# PHOTOVOLTAIC THERMAL COLLECTOR SYSTEM BASED ON HETEROJUNCTION INTRINSIC (HIT) PANEL

**MUHAMMAD NASRUL FAIZ BIN ROSLI**

**UNIVERSITI SAINS MALAYSIA**

**2018**

# PHOTOVOLTAIC THERMAL COLLECTOR SYSTEM BASED ON HETEROJUNCTION INTRINSIC (HIT) PANEL

**by**

**MUHAMMAD NASRUL FAIZ BIN ROSLI**

**Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Engineering (Electrical Engineering)**

**JUNE 2018**

# ACKNOWLEDGEMENT

In the name of Allah the Most Gracious and Most Merciful.

All praises to Allah SWT, whom with His willing to give me the strength and patience to complete this thesis in time. This thesis was prepared for Electrical Engineering Programme, School of Electrical and Electronic Engineering, Universiti Sains Malaysia.

First of all, I would like to express my gratitude to my supervisor, Dr. Mohd Khairunaz Bin Mat Desa for guiding me from the very beginning of the project. I truly appreciate all his contribution of time, his expert supervision and extensive knowledge towards this project. His invaluable support motivated me in the completion of this project.

Deepest thanks and appreciation to my parents; En. Rosli Ismail and Pn. Zaidah Mat for the love and encouragement, cooperation and full support for this thesis completion. My special thanks to En. Nazir, En. Amin and En. Jamal for their support and helped me to complete the project. My appreciation goes to individual those who direct and indirectly help me a lot to finish this project.

Million thank goes to my colleagues and my friends for supporting and helping me during the process of completion of this project. They always give me ideas so that I can improve my project in many ways.

# TABLE OF CONTENTS

**Page**

# LIST OF TABLES

**Page**

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | |
|---|---|
| A | Current |
| DC | Direct Current |
| I-V | Current-Voltage |
| Isc | Short Circuit Current |
| Iout | Output Current |
| PV | Photovoltaic |
| PVT | Photovoltaic Thermal |
| Pout | Output Power |
| SD Card | Secure Digital Card |
| UV | Ultraviolet |
| Vout | Output Voltage |
| Voc | Open Circuit Voltage |
| V | Voltage |
| W | Watt |

# SISTEM PENGUMPUL HABA FOTOVOLTAIK BERDASARKAN PANEL INTRINSIK SIMPANG HETERO (HIT)

## ABSTRAK

Dalam projek ini, sistem PVT berdasarkan panel intrinsik simpang hetero (HIT) direka, dibina dan diuji. Sistem ini bukan sahaja menghasilkan elektrik tetapi ia juga menjana air panas. Panel suria HIT dengan penyerap haba dan tanpa penyerap haba dibangunkan dan dianalisis. Objektif pertama projek ini adalah untuk merekabentuk dan menguji sistem PVT berdasarkan panel intrinsik simpang hetero (HIT). Objektif kedua adalah untuk membandingkan prestasi panel intrinsik simpang hetero (HIT) dengan penyerab haba dan tanpa penyerab haba. Sistem pengambilan data berdasarkan mikrokontroler dibina untuk mengukur data dari sistem. Semua parameter elektrik sistem diambil dan disimpan dalam kad SD mikro untuk setiap 5 minit menggunakan sistem penyimpan data yang dibangunkan menggunakan Arduino. Data ujiakaji yang diambil bertujuan untuk memerhatikan ciri-ciri perbezaan lengkungan I-V bagi panel panel suria intrinsik (HIT) dengan dan tanpa penyerap haba. Eksperimen kajian dijalankan selama lima jam untuk mendapatkan nilai arus keluaran, voltan keluaran dan kuasa keluaran maksimum. Keputusan menunjukkan bahawa solar panel HIT dengan penyerap haba telah menaikkan prestasi sebanyak 22.64% dan menurunkan suhu solar panel sebanyak 9.49%.

# Photovoltaic Thermal Collector System Based on Heterojunction Intrinsic (HIT) Panel

## ABSTRACT

In this project, Photovoltaic thermal or PVT system based on heterojunction intrinsic (HIT) panel was designed, built and tested. This system not only produces electricity but it also generates hot water. HIT PV solar panel with the solar thermal collector and without thermal collector will be presented and analysed. The first objective of this project is to design and test a PVT system based on heterojunction intrinsic (HIT) panel. The second objective is to compare the performance of the heterojunction intrinsic (HIT) panel with and without the thermal collector. Microcontroller data acquisition was built to measure and collect data from the system. All the electrical parameter were saved on micro SD card for every 5 minutes using data logger developed using Arduino. The data collected were used to observe the I-V characteristics of HIT panel with and without thermal collector and also the energy output generated from the system. The experiment was conducted for 5 hours to obtain output current, output voltage and maximum output power. From the result analysis, the HIT with thermal collector has improved its performance by 22.64% and lowered the solar panel temperature by 9.49%.

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

The non-renewable or conventional sources of energy are dropping fast. Energy is the motive power that keeps wheels of industry moving and other things live. Fossil fuel which includes coal, oil, petroleum and natural gas is the non-renewable energy which is the conventional sources of energy that are not sufficient to meet the fast increasing demand for energy as they are limited and may soon get depleted. Burning fossil fuels will cause environmental problems such as climate change, global warming and acid rain [1, 2]. According to the statistics released by World Health Organization (WHO), indirect and direct impacts of climate change has led to 160,000 deaths per year and the rate is estimated to double by 2020 [3]. Among renewables, wind and solar are estimated to have the greatest potential [4], with projections often assuming that the resource base provides no practical limitation if adequate investments are forthcoming.

