THE EFFECT OF PARTIAL SHADING ON PHOTOVOLTAIC PANEL PERFORMANCE

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2017

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By

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Thesis Submitted in Partial Fulfilment of the Requirement for the Degree of Bachelor of Engineering (Electrical Engineering)

JUNE 2017

ACKNOWLEDGEMENT

First of all, Alhamdulillah and thanks to Allah S.W.T for his mercy and blessing, I managed to finish this project within the period given. I would like to express a deep sense of gratitude to my supervisor, Dr Khairunaz Bin Mat Desa for his guidance and constant supervision. His valuable advice and guidance, lesson and also his support really helps me a lot in the completion of this project.

Because of science and engineering is not collection of knowledge, I would like to thank Ir Dr Dahaman Bin Ishak my project examiner for his positive feedback and suggestions in providing in deeper understanding. My special thank reach out to Power Lab technicians especially En. Nizam, En. Nazir and other for their support and guidance which helped me in completing my undergraduate project.

My appreciation goes to all individual those who was directly or indirectly help me a lot to finish this project. I would like to take this opportunity to thank School of Electrical and Electronic Engineering for providing me equipment to finish the project.

Besides, I also like to thank to my friends especially my colleagues who continuously help and give advice to solve the problem I faced in this project. My appreciation and thanks also go to all electrical lecturers who have helped share their input and contributed to improving this project.

Last but not least, I would like to thank my family for their continual encouragement and support. Their motivation and advice really helped me to finish up my work.

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LIST OF ABBREVIATIONS

PV	Photovoltaic
A	Ampere
V	Voltage
W	Watt
DC	Direct Current

LIST OF SYMBOLS

α (alpha)	Absorption coefficient
η_C	Cell efficiency
η_m	Module efficiency
Ω (ohm)	Resistance

THE EFFECT OF PARTIAL SHADING ON PHOTOVOLTAIC PANEL PERFORMANCE

ABSTRACT

Shading gives a great effect in the power output of the Photovoltaic panel. Shading can be divided into two type, uniform and non-uniformly distributed. Uniform shading created by using butter paper where all the area of solar panel cover by shading. Non-uniform shading created by using leaves and trees where the partial area of solar panel cover by shading. The performance of solar panel will be analyzed using measuring sensors. The performance of solar panel is being analyzed based on two main conditions. First uniform shading with series and parallel connection of solar panel. Second, non-uniform shading with series and parallel connection of solar panel. Firstly, solar panel testing is conducted with uniform shading with a series connection to observe I-V characteristic. Then, the connection change to parallel and the I-V characteristic was observed. Secondly, the same method which has been used for non-uniform shading. A number of performance parameters have been collected using Arduino Mega over 5 hours per a day for each condition. Based on results obtained, it shows that having 10 to 11% of shading will decrease the performance of the solar panel. The increasing percentage of shading will decrease the performance of the solar panel. In practical, the effect on uniform shading like dust will not give a great effect like butter paper.

KESAN TEDUHAN SEPARA ATAS PRESTASI PANEL PHOTOVOLTAIC

ABSTRAK

Teduhan memberikan kesan yang besar dalam kecekapan panel photovoltaic. Dalam projek ini, teduhan telah dibahagikan dengan dua jenis, seragam dan tidak seragam. Teduhan seragam dicipta dengan menggunakan kertas minyak di mana semua kawasan panel solar terkena teduhan. Bukan seragam teduhan dicipta dengan menggunakan daun dan pokok-pokok di mana separa kawasan panel solar terkena teduhan. Prestasi panel solar akan dianalisis menggunakan sensor pengukur. Prestasi panel solar dianalisis berdasarkan dua syarat utama. Teduhan seragam pertama dengan siri dan sambungan selari panel solar. Kedua, teduhan tidak seragam dengan siri dan sambungan selari panel solar. Pertama, ujian panel solar dijalankan dengan teduhan seragam dengan sambungan siri untuk memerhatikan ciri I-V. Kemudian, perubahan sambungan selari dan ciri I-V diperhatikan. Kedua, kaedah yang sama telah digunakan untuk teduhan tidak seragam. Berdasarkan keputusan yang diperolehi, menunjukkan bahawa mempunyai 10 hingga 11% daripada teduhan akan mengurangkan prestasi panel solar. Peningkatan peratusan teduhan akan mengurangkan prestasi panel solar. Dalam praktikal, kesan ke atas teduhan seragam seperti debu tidak akan memberi kesan yang besar seperti kertas mentega.

CHAPTER 1

INTRODUCTION

1.1 Background

The fossil fuel resources are limited. Alternative way due to limited fossil fuel is renewable energy. There are several types of renewable energy such as solar energy, biomass, hydropower and wind energy. Sunlight is the source of solar energy. The combination of many different wavelength spectrums make sunlight looks white. Solar energy is renewable energy sources and the application is more direct in comparison to the other renewable energy sources. Solar energy is the most environment-friendly source because it does not produce any pollution and can be easily accessible.

Photovoltaic (PV) is the technology that captures and convert solar energy to electricity. PV is the best possible choice for future energy requirement because of environment-friendly and sustainable. PV effect was discovered in 1839 by a French physicist, Edmund Becquerel. This effect was observed when Becquerel suddenly noticed that voltage appeared when one of two identical electrodes was light up [1]. When PV cell connected in series, it will be called module. Many PV modules are connected in series and parallel it will form PV array. This type of connection will increase voltage magnitude and current supplying capacity for larger solar plant [2].

There are two types of PV system that being use nowadays. Grid-connected (grid tied) and off-grid (standalone). Grid-connected uses two sources, one from solar PV system and the other one from the power grid. Whenever solar PV system generates energy more than the required demand, the energy will be transferred to the grid. Otherwise, if demand higher than energy generated from PV system or at night condition, the grid will supply the demand depending on requirement. On the other hand, an off-grid system capable of supplying a building demand without any backup from the grid system. This system needs a place where sunlight always an abundance in which grid is not easily accessible such as rural areas and off-shore islands [3].

