THE MATHEMATICAL MODEL OF PHOTOVOLTAIC ARRAY IN MATLAB/SIMULINK

NURLIYANA BINTI RADZALI

BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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NURLIYANA BINTI RADZALI

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in partial fulfillment of the requirements for the degree of
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2019

DECLARATION

I declare that this thesis entitled “THE MATHEMATICAL MODEL OF PHOTOVOLTAIC ARRAY IN MATLAB/SIMULINK is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

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APPROVAL

I hereby declare that I have checked this report entitled “THE MATHEMATICAL MODEL OF PHOTOVOLTAIC ARRAY IN MATLAB/SIMULINK” and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Electrical Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

Alhamdulillah, I have completed this project as planned. Firstly, I would like to express gratitude to Allah for His grace the consent and aid until I have finished this project.

During preparing this report, many people was contributed toward my understanding. In particular, I wish to express my sincere appreciation to my supervisor, Encik Mohd Saifuzam Bin Jamri for encouragement, guidance critics and friendship. I very appreciate his advice, valuable time and ideas in completion this report. Without his support, this project would not have been same as presented here.

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Lastly, thank you for all hand and heart that help me made this project. Without any assistance, I cannot completion this project as planned.

ABSTRACT

Photovoltaic (PV) is a material that can convert the solar energy from sun into electrical energy. The PV array may consists of multiple connected modules to form the PV generating system. This project proposed an approach to model and simulate the photovoltaic array. The photovoltaic module was modeled by using combination of circuit and mathematical technique. The interconnected of PV module in series or parallel will formed the PV array which yield the higher operating point in I-V and P-V characteristic curve. The modeled PV arrays was validated with multiple solar irradiant and ambient temperature input conditions.

ABSTRAK

Photovoltaic (PV) adalah bahan yang boleh menukar tenaga matahari dari matahari menjadi tenaga elektrik. Array PV mungkin terdiri daripada pelbagai modul yang disambungkan untuk membentuk sistem penjanaan PV. Projek ini bertujuan untuk memodelkan dan mensimulasikan array fotovoltaik. Modul fotovoltaik dimodelkan dengan menggunakan gabungan litar dan teknik matematik. Sambungan modul PV siri atau selari akan membentuk array PV yang menghasilkan titik operasi yang lebih tinggi dalam lengkung ciri I-V dan P-V. Array PV yang dimodelkan telah disahkan dengan pelbagai keadaan input iradiasi suria dan ambien.

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LIST OF SYMBOLS AND ABBREVIATIONS

PV	-	Photovoltaic
FYP	-	Final Year Project
I-V	-	Voltage vs current
P-V	-	Power vs voltage
I	-	current
V	-	Voltage
MATLAB	-	Matrix laboratory
Ø or G	-	Irradiance
T	-	Temperature
N_s	-	Number cell in series
N_p	-	Number cell in parallel
R	-	Resistance
I_{ph}	-	Photovoltaic current
q	-	Electron charge
IEEE	-	Institute of Electrical and Electronic Enginering

CHAPTER 1

INTRODUCTION

1.1 Overview

Chapter one explained about the introduction of this project. This chapter is divided into subtopic which described about the motivation and formulation of problem statement, objective and scope of project.

1.2 Project Background

Photovoltaic (PV) is a semiconductor material that can convert the light to electricity[1]. The light has come directly from sunlight. The material is absorbed proton and released electron is known as a photoelectric effect. The effect can be considered the prerequisite and essential sustainable resource among renewable energy. This is because it's produced solar irradiates that can be sustainability, ubiquity, and abundance. Electric current came from the free electron. The cell recharged the battery when direct current electricity is produced. Edmond Becquerel, in 1829, French physicist has noted the effects of photoelectric. He found the material that can produced the small electric current when there is light existed. Bell Laboratories in 1954 is the first-person who created the photovoltaic module. The module is known as a solar battery and too expensive. The industry began in the 1960s, to make the first technology that provides power aboard spacecraft. The space program was established and the cost decline. At long-term, the future economic increase depends on the affordable portable operation also the energy from a renewable source. Wind energy and solar energy is the utilization of the prime energy source. The portable operation are also the advantages connecting the number of solar cell that is connected [2].

A photovoltaic module is the connecting the number of the solar cell. The design of module followed by the certain voltage and current. PV generator system of the fundamental power unit represented by PV module. The solar irradiance, output voltage, and temperature cell effect the output of the PV module characteristic. The multiple modules can from an array by connecting wire together. More electricity can produced when the large module array created. The array of PV module can be arranged in series and parallel by the combination of voltage and current. Photovoltaic can produced two type of module. The first module is crystalline silicon (c-Si) PV module. Crystalline silicon can produce two type of PV module in single crystalline (monocrystalline silicon) and polycrystalline silicon (multi-crystalline). Both c-Si module have high efficiencies about 10 percent to 12 percent. Amorphous silicon (a-Si) is the second module of PV and it have efficiency around 6 percent. This module is made thinner than crystalline silicon and it can absorbed more light energy from the sunlight.

To enable researchers to have a great understanding of photovoltaic working, the mathematical modelling of PV module has continuously created. The simulation MATLAB is used to develop PV models. The data of voltage, solar irradiation and temperature in the study of (Walker 2001) and (Gonzalez-Longatt 2005) has been developed in MATLAB to calculate the current output. Figure 1 show the photovoltaic panel model.

Figure 1-1: Photovoltaic Model

1.3 Motivation

Photovoltaic is a material that has an ability to convert the solar irradiance from sun into an electrical energy. It is play an essential role in an electrical power grid. However, in order to consider this renewable energy source in the network model, it is important to understand its characteristic and describe its behavior in mathematical equation. This project proposed a technique to model the PV using combination between circuit and mathematical approach. By applying several parameters stated in the manufacturer datasheet, the proposed PV model yields the I-V and P-V characteristics curve with follow the manufacturer specification.

1.4 Problem Statement

Analyzing the PV system through mathematical model is the simplest way because it only require the simulation software instead of costly hardware. The hardware model needs a larger space to create a single PV module. The equipment for the model of PV systems such as real sensor are difficult to handle and require complicated data communication. Furthermore, the PV array has nonlinear characteristics and its operating power under varying irradiance and temperature conditions gives the larger results. To overcome this problem, the model of solar panel and array has been developed and integrated in the common engineering software. This project is conducted in MATLAB Simulink software.

This project focuses on developing the mathematical model for PV array which consist of a combination of multiple PV module connected in series and parallel. The performance is analysed in terms of output power and output voltage under the variations of solar irradiance and ambient temperature.

1.5 Objective

The objectives of this project are:

a) To develop the photovoltaic modelling equation using Simulink.

b) To study the combination of photovoltaic array model.

c) To observe the effect of photovoltaic model in terms of output power and voltage towards the variations of irradiance and temperature

1.6 Scope

This project is will focus on the standard mathematical equation of photovoltaic module using Simulink in MATLAB. Next, the photovoltaic array consist of five interconnected modules.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discussed on the basic of photovoltaic with the operation of cell and the different characteristic of the type module. Furthermore, the mathematical equation of photovoltaic and the type of resistance will affect the modelling demand also included in chapter 2. The advance information research about photovoltaic modelling will study further.

2.2 Basic of Photovoltaic

A photovoltaic or solar cell is created to convert the solar radiation energy into electrical energy for electrical load and the other electrical system. Photovoltaic (PV) array is assembled from PV modules that change the light energy from sunlight to direct current (DC). The array is often mounted on building or set up in open space. The more cell is used more electricity is generated. The electricity can use to run appliances such as a heater, toaster and fan until the sun goes behind the cloud. A more practical idea connects the PV array with the batteries. The energy stored in the batteries is commonly used in stand-alone system, but only design for the grid-tied system. There are many ways to use this technology. Figure 2.1 shows the energy conversion of the PV system on its application.

Photovoltaic (PV) cells is often used to supply power, such as streetlights and building. It's also often used in conjunction with other electricity sources. Arrays for large-scale power generation can be huge in solar farms. The most PV cell is silicon based. Silicon has chosen for its semiconductor potential. The silicon wafer is very thin.

The fundamental power conversion unit of a photovoltaic system is represented by PV module. The characteristic of the photovoltaic output depends on the solar irradiance and cell temperature [3]. Since the photovoltaic module characteristic is non-linear, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for photovoltaic system. Figure 2 1 shows the operation of Photovoltaic system. PV array absorbs energy from sunlight and converts to electrical energy for load.

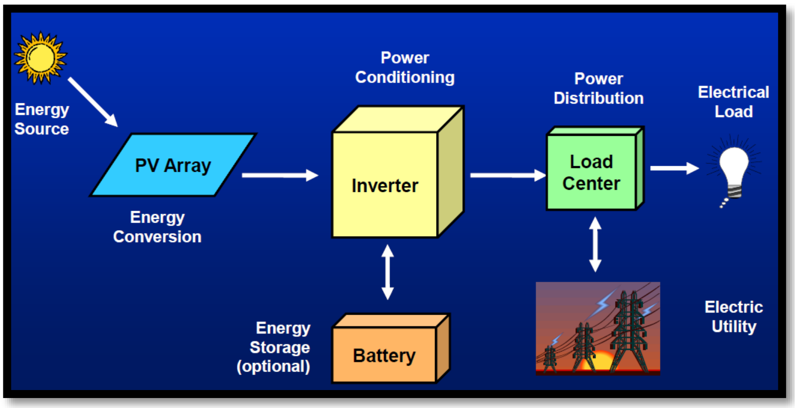


Figure 2-1: Photovoltaic system

2.2.1 Operation of Photovoltaic

The phenomenon of light energy generating electrical energy is called the photovoltaic effect. When the light was exposed in a semiconductor material, free electron will absorb and create electricity[2]. Photovoltaic effect utilized light energy to electricity system. The system is a basic unit of a photovoltaic cell. Photovoltaic cell is conducted by silicon and generate electricity used the Michael Faraday's principle of a magnet spinning of wire. The atom in photovoltaic cell is bonded together and produce covalent bond. The electron in atom produces a negative charge and the proton from the nucleus of atom carried the positive charge. The energy move randomly inside the atom of silicon. These moving electrons produce a current of electricity. This electricity can be used for a load, such as a hair dryer. The current generates is depends on how much light strikes the PV module.

Photovoltaic system operation is same like other electrical power. The equipment uses are better for conventional electromechanical generating system[3]. A PV array system needs other components to properly conduct, control, convert, distribute, and store the energy produced when it produce energy from sunlight. The operational and functional requirements are depending on the system. DC-AC power inverter, battery bank, system and battery controller, auxiliary energy sources and the specified electrical load is included in the system requirement.

For the purpose of storing energy produced by the PV array, batteries usually use during the night and cloudy weather. The batteries also use of the PV array operate near its maximum power point and it can control the voltage and current to electrical load and inverters. To keep the battery from overcharge and over discharge, a battery charge controller is used in systems.

2.2.2 The Photovoltaic cell effect

The photovoltaic effect is the process to expose the electromagnetic radiation[4]. The proton energy in a semiconductor material moves freely and generates the electricity. The motion of light through a wave and difference type of radiation are characterized as the individual wavelength. A frequency and an energy are matched up with the solar spectrum for each wavelength. A PV device created the amount of the electricity depends on the efficiency of device and solar radiation.

2.2.3 Cell, module and array

Photovoltaic cell produce the higher power, voltage and current. It is connected in series and parallel or both of position. The modules of photovoltaic consist of larger photovoltaic cell group and make the block of photovoltaic systems. The photovoltaic panel is a combination of one or more photovoltaic modules. The PV modules are gathering the electricity and mechanically to produce the power of DC. The complete power-generating unit consists of photovoltaic modules and panel is called photovoltaic array. An array is designed to construct a specified electrical output. Photovoltaic modules and array have rated under Standard Test Condition (STC). It is 25º C of temperature, 1000 W/m2 of solar irradiance level and 1.5 spectral under air mass. The usually actual performance of photovoltaic is around 85 to 90 percent[5]. The service lifetime of photovoltaic is 20 to 30 years. Figure 2-2: Photovoltaic cell, module, panel, array This figure shows a combination of photovoltaic cells to form a photovoltaic array[6].

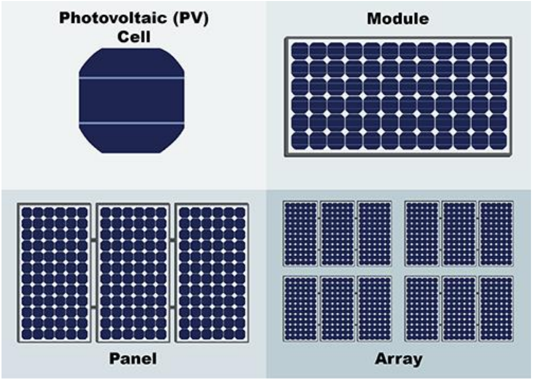


Figure 2-2: Photovoltaic cell, module, panel, array

2.3 Type of Photovoltaic cell

2.3.1 Monocrystalline Silicon Cell

This is the first type of solar cell, made from the pure silicon. These cell has a single crystal lattice structure. Monocrystalline can convert the energy from the sun to electricity around 15% and it's more efficient technology[7]. The manufacturing process of this cell is complicated and high cost. Figure 2-3: Monocrystalline cells in a solar panel shows the description of the monocrystalline cell in a solar panel.

Figure 2-3: Monocrystalline cells in a solar panel

2.3.2 Polycrystalline Silicon Cell

Polycrystalline or Multicrystalline cell is a single uniform crystal structure. It is made from molten silicon that is formed into a cube shape. Polycrystalline form is cut and packaged similar to monocrystalline cell. The manufacturing process of polycrystalline is simpler and cheaper than monocrystalline but it is less efficient. Figure 2-4 show the comparison monocrystalline and polycrystalline.