The renewable energy that is going to be used in this project is solar energy. Solar cell made up from semiconductor material such as silicon or germanium. The solar cell is also known as a photovoltaic cell or photoelectric cell. Solar energy is energy which is created from the sunlight or heat from the sun. The utilization of solar energy has traditionally been divided into two fields it is heat energy and electrical energy. Malaysia has abundant sunshine with the average daily solar insolation of 5.5 kW/m2, which is equivalent to 15 MJ/m2 [5].

The power energy and current that produces from the panel depends on the temperature and irradiance of sunlight. The temperature and UV light are not constant from time to time. The operating temperature is increased because a large part of the solar radiation is not converted to electrical but it is absorbed by the panel as heat. When the temperature of the panel increases, the current and power that produces from the panel is decreased. The overall efficiency of the system will decrease due to high temperature of the panel. The power output of solar panel will be reduced by between 0.25% (amorphous cells) and 0.5% (most crystalline cells) for each ºC of temperature rise [6].

This project is conducted to collect the excessive heat energy and remove it. PVT collector is a hybrid collector that generates electric and heat energy simultaneously. Water-based is used as the medium for collecting thermal energy. Propose of work is to create thermal collector to extracted heat from the solar panel thus increasing the overall efficiency of the system. The performance of solar panel with thermal collector and without thermal collector will be analysed based on the data collected.

## 1.2 Problem Statement

A photovoltaic-thermal (PVT) collector is a solar collector that combines a photovoltaic (PV) module with a solar thermal collector, which produces electricity and heat at the same time. The temperature of PV modules increases thus the efficiency decrease. Therefore, in order to overcome these effect, PVT collector will extract the heat in the form of hot water from the PV module and decrease its temperature. Thus, increase the efficiency as well providing heat energy.

## 1.3 Objectives

1) To design and test a PVT system based on heterojunction intrinsic (HIT) panel.
2) To compare the performance of the heterojunction intrinsic (HIT) panel with and without thermal collector.

## 1.4 Project Scope

Sun intensity and solar radiation are difference for each place in Malaysia. This project is conducted in Universiti Sains Malaysia Engineering Campus, Nibong Tebal. 240 W heterojunction intrinsic (HIT) panel was used in this project to test its performance. Water-based thermal collector was used in this project as a cooling unit to reduce the temperature of the solar panel as well as providing hot water. Water in the thermal collector will be circular in close loop system to transfer heat from the solar panel to heat storage. This technique is known as the active cooling system.

This research is carried out by using data logger and hardware setup. The performance of the PVT will be analysed based on the value of voltage, current, power, and temperature of the solar panel that record by the data logger. The performance of the HIT solar panel with and without thermal collector will be analysed. Sensors will be used to measure all the parameters and all the data will be saved in the data logger system developed by using Arduino Uno microcontroller.

## 1.5 Project Contribution

The sun plays a significant role in each of the other types of renewable energy. The most direct use of this renewable energy source, however is achieved by capturing the sun's energy directly through photovoltaics. A variety of solar energy technologies are used to convert the sun's energy and light into heat such hot water and electricity. Photovoltaic (PV) systems use solar cells to convert sunlight into electricity. In this project, the water-based thermal collector system is used. The PVT systems not only removes heat from the panel resulting in cooling down the temperature of the panel but it also produces hot water. The PVT systems provide higher efficiency, higher energy yield and return compared to PV systems. The solar PVT systems can be used to heat buildings by circulating water through flat-plate solar collectors. Commercial and industrial buildings can also leverage the sun's energy for larger scale needs such as ventilation and heating. Finally, thoughtful architectural designs can passively take advantage of the sun as a source of light and heating. Homeowners, businesses, and government entities can take advantage of the benefits of solar power in many ways: Install a home solar system or commercial solar panels; construct or retrofit a building to incorporate a solar hot water or ventilation systems; employ architectural designs for structures that take advantage of the sun's natural attributes for passive heating and lighting. By using solar as renewable energy, it does not produce harmful radiation.

## 1.6 Project Outline

This thesis has five main chapters that describe all the information, data, and details on this project. Chapter 1 is an introduction that covers the background of the project, problem statement, objective, and project scope. This chapter provides the basic knowledge of this project.

Chapter 2 is an overview of the solar energy and the explanation about the working principle of solar cell, the type of solar cell, and factor that affects the efficiency of the solar panel.

Chapter 3 explains the methodology that is implemented on this project. The methodology explained about hardware development, designing thermal heat collector, selection of components, current sensor, voltage sensor, and calculation.

Chapter 4 contains a detailed discussion of individual components of the thermal heat collector, solar panel temperature, water temperature and output power. This chapter represents the result and discussion of the project. The performance of the solar panel was discussed in this chapter.

Chapter 5 represent the conclusion of the whole projects and recommendation for the future improvement.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

Photovoltaics (PV) solar system is often called, semiconductor devices that convert sunlight into direct current (DC) electricity and bring about environmental benefits such as greenhouse gas (GHG) and pollution reduction [7]. A life span of PV system is expected of 20 years or more.