Shading has a significant effect on the performance of the Photovoltaic (PV) panel. The shading on PV panel can be caused by the passing of the clouds, trees, and dust. The effect of PV on PV panel performance shading is vary depending on the types of shading, uniformly as well cells interconnections.

In this project, the shading effects on PV panel will be investigated. For uniform irradiation, used butter paper with different quantities and layer to get a different percentage of shading. For partial shading, use other things such as leaves, under trees and cables [4].

1.2 Problem Statement

Shading is the one major problem PV system. Shading effect due to dust trees, clouds and building effect the performance of PV panels [4]. Usually, the PV panels will be installed at the open space where the PV panels can get direct sunlight. Most user not aware the installed PV panel on the roof are exposed to shading. This can effect energy output as well as payback period. Factor such as whether condition, haze and dust accumulation will contribute to significant shading on PV panel surface. These can reduce the intensity of sunlight falling on the solar cells hence the overall energy output [4]. This shading effect is a great concern as recently higher capacity PV were installed for residential as well as a commercial market such as PV farms. Thus this work will analysed in detail the shading effect on the energy output from PV panel.

1.3 Objectives

The objectives of this project:

1. To study the effect of uniform and non-uniform shading on the performance of PV panels under indoor light source.
2. To investigate the effect of uniform and non-uniform shading on PV module performance in parallel and series connection under outdoor light source.
3. To analyse the performance of solar panel under uniform and non-uniform shading by using microcontroller Arduino.

1.4 Project Scope

In this project, the performance of PV panels will be analysed base on four conditions. First, uniformly shading on PV panel with a series connection. Butter paper will be used to create uniform shading like haze. Second, uniformly shading with parallel connection of PV panels. Third, non-uniformly shading with a series connection. Leaves, cables, and other things will be used to make partially shaded on PV panels. Forth, non-uniformly shading with parallel connection of PV panels.

1.5 Project Outline

This thesis has five main chapters. The first chapter is the introduction that covers the background of the project, problem statement, objectives and project scope.

Chapter 2 covers the Literature Review of the project. In this chapter, the overview of the PV system, series and parallel connection and shading effect on PV panels. This chapter also explained the basic knowledge about efficiency of solar cells

Chapter 3 describes the methodology of this project. It represents the method to carry out this project. All methodology such as testing solar panel for I-V characteristics, system testing, and calculation.

Chapter 4 will discuss result and discussion of the project. The result will be represented in a table and graphical form. The performance of PV panels under shading will be discuss in this chapter.

Chapter 5 represent the conclusion of the project and the future improvement can be made.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The basic element in PV system is solar cells. Solar cells have one or more specific layers of conductor material. That material makes atoms absorb light, freeing electrons and creating holes to carry current. Voltage is created in each cell by the junction between two dissimilar semiconductor materials to drive electrons through a circuit. Solar cells are made from different type of semiconductors materials such as single crystals, polycrystalline or amorphous (non-crystalline) [5].

One complete PV panels are made by connecting solar cells together to form modules. The building block of PV system to produce more power output and provides protective packages for the cells. The thin film is inexpensive but low efficiency compares to crystalline cells. Crystalline cells are known as the best of the PV materials. There are two categories of PV modules which are flat-plate modules and concentrating modules. Flat-plate modules used under ordinary sunlight while concentrating modules include lenses or mirror to focus sunlight onto PV panel [6]. Although PV materials play important roles in their performances, the irradiance level that fall through on each panel surfaces may play greater roles on overall performance of PV system.

2.2 Working Principle of Solar Cell

PV effect is the basis of the conversion of light into electricity. Light enter the PV panels and give enough energy to some electron to free them from their atom. Each solar cells have built-in potential barrier where this barrier will act on these free electrons to produce a voltage which can be used to drive current through a circuit. When the light hit solar cells, it may be reflected or absorbed. When the light is fairly low energy is absorbed by a solid, it creates heat. This will make an electron in the solar cells vibrate. Otherwise, when the light of high energy can change the properties of solar cells and make atom bond missing an electron. Electron and holes freed from their position in solar cells and generated electron-holes pair. The generation of electron and hole by light is the main process of PV effect.

PV cells contain barrier with opposite charge facing to each other. This two barrier will send electron more to one side and hole to another side. During the separation process, electron and hole likely to join together again and losses their electrical energy. This charge separation set up a voltage difference between potential barriers. This will generate current that can be used in an external circuit. Potential barrier in solar cell separates light generated charge carrier shown in figure 2.1.

