

PHTOVOLTAIC ENERGY GENERATION UNDER PARTIALLY SHADING CONDITIONS

By

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FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
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for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Siti Amirah Binti Ibrahim

A project dissertation submitted to the
Department of Electrical & Electronic Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

Approved:

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June or December 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Siti Amirah Binti Ibrahim

ABSTRACT

This paper presents a MATLAB-based modeling and simulation scheme for reviews and analyzes the behaviour of a photovoltaic device (cell or module) under partial shading conditions. It can be used as a tool to study the effects of partial shading conditions on PV panels to optimize its operation. However, PV performance is often affected by solar insolation and shading. Often, the PV arrays get shadowed, completely or partially by the passing clouds, neighboring buildings and towers, tress, and utility or telephone poles [1]. Yet, the shadowed arrays will result in loss in generation. In addition, for a given number of PV modules, the array configuration (in parallel or series) significantly affects the maximum available power under partially shaded conditions. Firstly, the fundamental studies are done to get the clear information of this project. This project objective is to observe or studied how much power produced by the PV under certain partial shading condition. In order to achieve that, a few method/model has been used. From all the models mention in this paper, only one is chosen that seems to be the suitable and easy to understand how it will be implemented. However, this technique still does not showed successful. Some improvement is needed to obtain the required result. As conclusion, this project objective is not achieved within the time given. The work that left undone is to come out with new program that combined the matrix and the programmed model.

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LIST OF ABBREVIATIONS

UTP	Universiti Teknologi Petronas
PV	Photovoltaic
GDC	Gas District Cooling
TNB	Tenaga Nasional Berhad
AC	Alternating Current
Isc	Short-circuit Current
Voc	Open-circuit Current

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Solar energy is a renewable energy that comes from natural source and harnessing the energy from the sun. Solar photovoltaic technology is the most frequent technology applied using large array of solar panels to harness the sun radiation by converting the radiation from sunlight directly to electricity. The objective of this paper is to study the characteristic of a PV array under partially shading conditions. It is very important to understand them in order to have optimum operation. There are two sources that generate the electricity to Universiti Teknologi PETRONAS (UTP). One is the Gas District Cooling (GDC) as the primary source while the utility company Tenaga Nasional Berhad (TNB) acts as the backup source. In addition, the capacity of the GDC plant is rated at 8.4MW that consists of two gas turbine generators that generate 4.2MW each. The electricity usage of UTP is expected to be increase in the future. Therefore, in order to meet the demand, solar photovoltaic technology will be implemented in UTP area.

1.2 Problem Statement

Photovoltaic (PV) arrays generate maximum power as the radiation of sun strikes to all surfaces or areas of the arrays. However, PV performance is often affected by solar insolation and shading. Often, the PV arrays get shadowed, completely or partially by the passing clouds, neighboring buildings and towers, tress, and utility or telephone poles [1]. Yet, the shadowed arrays will result in loss in generation. Due to uncertainty of partially shading condition, maximum power to be generated is difficult to estimate if no analysis model and numerical value algorithm model is applied.

1.3 Significance of Project

By modeling a prediction model using a MATLAB, it will estimate the generated power produced by the PV arrays. It also can be a tool to study the effect of the partially shading to overcome the loss in generation and optimize its operation. Therefore, the estimated loss in generation will lead to a new development tracking techniques to extract the maximum possible power.

1.4 Objective

To study the I - V and P - V characteristic of a PV device under partial shading condition using a MATLAB-based modeling and simulation scheme.

1.5 Scope of Project

This project will start with some literature review related to PV energy generation. Then, model a PV using MATLAB software. The data obtained will be analyzed.

1.6 Relevancy of Project

Since the UTP load demand is expected to increase as well as the electricity usage in the future, MATLAB-based modeling will become appreciable. This model will help to enhance the solar photovoltaic technology by predicting the percentage of loss in generation. The loss in generation's prediction will become the input or set point in modeling the actual PV arrays so that the real maximum power generation is meeting the demand. Yet, the accuracy of the prediction will ensure the reliability and continuous supply to the consumers.

1.7 Feasibility of Project

This project will be done in two semesters which include three areas which are model improvement, research and development. The objective is to have fully developed infrastructure of PV system so that the installation of PV system in UTP area will not be hindered by limited knowledge and the requirements needed among the local utilities and code officials. In addition is to increase the efficiency of the PV cells and modules so that more energy can be produced by smaller arrays or in locations with a less-favorable solar radiation resource. This project is feasible to be carried out within the time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Photovoltaic

2.1.1 Current Photovoltaic Technology

Solar photovoltaic is categorized as an active solar energy technology. It uses unique properties of semiconductors to directly convert solar radiation into electricity. The conversion from solar radiation into electricity occurs by photoelectric effect. In addition, a thin slice of semiconductor called wafer is used to make the solar cells which are sensitive to sunlight and produce a small direct current when exposed to light. PV system can produce alternating current (AC) compatible with any conventional appliances with the appropriate power conversion equipment. It also operates in parallel with and interconnected to the utility grid.

2.1.2 Photovoltaic History

In the late 1950s, the first conventional photovoltaic cells were produced and throughout the 1960s, it was principally used to provide electrical power for earth-orbiting satellites. In the 1970s, reduction of costs and increasing number of opportunities for powering remote terrestrial occurs due to improvements in manufacturing, performance and quality of PV modules. During energy crises in the 1970s, an effort began to develop PV power systems for residential and commercial uses both for stand-alone, remote power as well as for utility-connected applications. In the 1980s, photovoltaic became a popular power source for consumer electronic devices. Today, the industry's production of PV modules is growing at approximately 25 percent annually, and major programs in the U.S., Japan and Europe. They are rapidly

accelerating the implementation of PV systems on buildings and interconnection to utility networks.

2.1.3 Photovoltaic Cells, Modules, Panels and Arrays

A solar cell is the basic building block of a PV system. The cells are connected electrically in series or parallel circuits to produce higher voltages, currents and power levels. A typical PV cell produces 0.5V to 1V of electricity. The combination of PV cells that had been sealed in environmentally protective laminate called PV modules will produce an appreciable amount of electrical power with no moving parts, noise or emissions. One or more PV modules assembled as a pre-wired, field-installable unit will become PV panels. A photovoltaic array consists of any number of PV modules and panels with complete power-generating unit.