Solar energy consists of light and heat from the Sun, it is harnessed using various progressing technologies such as solar heating, solar photovoltaic, solar thermal electricity, solar fuels, solar architecture and artificial photosynthesis [8]. The most popular application of solar energy is through the photovoltaic (PV) systems [9].

A typical silicon PV cell is composed of a thin wafer consisting of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type) silicon. An electrical field is created near the top surface of the cell where these two materials are in contact, called the P-N junction.

Energy independence and environmental compatibility are two attractive features of PV systems. At present, the high cost of PV modules and equipment as compared to conventional energy sources is the primary limiting factor for the technology. The research and development in PV system are needed to make PV system has high efficiency and cost-effective.

## 2.2 Working Principle of Solar Cell

The process of a solar cell converts light energy to electricity is called the photovoltaic effect. Some of the photons of the light ray will be absorbed by the semiconductor crystal when the solar cell is exposed to sunlight and break apart the electron-hole resulting free electrons. The electron created in the p-region reaches the p-n junction, it will cross to the n-region and accumulate with other electrons. The same process happens in reverse for the holes created in the n-region and the effect is a voltage build-up across the p-n junction [10]. Power can be extracted from the solar cell by connecting the p-region to the n-region to an external circuit.

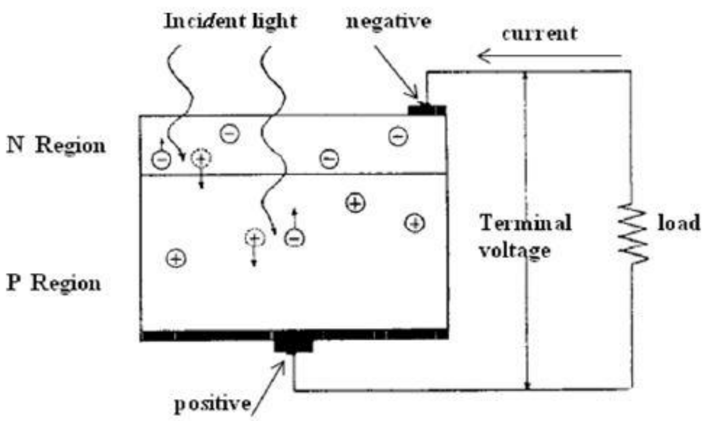



Figure 2.1: Solar cell connected with load [10].

## 2.3 Type of Solar Cell

Solar cell made up from the semiconductor material such as silicon or germanium. The solar cell is also known as a photovoltaic cell or photoelectric cell. An atom of silicon has 14 electrons and its outer shell has 4 electrons. The semiconductor of solar cell has two difference layer that is combined together. P-type layer of the semiconductor has doped with the trivalent element and has an excess amount of hole. N-type layer of the semiconductor has doped with the pentavalent element and has an excess amount of electron.

### 2.3.1 Monocrystalline Solar Cell

Monocrystalline cells are made out of silicon ingots, which are cylindrical in shape. Czochralski process is used to produce monocrystalline silicon. This type of material has been widely used in developing PV cells due to its high efficiency compared to polycrystalline cells by 15%. Among another type of solar cell material, the monocrystalline solar cell has the highest efficiency with more than 20% but for commercialization, the efficiency claim from the manufacturer is normally lying between 15% and 17% [2].

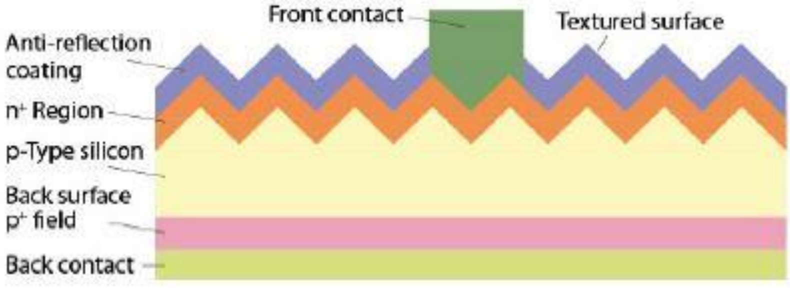



Figure 2.2: Simplified cross-section of a commercial monocrystalline silicon solar cell [11].

### 2.3.2 Polycrystalline Solar Cell

Polycrystalline cells are the most commonly used because it is not expensive. However, its efficiency is low compared to monocrystalline cells and other developing materials [12]. Polycrystalline solar panels do not require the Czochralski process. The polycrystalline cell has low flaws in metal contamination and crystal structure compared to monocrystalline cell [13]. Raw silicon is melted and poured into a square mold, which is cooled and cut into perfectly square wafers. The solar cell's efficiency is up to 17.37% and solar module efficiency is up to 14.62% [14].

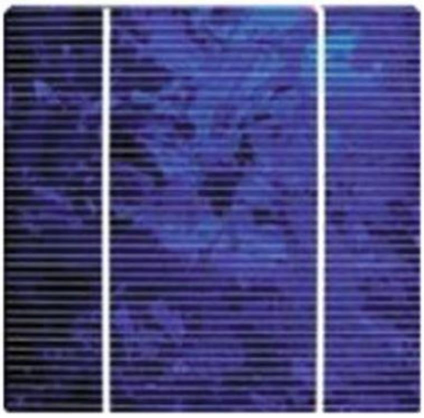


Figure 2.3: Front view camera image of a typical polycrystalline solar cell.