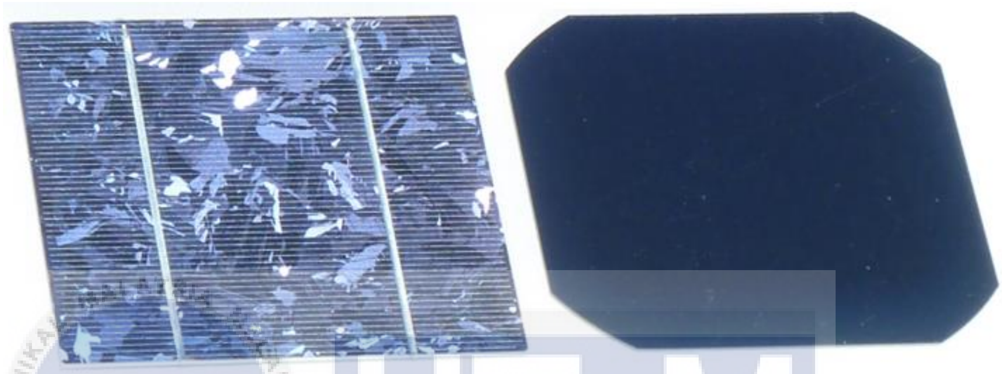


Figure 2-4: The comparison of polycrystalline silicon (left) and a monocrystalline silicon cell (right)

2.3.3 Thin Film

Thin film cell are more flexible, durable and thinner than crystalline cell. Amorphous silicon (a-Si) is a type of thin film cell, it makes from the depositing of the silicon layer to the glass substrate. It is cheaper and thinner produce because of the less raw material needed. Amorphous silicon is ideal for the curved surface. However, it is less efficient than crystalline. The combination atom are not stabile and easy inactive into electricity. The first month of use, the cell will reduce the efficiency around 20% before it stabilizes.

Copper indium gallium diselenide (CIGS) and cadmium Telluride (CdTe) are also the type of thin film cell. It requires extra precaution during manufacture, it is because this cell contains the rare and toxic element. This type is more efficiency that offer in technologies than the amorphous silicon.

2.4 Types of Photovoltaic system

Photovoltaic system has two main type. There are grid-connected (grid-tied) and off-grid (stand-alone) system[8].

2.4.1 Grid-connected solar PV system

This system are used in Singapore because they are covered by the national power grid. Most of the PV system are placed on building and mounted on the ground. For building, they are installed on the roof. Building Integrated Photovoltaic (BIPV) is known as the latter and usually displace the PV module to another building component. For examples is window glass or wall cladding.

A building has 2 parallel of power source. There are from the power grid and the photovoltaic system. The load are combined power source to the main ACDB in following figure.

The power grid and photovoltaic supply ratio are varied and depending on the size of the photovoltaic system. When the PV supply are pass in the building's demand, the electricity will excess into the grid. The power grid will supply electricity into the building when there no light energy from sunlight. A grid-connected system can be functional to improve the environment and reduce on utility power. Figure 2-5 show the grid-connected configuration.

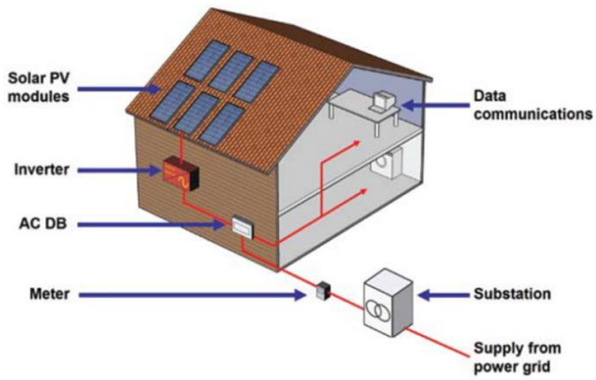


Figure 2-5: Grid-connected configuration

2.4.2 Off-grid solar PV system

This system are applicable for the area without power grid. They usually installed at the inconvenient area. An off-grid system needs deep rechargeable batteries to store electricity. This system are used under condition where no supply input from the PV system[8]. Figure 2.6 shows the off-grid system.

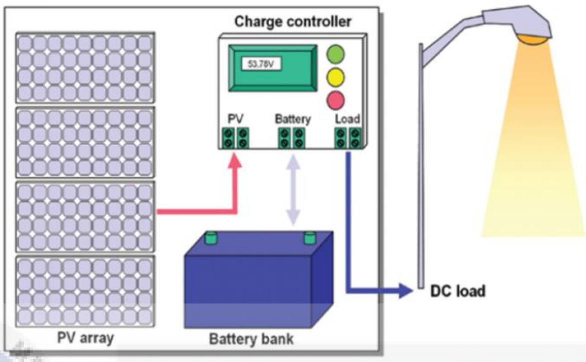


Figure 2-6: Off-grid system configuration

2.5 Photovoltaic Array

A group of several photovoltaic cells is combined to form a photovoltaic array which is electrically connected in series and parallel circuits. When the photovoltaic module combine to form a photovoltaic array, it can produce home or business needs. The use of inverters in most PV arrays is to convert the DC power generated by the modules into alternating current [9]. This scenario can turn on lights, motors, and other loads. The photovoltaic panels usually estimate under STC (standard test conditions) or PTC (PVUSA test state), at watts. The usual range of operating panel rating is less than 100 watts to more than 400 watts. The panel's total rating, in watts, kilowatts, or megawatts is comprised of various Photovoltaic assessments.

The output PV performance will depend on solar cells and array designs. Parallel cells Np and Ns are arranged in the same circuit for the photovoltaic array module shown in figure 2-7. The operating characteristics of the solar cell I-V are shown in Figure 2-8. Characteristics can be determined by multiplying the individual cell's voltage by the number of cells connected in the series and multiplying the current by the number of cells that are connected in parallel. Open circuit voltage, short circuit current and Maximum Power Point (MPP) are three important operating points used in PV modules[10].

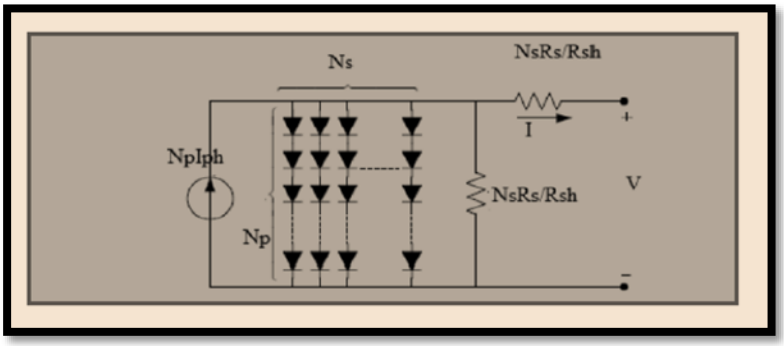


Figure 2-7: Equivalent circuit of solar array

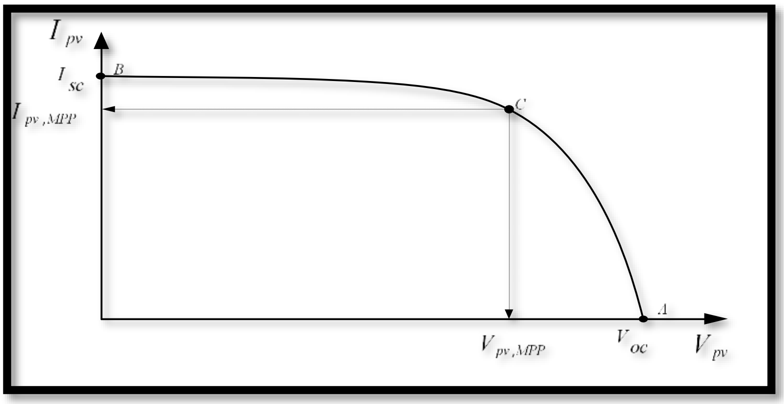


Figure 2-8: PV-cell operating point

2.5.1 Connecting of Photovoltaic Array

Photovoltaic connectivity has several options available parallel, series, or a combination of both. The parallel circuit generates the current path. The current will flow through this circuit without ignoring damage. Circuit connections are always used in electrical wiring. When the solar panel wiring is parallel, the current is additive, but the voltage remains the same[11]. Figure 2-9 shows a parallel panel connection of photovoltaic array model.

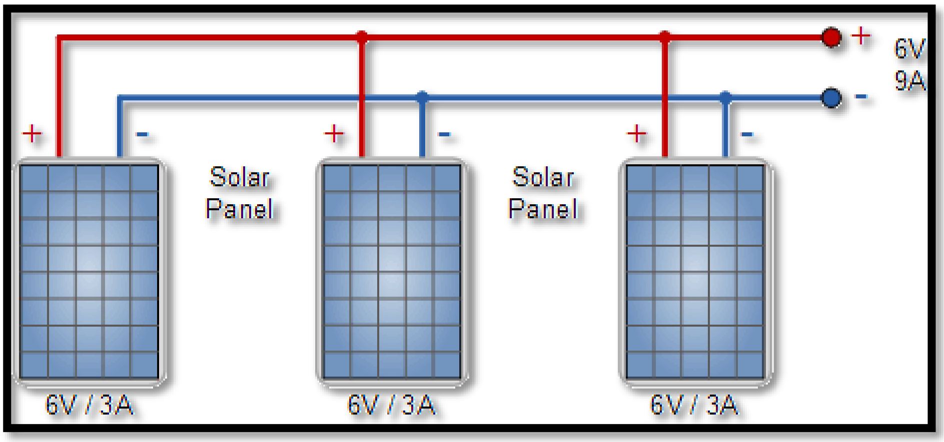


Figure 2-9: PV panel in parallel connection

In the series wiring, the current only flows in one direction. The current will go through all the load. The series circuit is known as a continuous closed loop. If a panel is not operating it will determine that all the load in the circuit also cannot operate. The solar panel in the series increases or the total voltage generated by each individual panel, giving the total output voltage of the array. Figure 2-10 shows a PV panel in series connection.

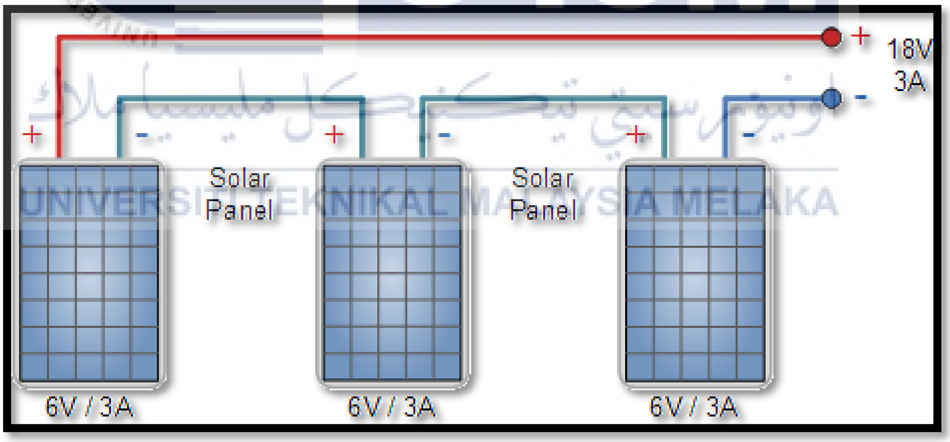


Figure 2-10: PV panel in series connection

2.6 Mathematical Model Of Photovoltaic

2.6.1 Equation Of Photovoltaic Cell

There are many types of mathematical modelling of a photovoltaic cell. The first modelling module is to define a simulation circuit process for PV cell in the interaction of the power converter.

Figure 2-11 (a) and (b) is the equivalent PV circuit using the single diode and the two diode parallel with a current source[12]. Four components are used in a single diode model. It is photo-current source, shunt resistor Rsh, series resistor Rs, and single diode connected parallel to source. Two diode model shows in Figure 2-11 (b). The model has an extra diode will produce the better curve-fitting. The Figure 2-11 (c) shows the simplified equivalent circuit model from Figure 2-11 (a) and (b).

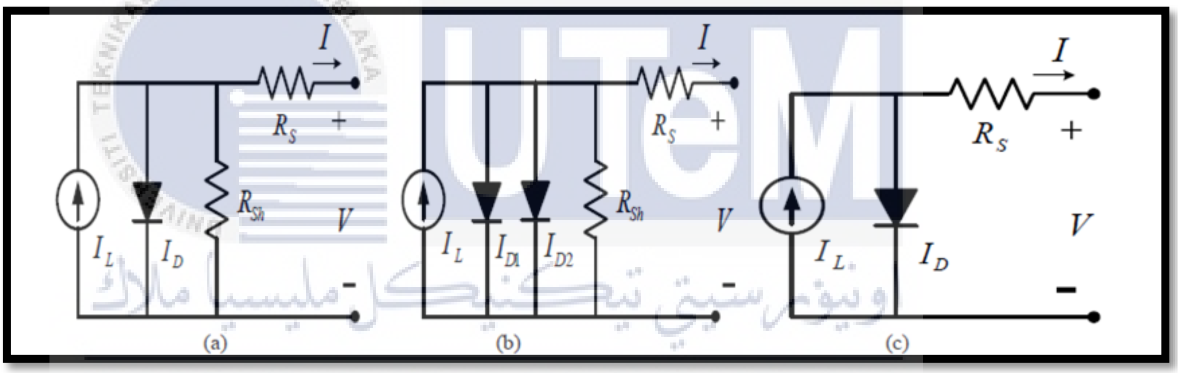


Figure 2-11:Equivalent circuit model of PV cell[13]

$$I = I_L - I_D = I_L - I_o \left[\exp\left(\frac{V+IR}{a}\right) - 1 \right] \quad (2\text{-}1)$$

The output voltage V and current I equation for the equivalent circuit show in equation (2-1). Where I_L is the photo current of a PV cell, Io is a saturation current module of a PV cell, I is the load current output and V is the voltage output of the cell. This model includes the series resistance R_s in the above equation. Thermal voltage timing completion factor is represent as a. The four parameters (I_L, I_o, R_s and α) must be determined in IV relationship.

To complete the equation (2-1), the modelling of light current is calculated as:

$$\boldsymbol{I_L = \frac{\emptyset}{\emptyset_{ref}}[I_{L,ref} + \mu_{I,sc}(T_c - T_{c,ref})}\qquad \textbf{(2-2)}$$

Where;

Ø = solar irradiance (W/m^2)

Øref = reference irradiance (1000 W/m^2)

$I_{L, ref}$ = the reference condition of the light current (1000W/m^2 and 25°C),

T_c = temperature of the photovoltaic cell (°C),

$T_{c, ref}$ = reference temperature (25 °C is used in this study),

$\mu_{I,sc}$ = temperature coefficient of the short-circuit current (A/°C)

The saturation current I_0 equation (2-3) can be modelled to express the value at reference conditions:

$$\boldsymbol{I_o = I_{o\,ref}\left(\frac{T_{c\,ref}+273}{T_c+273}\right)^3 exp(\frac{e_{gap}Ns}{q\,\alpha_{ref}}\left(1-\frac{T_{c\,ref}+273}{T_c+273}\right)}\qquad \textbf{(2-3)}$$

Where the I_0, ref is the saturation current (A) at reference conditions. e_{gap} represented as the band gap of the material (1.17 eV for Si materials), N_s is the series number of cells of PV module, q is charge of an electron (1.60217733×10^{-19} C), ref = the value of at reference conditions.