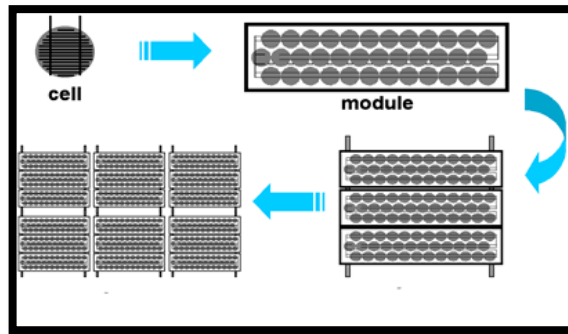


Figure 1: Photovoltaic Cells, Modules, Panels, and Arrays

2.1.4 Photovoltaic Cell Component

Solar cells are usually made of silicon that is a semiconductor material which means that can conduct electricity under some conditions but not others. Pure silicon is not conductive. However, by adding other element to its crystalline structure, it can be made conductive. PV cells consists of two type materials which are n-type silicon and p-type silicon. Silicon that has been chemically combined (doped) with phosphorus gas is called N-type silicon. Silicon is in group 14 according to the periodic table. It is situated between the aluminum and phosphorus. Therefore, the silicon atom has two

electrons in its first shell, eight electrons in its second shell and four electrons in its outer shell called valence shell.

Figure 2: Periodic Table

The silicon's valence electrons bond tightly with four surrounding silicon atoms which make them very stable. However, in order to disturb the stable state, doping atom is purposely inserted into the silicon. In this case phosphorous atom is doped. Phosphorus atom has five electrons, and when combined, the fifth electron becomes a "free" electron that moves easily within the crystal structure when a voltage is applied. N-type refers to a negative charge because the charge carriers are electrons.

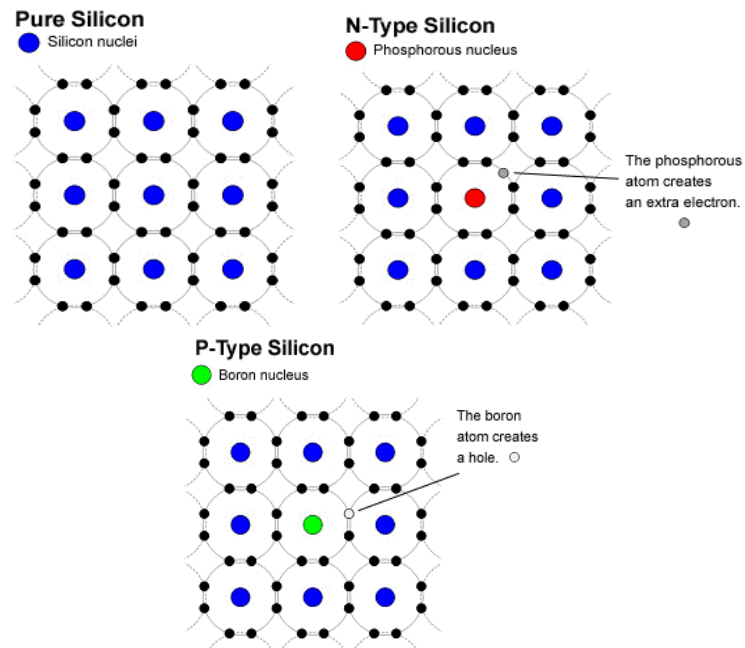


Figure 3: Pure Silicon, N-type and P-type Silicon Atom Structure

In contrast, p-type silicon is silicon doped with boron gas that turns it into a conductive material that readily accepts electrons when voltage is applied. The combination of boron and silicon will create a “hole” because boron only has three electrons in its outer shell and the hole is ready to be occupied by an electron. P-type has a positive charge because the charge carriers are holes.

2.1.5 Photovoltaic Cells Operation

One important way to convert solar radiation into electricity occurs by the photovoltaic effect [2]. The photoelectric effect relies on the principle that whenever light strikes the surface of certain metals, electrons are released. A solar cell consists of two silicon panels attached together. One layer is doped with N-type dopant while the other is doped with P-type dopant. Front and back contact is installed to the two layers to allow an electrical flow of electrons. In addition, the glass is installed on top of it to protect the layers and the electrical contacts from damage.

In the N-doped semiconductor, there is an excess electron while in P-doped semiconductor there is a positively charge electron hole. The electrons one layer will find their corresponding free hole in the other layer. Consequently, an internal electrical field is produced at this transition that does not permit electrons and holes to jump into the other layer. However, if photon hits the silicon layers, electron hole pairs will be created. If this happens in the electrical field, electrons are move to the N-doped layer while holes are move to the P-doped layer. The system will falls into the state which is imbalance because of the excess electrons on the N-doped layer.

The corresponding holes can be found in the P-doped layer. It goes without saying that the free electrons and free holes is try to combine. However, the electrical field does not allow such condition. If the N-doped layer is connected to the P-doped layer using a cable, electrons are traveling to the free holes through the cable. This flow called an electrical current.

