
20.2	0.06	1.212
20.2	0.05	1.01
20.3	0.03	0.609
20.3	0	0

width (m)	0.342
length (m)	0.291
G (w/m2)	1000

Temperature	30 °C			
Dust type	Red soil			
Dust density (mg/m3)	0	25	30	35
Voc(V)	20	20	20.1	20.3
Isc (A)	0.61	0.56	0.54	0.48
Pmax (W)	9.263	8.036	7.56	7.26
FF	0.759262295	0.7175	0.696517413	0.745073892
η	0.093074898	0.080745966	0.075963104	0.072948695

Appendix D

Data of effects white dust on PV module

Temperature 30°C /Dust density 20 mg/m3			Temperature 30 °C / Dust density 30 mg/m3		
V	I	P	V	I	P
0	0.53	0	0	0.51	0
4.7	0.53	2.491	4.4	0.51	2.244
6.4	0.53	3.392	4.5	0.51	2.295
9.2	0.52	4.784	4.6	0.51	2.346
12	0.52	6.24	7	0.51	3.57
15.1	0.51	7.701	12.6	0.49	6.174
17.5	0.37	6.475	15.3	0.48	7.344
18.4	0.32	5.888	16.5	0.45	7.425
18.7	0.31	5.797	17.8	0.38	6.764
18.9	0.27	5.103	18.5	0.34	6.29
19.2	0.24	4.608	18.9	0.3	5.67
19.4	0.22	4.268	19.2	0.26	4.992
19.5	0.2	3.9	19.5	0.22	4.29
19.6	0.19	3.724	19.7	0.2	3.94
19.7	0.18	3.546	19.8	0.18	3.564
19.8	0.16	3.168	19.9	0.17	3.383
19.9	0.14	2.786	20	0.15	3
20	0.13	2.6	20.1	0.14	2.814
20.1	0.12	2.412	20.2	0.13	2.626
20.2	0.1	2.02	20.3	0.12	2.436
20.3	0.08	1.624	20.4	0.11	2.244
20.4	0.07	1.428	20.4	0.09	1.836
20.5	0.06	1.23	20.5	0.08	1.64
20.5	0.05	1.025	20.6	0.07	1.442
20.6	0.04	0.824	20.7	0.05	1.035
20.6	0.03	0.618	20.8	0.04	0.832
20.7	0.02	0.414	20.8	0.03	0.624
20.7	0	0	20.9	0	0

Temperature 30°C / Dust density 40 mg/m3		
V	**I**	**P**
0	0.43	0
3.6	0.43	1.548
6.2	0.42	2.604
9.1	0.42	3.822
11.9	0.42	4.998
14.5	0.4	5.8
17.1	0.38	6.498
17.6	0.36	6.336
18	0.35	6.3
18.3	0.33	6.039
18.6	0.3	5.58
18.8	0.29	5.452
19.2	0.25	4.8
19.4	0.21	4.074
19.6	0.18	3.528
19.7	0.17	3.349
19.8	0.16	3.168
19.9	0.14	2.786
20	0.13	2.6
20.1	0.11	2.211
20.2	0.1	2.02
20.3	0.08	1.624
20.4	0.06	1.224
20.5	0.05	1.025
20.6	0.03	0.618
20.7	0.02	0.414
20.7	0.01	0.207
20.7	0	0

width (m)	0.342
length (m)	0.291
G w/m2)	1000

Temperature	30°C			
Dust type	white soil			
Dust density (mg/m3)	0	20	30	40
Voc (V)	20	20.7	20.8	20.9
Isc (A)	0.61	0.53	0.51	0.43
Pmax (W)	9.263	7.701	7.425	6.498
FF	0.759262295	0.701941482	0.699943439	0.723044397
η	0.093074898	0.077379876	0.07460662	0.065292096

Appendix E

Data of effects sand dust on PV module

Temperature 30°C / Dust density 25 mg/m3			Temperature 30 °C /Dust density30 mg/m3		
V	I	P	V	I	P
0	0.59	0	0	0.58	0
5.2	0.59	3.068	4.9	0.58	2.842
5.3	0.59	3.127	5	0.58	2.9
5.4	0.59	3.186	9.2	0.57	5.244
10.9	0.59	6.431	12.3	0.56	6.888
12.5	0.58	7.25	14.1	0.55	7.755
13.7	0.57	7.809	16.4	0.52	8.528
15.7	0.55	8.635	17.2	0.47	8.084
15.9	0.54	8.586	17.6	0.43	7.568
16.9	0.49	8.281	18.3	0.38	6.954
17.6	0.43	7.568	18.5	0.37	6.845
17.9	0.38	6.802	18.8	0.33	6.204
18.1	0.35	6.335	19	0.31	5.89
18.4	0.32	5.888	19.2	0.28	5.376
18.5	0.3	5.55	19.3	0.27	5.211
18.8	0.26	4.888	19.4	0.24	4.656
18.9	0.23	4.347	19.5	0.23	4.485
19	0.21	3.99	19.6	0.22	4.312
19.1	0.2	3.82	19.7	0.21	4.137
19.2	0.19	3.648	19.8	0.2	3.96
19.2	0.17	3.264	19.9	0.18	3.582
19.3	0.16	3.088	19.9	0.16	3.184
19.4	0.15	2.91	20	0.15	3
19.4	0.14	2.716	20.1	0.14	2.814
19.5	0.13	2.535	20.2	0.12	2.424
19.5	0.12	2.34	20.2	0.11	2.222
19.5	0.11	2.145	20.2	0.1	2.02
19.6	0.1	1.96	20.3	0.09	1.827
19.7	0.08	1.576	20.4	0.08	1.632
19.8	0.07	1.386	20.4	0.07	1.428
19.8	0.06	1.188	20.4	0.06	1.224
19.9	0.04	0.796	20.5	0.05	1.025
19.9	0.03	0.597	20.5	0.04	0.82
20	0.02	0.4	20.5	0.03	0.615
20	0	0	20.5	0	0