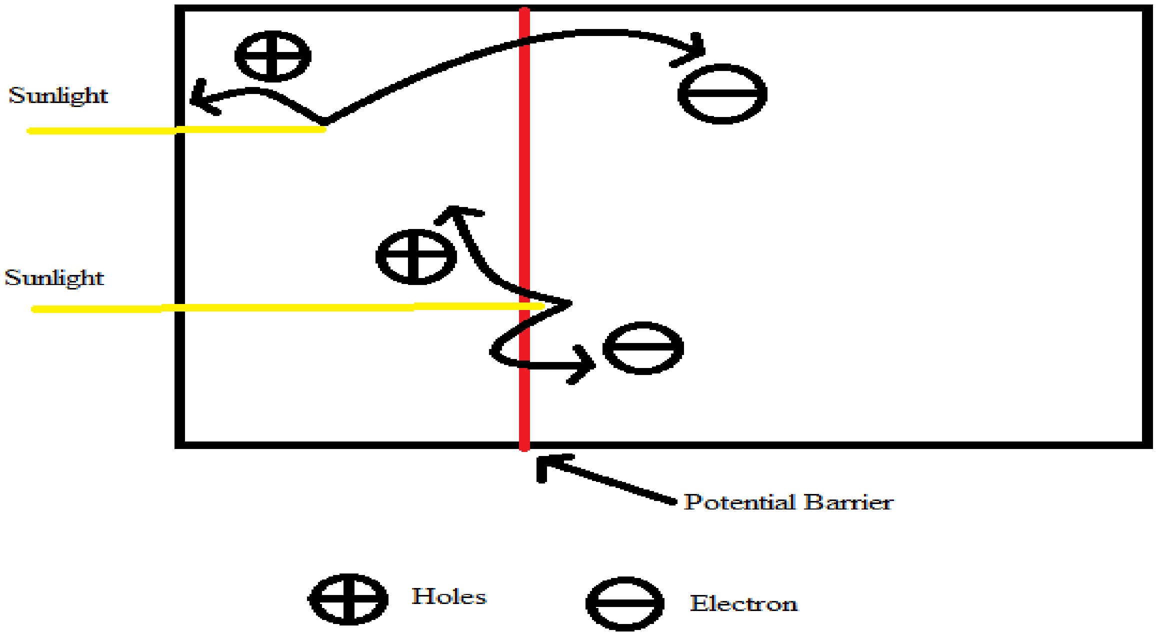

Figure 2.1 A potential Barrier in a solar cell separates light generated charge carrier, creating a voltage [1]

To make conversion sunlight into electricity more efficient, solar cells needs to harvest a significant fraction from solar radiation spectra. The absorption efficiency depends on the absorption coefficient (α) of the material [7].

2.3 Type of Photovoltaic Panel

There are three common type of PV panels that are popular, mono-crystalline PV panel, polycrystalline PV panel and thin film PV panel. Each of this PV panel has their own specification. Mono-crystalline has higher efficiency compare to poly-crystalline. The thin film is the latest development of PV panel. The thin film is less expensive but lower efficiency.

2.3.1 Mono-crystalline Photovoltaic

Mono-crystalline silicon or single-crystal silicon is based on the material for the silicon chip. Mono-crystalline is light absorbing material. It has crystal lattice of the entire solid, unbroken to its edge and free of grain boundaries. There is two type of mono-crystalline which is intrinsic and doped. Intrinsic has only pure silicon while a doped containing a very small portion of another element to change its semiconducting properties [8]. Mono-crystalline cell is most commonly used. It will continue as commonly used until more efficient and cost effective PV technology developed. The Czochralski method is used to manufacture mono-crystalline silicon by using a single crystal ingot. The efficiency of mono-crystalline cell is limited by the amount of energy produced by the photons since it decreases at a higher wavelength. Thermal dissipation due to the radiation with longer wavelength can cause the cell heat up and reduce efficiency. The maximum efficiency for mono-crystalline solar cell around 23% [9]. Mono-crystalline solar cell structure is shown in figure 2.2.

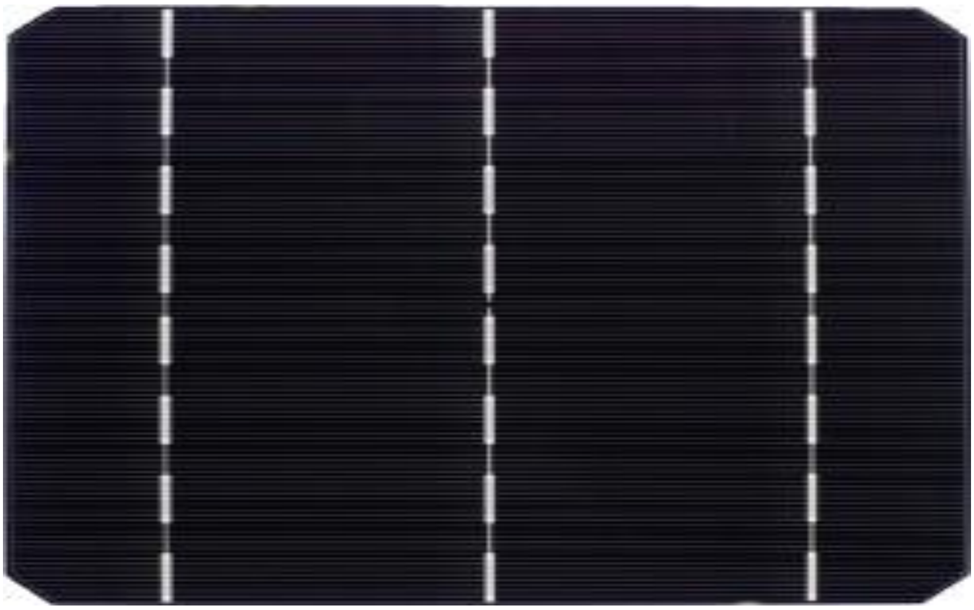

Figure 2.2 Mono-crystalline solar panel surface with single crystalline silicon based on material on a silicon chip [8].

2.3.2 Poly-crystalline Photovoltaic

Poly-crystalline was dominant for solar industry because the cost of silicon at that time was $340/kg [9]. Poly-crystalline technology becoming most popular because manufacturing cost is lower than mono-crystalline even though these cells are slightly less efficient. Poly-crystalline cell manufacturing is initiated by melting silicon and solidifying it orient crystals in a fixed direction producing a rectangular ingot of multi-crystalline silicon to be sliced into blocks and finally into thin wafers. The advantages of poly-crystalline over mono-crystalline is to reduce the flaws in metal contamination and crystal structure. Other than that, poly-crystalline is very promising PV material because of the low-cost production which is low-cost growth method and less pure feedstock. However, the disadvantages of poly-crystalline cells is it has crystallographic defect and impurities in the cell. A defect such as grain boundaries and dislocation can give a great effect on the performance of solar cell because they act as carrier combination centers [10]. Poly-crystalline silicon is shown in figure 2.3.