### 2.3.3 Thin-film Technology

Compared to solar cells that are based on crystalline silicon, thin-film technology is less expensive since it uses few materials and less manufacturing process. Thin-film technology depends on the type of material used to dope substrates such as metal, polymers or glass. An example of thin cells is cadmium telluride, copper indium gallium and amorphous silicon.

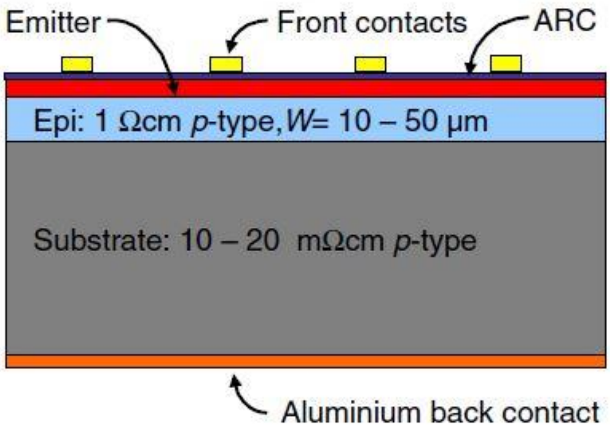



Figure 2.4: Structure of thin-film solar cell [15].

### 2.3.4 Amorphous Silicon

Amorphous silicon is very popular compared to other thin film material due to its efficiency. One of the attractive features of α-Si is that it is a direct band gap material, which allows a significant fraction of sunlight to be absorbed within a thin layer of a few micrometres [16]. This solar cell is used mainly in low power equipment such as calculator, watches and fan.

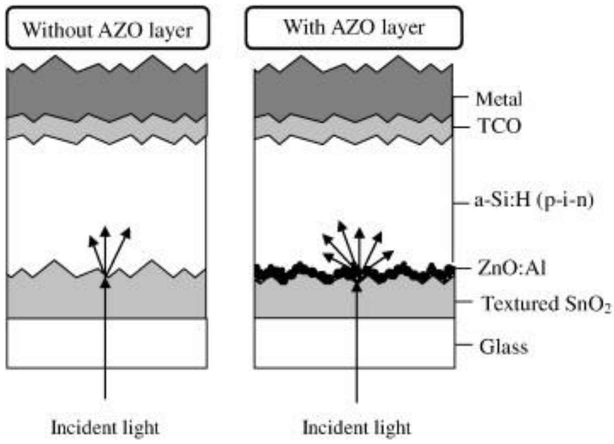



Figure 2.5: Light scattering mechanism of the amorphous silicon solar cells without aluminium-doped zinc oxide, AZO (left) and with AZO (right) thin film [17].

## 2.3.5 Heterojunction with Intrinsic Thin Layer (HIT) Solar Cell

In the HIT solar cell structure, an intrinsic a-Si:H layer followed by a p-type a-Si:H layer is deposited on a randomly textured n-type CZ c-Si wafer to form a p/n heterojunction. Presently, the conversion efficiency of the standard HIT solar cell has reached a level of 23% for a $100.4\text{cm}^2$ practical size crystalline silicon substrate [18]. Higher $V_{OC}$ provides a high conversion efficiency and a better temperature coefficient, which is comparable to amorphous silicon solar cells.

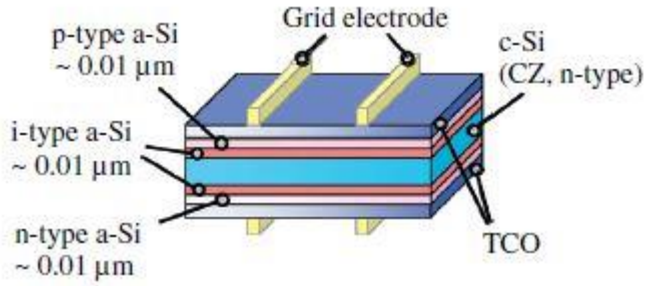



Figure 2.6: Structure of a HIT solar cell [18].

## 2.4 Factors That Affects The Efficiency of Solar Panel

The solar panel efficiency is the percentage of sunlight hitting the panel gets turned into electricity. Solar energy output is also affected by weather, seasonal variations and the angle of the sun to the solar panel changes with the time of day. The temperature of the solar panel also contributes to less effectiveness of the sunlight collection.

### 2.4.1 Temperature

One of the most important factors that play an important role in the efficiency of the PV panel is the temperature. A photovoltaic panel temperature reduction would lead to an increase in efficiency. High-temperature causes drop in voltage and power. High-quality panel is designed to maintain performance in high temperature. Low-quality panel loses efficiency and produce less energy.