Furthermore, the reference of the saturation current $I_{0,ref}$ can be calculated as equation (2-4):

$$\boldsymbol{I_{o,ref} = I_{L,ref}\ exp(-\frac{V_{oc}}{\alpha_{ref}})}\qquad \textbf{(2-4)}$$

Where Voc,ref is the open-circuit voltage (V) of PV module. This value is given in the data sheet of PV panel. αref can be calculated from:

$$\alpha_{ref} = \frac{2V_{mp,ref} - V_{oc,ref}}{\frac{I_{sc,ref}}{I_{sc,ref} - I_{mp,ref}} + \ln\left(1 - \frac{I_{mp,ref}}{I_{sc,ref}}\right)}\qquad \textbf{(2-5)}$$

Where $V_{mp,ref}$ and $I_{mp,re}$ are the voltage and current maximum power point at the reference condition. $I_{sc,ref}$ is short-circuit current (A) at reference conditions. The modelling of is a function of temperature, expressed in equation ((2-6) . Where, Tc is the input of temperature.

$$\alpha = \frac{T_C + 273}{T + 273}\alpha \qquad \textbf{(2-6)}$$

The equation (2-7) can be used to estimate the series resistance Rs if the value is not provided by manufacturer.

$$Rs = \frac{\alpha_{ref} \ln\left(1 - \frac{I_{mp\,ref}}{I_{sc\,ref}}\right) + V_{oc\,ref} - V_{mp\,ref}}{I_{mp\,ref}} \qquad \textbf{(2-7)}$$

The second module review is the mathematical modelling using one diode. The cell photocurrent represent current source as I_{ph}. The circuit also has two resistances represent as R_{sh} is the shunt resistance and R_s is the series resistance. The mathematical modelled must be started with module operating temperature (degree Celsius to Kelvin)[14]:

1. T_{rK}= 273 + 25 (reference temperature) **(2-8)**
2. T_{oK}= 273 + Top (operation temperature) **(2-9)**

*T_{rK} is the converting reference temperature from degree Celsius to Kelvin
*T_{oK} is the converting operating temperature from degree Celsius to Kelvin

Equation (2-10) is the equation of the Module photo-current.

$$I_{ph} = [I_{SCr} + K_i(\text{ToK-TrK})] \times \frac{G}{1000} \qquad \textbf{(2-10)}$$

Where:

I_{ph} = photo-current
I_{scr}= short circuit current

Ki = temperature coefficient of short circuit current

G = PV module illumination (W/m^2) = 1000 W/m^2

Module reverse saturation current Irs equation show in ((2-11)

$$I_{rs} = I_{SCr}/[e^{\left(\frac{qV_{oc}}{Ns\,kAT}\right)} - 1] \tag{2-11}$$

Where; V_{oc} = the open circuit voltage of solar

q = the electron charge

k = the Boltzmann constant

T = temperature in kelvin

N_s = number of cell connected in series

A = the constant ideality diode

$$I_o = I_{rs}\left[\frac{T_{oK}}{T_{rK}}\right]^3 e^{\left[\frac{q\times Eg}{Bk}\left\{\frac{1}{TrK}-\frac{1}{ToK}\right\}\right]} \tag{2-12}$$

Equation (2-12) is module saturation current of PV module. Where Eg is the band gap of silicon. It is 1.1 eV. B is ideality factor, 1.6. This equation is generate to know the current lost.

$$I_o = I_{ph} - I_o[exp\{\frac{q\times(V_{pv}+I_{pv}R)}{N_sAkT}\}] \tag{2-13}$$

Equation (2-13) is the equation of current output for PV module. Where V_{pv} is output voltage and I_{pv} is output current of a photovoltaic module. Ns is the number of cell in series connected. The output current produce from the current of light energy source and the saturation current.

2.6.2 Equivalent Circuit For Photovoltaic Array

Photovoltaic cells must be connected in a series-parallel configuration to produce high power. To generate the current and voltage required by home and business, some PV modules are electrically connected in series and in parallel circuits. The equation for the photovoltaic module is composed in parallel N_P and N_S series[15]. The PV array, can write the current equation (2-14 until 2-17) of output as given below:

$$I = N_p I_{ph} - N_s I_d \quad (2\text{-}14)$$

$$I_d = I_0(e^{\frac{q(V+IR_s)}{nkTN_s}} - 1) \quad (2\text{-}15)$$

$$I_0 = I_{0(Tr)} \times (\frac{T}{Tr})^3 \times e^{\frac{qVg}{nk}\times(\frac{1}{Tr}-\frac{1}{T})} \quad (2\text{-}16)$$

$$I_{0(Tr)} = \frac{I_{sc(Tr)}}{e^{(\frac{qVoc(Tr)}{nkTNs}-1}} \quad (2\text{-}17)$$

2.7 Resistance in PV circuit

2.7.1 Series resistance

The series resistance has three causes in a solar cell. The first cause, the current movement through the emitter and base. Secondly, contact between the silicon and metal contact as resistance or load contact in the circuit. The third cause contact from the top and rear metal. The series resistance in the circuit is to reduce the high value of the fill factor and the short current impact[16].
The equation (2-18) is for output current of PV module.

$$I = I_L - I_0[e^{\{\frac{q\times(V \times IRs)}{nkT}\}} - 1] \quad (2\text{-}18)$$

Where I is the output current of photovoltaic cell. I_L is the light generated current, I_0 is the saturation current, V is the voltage supply to photovoltaic cell terminal, T is the temperature of cell in kelvin, n is the ideality factor, and Rs is the value of series resistance. The value of q and k are constant. The q is 1.6 x 10^{-19} C and k is 1.3805 x 10^{-23}. The Figure 2-13 show the IV curve that affect the series resistance.

If voltage the resistance increase, the current will increase until maximum point then it will drop to zero. The fill factor of cell will effect by series resistance[17]. Cell series resistance, Rs unit can be ohm or ohm cm2. Series resistance is not effect by the short circuit current. Figure 2-12 show the resistance in series circuit.

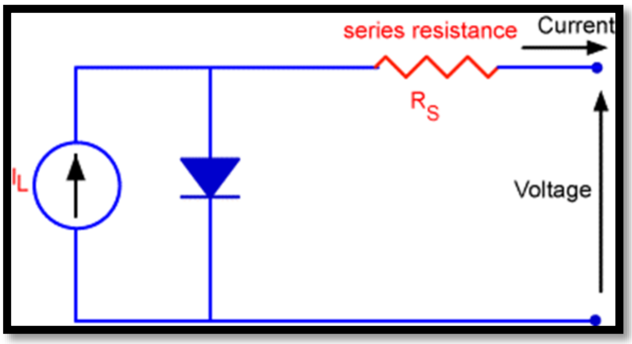


Figure 2-12: Resistance in series circuit[18]

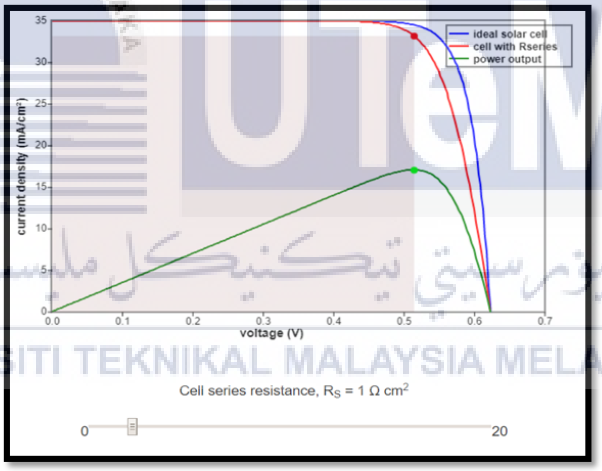


Figure 2-13: the graph current density vs voltage

2.7.2 Shunt Resistance

A shunt resistance, R_{sh} will cause the power losses in the circuit of photovoltaic cell. It produce the light-generated current path. The photovoltaic cell will reduce the voltage and current flow into the junction. When the photovoltaic cell at the low light level, it will impact the current flow through the circuit during operation. Furthermore, the effective resistance will increase when the voltage is lower[19]. Figure 2-14 show the shunt resistance for PV circuit.

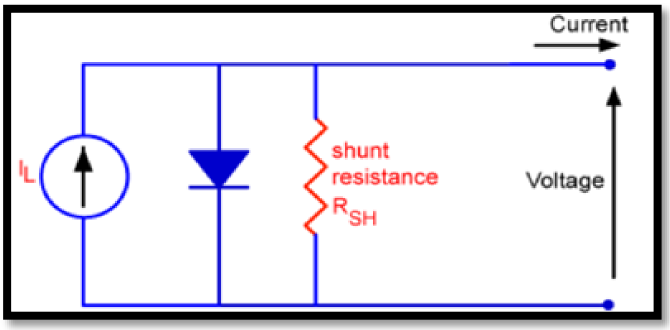


Figure 2-14: A solar cell circuit with shunt resistance

2.8 Effect of Solar Radiation variation

Solar energy has great potential in renewable energy for various functions. Photovoltaic effects change energy from solar to electricity for a wide range of widely used applications such as water heaters, street lights, and electric vehicles. Different weather conditions will have a big impact on PV modules and panels[20].

The photocurrent equation in the photovoltaic model depends on the value of radiation and temperature included in this equation (2-19).

$$I_L = G \times \frac{I_{SC(Tr)}}{G_r}(1 + a_{I_{SC}}(T - T_r)) \quad (2\text{-}19)$$

2.9 Effect of variation in cell Temperature

The main effect of temperature on solar panels is that it reduces the efficiency of the solar cells at converting solar energy from the sunlight into electricity. Cooler temperature is more effective during the solar panel operation. PV panels in hot temperatures will provide less power. The diode reverse saturation current in equation **(2-21)** varies as a cubic function of the temperature[21].

$$I_o = I_{o(Tr)} \times (\frac{T}{T_r})^3 \times e^{\frac{qVg}{nk}} \times (\frac{1}{T_r} - \frac{1}{T}) \quad \textbf{(2-20)}$$

$$I_{o(Tr)} = \frac{I_{SC(Tr)}}{e^{(\frac{qV_{OC(Tr)}}{nkT})} - 1} \quad \textbf{(2-21)}$$

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter will explain about the flow of the project. The timeline for the overall final year project tasks will show in the Gantt chart. This section will briefly explained about the project research and flowchart of the work plan and the list of equations.

3.2 Proposal Gantt

The overview of final year project 1 (FYP 1) in year 2018 is shown in the table 3.1. The title of FYP 1 was choose by student in ULEARN. The project was started with the literature review. FYP 1 was the focused on the PV module mathematical models and simulation. The array modelling simulation was conducted in FYP 2 in year 2019.

The literature review continues until the end of the overall project. The PV module circuit is transformed into a PV array. The analysis is based on the validation of equation and PV circuit in MATLAB simulation.

Table 3-1: Project Gantt Chart

Tasks	September			October				November				December				January				February				March				April				May			
	2	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Literature Review																																			
PV module model development																																			
PV module model validation process																																			
PV array model development														**Final**			**Midterm break**																		
PV array validation process																																			
Analysis of PV module and array																																			

3.3 Flowchart of workplan

The flowchart in figure 3.1 shows the plan of the project. It is briefly explained the flow of each section. This project started with research through the literature review. After that, this project focuses on to study the mathematical equation and modelling of photovoltaic in simulation and analysis data. This project end with the writing report.

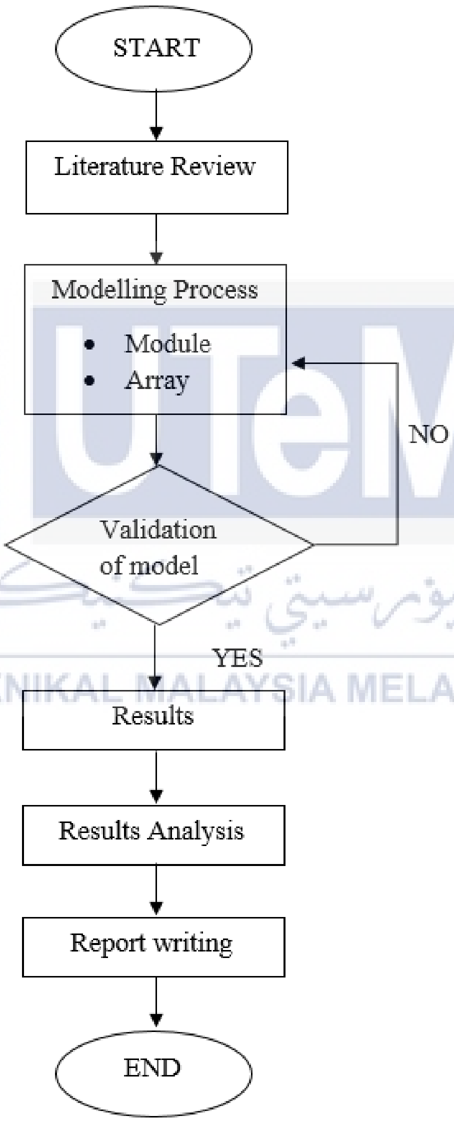


Figure 3-1: Flowchart plan of project

3.3.1 Literature Review

Literature review is the first step of project. The research are through the online base sources, book and articles. The research is focus on the mathematical model of photovoltaic cell and array. Each equation must understand before do the Simulink of project. In addition, the basic concept operation of photovoltaic review is need to this project. The details theoretical and information for this part already mentioned in Chapter 2.

3.3.2 Reference Photovoltaic (PV) Model

Figure 3.2 shows the solar panel model at Faculty of Electrical Engineering selected for this project. Model name is ETA-L080ma. Figure 3.3 shows the datasheet of PV model. The datasheet values indicate the characteristic of model. The open circuit voltage (Voc), short circuit current (Isc) and number of cell (Ns) value have been taken in this datasheet. The maximum power exceeding this model is 80 Wp and the current at power maximum is 4.65 A. STC is mean standard test condition.