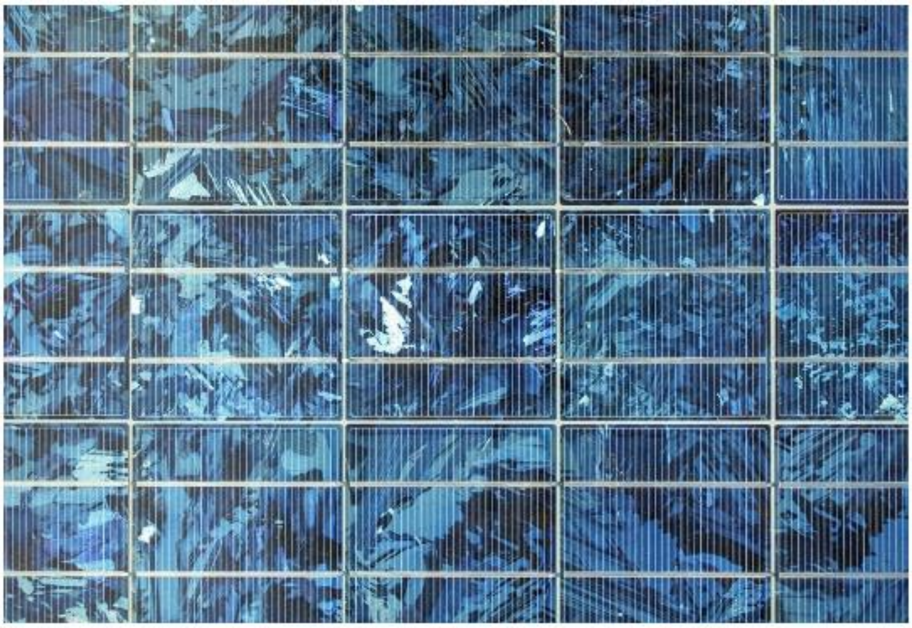

Figure 2.3 Poly-crystalline solar panel surface where multi-crystalline silicon to be sliced into blocks [11].

2.3.3 Thin Film Photovoltaic

The thin film solar cell is a solar cell that is made by depositing one or more thin layer of photovoltaic material on a substrate. Thin film modules are created by depositing thin layers of certain materials on glass or stainless steels (SS) substrates, using sputtering tools. The layer of thin film has a range of thickness from a few nanometers to ten of micrometers. The thin film is categories by the materials used which is amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium selenide (CIS) and dye-sensitized solar cell (DSC) and other organic solar cells. The efficiency achieved by a thin film about 15% - 20% [12]. The development goal of thin film technology is to reduce the cost of PV array. This is because thin-film solar cells are less expensive to manufacture compared to crystalline solar cells. Otherwise, the layer of thin film is much thinner than a crystalline solar cell. It makes less photovoltaic material absorb the incoming solar radiation for the thin film. Figure 2.4 shows the thin film solar panel surface.

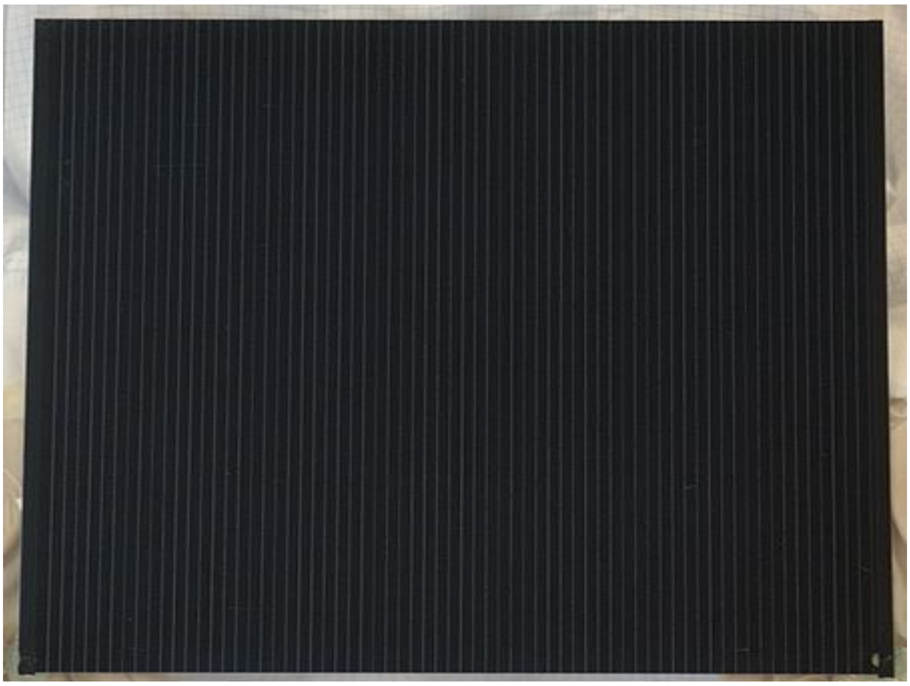

Figure 2.4 Thin film solar panel surface that is created by depositing thin layers of certain materials of glass.

2.4 Parallel and Series Photovoltaic Connection

2.4.1 Solar Cell Connection

2.4.1.1 Parallel Connection

Parallel wiring makes the voltage output the same while increasing the current output of solar arrays. Parallel connection happens when positive of multiple modules is connected together and all negative for the same module are connected together as shown in figure 2.5 (a).