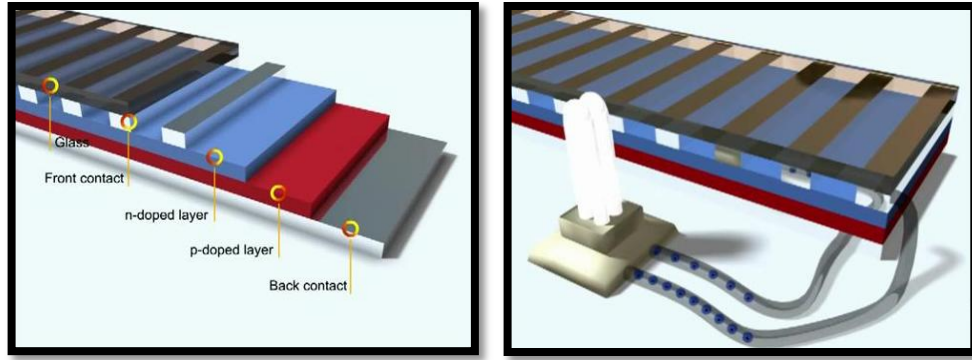


Figure 4: Layers of Solar Cell and Electrons Flow through the Cable

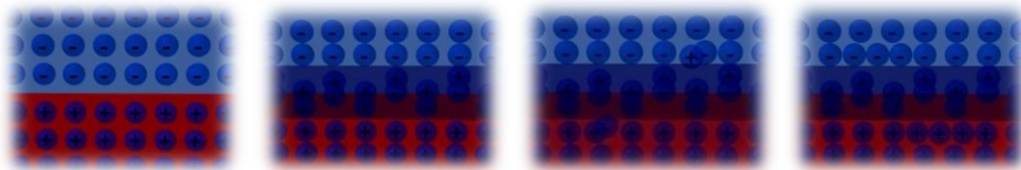


Figure 5: Semiconductor Layer

2.1.6 Photovoltaic System

Solar panel can be installed on the ground or on the roof top of a house. The solar cells collect the rays of the sun and convert solar radiation into direct current which is eventually converted to more useable alternating current by a piece of equipment called an inverter. Another device connected to the inverter that will measure the electricity produced by the photovoltaic system. Generated electricity is sent to the grid by a transformer. The transformer will step up the voltage of the generated electricity to ensure the same voltage potential with the grid.

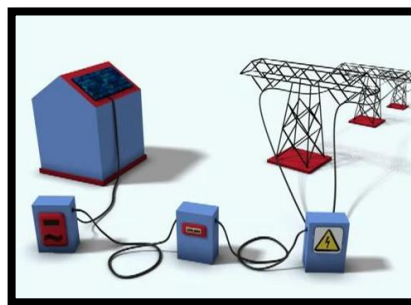


Figure 6: Photovoltaic System

CHAPTER 3

METHODOLOGY

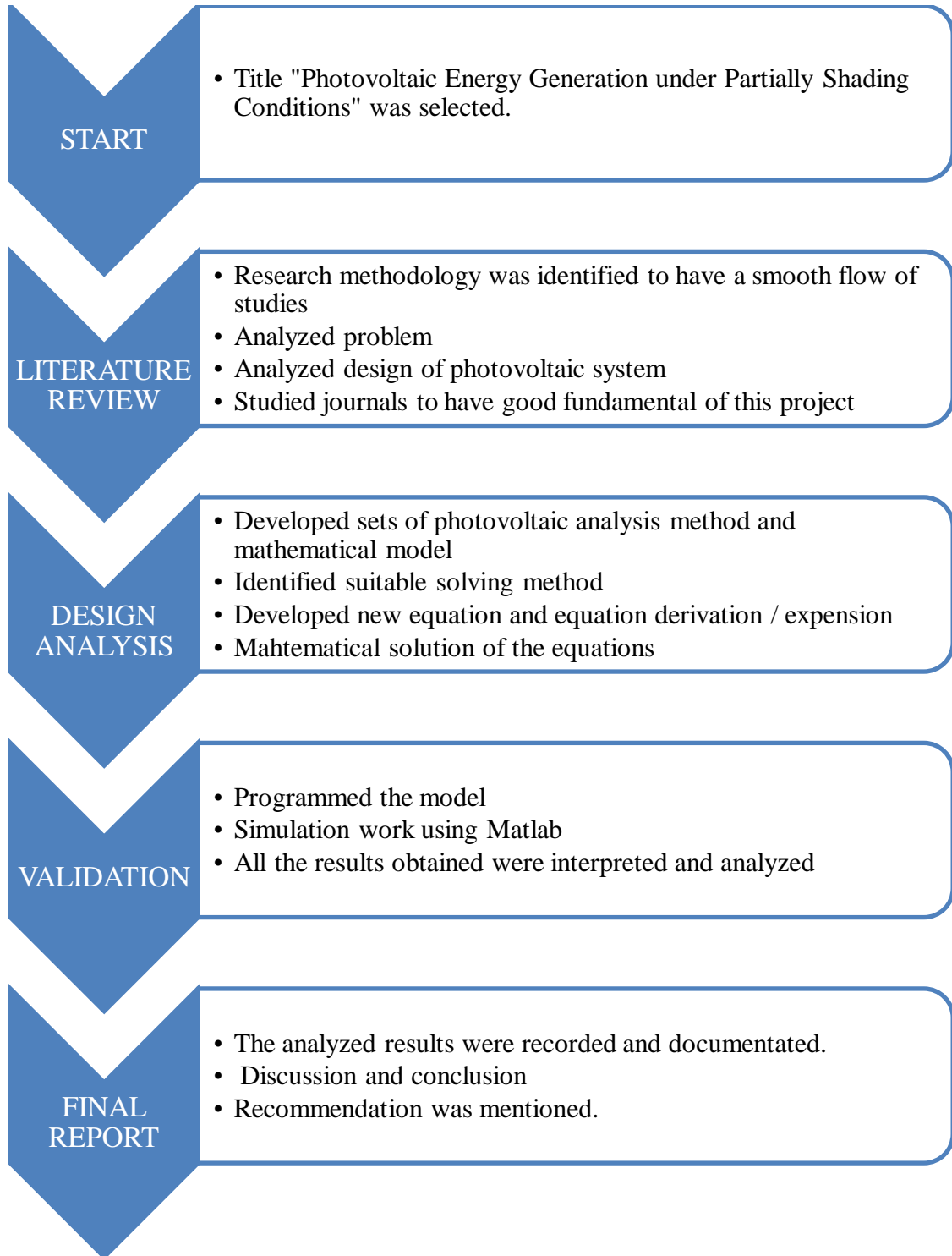
3.1 Research Methodology

In order to gain information regarding the major scope of the project, some research had been done. The sources of the research cover e-journal and several trusted link.

The steps of research:

1. Gain information of the environmental friendly renewable energy which focuses on solar power and the type of photovoltaic cell.
2. Compare all alternative methods in modeling the PV system.
3. Identify the most suitable method for this project.