Figure 3-2: Solar Panel ETA-L080

Table 3-2: Datasheet of PV model ETA-L080

Model No.	80
Electrical Data at STC	
Maximum Power (Pmax)	80 Wp
Voltage at Maximum Power (Vmpp)	17.2 V
Current at Maximum Power (Impp)	4.65 A
Open Circuit Voltage (Voc)	21.6 V
Short Circuit Current (Isc)	5.2 A
Panel Efficiency	12.6 %
	Standard Test Conditions (STC): air mass AM 1.5, irradiance 1000W/m2, cell temperature 25ºC
Thermal Ratings	
Operating Temperature Range	-20 ~ 60 ºC
Maximum Ratings	
Maximum System Voltage	600 V
Material Data	
Panel Dimension (H/W/D)	$\mathbf{1185 \times 536 \times 35\ mm}$
Weight	7.9 kg
Cell Type	Monocrystalline
Cell size	$\mathbf{125 \times 125\ mm}$
Cell number	36
Encapsulant Type	EVA

3.4 Modelling proses

3.4.1 Mathematic model of Photovoltaic cell

The modelling of project has referred to the equivalent circuit at figure 2.6 in chapter 2. The photovoltaic model in this project focuses on the current flow. Figure 3.2 shows a flowchart of the photovoltaic (PV) model development. The PV model start to develop with illustration of mathematical equation. The input of irradiation and temperature are required when developing a model.

Each model in this project have been validated using MATLAB simulation. The validation will be repeated when the model in simulation cannot show the output. After verifying the model, the output will analyse in the report writing. The table shows the list of parameter uses in modelling proses.

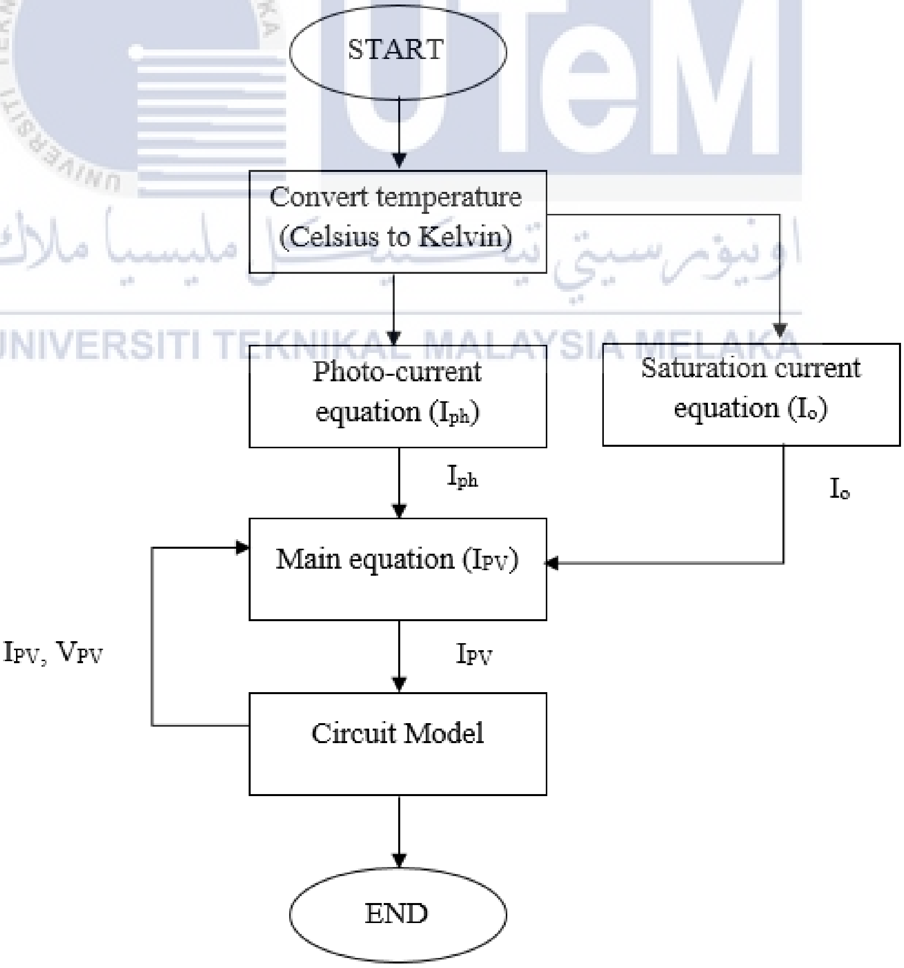


Figure 3-3: Developing the PV module model

Table 3-3: List of parameter for model

No	Parameter	value
1	Temperature constant (Tac)	273.15 ∘C
2	Boltzmann Constant (ki)	1.3805×10^{-23}
3	Ideality factor (n)	1.3
4	Short circuit current (I_{sc})	2.54 A
5	Irradiance nominal	1000W/m^2
6	Open circuit voltage (V_{oc})	21.8 V
7	Electron charge (q)	$1.6e^{-19}$

3.4.1.1 Simulation process of PV module

The first step to develop the mathematical model of PV is to converting the temperature from input from unit Celsius to Kelvin. Figure 3.4 show the Simulink block of converting module operating temperature. Tac is the ambient temperature of PV and Tref is temperature reference under standard test condition. After both of temperature added with constant value (273) the difference between 2 temperature produce T (temperature value in kelvin). Equation 3.1 shows the equation of temperature operating module.

$$\mathrm{T} = (\mathrm{Tac} + 273) - (25 + 273) \tag{3-1}$$

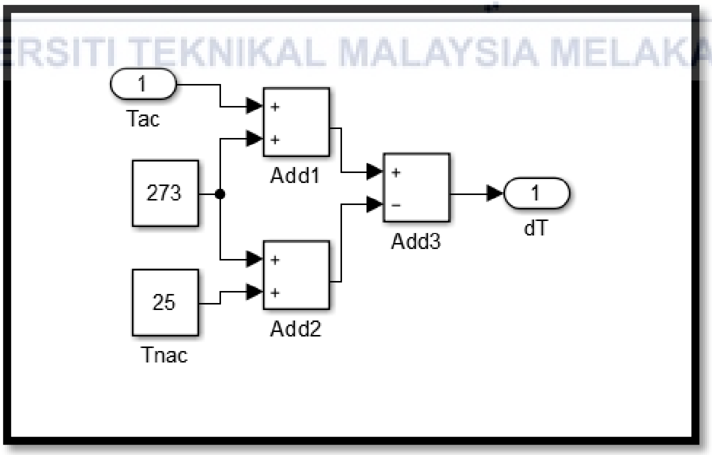


Figure 3-4: Simulink block of temperature operating module

Figure 3-5 shows the Simulink block of Photo-current module $I_{pv,cell}$. This module operate with irradiance input divide by nominal 1000W/m^2 under standard test condition. Short circuit current (Isc) is referred to datasheet in Table 3-2: Datasheet of PV model ETA-L080. The equation (3-2) shows the equation of photo-current model.

$$I_{pv,cell} = [I_{SC} + K_i(ToK - TrK)] \times \frac{G}{1000} \tag{3-2}$$

Where; Isc = short circuit current

Ki = Temperature short circuit current coefficient

G = solar irradiance

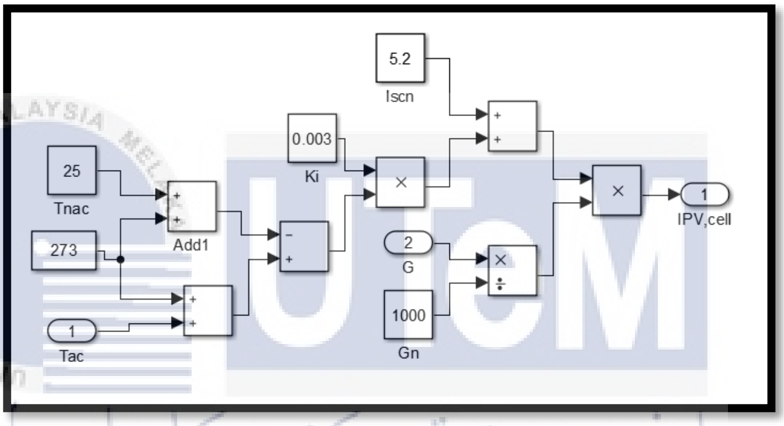


Figure 3-5: Simulink block of photo-current module

The simulation of the saturation current output module show in Figure 3-6. The cell quality can be indicate by saturation current (Io) and ideality factor (A). This module is expressed by following equation (3-3):

$$I_o = \frac{I_{sc} + Ki\Delta T}{e\left(\frac{V_{oc} + Kv\Delta T}{aVi}\right) - 1} \tag{3-3}$$

Where Ki and Kv is the coefficient of open circuit voltage or temperature and the coefficient of short circuit current or temperature. The short circuit current Isc and open circuit voltage Voc is under standard test condition.

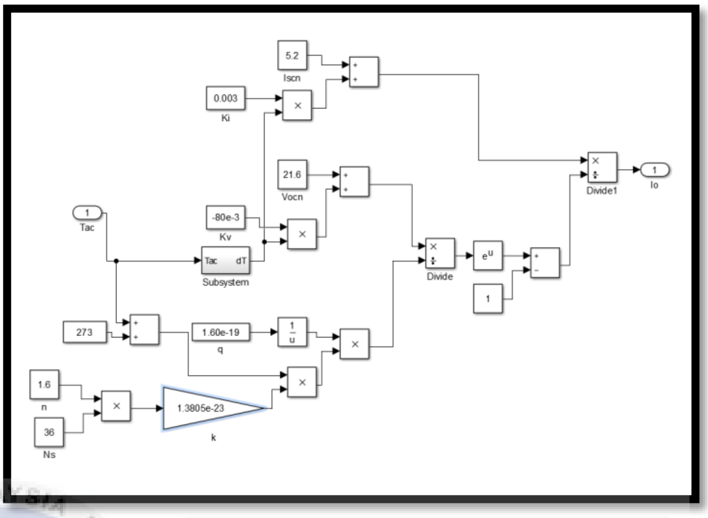


Figure 3-6: Simulink block of saturation current module

The output current produce the difference of photo-current and saturation current. The equation (3-4) of the output current module is:

$$I_{pv} = I_{ph} - I_o[\, e(\frac{q \times (V + IRs)}{Ns\, AkT}] \qquad (3-4)$$

Where; V = the output voltage of solar

I = the output current of solar

q = the electron charge ($1.6e^{-19}$)

k = the Boltzmann constant ($1.3805e^{-23}$)

T = temperature in kelvin

Ns = number of cell connected in series

A = the constant ideality diode

The Simulink block of the output current module is shown in Figure 3-7: Simulink block of output current module. It consist of 2 module which are photo-current and saturation current.

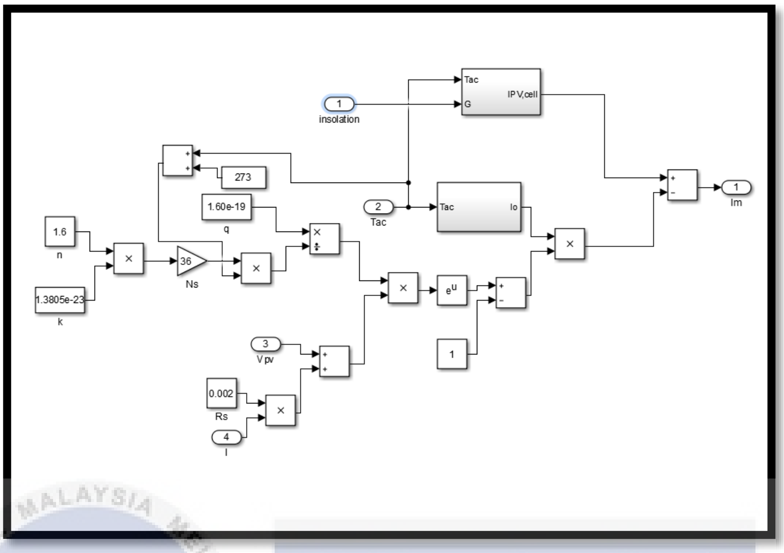


Figure 3-7: Simulink block of output current module

The equivalent circuit module of photovoltaic (PV) model is shown in Figure 3-8: Simulink block of circuit PV module. The model use controlled current source block to show the symbol of current input signal. The block show the positive current direction. The multimeter block is used to measure the current flow.

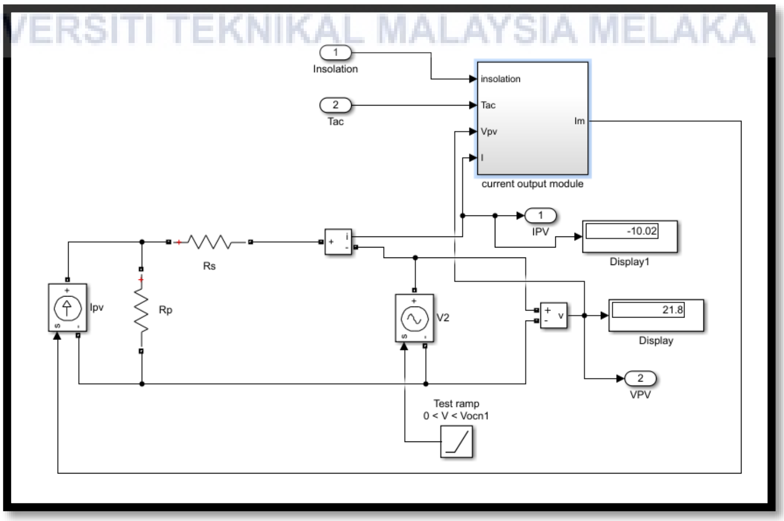


Figure 3-8: Simulink block of circuit PV module

The figure 3.9 is shown the final model of cell model. The workplace is added in this model to measure output current I, output voltage V and the power P of photovoltaic model. The value of irradiance, temperature in Celsius and module voltage as input is taken in final model. The final model gives the output current and output voltage of photovoltaic model.