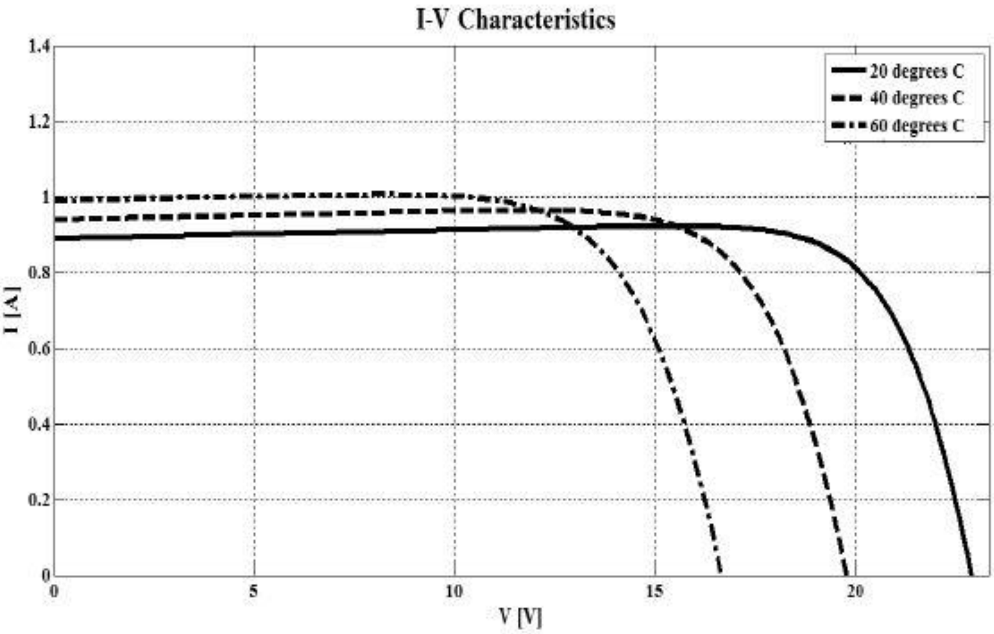



Figure 2.7: I-V characteristic at various temperature [19].

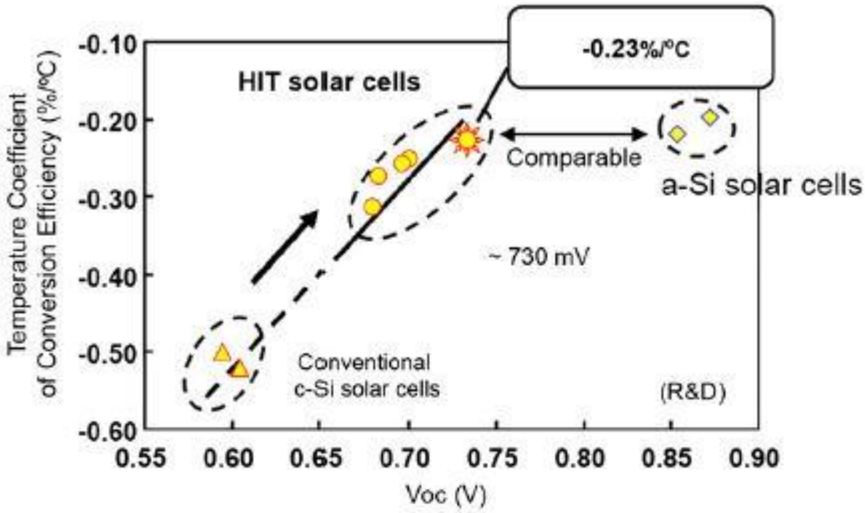



Figure 2.8: Temperature coefficient of the conversion efficiency of HIT solar cells [18].

### 2.4.2 Sun Intensity

Photovoltaic efficiency increases with increasing irradiance (up to a design specific limit) [20]. Irradiance is an amount of light intensity that reaches the solar cell. The light intensity can affect the parameter taken such as Ioc, Voc and the efficiency. The higher the light intensity, more electrical energy produced.

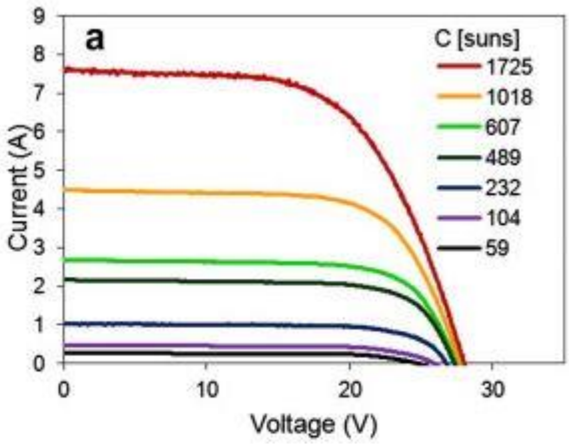



Figure 2.9: I-V curves of solar panel under various sun intensity [21].

## 2.5 Combined Photovoltaic – Thermal

Photovoltaic-thermal (PVT) technology refers to the integration of a PV module and a solar thermal collector in a single piece of equipment. Most of the incident solar energy is converted into heat, causing an increase in the cell's temperature. By cooling the PV module with a fluid stream like air or water, the electricity yield can be improved. At the same time, the heat pick-up by the fluid can be used to support space heating or service hot-water systems. The PVT system can reduce the heat loss from the collector when the solar cells act as selective absorbers [22].