Temperature 30°C /Dust density 35 mg/m3		
V	**I**	**P**
0	0.55	0
5	0.55	2.75
5.8	0.55	3.19
6	0.55	3.3
7.2	0.55	3.96
7.5	0.55	4.125
8.6	0.54	4.644
12.3	0.53	6.519
15.8	0.52	8.216
17.5	0.47	8.225
18.5	0.39	7.215
19	0.34	6.46
19.2	0.33	6.336
19.3	0.3	5.79
19.4	0.29	5.626
19.5	0.28	5.46
19.6	0.26	5.096
19.7	0.25	4.925
19.8	0.22	4.356
20	0.2	4
20	0.19	3.8
20.1	0.17	3.417
20.2	0.16	3.232
20.3	0.14	2.842
20.4	0.13	2.652
20.5	0.12	2.46
20.6	0.09	1.854
20.6	0.08	1.648
20.7	0.06	1.242
20.8	0.03	0.624
20.8	0	0
width(m)	0.342	
length (m)	0.291	
G (w/m2)	1000	

Temperature	30°C			
Dust type	sand			
st density (mg/m3)	0	25	30	35
Voc (V)	20	20	20.5	20.8
Isc (A)	0.61	0.59	0.58	0.55
Pmax (W)	9.263	8.635	8.528	8.225
FF	0.759262295	0.731779661	0.717241379	0.718968531
η	0.09307	0.08676	0.085689	0.082645

Appendix F

Data of effects wind speed on PV module

Wind speed 1 m/s			Wind speed 2 m/s			Wind speed 3 m/s		
V	**I**	**P**	**V**	**I**	**P**	**V**	**I**	**P**
0	0.6	0	0	0.6	0	0	0.59	0
6.2	0.6	3.72	6.1	0.6	3.66	7.9	0.59	4.661
6.9	0.6	4.14	7	0.6	4.2	10	0.57	5.7
7.9	0.59	4.661	8.1	0.6	4.86	13.3	0.54	7.182
10	0.56	5.6	8.4	0.6	5.04	14.3	0.46	6.578
12.8	0.52	6.656	11.1	0.59	6.549	14.6	0.42	6.132
13.7	0.45	6.165	11.9	0.58	6.902	14.8	0.4	5.92
14.1	0.42	5.922	13.2	0.52	6.864	15.3	0.36	5.508
14.2	0.39	5.538	14.4	0.42	6.048	15.7	0.3	4.71
14.5	0.37	5.365	14.6	0.39	5.694	15.9	0.29	4.611
14.7	0.35	5.145	14.8	0.37	5.476	16	0.27	4.32
14.9	0.33	4.917	15	0.36	5.4	16.2	0.26	4.212
15	0.3	4.5	15.2	0.34	5.168	16.4	0.23	3.772
15.1	0.29	4.379	15.4	0.31	4.774	16.5	0.21	3.465
15.2	0.28	4.256	15.5	0.29	4.495	16.6	0.2	3.32
15.3	0.27	4.131	15.7	0.27	4.239	16.6	0.19	3.154
15.4	0.26	4.004	15.8	0.24	3.792	16.7	0.18	3.006
15.5	0.24	3.72	15.9	0.22	3.498	16.8	0.16	2.688
15.7	0.22	3.454	16	0.21	3.36	16.9	0.14	2.366
15.8	0.19	3.002	16.1	0.19	3.059	17	0.13	2.21
15.9	0.18	2.862	16.2	0.18	2.916	17.1	0.12	2.052
16	0.17	2.72	16.3	0.17	2.771	17.2	0.11	1.892
16.1	0.15	2.415	16.4	0.15	2.46	17.3	0.09	1.557
16.2	0.14	2.268	16.5	0.14	2.31	17.4	0.08	1.392
16.3	0.13	2.119	16.6	0.12	1.992	17.5	0.06	1.05
16.4	0.11	1.804	16.7	0.11	1.837	17.6	0.04	0.704
16.5	0.09	1.485	16.8	0.09	1.512	17.7	0.03	0.531
16.6	0.08	1.328	16.9	0.07	1.183	17.8	0.02	0.356
16.7	0.06	1.002	17	0.06	1.02	17.8	0.01	0.178
16.8	0.04	0.672	17.1	0.04	0.684	17.8	0	0
16.9	0.03	0.507	17.2	0.02	0.344			
17	0.02	0.34	17.3	0	0			
17	0	0						

Wind speed 4 m/s			Wind speed 5 m/s		
V	I	P	V	I	P
0	0.59	0	0	0.56	0
6.1	0.59	3.599	6.2	0.56	3.472
6.4	0.59	3.776	7	0.56	3.92
7.9	0.59	4.661	8.1	0.55	4.455
8.1	0.59	4.779	10.7	0.54	5.778
11.3	0.57	6.441	11.3	0.54	6.102
13.7	0.55	7.535	13.4	0.53	7.102
14.4	0.51	7.344	15	0.51	7.65
14.9	0.48	7.152	16.1	0.5	8.05
15.3	0.45	6.885	16.8	0.48	8.064
15.6	0.42	6.552	17	0.47	7.99
15.8	0.39	6.162	17.3	0.45	7.785
16	0.37	5.92	17.5	0.42	7.35
16.3	0.33	5.379	17.7	0.4	7.08
16.4	0.31	5.084	17.9	0.38	6.802
16.5	0.3	4.95	18.1	0.35	6.335
16.7	0.28	4.676	18.2	0.33	6.006
16.8	0.27	4.536	18.3	0.31	5.673
16.9	0.25	4.225	18.4	0.3	5.52
17	0.23	3.91	18.6	0.28	5.208
17.1	0.22	3.762	18.7	0.26	4.862
17.2	0.21	3.612	18.8	0.25	4.7
17.3	0.19	3.287	19	0.22	4.18
17.4	0.18	3.132	19.1	0.21	4.011
17.5	0.16	2.8	19.2	0.19	3.648
17.6	0.15	2.64	19.3	0.18	3.474
17.7	0.13	2.301	19.4	0.16	3.104
17.8	0.11	1.958	19.5	0.14	2.73
17.9	0.1	1.79	19.6	0.12	2.352
18	0.08	1.44	19.7	0.1	1.97
18.1	0.06	1.086	19.8	0.09	1.782
18.2	0.04	0.728	19.9	0.06	1.194
18.3	0.02	0.366	20	0.04	0.8
18.4	0.01	0.184	20.1	0.03	0.603
18.5	0	0	20.2	0	0

width (m)	0.342
length (m)	0.291
G(w/m2)	1000

Temperature	40					
Wind speed (m/s)	0	1	2	3	4	5
Voc(V)	18	17	17.3	17.8	18.5	20.2
Isc (A)	0.64	0.6	0.6	0.59	0.59	0.56
Pmax (W)	8.208	6.656	6.902	7.182	7.535	8.064
FF	0.7125	0.652549	0.664933	0.68387	0.690334	0.712871
η	0.08247	0.06688	0.06935	0.072165	0.07571	0.08102

Appendix G

Data of relationship between dust and irradiation

red soil dust		sand soil dust	
irradiation (W/m2)	Dust density (mg/m3)	irradiation (W/m2)	Dust density (mg/m3)
1000	0	1000	0
916	25	965	25
885	30	950	30
785	35	920	35

calcium carbonate dust	
irradiation (W/m2)	Dust density (mg/m3)
1000	0
870	20
830	30
710	40

Appendix H

Result of dust sensor at (25 mg/m^{3}) for red dust.