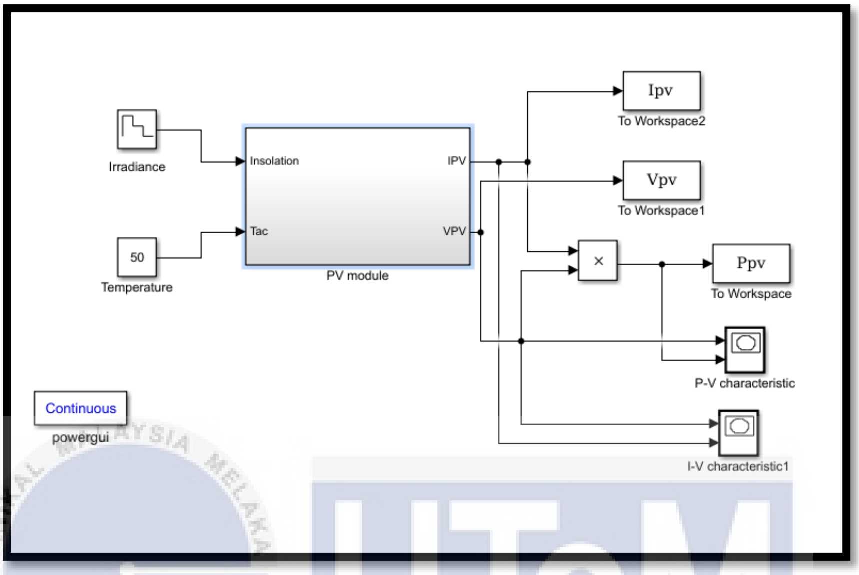


Figure 3-9: Simulink block of Photovoltaic module

3.4.2 Mathematical of Photovoltaic array

Figure 3-10: Flowchart of developing PV array model shows a flowchart of the photovoltaic array development. The PV array model is modification of the PV module model created during FYP 1 project. The modification of the PV module circuit is divided by two connecting method. The first method is to connect in series while the second connection is parallel.

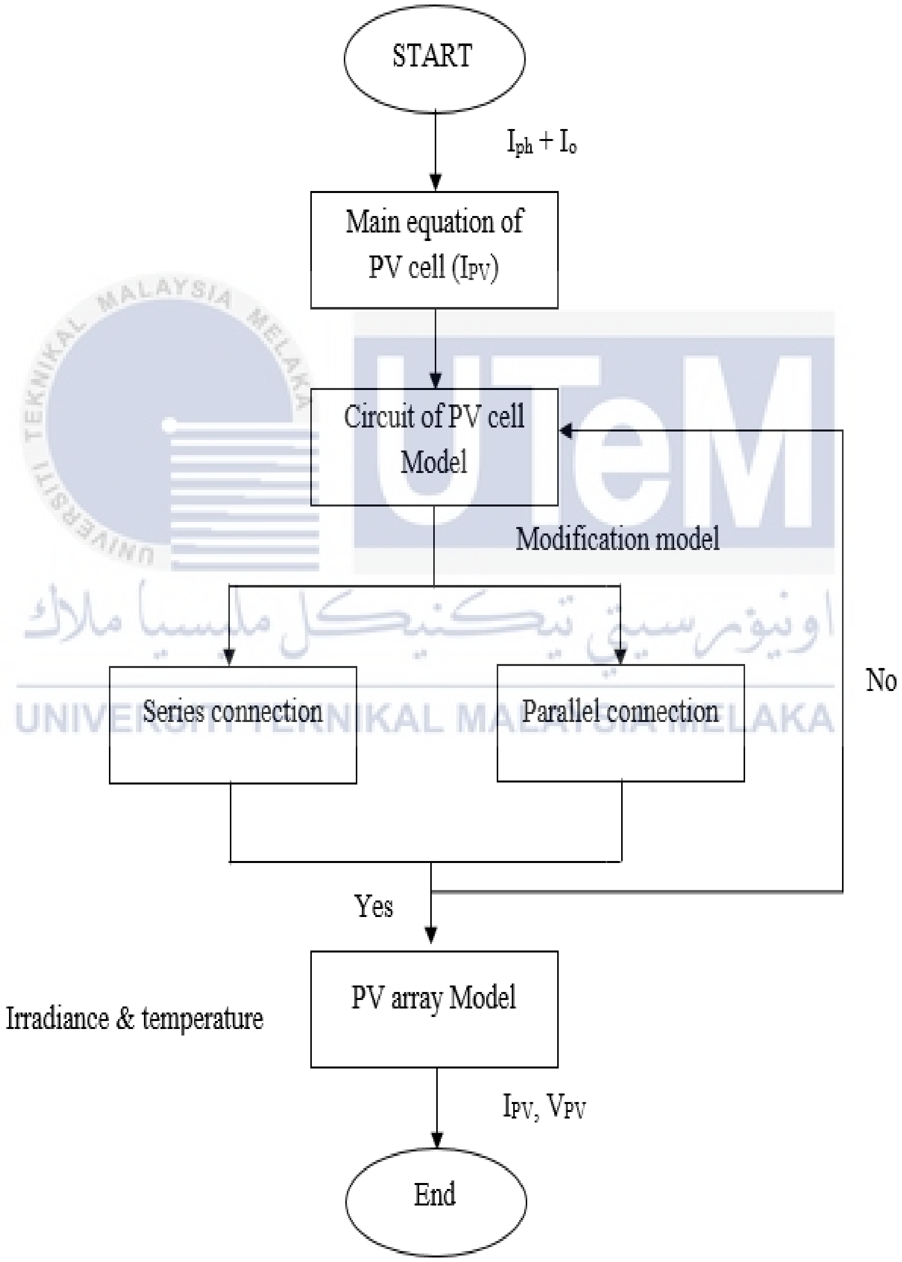


Figure 3-10: Flowchart of developing PV array model

The modified circuit is shown in figure 3.10 where the block positive and negative terminal was added.

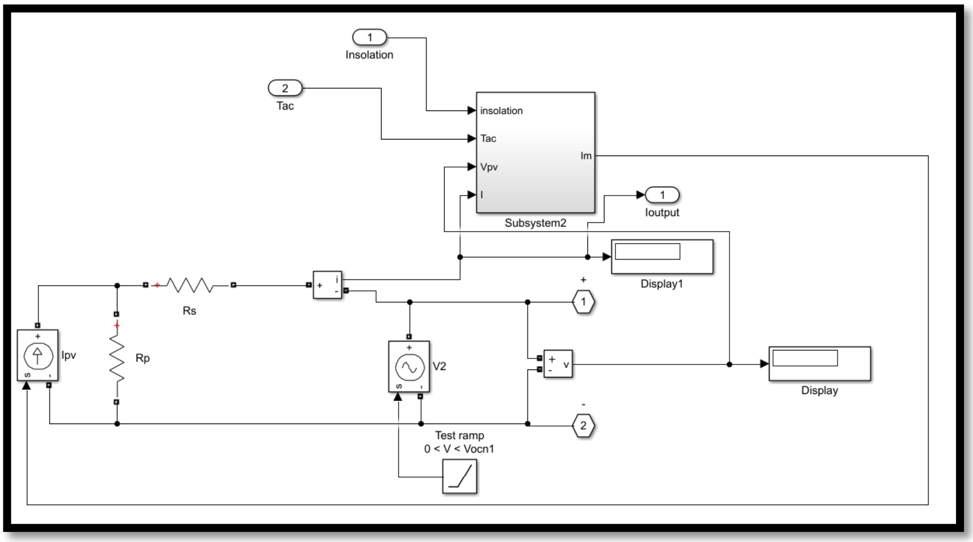


Figure 3-11: PV circuit model

3.4.2.1 Simulation of Photovoltaic Array

The simulation to form a PV array starts with a series connection. A series connection is used to increase the voltage value in the PV system. The positive terminal is connected to the negative terminal of each module panel. Figure 3.12 show the three modules of PV connected in series. There are several scenarios to be tested on the connection associated with the PV array effect by irradiance and temperature.

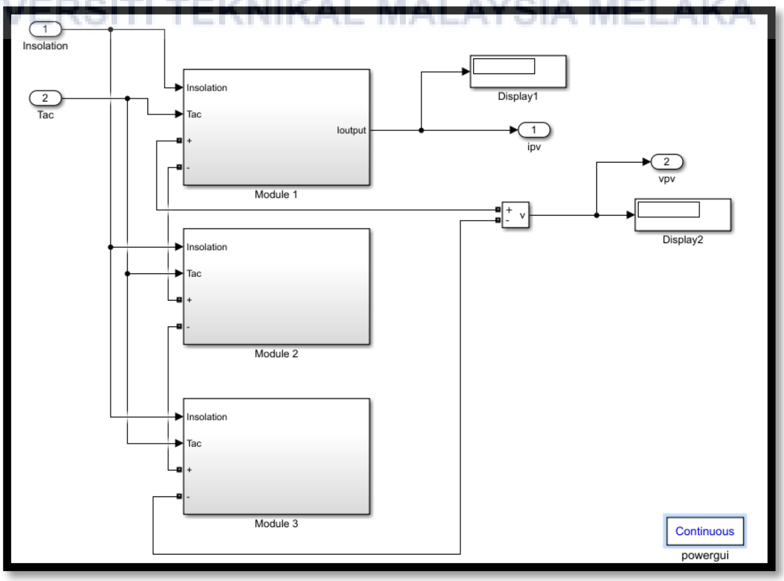


Figure 3-12: PV module panel in series connection

The second connecting module to form PV array is parallel connection. Series photovoltaic array was connected together in parallel. As study, the current in a parallel circuit is different and the voltage is remain same. Figure 3.13 show the PV panel connection in parallel.

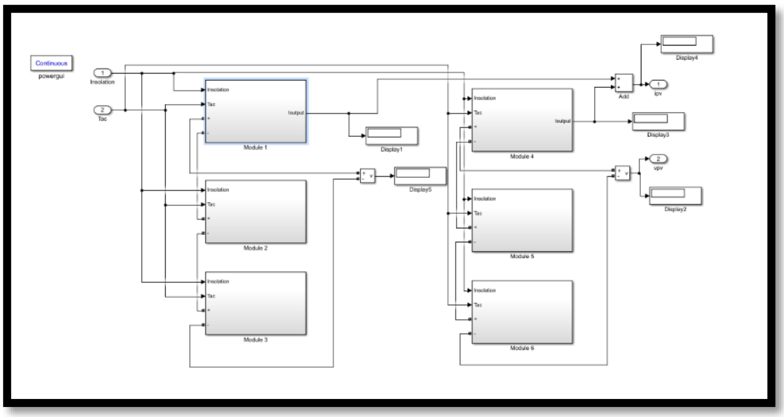


Figure 3-13: PV array in parallel

Figure 3.14 show the final circuit of the PV array model. The input value entered into the model is temperature and irradiance. Both input values are varied according to the scenario.

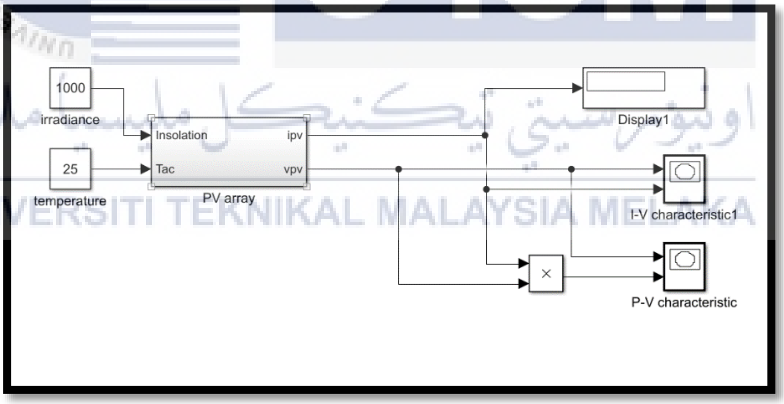


Figure 3-14: PV array Model

3.4.2.2 Test for PV array module

To identify the effect of irradiance and temperature on the PV array model, two methods of testing are performed. The first input value of irradiance and temperature based on table Table 3-4 : Input value for PV array model is tested on the PV array model there are connected in series and parallel. The second scenario PV array is tested based on input in Table 3-5: Input value for PV module connecting in PV array model on each of the connected modules to form a PV array model.

Table 3-4 : Input value for PV array model

Scenario	Value of Irradiance (W/m^2)	Value of Temperature (ºC)
1	1000	50
2	1000	[75 50 25]
3	[1000 750 500]	50
4	[1000 750 500]	[75 50 25]

Table 3-5: Input value for PV module connecting in PV array model

Scenario	Value of Irradiance (W/m^2)	Value of Temperature (ºC)
1	800	30
2	800	[70 50 30]
3	[800 600 200]	30
4	[800 600 200]	[70 50 30]

3.5 Summary

The Gantt chart and flowchart in this chapter show the review of project. The simulation analysis is the best method to validate the equation. The difference input values are made to investigate the effect of the temperature and radiance in the photovoltaic array model. The analysis of the model is discussed in chapter 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Overview

This chapter present the results and analysis of the project in details. The analysed data are explained based on the performance of mathematic equation of photovoltaic in MATLAB Simulink in term of I-V and P-V characteristics.

4.2 Result and analysis of Photovoltaic module

The results is obtained from the mathematical model of photovoltaic module using MATLAB Simulink. The characteristic of photovoltaic module is estimated with the development model. Table 4.1 shows the input values for this model. Figure 4.1 - 4.4 shows the simulation result under four test conditions to investigate the effect of photovoltaic module model toward the irradiance and temperature. Test 1 simulation is for the I-V and P-V characteristic under variation of irradiance with constant temperature. Then, test 2 is for the I-V and P-V characteristic under the constant radiance with varying temperature. Next, test 3 is for the I-V and P-V characteristic under different temperature and irradiance and test 4 is for the I-V and P-V characteristic under constant irradiance and temperature.

The stair block in simulation figure 4.1, figure 4.2 and figure 4.3 are used to show different input of irradiance and temperature. There are three different input value is used to analyze affect the output I-V and P-V characteristic.