3.2 Methodology of Project



3.3 Project Duration

Table 1: Project Duration

No	Detail/Week	1	2	3	4	5	6	7	Mid-Semester Break	8	9	10	11	12	13	14
1	Selection of Project Topic: MATLAB-Based Modeling of Photovoltaic Panel and Examining Effect under Partially Shading Conditions															
2	Preliminary Research Work: Research on literatures related to the topic															
3	Submission of Extended Proposal															
4	Project Work: Study on the research scope and method															
5	Viva: Proposal Defense and Progress Evaluation															
6	Draft Report Submission															
7	Final Report Submission															

3.4 Tool Required

The main tool for this project is MATLAB R2009b software. MATLAB is an ideal tool as it is available in most academic, research, and industrial organizations and considered useful for several engineering disciplines. It provides several features that can be used to simulate highly complex systems, electronic and power electronic circuits and systems, and distributed generation power systems [1].

CHAPTER 4

RESULT AND DISCUSSION

4.1 Design

A model of photovoltaic device will be created and several simulations will be run to test the model. The test can be done effectively using the program Simulink. An interactive tool called Simulink is used for modeling, simulating, and analyzing dynamic systems, including controls, signal processing, communications, and other complex systems [4]. It is an excellent and frequently used resource for modeling and simulating mathematical system and subsystems. Within this resource, block diagrams are used to design and model a system with Simulink. It is also possible to add in MATLAB functions into a block.

4.1.1 Modeling the Solar Cell

This model of photovoltaic cell was based on a MATLAB model from Akihiro Oi's thesis paper [5]. A simple PV cell circuit is basically an ideal current source in parallel with an ideal diode. The current source represents the current generated by the PV cell due to the photons received by it [6]. Short-circuit current and open-circuit voltage are the parameters that often used to characterize a PV cell are. These parameters are generally provided by the manufacturer.

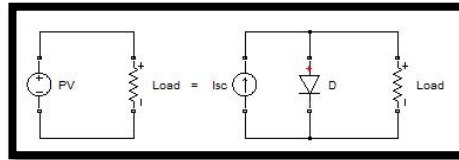


Figure 7: Equivalent Circuit of a Simple PV Cell

From figure 7, PV cell is equivalent with the current source parallel with a diode. The output current of the PV cell can be found using the equation:

$$I = I_{sc} - I_d$$

Where:

- I_{sc} is the short-circuit current that is equal to the photon generated current
- I_d is the current shunted through the intrinsic diode

The diode current is given by the Shockley's diode equation:

$$I_d = I_o * (e^{q*V_d/(k*T)} - 1)$$

Where:

- “ I_o ” is the reverse saturation current of diode (A),
- “ q ” is the electron charge (1.602×10^{-23} C),
- “ V_d ” is the voltage across the diode (V),
- “ K ” is the Boltzmann's constant (1.381×10^{-23} J/K),
- “ T ” is the junction temperature in Kelvin (K).

Combining the diode current equation with the equation for the output current of the PV cell creates:

$$I = I_{sc} - I_o * (e^{q*V/(k*T)} - 1)$$

Where:

- “ V ” is the voltage across the PV cell
- “ I ” is the output current

However, in I-V characteristic of PV cell, there are reverse biased condition. We can solve for the reverse saturation current (I_o) by setting $I = 0$ (no output current).

$$0 = I_{sc} - I_o * (e^{q*V/(k*T)} - 1)$$

$$I_o = I_{sc} / (e^{q*V/(k*T)} - 1)$$

Often, a simple PV cell model neglects to account for a few things. In order to create a more accurate model, series resistance, R_s , parallel resistance, R_p , and recombination must be factored into the equation. In an ideal cell, $R_s = R_p = 0$, which are relatively common assumption [7]. A series resistance R_s was included which represents the resistance inside each cell in the connection between cells [8]. A shunt resistance is parallel with the diode. Its effect is minimal so it will be neglected. Therefore, we can assume that $R_{sh} = \infty$. The simplified photon-generated current equation is:

$$I = I_{sc} - I_o * (e^{q*(V+I*R_s)/(k*T)} - 1)$$

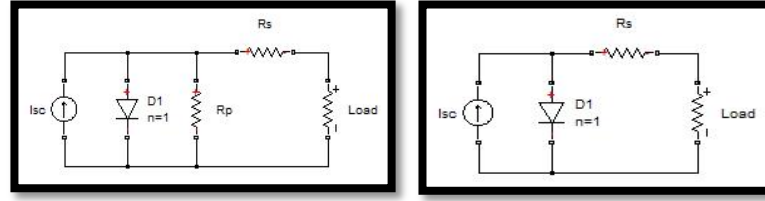


Figure 8: Simplified Equivalent Circuit of PV Cell (from left to right)

The value of the photon generated current, I_{sc} can be assumed to be directly proportional to the irradiance, and the short circuit current value under standard test conditions, G_o is 1000 W/m^2 . Therefore, the photon generated at any other irradiance, $G \text{ (W/m}^2\text{)}$ equation is:

$$I_{sc} * I_G = I_{sc} * T_{Go} * (G/G_o)$$

4.1.2 Simulink Diagram

4.1.2.1 A Photovoltaic Cell Simulink Diagram (1)

A Photovoltaic cell simulink diagram is represented as shown below:

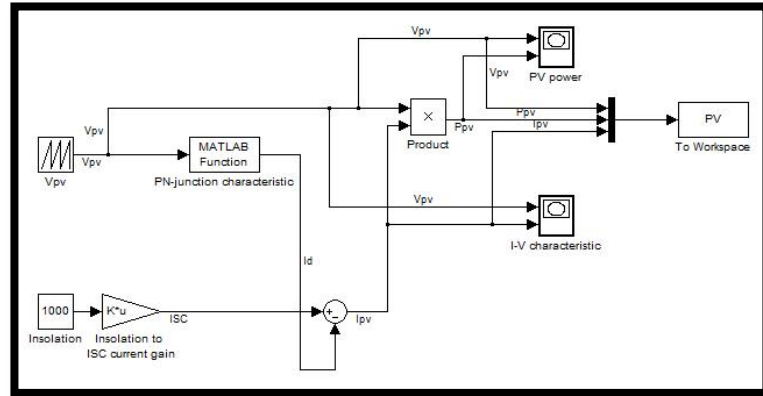


Figure 9: Simulink Diagram of a PV Cell

4.1.2.1.1 Description of Simulink Diagram of Photovoltaic Cell

Based on Figure 9 above, the simulink diagram contains insolation constant block that represent the standard value of irradiance which is 1000 W/m^2 . We assume that the irradiance is equal to the current source and we can say it is an input, I_{pv} to the model. In addition, there is another input to the model which will be subtracted to the current input. It is the repeating signal of voltage, V_{pv} which is given by V_{pv} block. Within the MATLAB function block, we need to insert user define function as shown in Figure 10. The function is for P-N junction characteristic. Also, the parameter of the I_{sc} gain is set as shown in Figure 14. The product of the current, I_{pv}

and voltage, V_{pv} is output power, P_{pv} . The output of the system which is I-V and P-V characteristics will be displayed in the X-Y Plot Window.