Raw Signal Value (0-1023): 257.00 - Voltage: 1.25 - Dust Density: 0.11

Raw Signal Value (0-1023): 237.00 - Voltage: 1.16 - Dust Density: 0.10

Raw Signal Value (0-1023): 256.00 - Voltage: 1.25 - Dust Density: 0.11

Raw Signal Value (0-1023): 442.00 - Voltage: 2.16 - Dust Density: 0.27

Raw Signal Value (0-1023): 260.00 - Voltage: 1.27 - Dust Density: 0.12

Raw Signal Value (0-1023): 763.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 671.00 - Voltage: 3.28 - Dust Density: 0.46

Raw Signal Value (0-1023): 432.00 - Voltage: 2.11 - Dust Density: 0.26

Raw Signal Value (0-1023): 764.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 329.00 - Voltage: 1.61 - Dust Density: 0.17

Raw Signal Value (0-1023): 697.00 - Voltage: 3.40 - Dust Density: 0.48

Raw Signal Value (0-1023): 420.00 - Voltage: 2.05 - Dust Density: 0.25

Raw Signal Value (0-1023): 447.00 - Voltage: 2.18 - Dust Density: 0.27

Raw Signal Value (0-1023): 764.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 487.00 - Voltage: 2.38 - Dust Density: 0.30

Raw Signal Value (0-1023): 347.00 - Voltage: 1.69 - Dust Density: 0.19

Raw Signal Value (0-1023): 451.00 - Voltage: 2.20 - Dust Density: 0.27

Raw Signal Value (0-1023): 340.00 - Voltage: 1.66 - Dust Density: 0.18

Raw Signal Value (0-1023): 384.00 - Voltage: 1.88 - Dust Density: 0.22

Raw Signal Value (0-1023): 291.00 - Voltage: 1.42 - Dust Density: 0.14

Raw Signal Value (0-1023): 763.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 268.00 - Voltage: 1.31 - Dust Density: 0.12

Result of dust sensor at (30 mg/m^{3}) for red dust.

Raw Signal Value (0-1023): 258.00 - Voltage: 1.26 - Dust Density: 0.11

Raw Signal Value (0-1023): 248.00 - Voltage: 1.21 - Dust Density: 0.11

Raw Signal Value (0-1023): 253.00 - Voltage: 1.24 - Dust Density: 0.11

Raw Signal Value (0-1023): 383.00 - Voltage: 1.87 - Dust Density: 0.22

Raw Signal Value (0-1023): 357.00 - Voltage: 1.74 - Dust Density: 0.20

Raw Signal Value (0-1023): 295.00 - Voltage: 1.44 - Dust Density: 0.14

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 276.00 - Voltage: 1.35 - Dust Density: 0.13

Raw Signal Value (0-1023): 395.00 - Voltage: 1.93 - Dust Density: 0.23

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 279.00 - Voltage: 1.36 - Dust Density: 0.13

Raw Signal Value (0-1023): 679.00 - Voltage: 3.32 - Dust Density: 0.46

Raw Signal Value (0-1023): 766.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 396.00 - Voltage: 1.93 - Dust Density: 0.23

Raw Signal Value (0-1023): 412.00 - Voltage: 2.01 - Dust Density: 0.24

Raw Signal Value (0-1023): 294.00 - Voltage: 1.44 - Dust Density: 0.14

Raw Signal Value (0-1023): 444.00 - Voltage: 2.17 - Dust Density: 0.27

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 764.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 400.00 - Voltage: 1.95 - Dust Density: 0.23

Raw Signal Value (0-1023): 380.00 - Voltage: 1.86 - Dust Density: 0.22

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 584.00 - Voltage: 2.85 - Dust Density: 0.38

Raw Signal Value (0-1023): 764.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 564.00 - Voltage: 2.75 - Dust Density: 0.37

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 629.00 - Voltage: 3.07 - Dust Density: 0.42

Raw Signal Value (0-1023): 443.00 - Voltage: 2.16 - Dust Density: 0.27

Raw Signal Value (0-1023): 327.00 - Voltage: 1.60 - Dust Density: 0.17

Raw Signal Value (0-1023): 482.00 - Voltage: 2.35 - Dust Density: 0.30

Raw Signal Value (0-1023): 765.00 - Voltage: 3.74 - Dust Density: 0.54

Raw Signal Value (0-1023): 634.00 - Voltage: 3.10 - Dust Density: 0.43

Raw Signal Value (0-1023): 629.00 - Voltage: 3.07 - Dust Density: 0.42

Result of dust sensor at (35 mg/m^{3}) for red dust.

Raw Signal Value (0-1023): 242.00 - Voltage: 1.18 - Dust Density: 0.10

Raw Signal Value (0-1023): 237.00 - Voltage: 1.16 - Dust Density: 0.10

Raw Signal Value (0-1023): 760.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 745.00 - Voltage: 3.64 - Dust Density: 0.52

Raw Signal Value (0-1023): 438.00 - Voltage: 2.14 - Dust Density: 0.26

Raw Signal Value (0-1023): 697.00 - Voltage: 3.40 - Dust Density: 0.48

Raw Signal Value (0-1023): 573.00 - Voltage: 2.80 - Dust Density: 0.38

Raw Signal Value (0-1023): 760.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 253.00 - Voltage: 1.24 - Dust Density: 0.11

Raw Signal Value (0-1023): 544.00 - Voltage: 2.66 - Dust Density: 0.35

Raw Signal Value (0-1023): 759.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 411.00 - Voltage: 2.01 - Dust Density: 0.24

Raw Signal Value (0-1023): 760.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 286.00 - Voltage: 1.40 - Dust Density: 0.14

Raw Signal Value (0-1023): 275.00 - Voltage: 1.34 - Dust Density: 0.13

Raw Signal Value (0-1023): 327.00 - Voltage: 1.60 - Dust Density: 0.17

Raw Signal Value (0-1023): 508.00 - Voltage: 2.48 - Dust Density: 0.32

Raw Signal Value (0-1023): 760.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 761.00 - Voltage: 3.72 - Dust Density: 0.53

Raw Signal Value (0-1023): 440.00 - Voltage: 2.15 - Dust Density: 0.27

Raw Signal Value (0-1023): 759.00 - Voltage: 3.71 - Dust Density: 0.53

Raw Signal Value (0-1023): 759.00 - Voltage: 3.71 - Dust Density: 0.53

Result of dust sensor at (20 mg/m^{3}) for white dust.