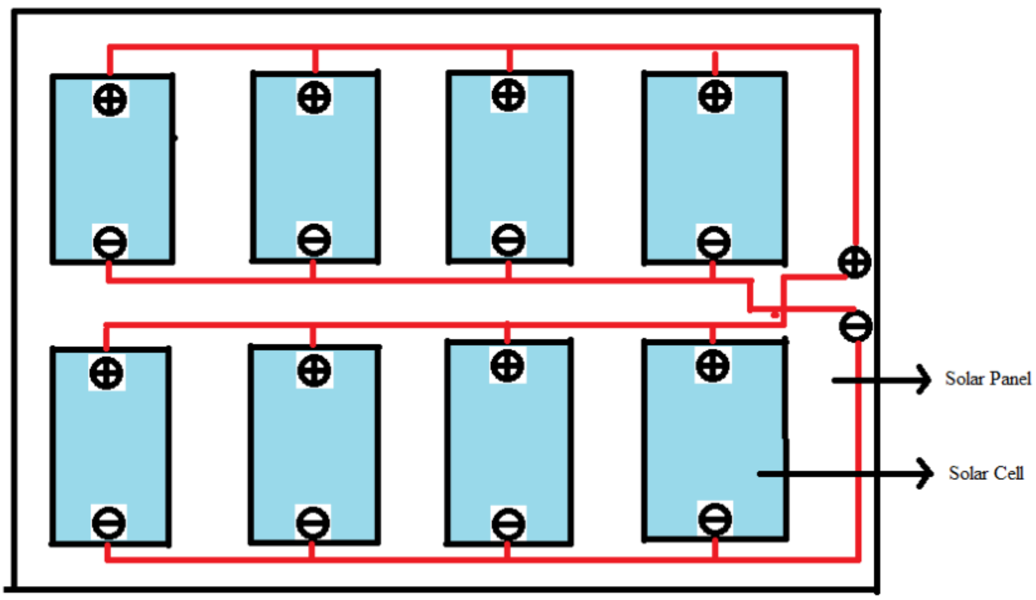

Figure 2.5 (a) Example parallel connection of solar cell in solar panel to increase current output while same voltage output.

2.4.1.2 Series Connection

Series wiring makes the current output the same while increasing the current output of solar arrays. Series connection happens when positive one of the solar module and negative of another solar module connected together as shown in figure 2.5 (b)

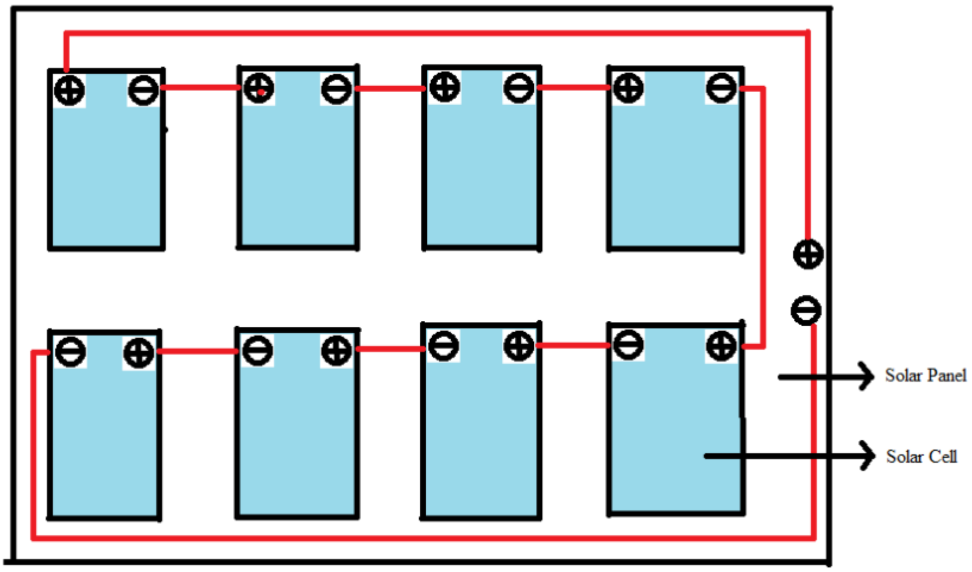

Figure 2.5 (b) Example series connection of solar cells in solar panel to increase voltage output while same current output.

2.4.2 Panel Connection

2.4.2.1 Parallel Connection

Parallel wiring makes the voltage output the same while increasing the current output of solar arrays. Parallel connection happens when positive of multiple modules is connected together and all negative for the same module are connected together as shown in figure 2.6 (a).

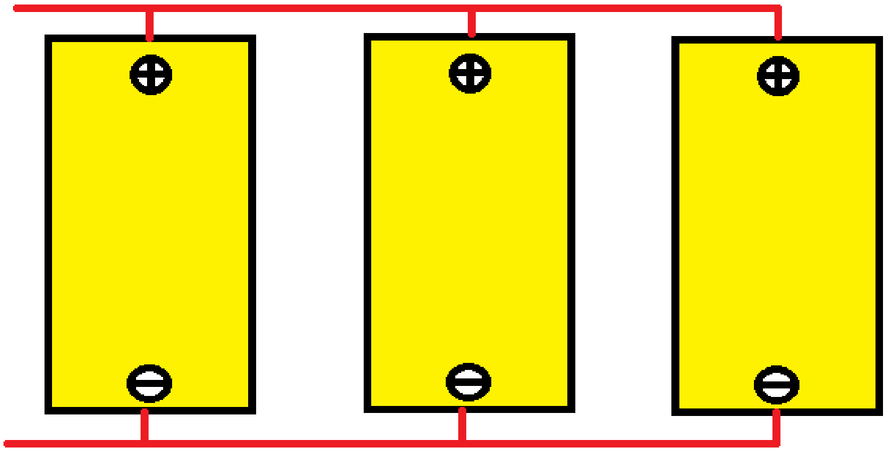

Figure 2.6 (a) Example parallel connection of solar panel to increase current output while same voltage output [13].