Table 4-1: Value for PV module

Test	Value of Irradiance (W/m^2)	Value of Temperature (ºC)
1	[1000 750 500]	50
2	1000	[75 50 25]
3	[1000 750 500]	[75 50 25]
4	1000	50

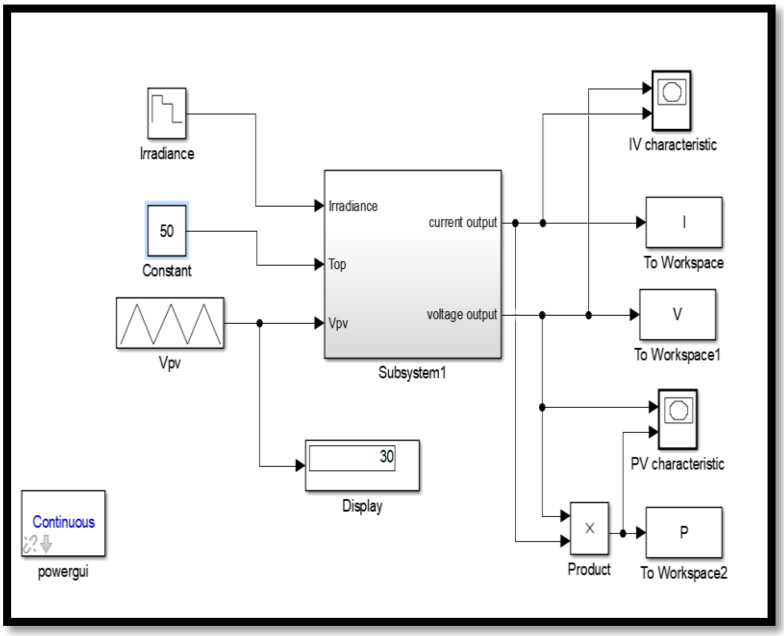


Figure 4-1: Simulink block for test 1

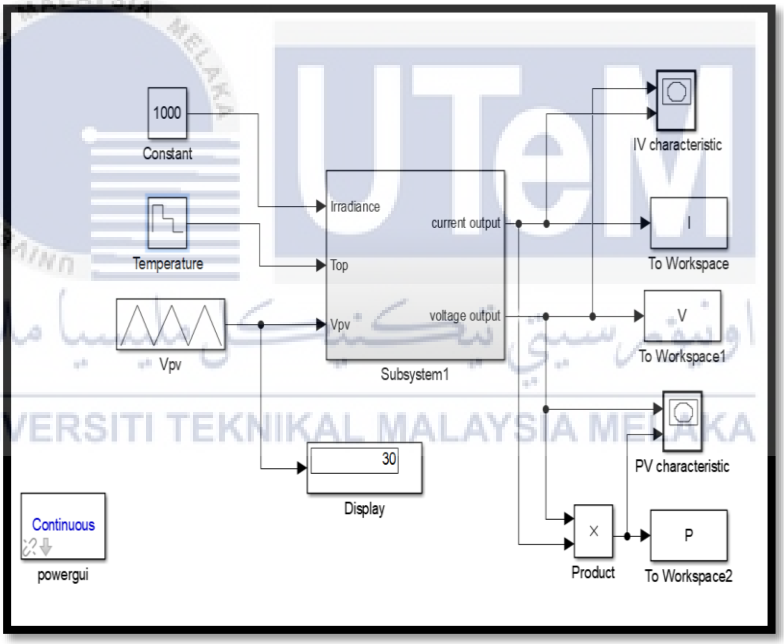


Figure 4-2: Simulink block for test 2

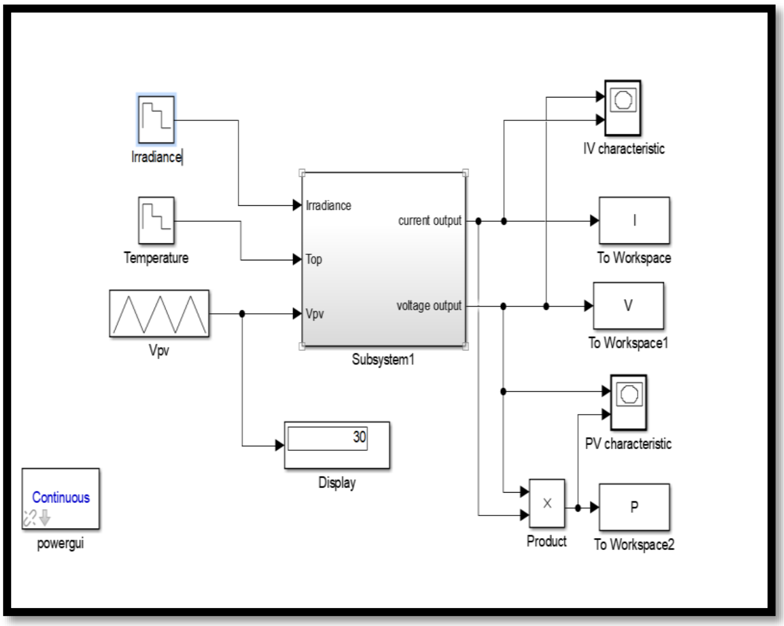


Figure 4-3: Simulink block for test 3

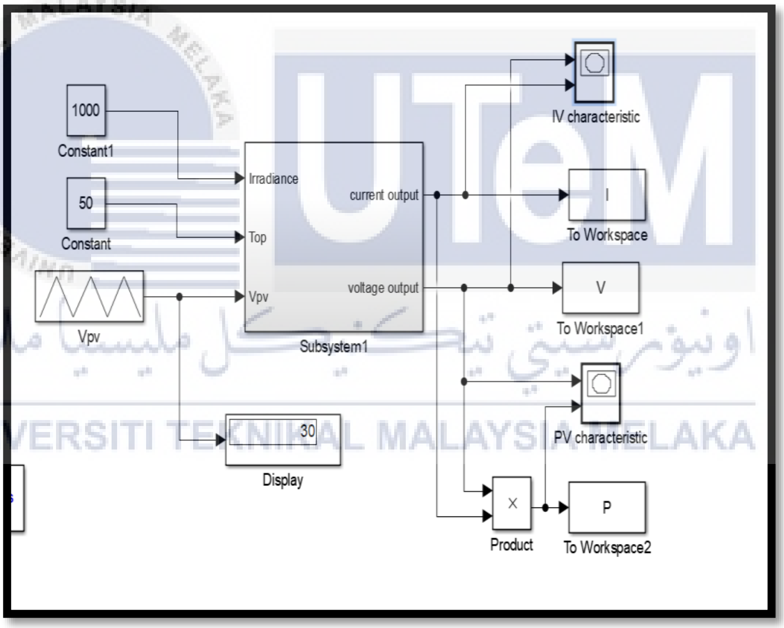


Figure 4-4: Simulink block for test 4

4.2.1 Result for test 1

The I-V and P-V characteristic output of photovoltaic cell under variable irradiation with constant temperature are shown in figure 4.5 and figure 4.6. Radiance value will affect the short circuit. Short circuit current is exactly equal to the photon current under the assumption that the series resistance is very small. Y axis represent as current and X axis is represented as a voltage.

The first curve is a thousand watts per square meter. It is corresponding to the sort of the maximum irradiance under standard test condition. The irradiance level is reduced to 750 watts per square meter. The last curve is 500 watts per square meter. The difference solar irradiance are reduced by 150 watts per square meter. The effect of irradiance is linear to short circuit current increases linearly proportionately with the solar irradiance level.

The current in figure 4.5 start from at maximum current and the zero voltage. It is called as short circuit current, Isc. The maximum voltage produce at zero current and called as open circuit voltage. The current and voltage output of photovoltaic cell decrease when the irradiance value is decrease. The power output also decrease at contant temparature

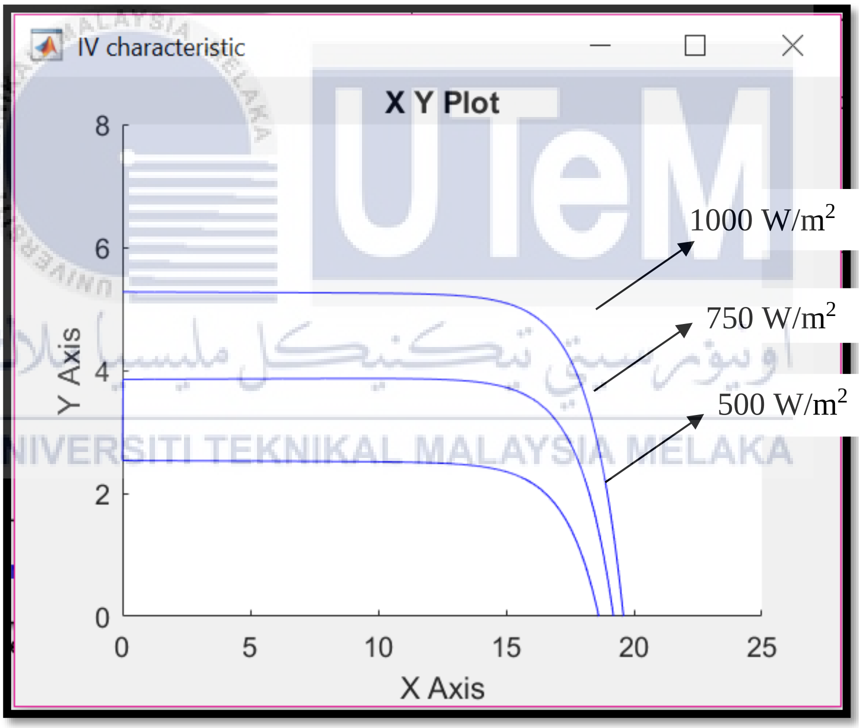


Figure 4-5 : I-V characteristic with variable irradiance and constant temperature

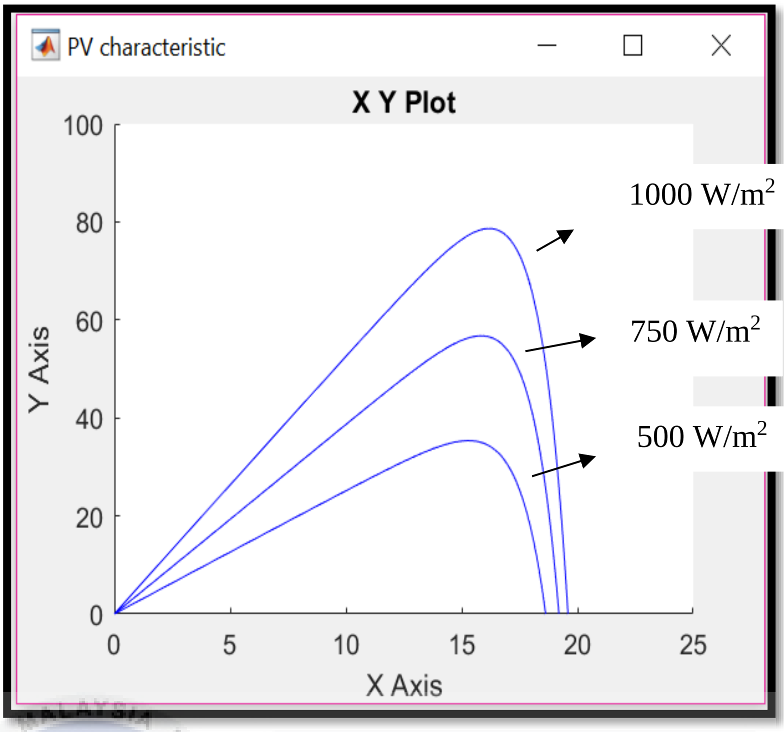


Figure 4-6: P-V characteristic with variable irradiant and constant temperature

4.2.2 Result for test 2

Figure 4.7 and 4.8 show the I-V and P-V characteristic of the photovoltaic output under the constant radiance with varying temperature value. The temperature significantly affects the I-V characteristic and it is the dominant impact on the open circuit voltage Voc. The open circuit voltage has a large negative temperature coefficient of about minus 0.35 percent per degree Celsius or minus 2.2 millivolts per degree Celsius.

The graph in figure 4.7 is illustrated three different inputs of temperature. 25 degree Celsius is a module temperature under standard test condition. Open circuit voltage Voc in this figure show is close to 21.6 V. The higher temperature operation, the current output of photovoltaic will increase, but the voltage output will drastically drop. The result of test 2 is a reduction in power output with high temperature.

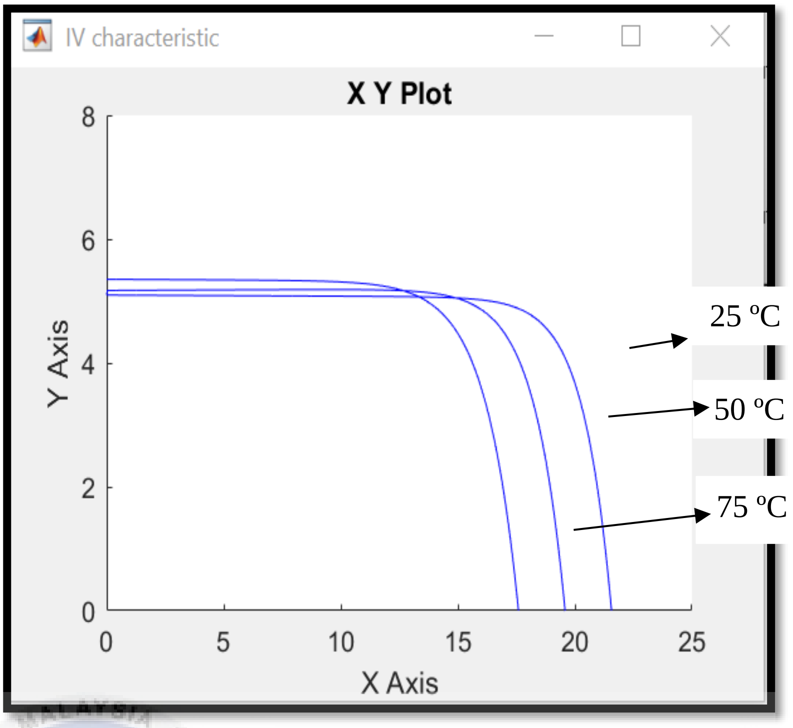


Figure 4-7: I-V characteristic of photovoltaic with varying temperature

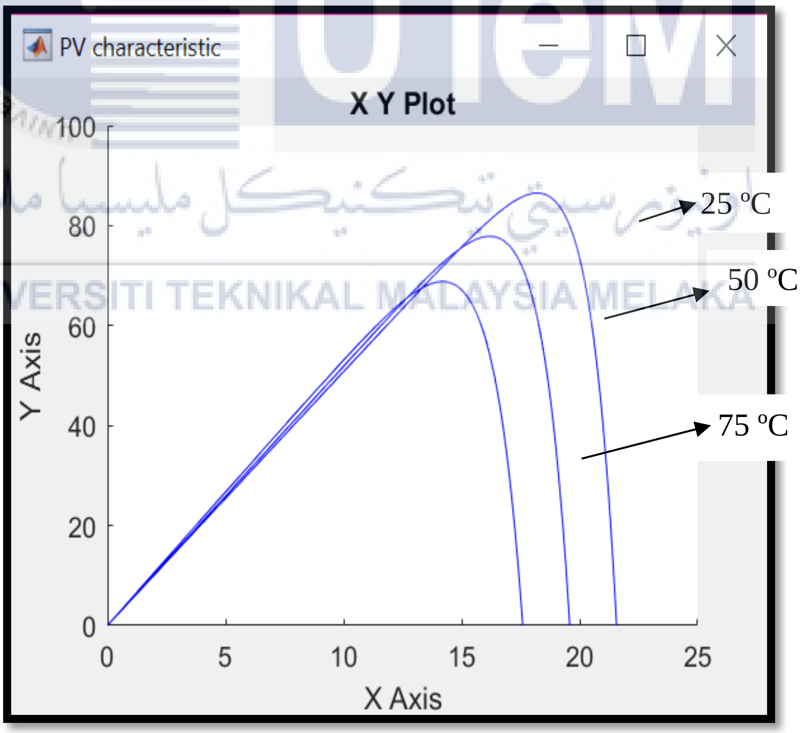
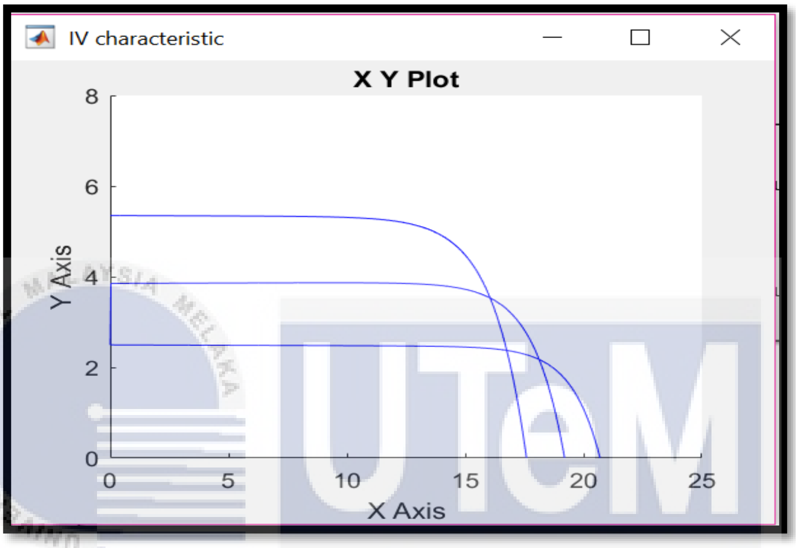