Raw Signal Value (0-1023): 275.00 - Voltage: 1.34 - Dust Density: 0.13

Raw Signal Value (0-1023): 283.00 - Voltage: 1.38 - Dust Density: 0.13

Raw Signal Value (0-1023): 282.00 - Voltage: 1.38 - Dust Density: 0.13

Raw Signal Value (0-1023): 284.00 - Voltage: 1.39 - Dust Density: 0.14

Raw Signal Value (0-1023): 550.00 - Voltage: 2.05 - Dust Density: 0.29

Raw Signal Value (0-1023): 770.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 416.00 - Voltage: 1.55 - Dust Density: 0.22

Raw Signal Value (0-1023): 341.00 - Voltage: 1.30 - Dust Density: 0.18

Result of dust sensor at (30 mg/m^{3}) for white dust.

Raw Signal Value (0-1023): 263.00 - Voltage: 1.28 - Dust Density: 0.12

Raw Signal Value (0-1023): 278.00 - Voltage: 1.36 - Dust Density: 0.13

Raw Signal Value (0-1023): 271.00 - Voltage: 1.32 - Dust Density: 0.12

Raw Signal Value (0-1023): 262.00 - Voltage: 1.28 - Dust Density: 0.12

Raw Signal Value (0-1023): 331.00 - Voltage: 1.62 - Dust Density: 0.17

Raw Signal Value (0-1023): 261.00 - Voltage: 1.27 - Dust Density: 0.12

Raw Signal Value (0-1023): 317.00 - Voltage: 1.55 - Dust Density: 0.16

Raw Signal Value (0-1023): 779.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 778.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 530.00 - Voltage: 2.59 - Dust Density: 0.34

Raw Signal Value (0-1023): 778.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 778.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 779.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 778.00 - Voltage: 3.80 - Dust Density: 0.55

Raw Signal Value (0-1023): 322.00 - Voltage: 1.57 - Dust Density: 0.17

Raw Signal Value (0-1023): 286.00 - Voltage: 1.40 - Dust Density: 0.14

Raw Signal Value (0-1023): 778.00 - Voltage: 3.80 - Dust Density: 0.55

Result of dust sensor at (40 mg/m$^{3)}$ for white dust.

Raw Signal Value (0-1023): 282.00 - Voltage: 1.38 - Dust Density: 0.13

Raw Signal Value (0-1023): 256.00 - Voltage: 1.25 - Dust Density: 0.11

Raw Signal Value (0-1023): 269.00 - Voltage: 1.31 - Dust Density: 0.12

Raw Signal Value (0-1023): 264.00 - Voltage: 1.29 - Dust Density: 0.12

Raw Signal Value (0-1023): 353.00 - Voltage: 1.72 - Dust Density: 0.19

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 2.76 - Dust Density: 0.39

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 772.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 1.55 - Dust Density: 0.22

Raw Signal Value (0-1023): 771.00 - Voltage: 2.2 - Dust Density: 0.31

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 772.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Result of dust sensor at (25 mg/m$^{3)}$ for sand dust.

Raw Signal Value (0-1023): 241.00 - Voltage: 1.18 - Dust Density: 0.10

Raw Signal Value (0-1023): 246.00 - Voltage: 1.20 - Dust Density: 0.10

Raw Signal Value (0-1023): 333.00 - Voltage: 1.63 - Dust Density: 0.18

Raw Signal Value (0-1023): 261.00 - Voltage: 1.27 - Dust Density: 0.12

Raw Signal Value (0-1023): 620.00 - Voltage: 3.03 - Dust Density: 0.41

Raw Signal Value (0-1023): 290.00 - Voltage: 1.42 - Dust Density: 0.14

Raw Signal Value (0-1023): 764.00 - Voltage: 3.73 - Dust Density: 0.53

Raw Signal Value (0-1023): 275.00 - Voltage: 1.34 - Dust Density: 0.13

Raw Signal Value (0-1023): 267.00 - Voltage: 1.30 - Dust Density: 0.12

Raw Signal Value (0-1023): 402.00 - Voltage: 1.96 - Dust Density: 0.23

Raw Signal Value (0-1023): 444.00 - Voltage: 2.17 - Dust Density: 0.27

Raw Signal Value (0-1023): 345.00 - Voltage: 1.68 - Dust Density: 0.19

Raw Signal Value (0-1023): 282.00 - Voltage: 1.38 - Dust Density: 0.13

Raw Signal Value (0-1023): 348.00 - Voltage: 1.70 - Dust Density: 0.19

Raw Signal Value (0-1023): 491.00 - Voltage: 2.40 - Dust Density: 0.31

Raw Signal Value (0-1023): 462.00 - Voltage: 2.26 - Dust Density: 0.28

Raw Signal Value (0-1023): 417.00 - Voltage: 2.04 - Dust Density: 0.25

Raw Signal Value (0-1023): 770.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 362.00 - Voltage: 1.77 - Dust Density: 0.20

Raw Signal Value (0-1023): 447.00 - Voltage: 2.18 - Dust Density: 0.27

Raw Signal Value (0-1023): 447.00 - Voltage: 2.18 - Dust Density: 0.27

Result of dust sensor at (30 mg/m$^{3)}$ for sand dust.