2.4.2.2 Series Connection

Series wiring makes the current output the same while increasing the current output of solar arrays. Series connection happens when positive one of the solar module and negative of another solar module connected together as shown in figure 2.56 (b)

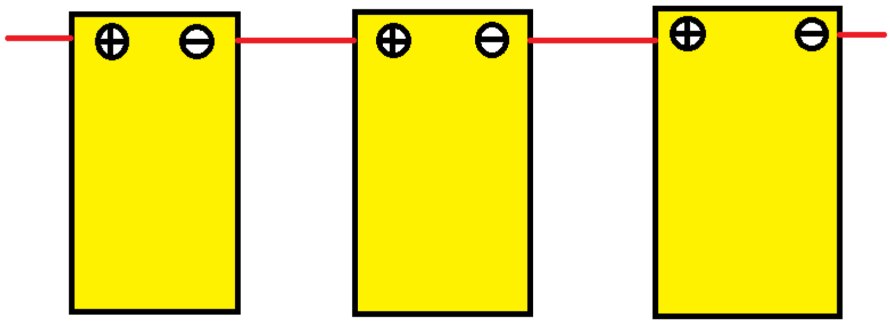

Figure 2.6 (b) Example series connection of solar panel to increase voltage output while same current output [13].

2.4.3 Combine Series and Parallel Connection

The combination of series and parallel connection make the voltage and current output of solar array increase as shown in figure 2.7

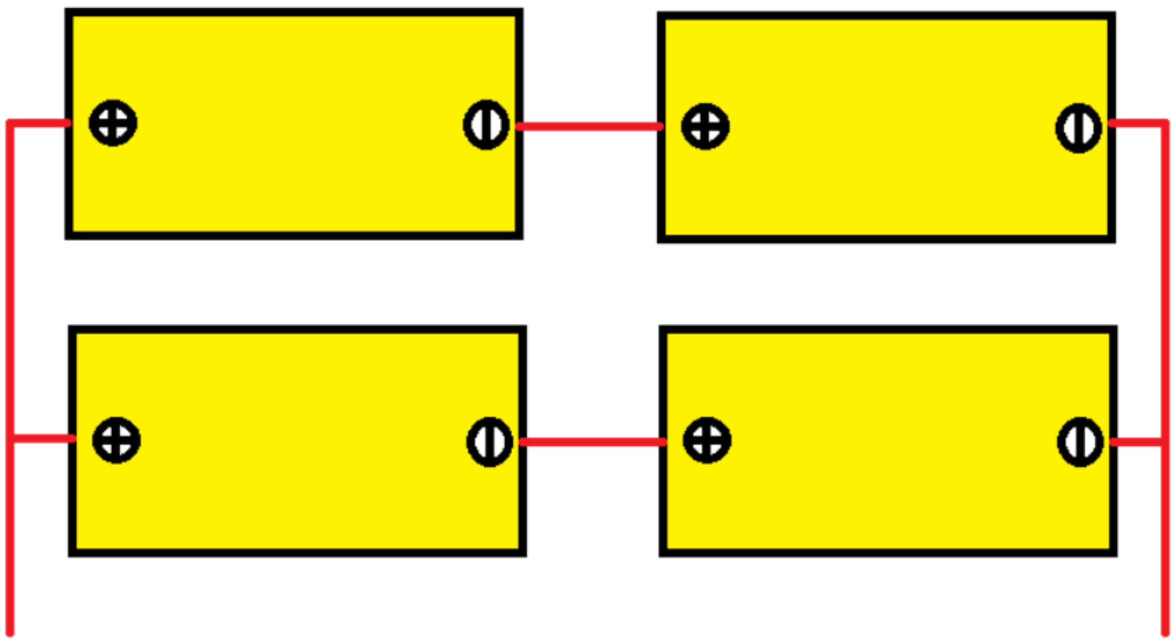

Figure 2.7 Example series and parallel connection of solar panel to increase both current and voltage output [13].

2.5 Factor that affects the efficiency of Solar Panel

There are some factors that affect the efficiency of the solar panels such as temperature, shading effect, and dust. All these factors will give a great effect on a solar panel at certain place and region. For example, in India temperature is the major factor that effects solar panel power output. Other than that, dust is the major factor that effects solar panel power output in Arabian.

2.5.1 Temperature

Temperature is the most important role in the conversion of photovoltaic. The power output of PV module depends directly on operating temperature [14]. As the working temperature of PV module increase, the efficiency decrease. The cell temperature is the important factor that causes the efficiency and the power output of the module will decrease. The increasing of the temperature will make the band gaps in the solar cells shrinkage. This will reduce the voltage output. Mono-crystalline solar cells have a higher effect on temperature compare to poly-crystalline and thin film solar cells. Mono-crystalline solar cells have efficiency decrease by 15% while the thin film solar cells have 5% [15] as shown in figure 2.8 (a).

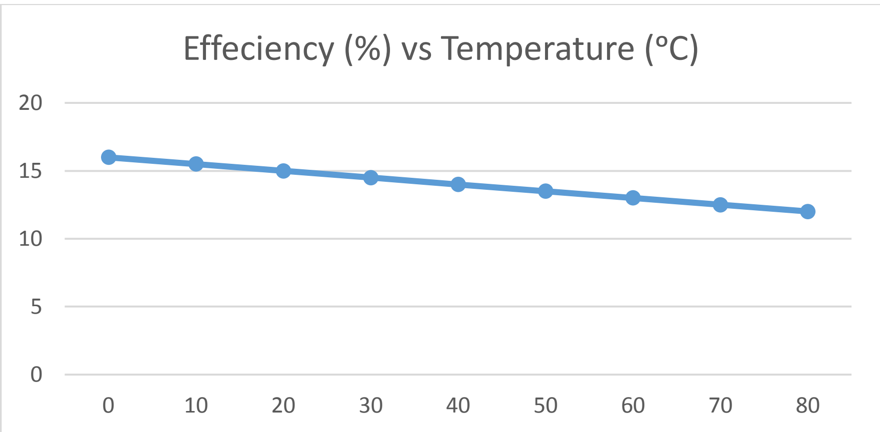

Figure 2.8 (a) Photovoltaic monocrystalline cell efficiency versus temperature, as the temperature increase, the efficiency of solar panel will decrease [15].