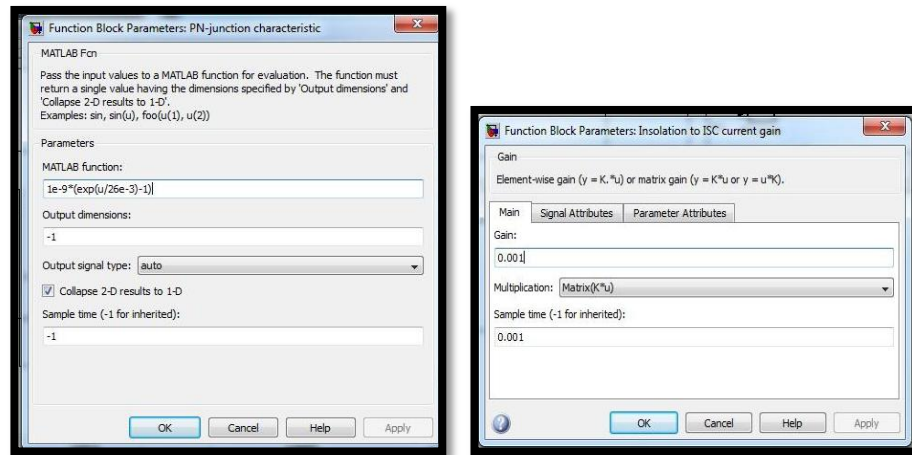


Figure 10: PN-junction Characteristic and Short-Circuit Current, Isc Gain Parameter

4.1.2.1.2 Result of the Photovoltaic Cell

The short-circuit current, I_{sc} depends on the radiation of the moment. The higher the irradiation, the greater the current [10]. However, voltage is not much varied and maintains almost constant value even though the irradiance is increasing or decreasing. . The output current of a PV cell is depends on the external voltage applied to it and the amount of sunlight strikes on the cell. When the cell is short-circuited, the current is at maximum (short-circuit current, I_{sc}), and the voltage across the cell is 0 [2]. When the PV cell circuit is open, with the leads not making a circuit, the voltage is at maximum (open circuit voltage, V_{oc}), and the current is 0 [11].

Figure 11 (on the left) shows the resultant of I-V characteristic curve of a solar cell at 1000 W/m^2 irradiance and at a fixed cell temperature. Figure 11 (on the right) shows the I-V curve of a diode without illumination in a green colour. When forward bias potential is applied, the curve shows the turn-on and buildup the forward bias current in the diode. Without illumination, no current flows through the diode unless there is external potential applied [12]. The IV curve shifts up when there is incident sunlight and it indicates there is also external current flow from the solar cell to a passive load.

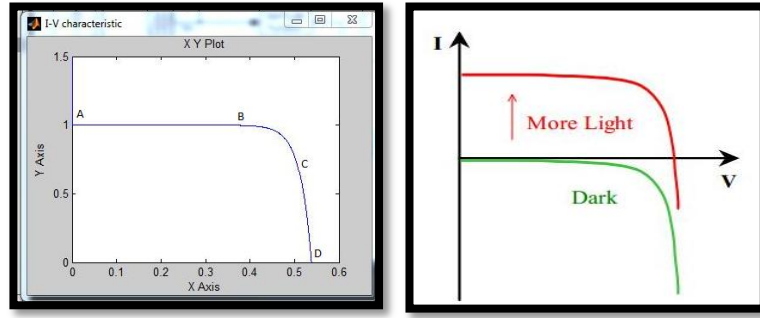


Figure 11: I-V Characteristic Curve and Progression of Solar Cell I-V Curve as the Incident Light Increases

Based on figure 11(on the left), the cell behaves as a constant current from point A to B because it is almost equal to the short circuit current. The cell operates in this region because of the small load. However, if the load is large, the cell operates at the region C to D and behaves more as a constant voltage source which is almost equal to the open-circuit voltage. According to figure 12 (on the left), the power delivered to the load is zero at both extremes and it reaches its maximum value, P_{max} , at a finite load resistance value.

The P_{max} is shown as the area of the shaded rectangle. It indicates the maximum power delivered by the solar cell. Figure 12 (on the right), shows the maximum power, P_{max} , that the solar cell can deliver to a load, and the value of the load resistance needed for the maximum power transfer. Each point on the IV-curve is related to the load resistance and the power delivered to the load. Therefore, the I-V curve can be converted to a power vs. voltage curve.

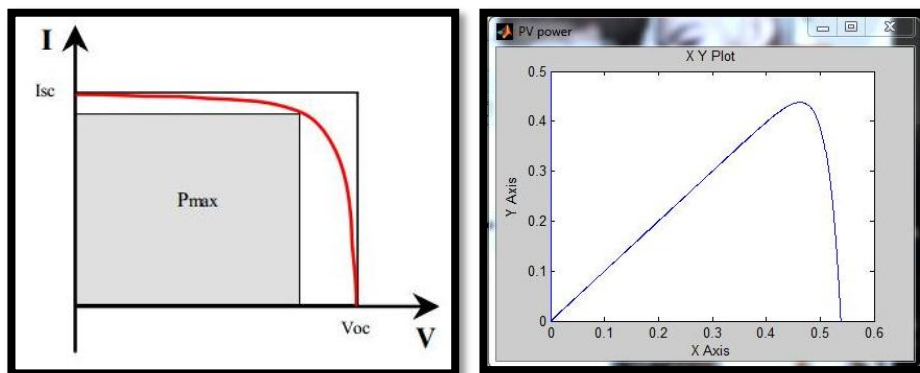


Figure 12: Maximum Power Delivered by Solar Cell, P_{max} and P-V Characteristic Curve