Raw Signal Value (0-1023): 336.00 - Voltage: 1.64 - Dust Density: 0.18

Raw Signal Value (0-1023): 267.00 - Voltage: 1.30 - Dust Density: 0.12

Raw Signal Value (0-1023): 261.00 - Voltage: 1.27 - Dust Density: 0.12

Raw Signal Value (0-1023): 542.00 - Voltage: 2.65 - Dust Density: 0.35

Raw Signal Value (0-1023): 280.00 - Voltage: 1.37 - Dust Density: 0.13

Raw Signal Value (0-1023): 477.00 - Voltage: 2.33 - Dust Density: 0.30

Raw Signal Value (0-1023): 432.00 - Voltage: 2.11 - Dust Density: 0.26

Raw Signal Value (0-1023): 770.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 318.00 - Voltage: 1.55 - Dust Density: 0.16

Raw Signal Value (0-1023): 317.00 - Voltage: 1.55 - Dust Density: 0.16

Raw Signal Value (0-1023): 270.00 - Voltage: 1.32 - Dust Density: 0.12

Raw Signal Value (0-1023): 310.00 - Voltage: 1.51 - Dust Density: 0.16

Raw Signal Value (0-1023): 271.00 - Voltage: 1.32 - Dust Density: 0.12

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 352.00 - Voltage: 1.72 - Dust Density: 0.19

Raw Signal Value (0-1023): 531.00 - Voltage: 2.59 - Dust Density: 0.34

Raw Signal Value (0-1023): 545.00 - Voltage: 2.66 - Dust Density: 0.35

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 461.00 - Voltage: 2.25 - Dust Density: 0.28

Raw Signal Value (0-1023): 549.00 - Voltage: 2.68 - Dust Density: 0.36

Raw Signal Value (0-1023): 743.00 - Voltage: 3.63 - Dust Density: 0.52

Raw Signal Value (0-1023): 474.00 - Voltage: 2.31 - Dust Density: 0.29

Raw Signal Value (0-1023): 771.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 363.00 - Voltage: 1.77 - Dust Density: 0.20

Raw Signal Value (0-1023): 438.00 - Voltage: 2.14 - Dust Density: 0.26

Raw Signal Value (0-1023): 627.00 - Voltage: 3.06 - Dust Density: 0.42

Raw Signal Value (0-1023): 770.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 664.00 - Voltage: 3.24 - Dust Density: 0.45

Result of dust sensor at (35 mg/m^{3}) for sand dust.

Raw Signal Value (0-1023): 314.00 - Voltage: 1.53 - Dust Density: 0.16

Raw Signal Value (0-1023): 456.00 - Voltage: 2.22 - Dust Density: 0.28

Raw Signal Value (0-1023): 388.00 - Voltage: 1.89 - Dust Density: 0.22

Raw Signal Value (0-1023): 355.00 - Voltage: 1.73 - Dust Density: 0.19

Raw Signal Value (0-1023): 773.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 393.00 - Voltage: 1.92 - Dust Density: 0.23

Raw Signal Value (0-1023): 352.00 - Voltage: 1.72 - Dust Density: 0.19

Raw Signal Value (0-1023): 587.00 - Voltage: 2.87 - Dust Density: 0.39

Raw Signal Value (0-1023): 380.00 - Voltage: 1.86 - Dust Density: 0.22

Raw Signal Value (0-1023): 573.00 - Voltage: 2.80 - Dust Density: 0.38

Raw Signal Value (0-1023): 297.00 - Voltage: 1.45 - Dust Density: 0.15

Raw Signal Value (0-1023): 772.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 772.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 773.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 455.00 - Voltage: 2.22 - Dust Density: 0.28

Raw Signal Value (0-1023): 403.00 - Voltage: 1.97 - Dust Density: 0.23

Raw Signal Value (0-1023): 353.00 - Voltage: 1.72 - Dust Density: 0.19

Raw Signal Value (0-1023): 309.00 - Voltage: 1.51 - Dust Density: 0.16

Raw Signal Value (0-1023): 773.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 773.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 772.00 - Voltage: 3.77 - Dust Density: 0.54

Raw Signal Value (0-1023): 656.00 - Voltage: 3.20 - Dust Density: 0.44

Raw Signal Value (0-1023): 770.00 - Voltage: 3.76 - Dust Density: 0.54

Raw Signal Value (0-1023): 456.00 - Voltage: 2.22 - Dust Density: 0.28

Raw Signal Value (0-1023): 771.00 - Voltage: 3.75 - Dust Density: 0.54

Raw Signal Value (0-1023): 364.00 - Voltage: 1.78 - Dust Density: 0.20

Appendix I

Specification for 10W Monocrystalline PV Module

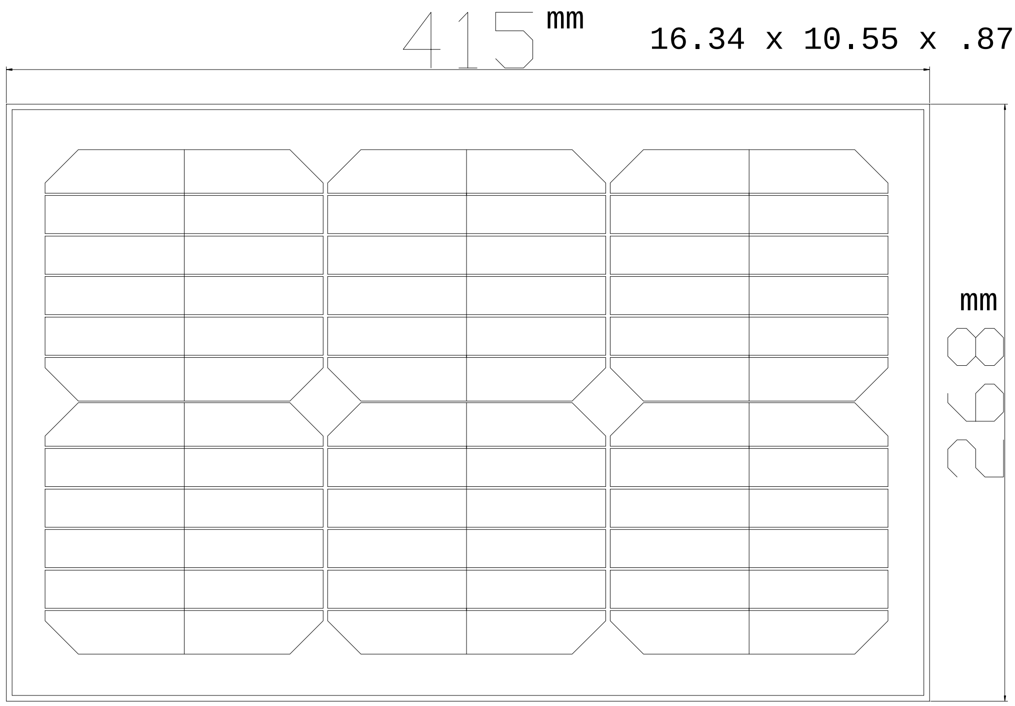
1. Technical Data

Table 1: Main Technical and Configuration Data

Peak Power(W)		10
Open Circuit Voltage (V)		21.60 V
Short Circuit Current (A)		0.59 A
Max. Power Voltage (V)		18.00 V
Max. Power Current (A)		0.51 A
Max. Rated System Voltage (V)		1000 V
Working Temperature		-20℃——60℃
Dimension		415x 268×22mm 16.34 x 10.55 x .87 in.
Installations Hole	D1 (mm)	--------
	D2 (mm)	--------
	D3 (mm)	--------
	Diameter	--------
Net Weight (kg)		1.5 kg 3.3 lbs.