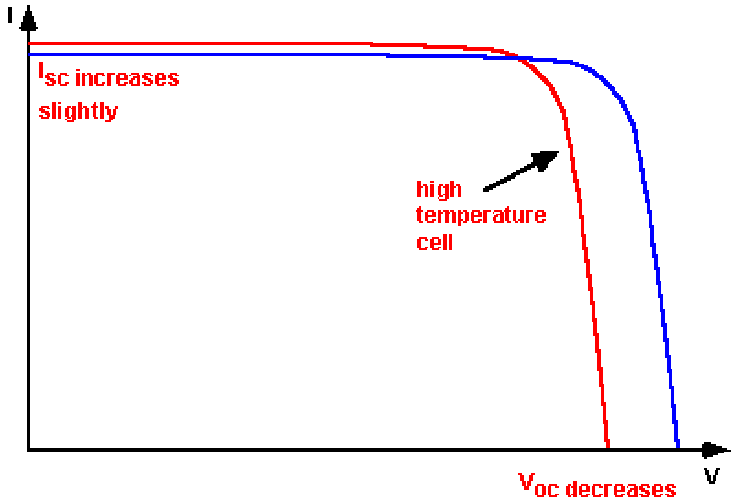

Figure 2.8 (b) The effect of temperature on IV characteristic of solar cell where it decreases the value of V_{OC} of monocrystalline solar panel as temperature increase [16].

2.5.2 Shading Effect

The other factors that affect the efficiency of the solar panel are shading effect. The output of solar panel is very sensitive to shading. Solar panel should be located at open space where no shadow lay on them. This because power loss depends on the area of the solar panel that is shaded and type of shading. Type of shading source can be categories as hard and soft sources. Soft source shading is a shadow dispersed due to an item from far distance diffuses the sunlight falling on the module such as chimney and vent. Hard source stops the light from reaching the solar cells such as tree leaves, bird droppings, snow, and thick dust. Type of shading also can be categories as uniform and non-uniform shading. Uniform shading happen when most of the part of solar panel cannot receive sunlight. An example is a haze and cloud. Non-uniform shading happens when the partial area of solar panel cannot receive sunlight. An example is leaves and trees. The half-shaded cells will reduce current about 50% [15]. Even small shade gives a great effect on solar panel performance. If the solar cell is shaded completely, it will consume power rather than generation and acts as a load. Figure 2.9 shows shading due to trees on solar panels.

Figure 2.9 Shading due to trees on solar panels which is called as non-uniform shading.

2.5.3 Effect of dust on the PV panel

Dust is any particular matter less than 500µm in diameters such as vegetation pollens, animal cells, carpet and textile fibres, sand, clay or eroded limestone. Dust give worst effect on the PV efficiency. This because dust may resist the incoming irradiance to reached PV module. Solar module efficiency can reduce until 50% for one month only for dust. This was proved by a lot of experiment conducted regarding the PV module efficiency. To get a better performance of PV panel, the surface must be clean. However, dust effect can be minimized with the increment of irradiation intensity [15].

2.6 Chapter Summary

From this chapter, the development of solar cell by using new crystalline technique can reduce the cost. The improvement of the mono-crystalline solar cell to poly-crystalline solar cell until the thin film make benefit to the world. All factor that affect the power output of solar panel can be reduced by doing cleaning regularly especially dust. However, shading gives great effect on solar cell efficiency.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the hardware, software, and method that will be applied in this project. The detail of hardware and software that being used will be discussed. All details on how the project will be conducted are discussed in this chapter.

3.2 Project Implementation Flow

A flow chart which explain the flow of this project is shown in Figure 3.1.

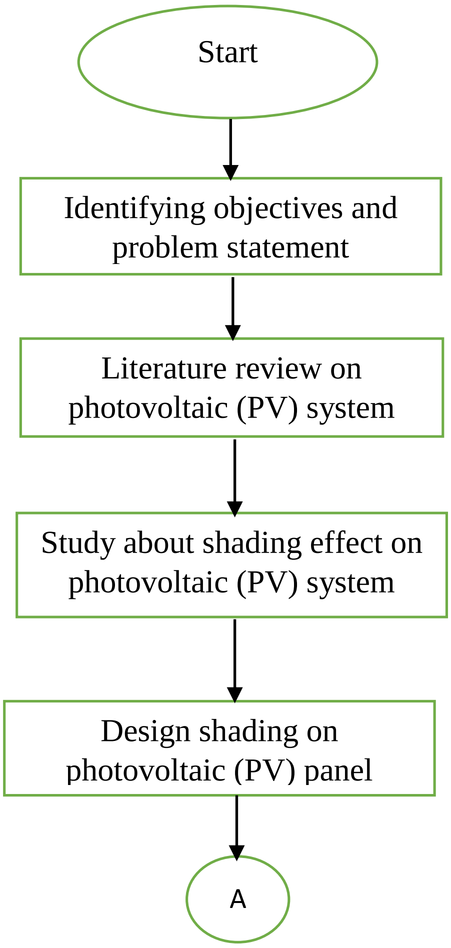

Figure 3.1 Project Flow Chart (continues…)