### 2.5.1 Liquid Collector

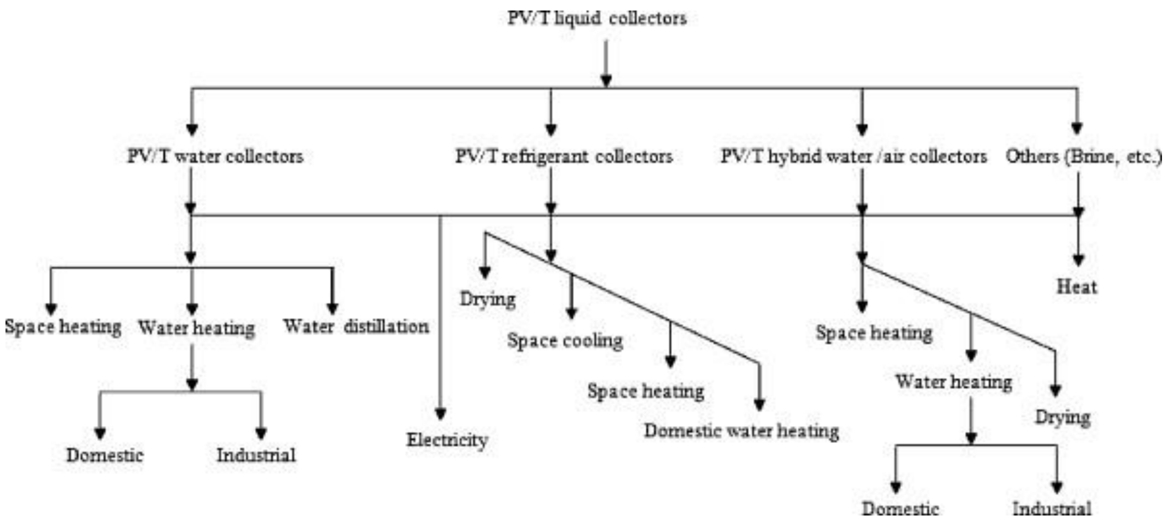



Figure 2.10: A classification of PVT liquid-based collectors [23].

Figure 2.10: shows that the PVT liquid collectors consists of water collector, refrigerant collector, hybrid water/air collector and others. Most of the PVT liquid collector is used in space heating, water heating and drying.

Natural or forced air circulations are simple and low-cost methods to remove heat from PV modules but they are less effective if the ambient air temperature is over 20°C [24]. To overcome this effect, the heat can be extracted by circulating water through the collector. A water-based PVT system is able to achieve a higher overall energy output per unit collector area. Water absorbs light mainly in the infrared region and thus is compatible with PV modules using shorter wavelengths in the solar radiation spectra for its conversion to electricity [25].

The solar collector serves as an evaporator where the refrigerant absorbs thermal energy from solar radiation [26]. A PVT system, which applies a coolant onto the solar cells, can override such a limitation by bringing down its operating temperature and re-utilizing the captured heat energy. The refrigerant as the working fluid at the solar collector undergoes phase change at a relatively low temperature. The energy conversion efficiency is therefore improved [27].

### 2.5.2 Air Collector

The performance of the PVT air collectors has been paid much attention by researchers. The performances of single-pass and double-pass combined photovoltaic thermal collectors were analysed with steady-state models. The double-pass photovoltaic thermal collector had superior performance over the single-pass photovoltaic thermal collector. The thermal, photovoltaic and combined efficiencies were 24-28%, 6-7% and 30-35% for the single-pass photovoltaic thermal collector. The thermal, photovoltaic and combined efficiencies were 32-34%, 8-9% and 40-45% for the double-pass photovoltaic thermal collector [28].

A theoretical model of a direct-coupled PVT air collector with a thin aluminium sheet suspended in the middle of air channel was developed. It was concluded that thermal efficiency increased with increasing the air mass flow rate due to increased heat transfer coefficient. The results also indicated that setting glass cover on photovoltaic panels leads to an increase in thermal efficiency and decrease in electrical efficiency of the system [29].

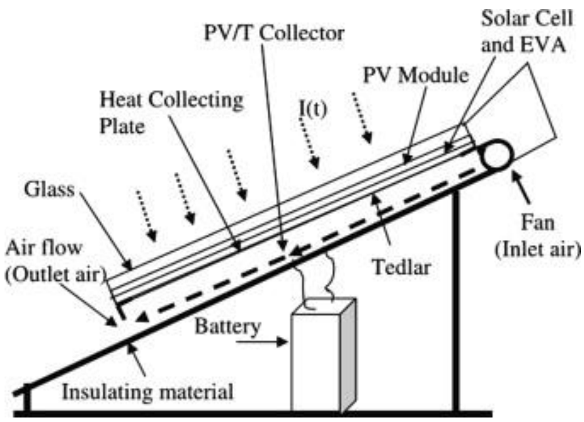



Figure 2.11: A schematic diagram of a PVT air collector [30].

## 2.6 Summary

This chapter explained about the working principle of solar cells and a few types of the solar cells. The heterojunction with intrinsic thin layer (HIT) will be used in this project. There are a few factors that affect the efficiency of the solar panel. First is the temperature of the panel and second is the sun intensity. The air collector and liquid collector were briefly explained in this chapter. Air circulations are simple and low-cost method but it is less effective if the ambient air temperature is over 20ºC. A water-based PVT system is able to achieve a higher overall energy output per unit collector area.