2. Product Drawing:

16.34 x 10.55 x .87 inches



3. Statement of Raw Material

Table 2 Statement of Raw Material for the Module

No.	Item	Specification	Quantity	Unit	Material	Remark
1	Silicon Solar Cell	125×17.1	36	sheet	mono-crystalline	
2	EVA	410×263	2	sheet		
3	Back Film	410×263	1	sheet	TPT	
4	Front Surface Glass	410×263×3.2	1	piece	Low iron tempered surface textured	
5	Cable			piece		
6	Plug			pair		
7	Junction			set		
8	By-pass Diode			piece		
9	Frame	22mm	1	set	Stainless steel 304	

Appendix J

GP2Y1010AU0F

Compact Optical Dust Sensor

■ Description

GP2Y1010AU0F is a dust sensor by optical sensing system.
An infrared emitting diode (IRED) and an phototransistor are diagonally arranged into this device.
It detects the reflected light of dust in air.
Especially, it is effective to detect very fine particle like the cigarette smoke.
In addition it can distinguish smoke from house dust by pulse pattern of output voltage.

■ Features

1. Compact, thin package (46.0 × 30.0 × 17.6 mm)
2. Low consumption current (Icc: MAX. 20 mA)
3. The presence of dust can be detected by the photometry of only one pulse
4. Enable to distinguish smoke from house dust
5. Lead-free and RoHS directive compliant

■ Compliance

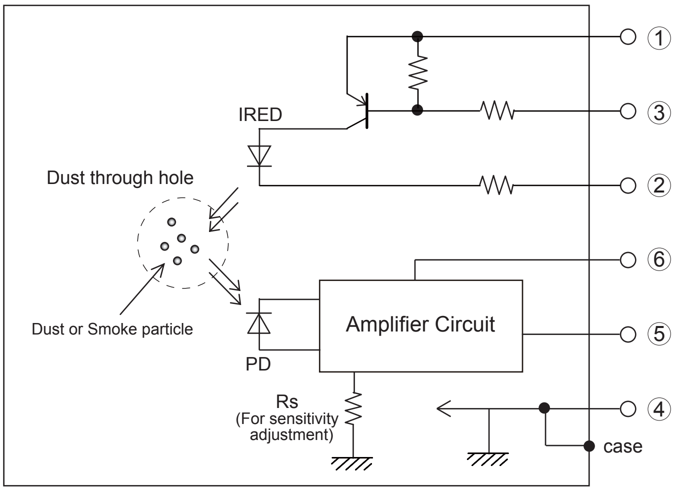
1. Compliant with RoHS directive (2002/95/EC)

■ Applications

1. Detecting of dust in the air.
2. Example: Air purifier, Air conditioner, Air monitor

Sheet No.: E4-A01501EN
Date Dec. 1. 2006

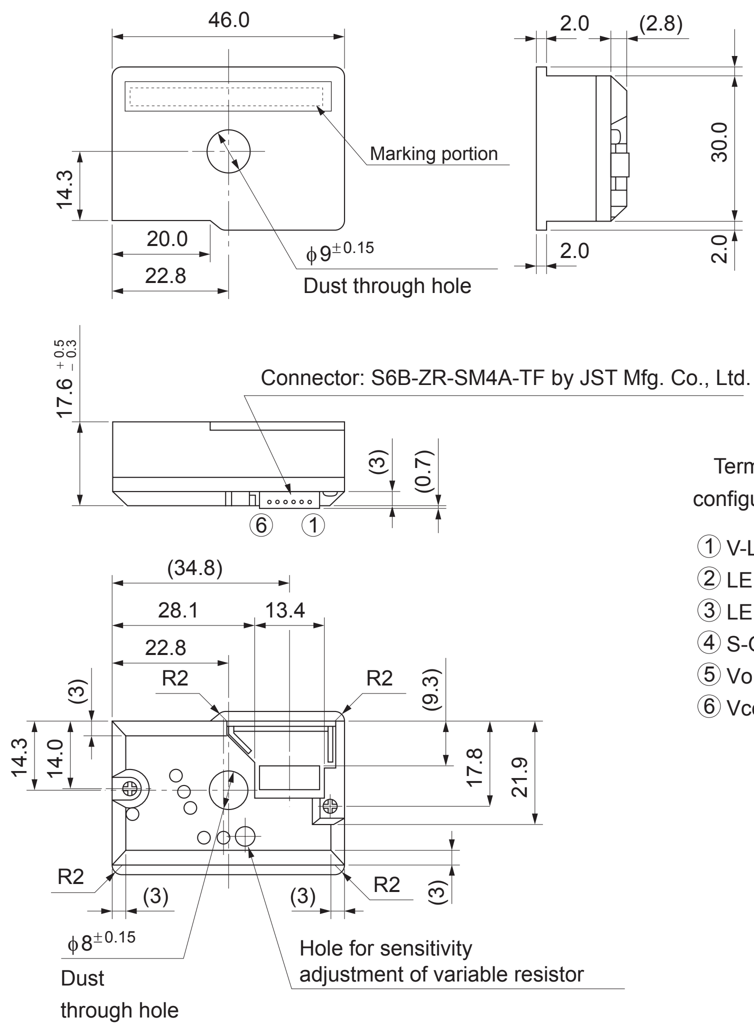
■ Internal schematic



① V-LED
② LED-GND
③ LED
④ S-GND
⑤ V_O
⑥ V_{CC}

■ Outline Dimensions

(Unit : mm)



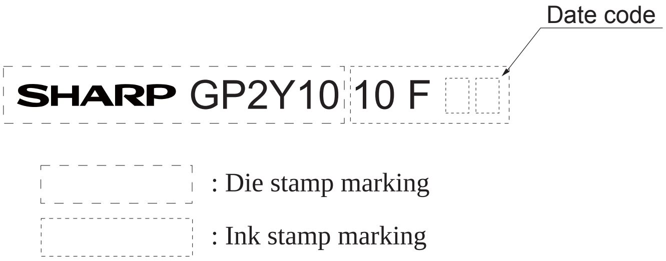
Terminal configuration

① V-LED
② LED-GND
③ LED
④ S-GND
⑤ Vo
⑥ Vcc

* Unspecified tolerance : ± 0.3 mm.
The dimensions in parenthesis are shown for reference.