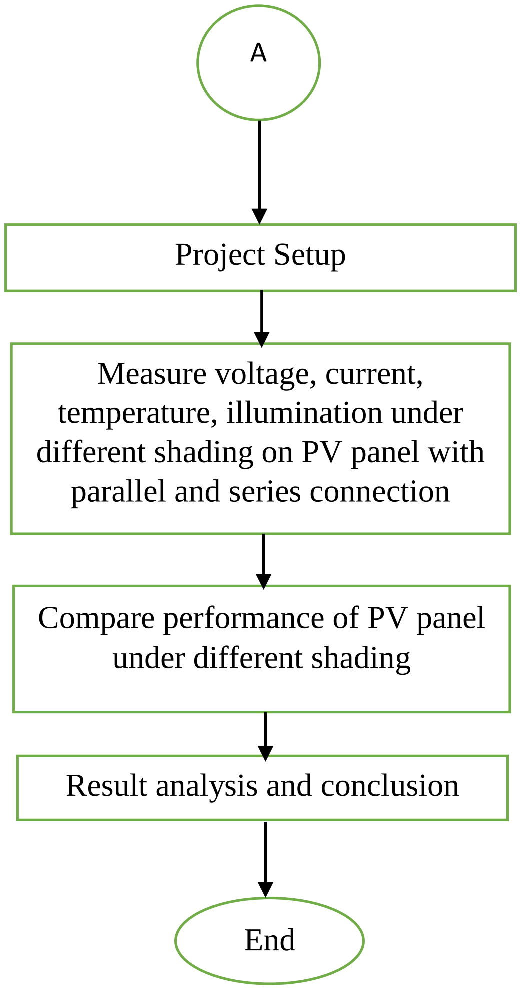

Figure 3.1 Project Flow Chart from the beginning of experiment until the end of experiment.

3.3 Project Requirement

3.3.1 Solar Panel

A 50W of solar panel is used in this project as a photovoltaic system. This panel is made up of poly-crystalline silicon solar cells. This solar panel manufactured by SC ORIGIN (M) SDN BHD. Specification and physical parameters of the 50W solar panel are shown in Table 3.1.

Table 3.1 Specification and Physical Parameters of 50W Solar Panel according to data sheet by SC ORIGIN (M) SDN BHD

Electrical Properties	**Values**			
Rated Maximum Power (P_{max})	50W			
Current at P_{max} (I_{mp})	2.65A			
Voltage at P_{max} (V_{mp})	18.8V			
Short-circuit current (I_{sc})	2.84A			
Open-circuit Voltage (V_{oc})	21.3V			
Physical Parameters				
Maximum System Voltage	DC 715V			
Cell Technology	Poly Silicon			
All technical data at standard test condition:				
AM=1.5	$E=1000W/m^2$	$T_C=25°C$	$\eta_C=13.2\%$	$\eta_m=10.0\%$

3.3.2 Arduino Mega 2560

The Arduino Mega 2560 is a microcontroller that has 54 digital input and output pin which 14 of it can be used as PWM output, 16 pin analog input, 4 hardware serial port, a 16MHz crystal oscillator, a USB connection, a power jack, an ICSP header and a reset button. This board contains everything needed to support the microcontroller. It user-friendly since it easy to use. Simply connect it to a computer with USB cable or power it with an AC-to-DC adapter or battery to get started.

Figure 3.2 Arduino Mega 2560 use as microcontroller connected to all sensor and show the data on a serial monitor.

3.3.3 Analog Output K-Type Thermocouple Amplifier

This thermocouple is very sensitive. It is required a good amplifier with a cold-compensation reference. This thermocouple works with the amplifier to measure the temperature of the solar panel. The board will be power up with 3.3V DC and the output voltage will be measured on the OUT pin. The OUT pin will be connected to an Arduino. Figure 3.3 and Figure 3.4 below show Analog output k-type thermocouple amplifier and Thermocouple type-k glass braid insulated-k respectively.

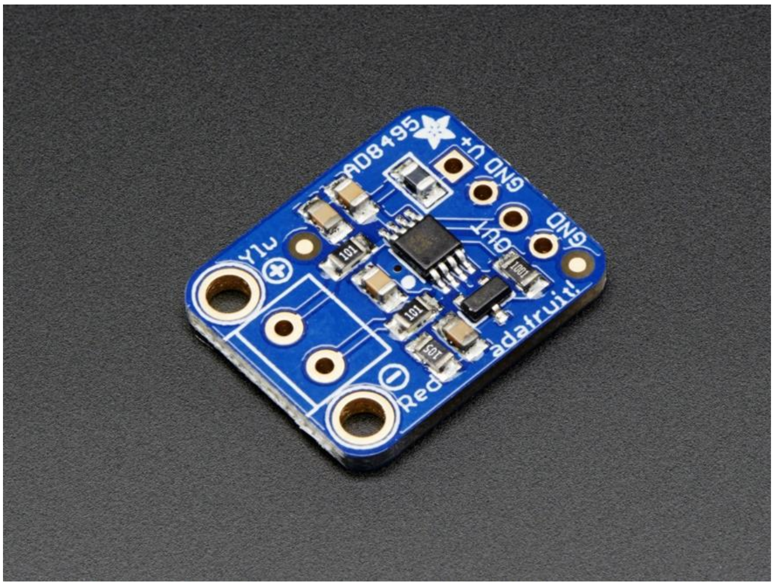

Figure 3.3 Analog Output K-Type Thermocouple Amplifier to convert low voltage output signal.

Figure 3.4 Thermocouple Type-K Glass Braid Insulated-K to measure the temperature of solar panel.

3.3.4 5A AC Current Sensor

This current sensor is used to measure the output current of the solar panel. The value read by the sensor will be shown on the serial monitor. The VCC pin will be connected to the 3.3V and GND pin to ground. The OUT pin will be connected to the Arduino. Figure 3.4 below shows 5A current sensor.

Figure 3.5 5A ACS712 current sensor that detects current in the wire and generates a signal and sent it to Arduino.

3.3.5 150kΩ and 10kΩ resistances

The output voltage of solar panel will be measured by using the voltage divider. There two resistances will be used for the voltage divider, R1=150kΩ, and R2=10kΩ. The V_{out} of the voltage divider will be connected to Arduino. The voltage divider the voltage that is measured within the Arduino analog input range. Figure 3.5 below shows the voltage divider circuit.