Figure 4-8: P-V characteristic of photovoltaic with varying temparature

4.2.3 Result for test 3

The different irradiance and temperature show the output of I-V characteristic in figure 4.9. The higher irradiance input, the higher current of a short circuit Isc. The voltage of open circuit current will decrease when irradiance is higher and the temperature is low. The PV characteristic output is shown in figure 4.10. The highest level of power output in this figure is lower than the highest level of power output in the figure 4.6.



Irradiance: 1000 W/m^2, 750 W/m^2, 50 W/m^2

Temperature: 25 ºC, 50 ºC , 75 ºC

Figure 4-9: I-V characteristic output with difference irradiance and temperature

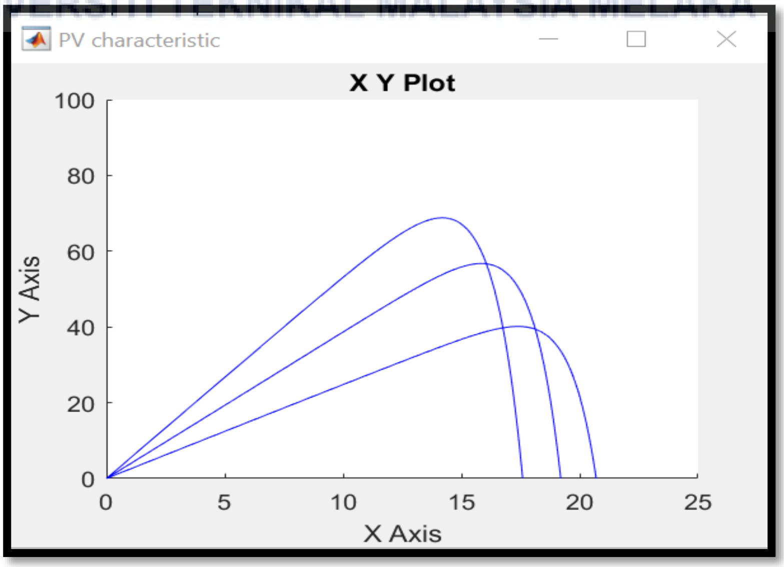


Figure 4-10 : P-V characteristic output with difference irradiance and temperature

4.2.4 Result for test 4

The figure 4.11 and figure 4.12 show the I-V and P-V characteristic under the constant irradiance and temperature. The short circuit current Isc and the voltage open circuit of the all curve almost the same value. The maximum power output is close to 80 Wp and matching with the data sheet curve.

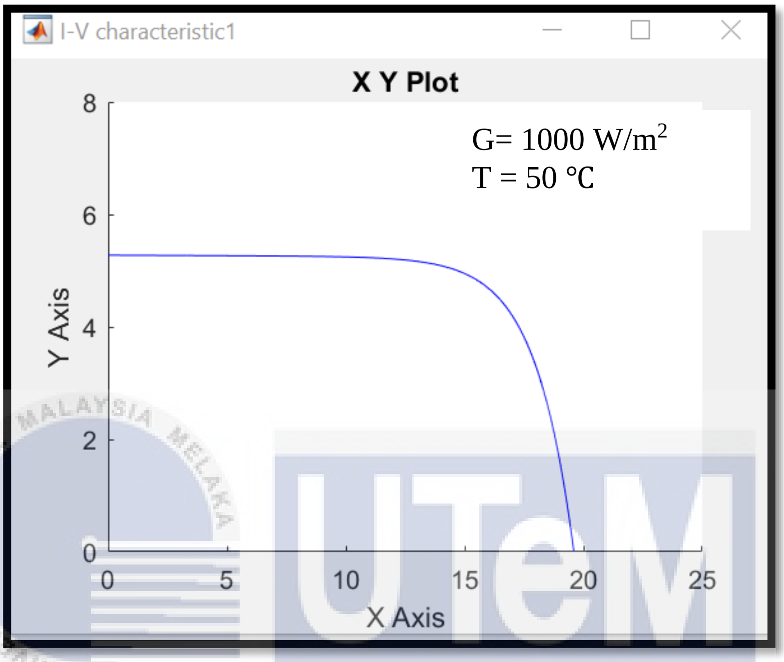


Figure 4-11: I-V characteristic output with constant irradiance and temperature

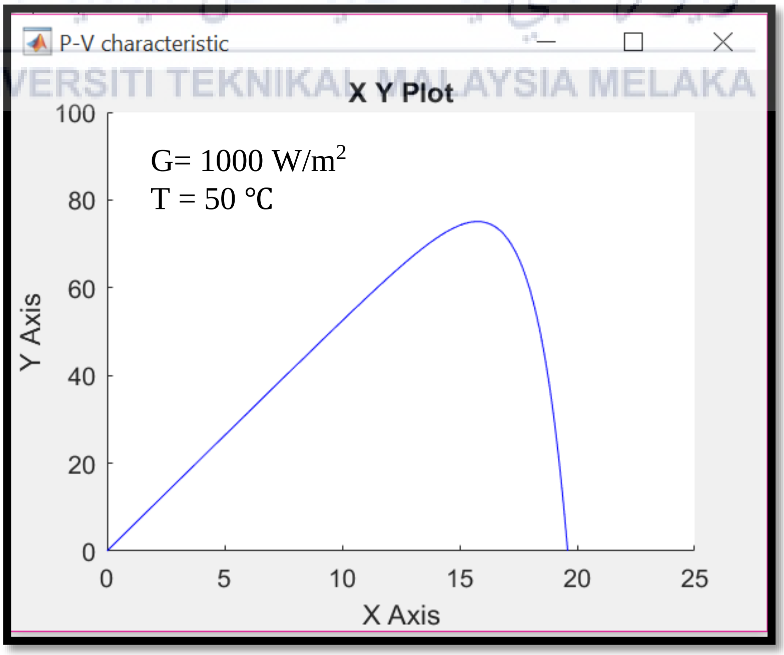


Figure 4-12: P-V characteristic output with constant irradiance and temperature

4.3 Result and analysis of Photovoltaic Array model

There are two case studies on the PV array model. The first case is the input value study on the PV array model and the second case is the study of each module that is connected to form a PV array. The two case test is to see the impression of irradiance and temperature input on the performance of PV array model.

4.3.1 Case 1: All scenarios are tests on the input of PV array model

Figure 4-13: PV array model is shows the simulink block of PV array model. In this case, input values of irradiance and temperature change according to the scenario.

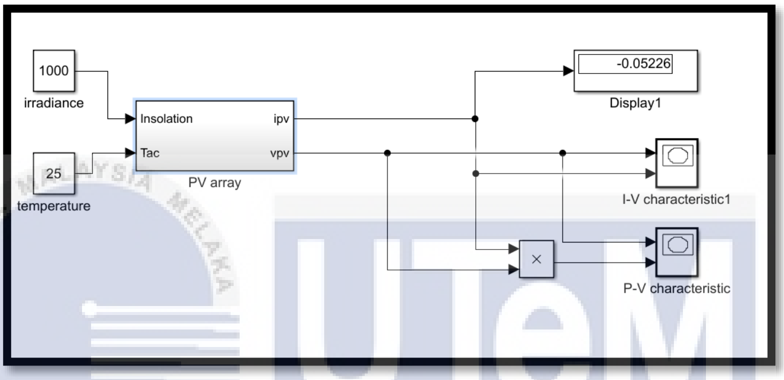


Figure 4-13: PV array model

4.3.1.1 Scenario 1: Fixed the value input of radiance and temperature.

The value input of irradiance is 1000 W/m2 and temperature input is 50°C

Table 4-2: Result for scenario 1

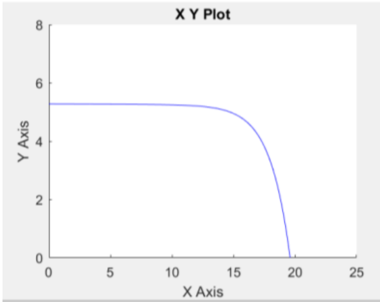
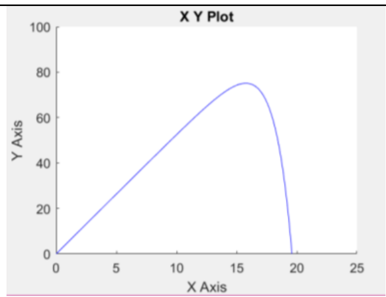
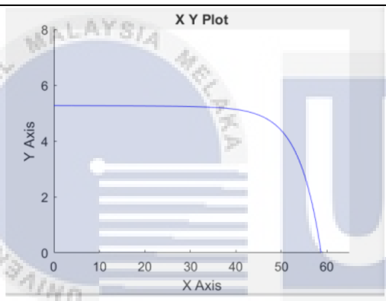
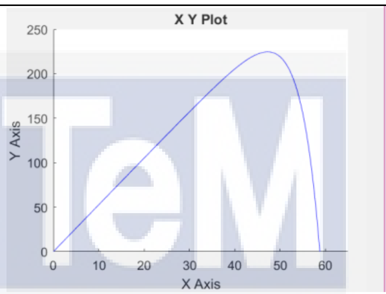
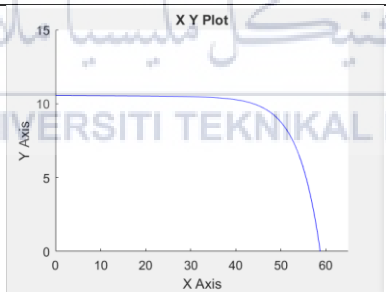
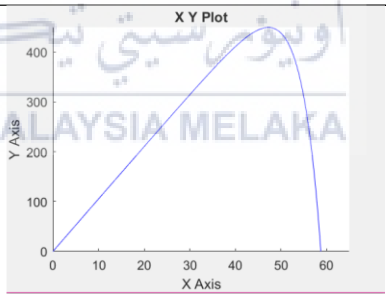
Module	I-V characteristic	P-V characteristic	Result
PV module			Isc = 5.2A Voc = 19.5V Power = 80W
PV array in series			Isc = 5.2 A Voc = 64. 8V Power = 240W
PV array in parallel			Current = 10.5A Voltage = 64.8V Power = 450 W

Table 4-2 shows the output response of I-V and P-V characteristic for the purposed PV model. By comparing 3 modules, the current and voltage values in the table show the change value and output graph. PV currents connecting in series have increased the voltage value while the current output is the same as compared to PV modules. During PV parallel, current output value is increase. If current or voltage increases, power also increases (P=I*V)

4.3.1.2 Scenario 2: Fixed the value input of irradiance, different value input of temperature.

The value input of irradiance is 1000 W/m^2. The temperature input value are 25°C, 50°C, and 75°C.