Product mass : approx. 16 g

Marking information



Date code (2 digit)

1st digit		2nd digit	
Year of production		Month of production	
A.D.	Mark	Month	Mark
2000	0	1	1
2001	1	2	2
2002	2	3	3
2003	3	4	4
2004	4	5	5
2005	5	6	6
2006	6	7	7
2007	7	8	8
2008	8	9	9
2009	9	10	X
2010	0	11	Y
:	:	12	Z

repeats in a 10 year cycle

Country of origin

Philippines

■ Absolute Maximum Ratings

(T_a=25°C)

Parameter	Symbol	Rating	Unit
Supply voltage	V_{CC}	–0.3 to +7	V
*1 Input terminal voltage	V_{LED}	–0.3 to V_{CC}	V
Operating temperature	T_{opr}	–10 to +65	°C
Soldering temperature	T_{sol}	–20 to +80	°C

*1 Open drain drive input

■Electro-optical Characteristics

(T_a=25°C, V_{CC}=5V)

Parameter	Symbol	Conditions	MIN.	TYP.	MAX.	Unit
Sensitivity	K	*1 *2 *3	0.35	0.5	0.65	$V/(0.1mg/m^3)$
Output voltage at no dust	V_{OC}	*2 *3	0	0.9	1.5	V
Output voltage range	V_{OH}	*2 *3 R_L =4.7kΩ	3.4	–	–	V
LED terminal current	I_{LED}	*2 LED terminal voltage = 0	–	10	20	mA
Consumption current	I_{CC}	*2 R_L =∞	–	11	20	mA

*1 Sensitivity is specified by the amount of output voltage change when dust density changes by 0.1 mg/m^3.
And the dust density for detection is a value of the density of cigarette (MILD SEVEN®) smoke measured by the digital dust monitor (P-5L2: manufactured by SHIBATA SCIENTIFIC TECHNOLOGY LTD.).
*2 Input condition is shown in Fig. 1
*3 Output sampling timing is shown in Fig. 2

■Recommended input condition for LED input terminal

Parameter	Symbol	Value	Unit
Pulse Cycle	T	10 ± 1	ms
Pulse Width	P_W	0.32 ± 0.02	ms
Operating Supply voltage	V_{CC}	5 ± 0.5	V

Fig. 1 Input Condition for LED Input Terminal

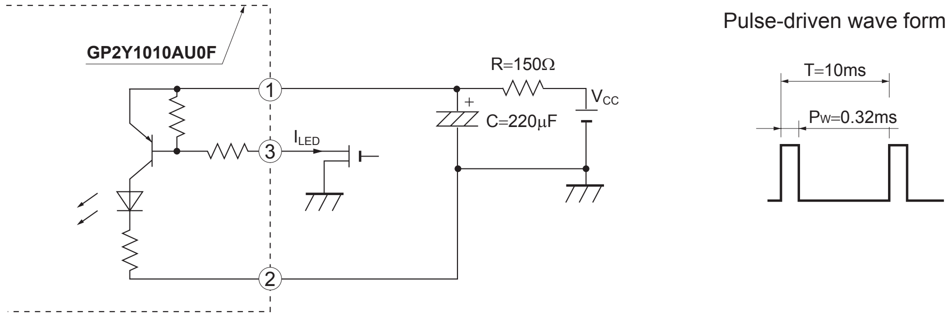


Fig. 2 Sampling Timing of Output Pulse

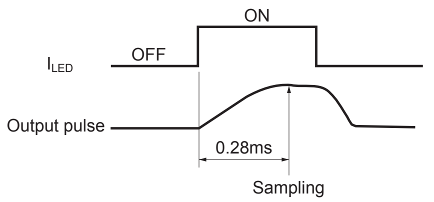
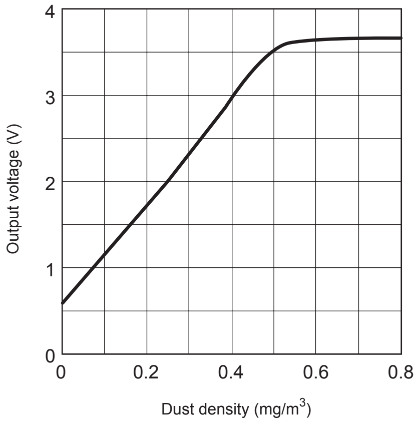


Fig. 3 Output Voltage vs. Dust Density



Remarks : Please be aware that all data in the graph are just for reference and are not for guarantee.

● Notes

1 Connection of case and GND
Case material use conductive resin as cover case {printed model No.} and metal {test terminal side} as bottom cover. The metal case connects with GND in sensor.

2 Cleaning
Please don't do cleaning, because there is a case that this device is not satisfied with its characteristics by cleaning.

3 Pulse input range
Please subject to recommendation as regard input condition for LED in order to keep reliability.

4 Dust adhesion
There is a case that this product does not detect the dust density correctly, since the dust adhered to the inside of the dust through hole may project into the detecting space which consist of emitter and detector light axis. Please take the structure and mechanism of the equipment into consideration to avoid the influence of adhered dust. And when the dust is adhered, please consider the maintenance such as vacuuming or blowing off the dust by air.
In addition, please pay attention to structure and placing location of the application to avoid any adhesive particle like oil, etc. to gets into the device. If it sticks to optical part, malfunction may occur.

5 Light output
In circuit designing, make allowance for the degradation of the light emitting diode output that results from long continuous operation. (50% degradation/5 years)

6 Sensitivity adjustment VR
VR for sensitivity adjustment is set up at shipping from sharp. Please do not touch the VR or Electro-optical characteristics specified on the specification will be invalid.

7 Resolution
Please do not disassemble the device such as removing tapping screw and so on. Even if the device is reassembled, it may not satisfy the specification.

8 Application to fire alarm
Please do not use this device for a fire alarm application. When using this device to application other than air purifying and equipment with air purifying function, please inform us before usage.