4.1.2.2 A Photovoltaic Cell Simulink Diagram (2)

A Photovoltaic cell simulink diagram is represented as shown below:

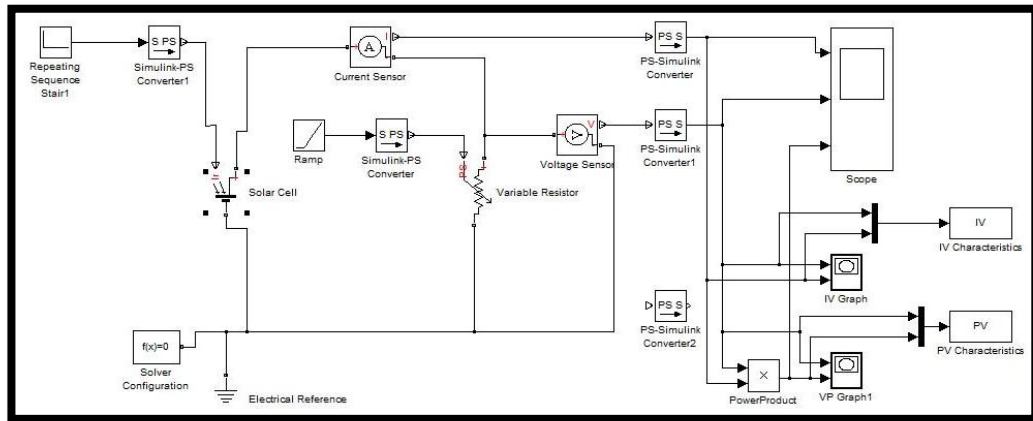


Figure 13: Simulink Diagram of a PV Cell

4.1.2.2.1 Description of Simulink Diagram of Photovoltaic Cell

Based on Figure 13 above, the simulink diagram is created using Simscape, another features in Matlab. The diagram contains Repeating Sequence Stair block that acts as insolation constant block that represent the standard value of irradiance which is 1000 W/m². Simulink-PS Converter block is needed to convert simulink input signal to physical signal. It connects Simulink sources or other Simulink blocks to the inputs of a Physical Network Diagram. In addition, Solver Configuration is required to do the simulation as it will give specifies solver parameter that the model needed. The parameter of the Repeating Sequence Stair (on the left) and Solar Cell is set as shown in Figure 14.

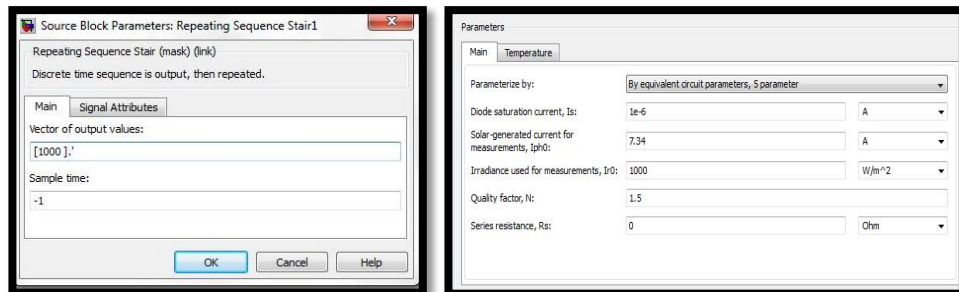


Figure 14: Repeating Sequence Stair and Solar Cell Parameters

4.1.2.2.2 Result of the Photovoltaic Cell

Figure 15 shows the I-V and P-V Curve of Figure 13 Diagram. Even though Simulink Diagram (1) and (2) have the same objective which is to produce the curve of a photovoltaic cell, the resultant curves are slightly different in terms of voltage and current. This is because, in Simscape, the Solar Cell behavior is the same as the real solar cell while in Simulink Diagram (1), the solar cell behavior is an ideal behavior where it is possible to be achieved in the real world.

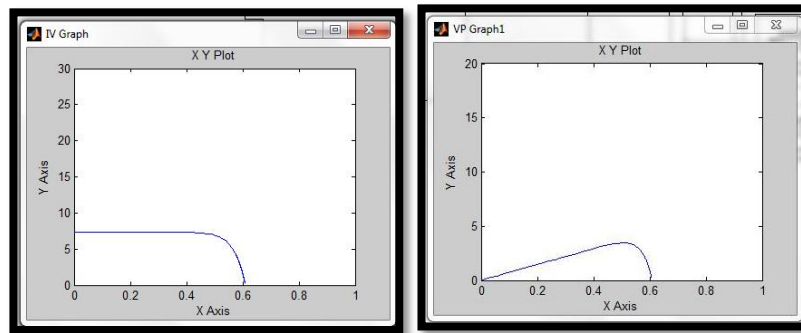


Figure 15: I-V and P-V Characteristic Curve

4.1.2.3 Photovoltaic Module

Photovoltaic module simulink diagram is represented as shown below:

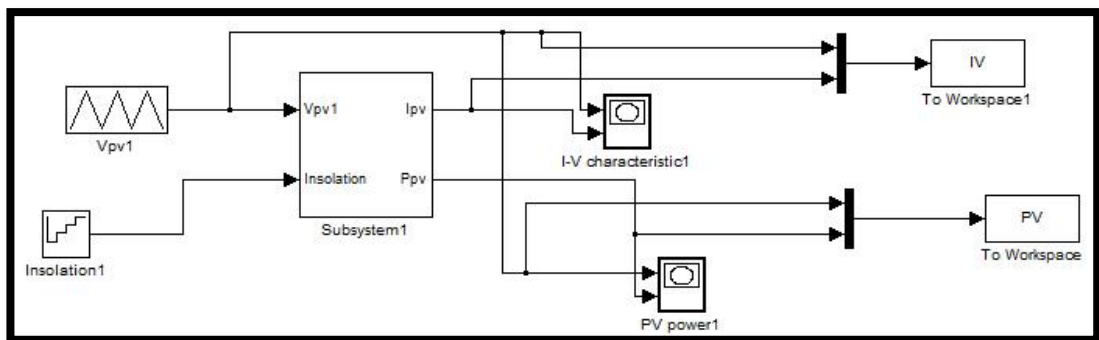


Figure 16: Simulink Diagram of Photovoltaic Module

4.1.2.3.1 Description of Simulink Diagram of Photovoltaic Module

Figure 16 is the simplified block diagram for photovoltaic module from photovoltaic cell block diagram. Figure 18 shows how the cell block diagram is being simplified and becomes module. A few new block diagrams have been added to the cell block diagram such as algebraic constant, switch, and constant. Also, the gain is added for shunt resistant, parallel resistant and number of cell. The model parameters