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

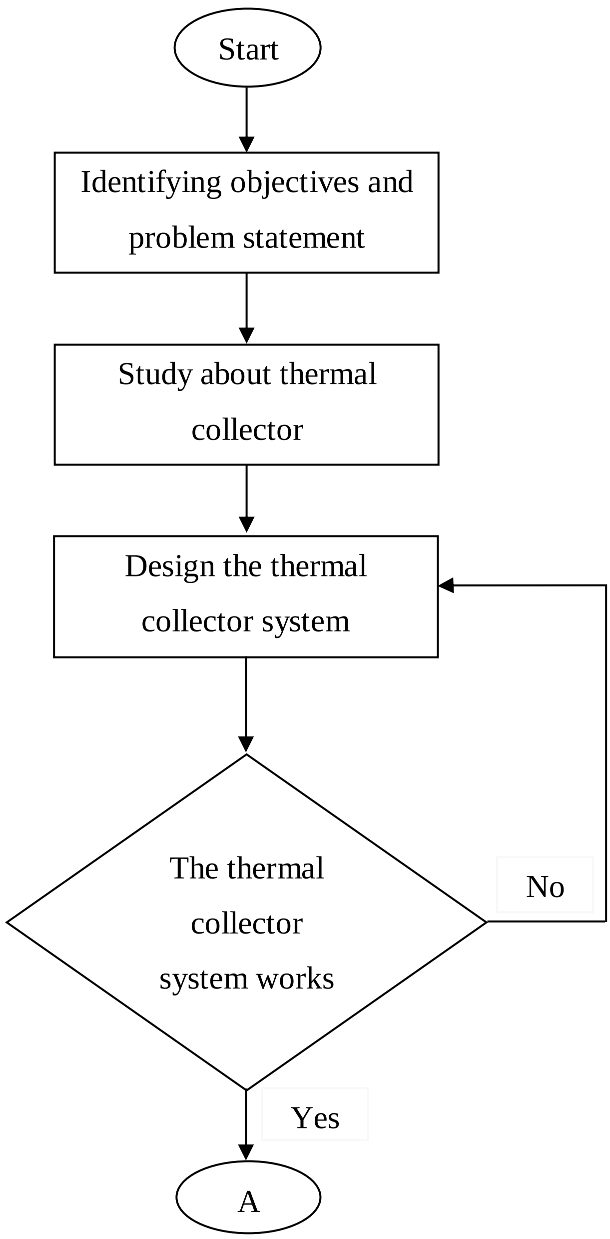
This chapter describes the hardware, software, method and process that applied in this project to achieve the objectives. All details on how the project has been conducted are discussed in this chapter. The project was composed of a solar PV module of the 240W HIT solar panel that are combined with solar thermal collector. Water-based is used as working fluid to cool the panel and to extract the excess heat of solar panel.

Microcontroller data acquisition for the PVT system will be made up by using Arduino Uno and three types of sensor. The values of the voltage, current, power, photovoltaic panel operating temperature and light intensity will be stored in the data logger. The performance of solar panel with and without thermal collector will be analysed based on the data saved in the data logger.

## 3.2 Project Implementation Flow

The first step to conduct this project is identifying the objectives and problem statement. All the method and process that carry out is to meet the objectives of this project. The study about the thermal collector has been done. The thermal collector is a process produces heat energy from sunlight. The thermal collector is designed using copper pipe and aluminium sheet. Data acquisition is created to measure voltage, current, power, temperature and light intensity.

The data logger is set up to collect all the data for analysing the performance of PVT solar panel. When the hardware and software are complete, the whole system of PV thermal collector is set up to test the performance. The last step is making a conclusion about the performance of both solar panels. Figure 3.1 shows the flowchart of this project.