9 Noise influence
If the sensor is located close to noise generator (ex. Electric dust collector, etc.), the sensor output may be affected by leaded noise. On top of that noise from power supply line also may affect the sensor output. When desinging the system, please consider the effect from noise.

10 Vibration influence
The sensor may change its value under mechanical oscillation. Before usage, please make sure that the device works normally in the application.

11 Incident light influence
There is a case that the sensor output may be affected when outer-light comes through dust through hole on printed side. In order to avoid any influence from outer-light, please locate the printed side of sensor facing to inside of the application.

12 When inside of the sensor is moisturized, this product does not keep its proper function. Please design the application so that moisturization of the sensor does not happen.

● Presence of ODC etc.

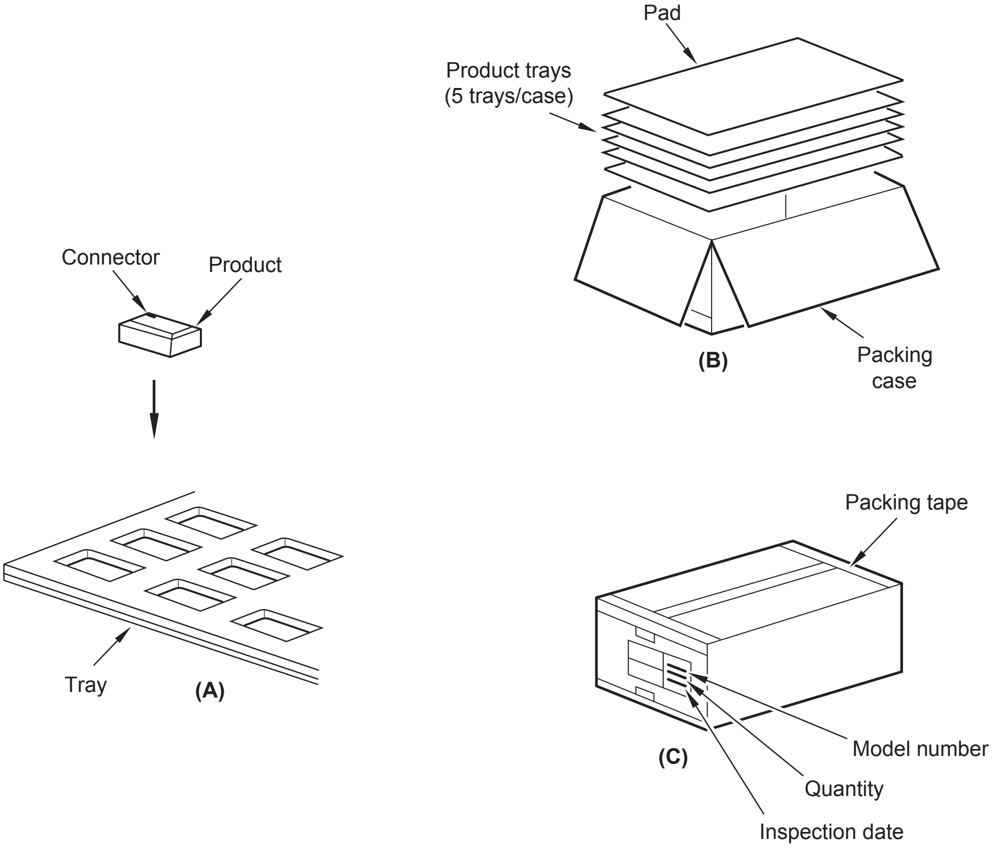
This product shall not contain the following materials.
And they are not used in the production process for this product.
Regulation substances : CFCs, Halon, Carbon tetrachloride, 1.1.1-Trichloroethane (Methylchloroform)

Specific brominated flame retardants such as the PBB and PBDE are not used in this product at all.

This product shall not contain the following materials banned in the RoHS Directive (2002/95/EC).

- Lead, Mercury, Cadmium, Hexavalent chromium, Polybrominated biphenyls (PBB), Polybrominated diphenyl ethers (PBDE).

■ Packing Specification



PACKING METHOD

1. Each tray holds 50 pieces. Packing methods are shown in (A).
2. Each box holds 5 trays. Pads are added to top (B).
3. The box is sealed with packing tape. (C) shows the location of the Model number, Quantity, and Inspection date.
4. Weight is approximately 5.6 kg

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(i) The devices in this publication are designed for use in general electronic equipment designs such as:

--- Personal computers
--- Office automation equipment
--- Telecommunication equipment [terminal]
--- Test and measurement equipment
--- Industrial control
--- Audio visual equipment
--- Consumer electronics

(ii) Measures such as fail-safe function and redundant design should be taken to ensure reliability and safety when SHARP devices are used for or in connection with equipment that requires higher reliability such as:

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--- Traffic signals
--- Gas leakage sensor breakers
--- Alarm equipment
--- Various safety devices, etc.

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--- Telecommunication equipment [trunk lines]
--- Nuclear power control equipment
--- Medical and other life support equipment (e.g., scuba).

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Appendix K

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TENMARS TM-206
Solar Power Meter

This meter is essential for determining the optimal position for setting up solar PV panels. It is small and lightweight, ideal for use in the field.

DISPLAY:
- **3½ digits LCD display with maximum reading of 2000.**
- **End -mount sensor.**
- **Select either power or transmission.**
- **Select wither W/m2 or BTU/ (ft2 x h)**
- **Data Hold/ MAX/MIN functions.**

APPLICATION
- **Solar radiation measurement.**
- **Solar power research.**
- **Physics and optical laboratories.**
- **Identify high performance windows.**
- **Simple to use General data.**

SPECIFICATIONS

Model	TM-206
Display	3½ digits, 2000 readings
Range	2000 W/m2, 634BTU / (ft2xh)
Accuracy	Typically within +/- 10W/m2 [+/-3 BTU/ (ft2xh)] or +/- 5% whichever is greater in sunlight; Additional temperature included error +/- 0.38 W/m2 / º C [+/-0.12 BTU/ (ft2xh)] / º C] from 25 º C
Angular accuracy	Cosine corrected <5% for angles <60º
Drift	< +/- 2% per year
Over-input	Display "OL"
Sampling time	0.25 second
Operating Temp. and Humidity	0º C ~ 50 º C below 80% RH
Size	130x 55x 39mm(LxWxH)
Weight	Approx. 0.15KG