Table 4-3: Result of scenario 2

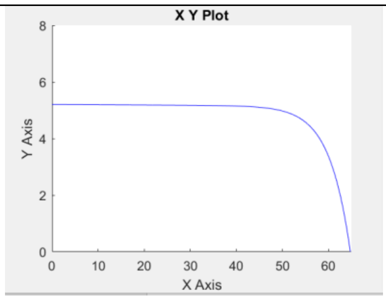
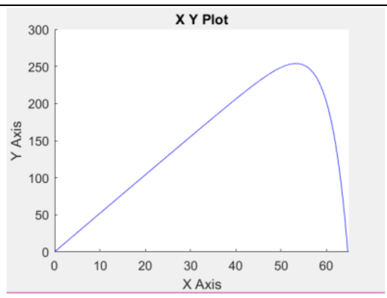
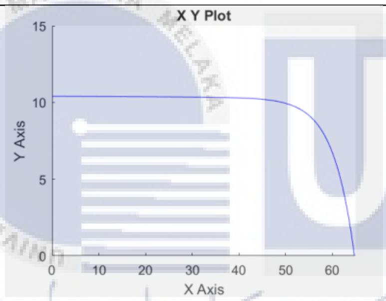
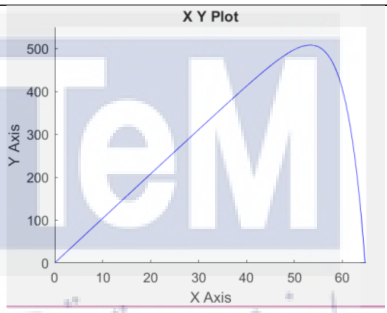
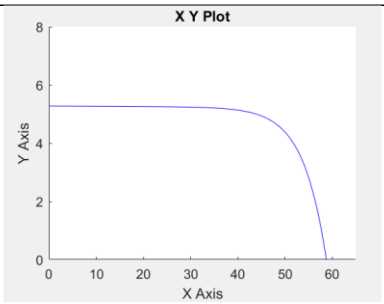
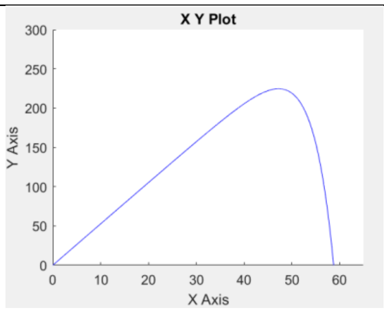
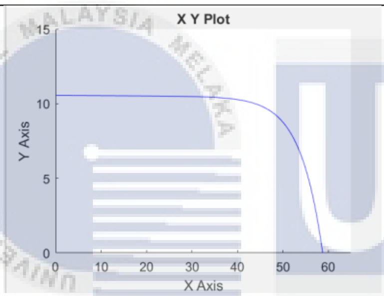
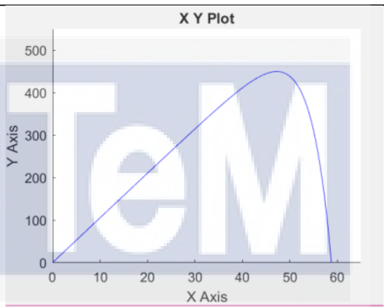
<table>
<tr><th>Module</th><th>I-V characteristic</th><th>P-V characteristic</th><th>Result</th></tr>
<tr><td>PV array in series</td><td>
</td><td>
</td><td>Current = 5.2 A Voltage = 64. 8V Power = 240W</td></tr>
<tr><td>PV array in parallel</td><td>
</td><td>
</td><td>Current = 10.5 A Voltage = 64.8V Power = 500 W</td></tr>
</table>

Table 4-3: Result of scenario 2 shows the scenario 2 is to test the input of different temperature values and the same value of irradiance into the PV model. After running MATLAB, the output graph of the I-V and P-V characteristic is equal to result in scenario 1. Power output shows an increase during temperature value changes. The results show that the temperature will affect the output of the PV model.

4.3.1.3 Scenario 3: Difference radiance, fixed temperature.

The value input of irradiance are 1000 W/m^2, 75 W/m^2, and 50 W/m^2. The temperature input is 50°C.

Table 4-4: Result for scenario 3

Module	I-V characteristic	P-V characteristic	Result
PV array in series			Current = 5.2 A Power = 240W
PV array in parallel			Current = 10.5 A Power = 450 W

According Table 4-4: Result for scenario 3 I-V and P-V characteristic response shows the same value of voltage but increase the current and power. By comparing Table 4-3: Result of scenario 2 and Table 4-4: Result for scenario 3 there are some differences in output voltage values in the I-V and P-V characteristic. The change in value of the irradiance causes the voltage in the PV module to show a reduction. The power output in the I-V and P-V characteristic decrease. The current output shows in scenarios 2 and 3 remain the same.

4.3.1.4 Scenario 4: Difference value input of irradiance and temperature.

The value input of irradiance are 1000 W/m^2, 75 W/m^2, and 50 W/m^2. The temperature input is 75°C, 50°C, and 25°C.

Table 4-5: Result for scenario 4

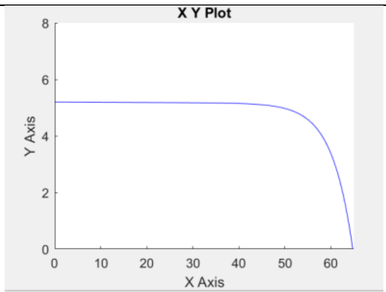
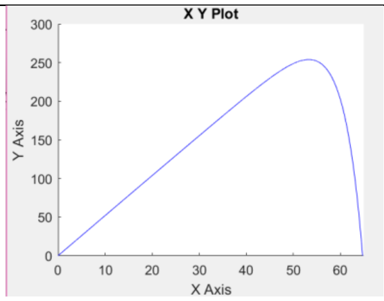
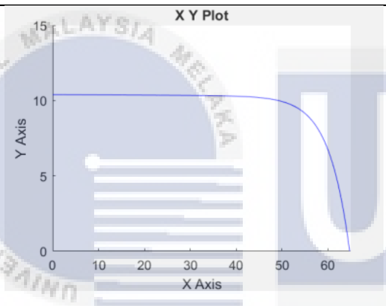
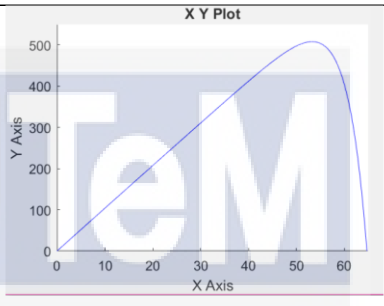
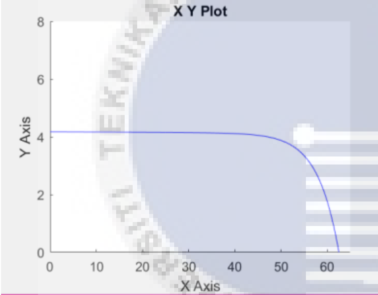
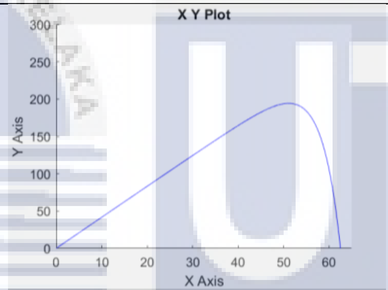
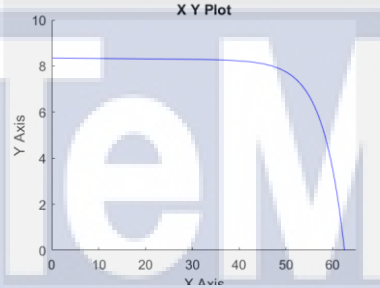
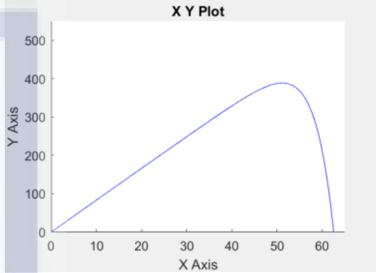
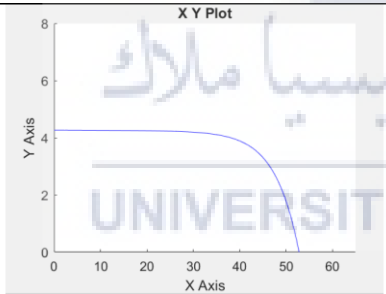
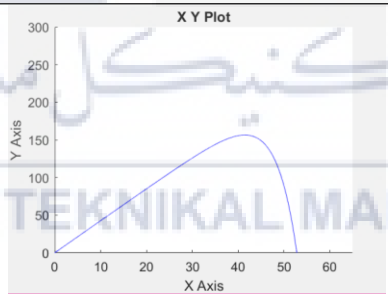
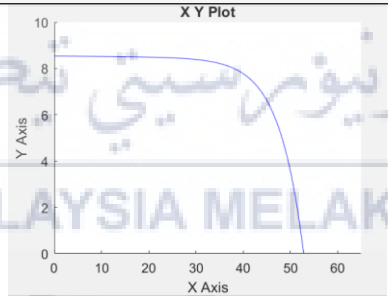
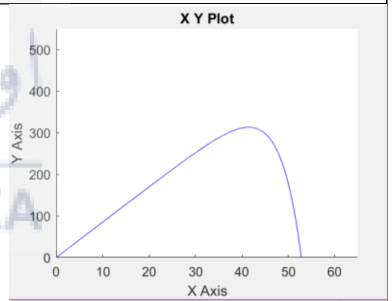
Module	I-V characteristic	P-V characteristic	Result
PV array in series			Current = 5.2 A Voltage = 64. 8V Power = 250W
PV array in parallel			Current = 10.5 A Voltage = 64.8V Power = 500 W

Table 4-5: Result for scenario 4 shows result of scenario 4 when temperature and irradiance values are differenced. The current output in I-V and P-V characteristic is higher in parallel connection. The graph output characteristic shown in this table is roughly the same as when exiting when the temperature and irradiation values are the same in Table 4-2: Result for scenario 1

4.3.2 Case 2: All scenarios are tests on each PV module

Each module that is connected to PV array will be converted the input value of irradiance and temperature according to the scenario.

Figure 4-14: PV array series vs PV array in parallel

Scenario	PV array connected in series		PV array connected in parallel	
	I-V characteristic	P-V characteristic	I-V characteristic	P-V characteristic
Fixed value of irradiance (800 W/m^2) and temperature (30°C)				
Same value of irradiance (800 W/m^2) and difference value of temperature (70°C,50°C, 30°C)				

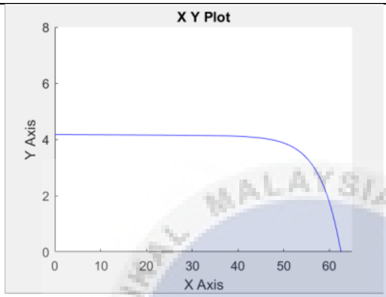
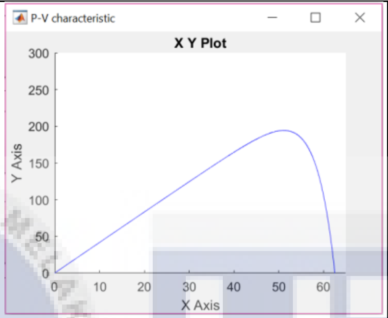
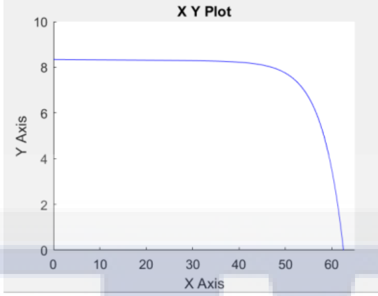
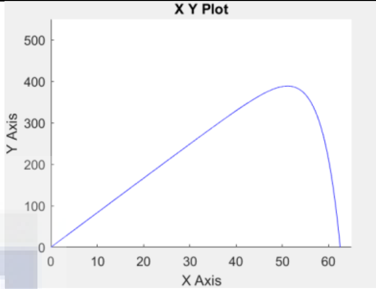
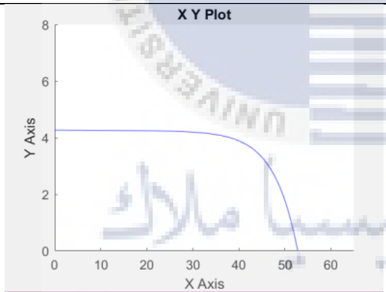
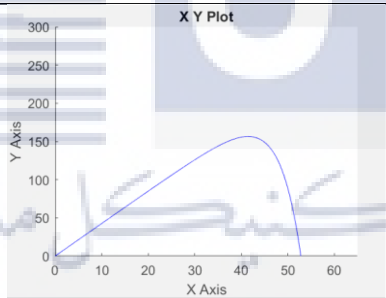
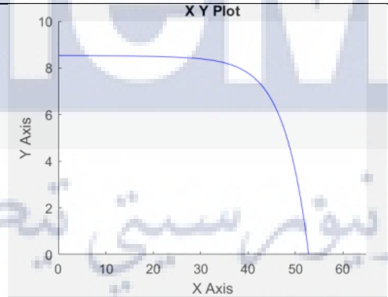
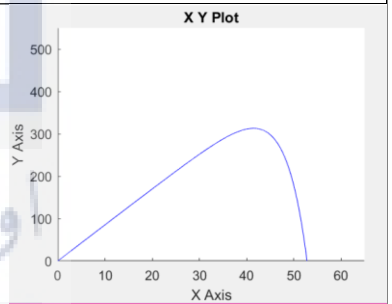
<table>
<tr>
<td>Difference value of irradiance (800 W/m^2, 600 W/m^2, 200 W/m^2) and same temperature (30°C).</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Difference value of irradiance (800 W/m^2 , 600 W/m^2, 200 W/m^2) and temperature (70°C,50°C, 30°C)</td>
<td>
</td>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
</table>

Figure 4-14: PV array series vs PV array in parallel shows the list of result for the case 2 study between series and parallel PV array. There is clearly shows the open circuit current and the open circuit voltage are difference depending on the type of photovoltaic array connection. The current shows in I-V and P-V characteristic was increased in parallel connected while the voltage was increase in the PV array connected in series.

From the result, the open circuit voltage in I-V and P-V characteristic shows the clearly display change the voltage when changing the temperature value. This case shows that temperature values affect by changing weather response. The different value of temperature in photovoltaic panel, the reduce voltage and power value. The effect of changing open circuit voltage can relate with the gap band in Photovoltaic model. Reducing the temperature, the band gap in PV model will increase.

4.4 Summary

The result of I-V and P-V characteristic module is verified and matched with the manufacturer's data sheet output curve. When radiation increases, open-circuit voltages also increase for PV modules. The open circuit voltage will change when the temperature input changes the value. More parallel PV connections, more current outputs will be generated. The series connection of PV array will increase voltage value. The value of irradiance and temperature affects the output of the photovoltaic model.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Overview

This chapter will conclude the objective, methodology, and analysis of the project. Any improvement will be discussed in the recommendation part.

5.2 Conclusion

The main goal of this task is to produce a photovoltaic modelling equation using MATLAB Simulink. It focuses on using photovoltaic standard mathematical models. The developed model will help investigators to better understand the work system. The photovoltaic modelling system using the simulation is the easiest way to analyse the output of the photovoltaic module characteristic. The standard model of the photovoltaic model is discussed in chapter 2. In this chapter it also briefly explains the type of PV cell and how the PV works. Project mathematical models have been reviewed and identified from previous project articles. Most journals and articles found did not show a complete set of photovoltaics connections in MATLAB simulation. Based on my research, there is variety of photovoltaic simulations were formed and the simulation model step is shown in chapter 3. The work plan for this final project has been done.

The results of simulation of the mathematical model under radiation and temperature are analysed in chapter 4. Based on the graph and table result, the value of irradiance and temperature affects the output of the photovoltaic model. The current output in parallel connection is higher during operation. The voltage performance will change and high when the photovoltaics are connected in series.

5.3 Recommendation

For the recommendation, this work can expand for more detail of mathematical model which consist of MPPT and DC-DC regulation. Furthermore, the analysis can be expand to get the comparison with the real photovoltaic panel.

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