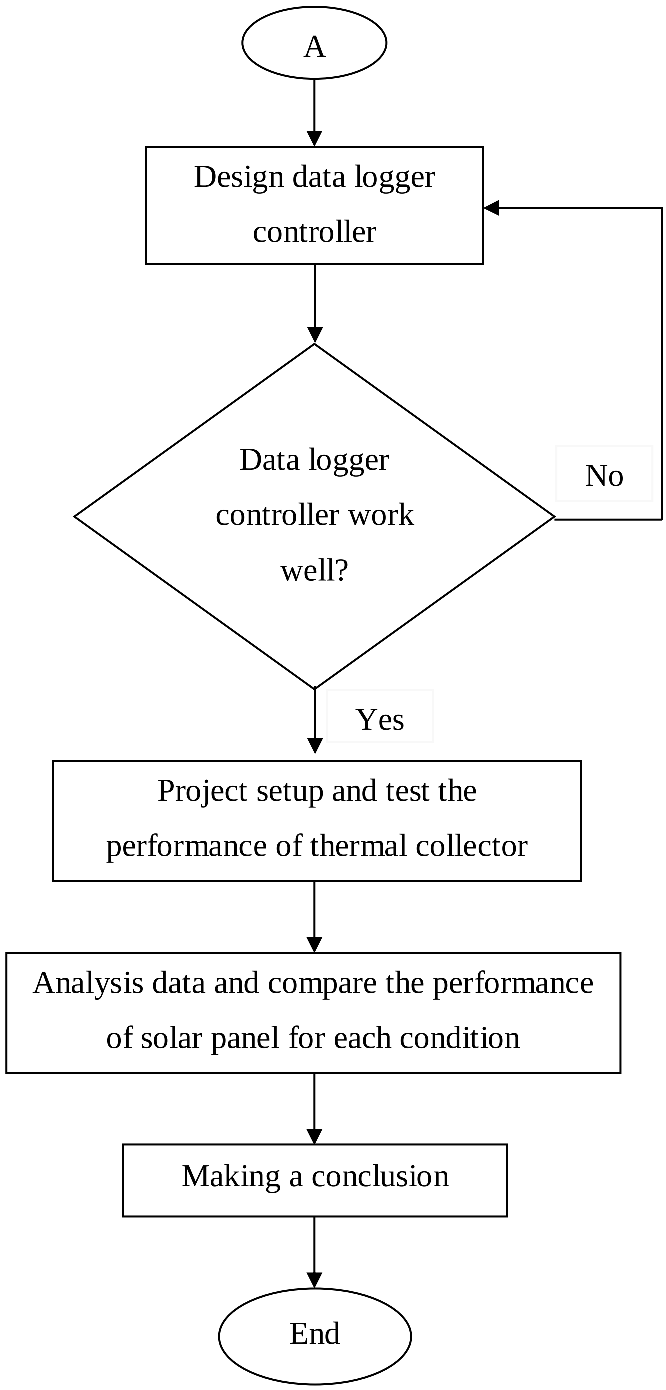



Figure 3.1: Flowchart from the beginning until the end of the entire project.

## 3.3 Project Requirement

Hardware is used in this project to design and build water-based thermal collector system. Software is used to design data logger circuit. All the project requirements have been selected based on the application in industry or used by many researchers.

### 3.3.1 Software

The software is used in this project is Arduino (IDE) software. This software is used to write the data logger coding and upload it to the Arduino board. The electrical measured by the sensor will be automatically saved in micro SD card.

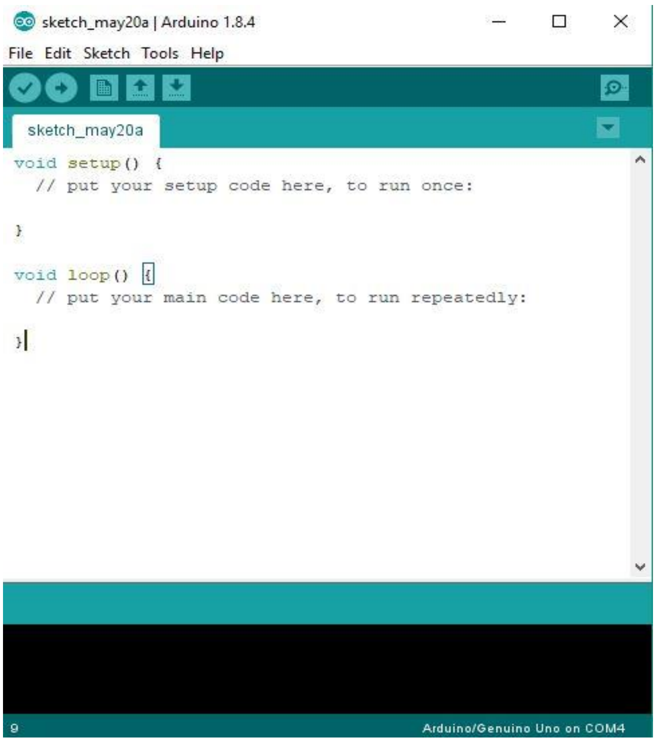



Figure 3.2: Arduino program interface.

### 3.3.2 Hardware

Hardware is used to design and build thermal collector system that combined with the solar panel. The hardware is used to flow the water and to transfer heat from solar panel to the water storage. The hardware used are listed below:

#### 3.3.2.1 Aluminium Sheet

Figure 3.3: Aluminium sheet as a heat absorber.

Aluminium sheet will be used to absorb heat at the back of the solar panel and transfer the heat to copper pipe. It can absorb and transfer more heat to water through copper pipe due to its large surface. Besides, aluminium also is a good thermal conductor material.

### 3.3.2.2 Copper Pipe

Figure 3.4: Copper pipe as a heat absorber.

Copper pipe is used to flow water and absorb heat from the aluminium sheet and transfer the heat to water. Copper pipe is stick together with aluminium sheet. The length of the copper pipe is 15 metres, the diameter is 3/8 inches or 9.52 mm and the thickness is 2.55 WG or 0.51 mm.

### 3.3.2.3 Polystyrene Sheet

Figure 3.5: Polystyrene sheet will be placed in between the copper pipe.

Polystyrene sheet will be placed in between the copper pipe to prevent heat loss. The polystyrene sheet is made of trapped air bubbles that prevent heat energy from flowing through it.

### 3.3.2.4 Perspex

Figure 3.6: Perspex will be put at the back of solar panel.

Perspex is used to ensure the copper pipe and aluminium sheet stick together with the solar panel. Perspex will be used to support the overall position of solar thermal collector system.

### 3.3.2.5 Water Pipe

Figure 3.7: Water pipe to flow the water.

The water pipe is used to flow the water from water storage to copper pipe. The water pipe also acts as a connector between copper pipe and heat storage. The water pipe is connected to the water pump to flow the water in circulations.

### 3.3.2.6 Heat Exchanger

The heat exchanger will be made up from the copper pipe. The heat exchanger is a wound coil of copper carrying hot water that heats water inside the water tank. Cold water in the water container and hot water will be pumped through the heat exchanger. The heat that absorbed from solar panel will transfer to water tank through the heat exchanger.

### 3.3.2.7 Plastic Ice Box


Figure 3.8: Plastic ice box as water tank to store hot water.

Heat from solar panel will transfer water to water tank through the heat exchanger. The heat exchanger will be placed in this water tank. Plastic ice box will be used to avoid ambient temperature or direct sunlight heats water in water storage. It contained 6.0L of water.