have been set as shown in figure 17. The PN-junction parameter, terminal voltage, V_t and current output, I_o for PV module is set. N_s , variable that indicates PV module is made of a certain number of PV cell. For example, 'A' type PV module will have 72 cells of PV cell while 'B' type PV module will have 62 cells of PV cell. The number of the PV cell is different depends on the requirements.

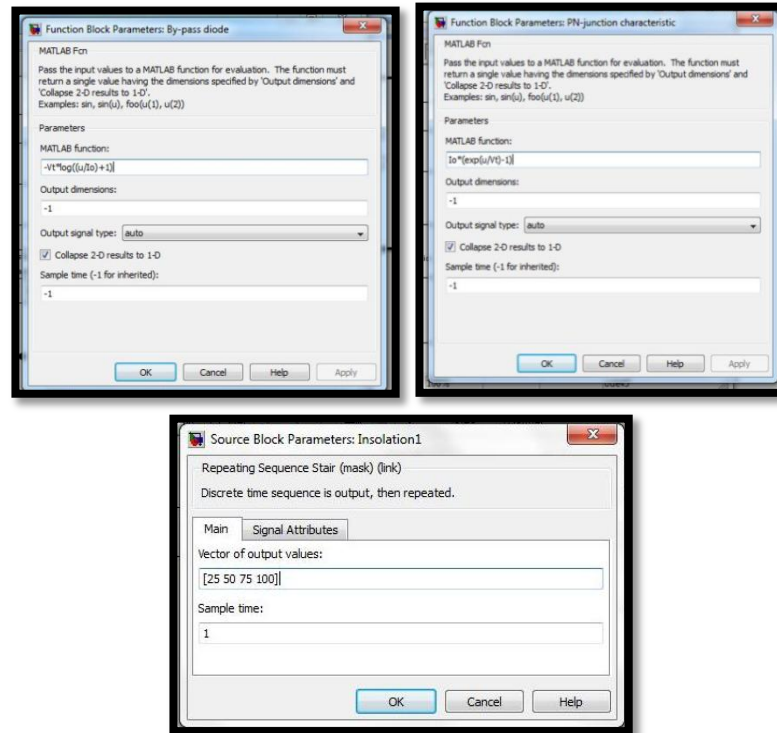


Figure 17: By-pass Diode, P-N Junction and Insolation Parameters

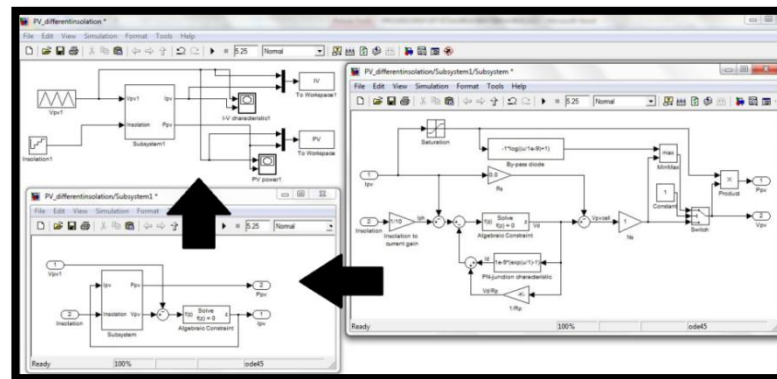


Figure 18: Subsystem

4.1.2.3.2 Result of Simulink Diagram of Photovoltaic Module

Figure 19 shows the resultant of I-V and P-V curve for different insolation. The insolation level is set as shown in Figure 17. The insolation had been set to 25W/m^2 , 50W/m^2 , 75W/m^2 and 100W/m^2 . As the insolation gets lower, the product of current-voltage and the current is decrease. However, there are slightly changes in the voltage. This module is equal to a cell of photovoltaic. This is because the value of gain of number of cell is 1 in the diagram.

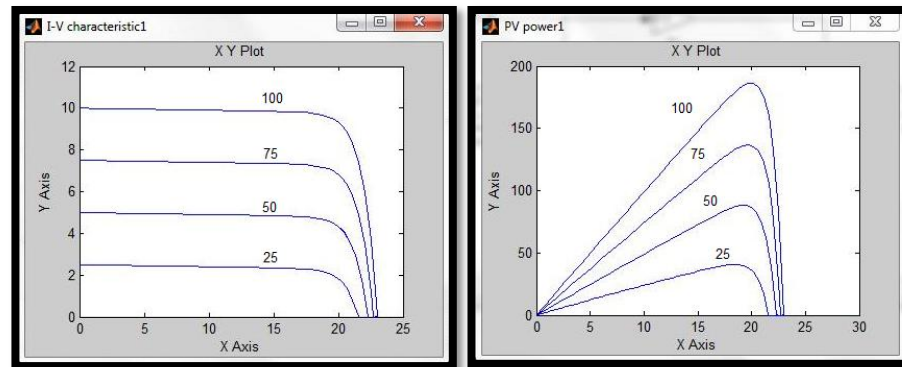


Figure 19: I-V and P-V Characteristics of PV Cell for Changing Insolation

4.1.2.4 Photovoltaic Cells connected in Series

Simulink diagram of photovoltaic cells connected in series is represented as shown below:

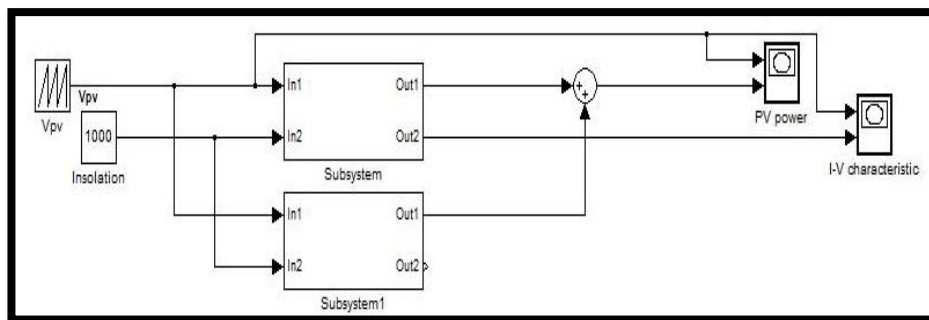


Figure 20: Simulink Diagram of Photovoltaic Cells Connected in Series

4.1.2.4.1 Description of Photovoltaic Cells Connected in Series

From figure 20, the PV cells are connected in series. We assume that a cell of photovoltaic can act like a battery. As the battery is connected in series, the current remains unchanged while the voltage is added.

4.1.2.4.2 Result of Photovoltaic Cells Connected in Series

From Figure 21, we assume that 'Subsystem' and 'Subsystem1' is the module. If these two PV modules are connected in series, they will conduct the same current, but the voltage across them will be different [1]. As shown in figure 21, the power of the module is increased while the current remains.

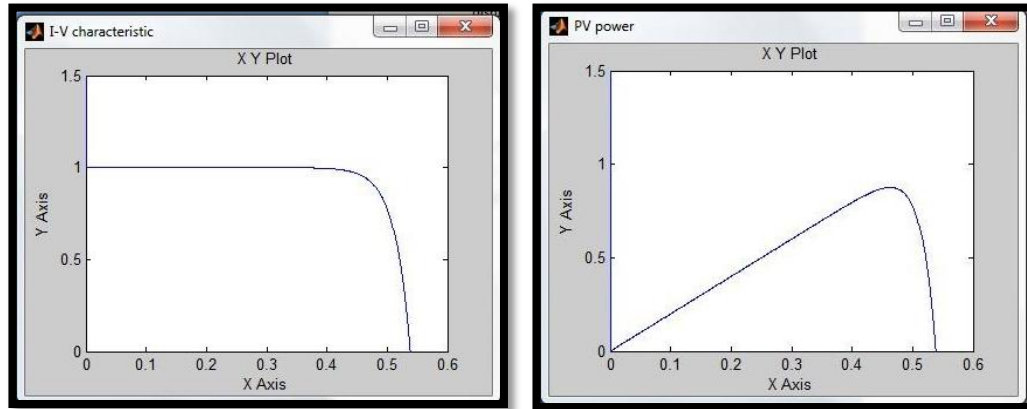


Figure 21: I-V and P-V Characteristic of Photovoltaic Cells Connected in Series

4.1.2.5 Photovoltaic Cells connected in Parallel

Simulink diagram of photovoltaic cells connected in parallel is represented as shown below:

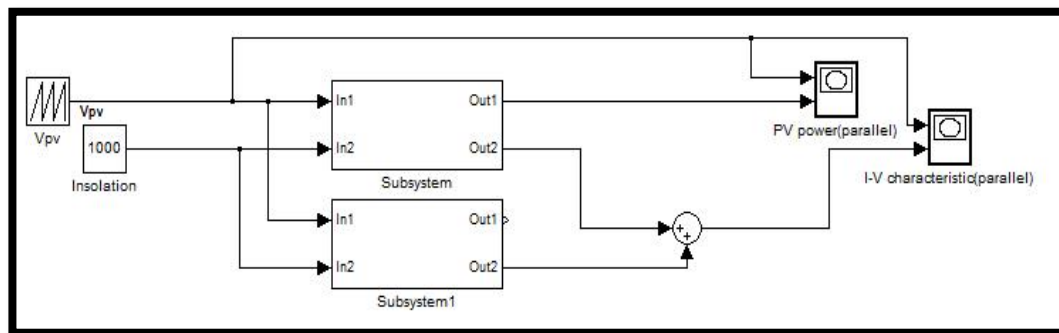


Figure 22: Simulink Diagram of Photovoltaic Cells Connected in Parallel

4.1.2.5.1 Description of Photovoltaic Cells Connected in Parallel

From figure 22, the PV cells are connected in parallel. When a cell of photovoltaic is connected in parallel, the current is multiplied while the voltage is remains unchanged.

4.1.2.5.2 Result of Photovoltaic Cells Connected in Parallel

From figure 23, the 'Subsystem' and 'Subsystem1' is connected in parallel. We assume the modules are similar series with identical insolation. If these similar series having identical insolation patterns are connected in parallel to form a group, the current output is multiplied, but there is no change in the output voltage [1]. As shown in figure 23, the power of the module remains unchanged while the current is increased by double.

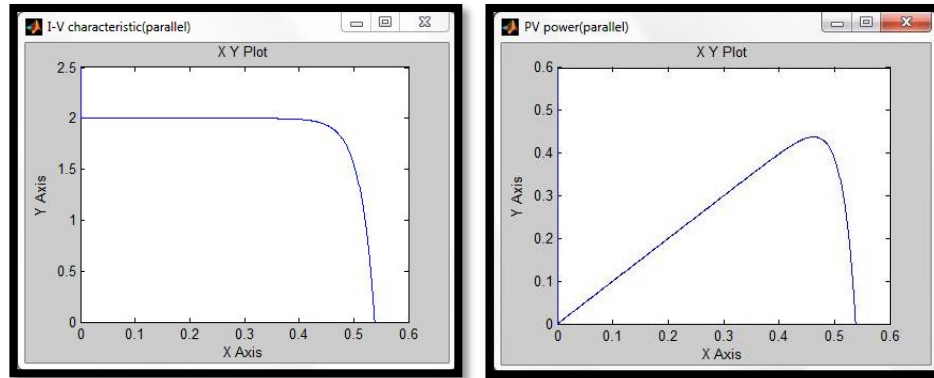


Figure 23: I-V and P-V Characteristic of Photovoltaic Cells Connected in Parallel

4.1.2.6 Photovoltaic Array

Model programming is used to model photovoltaic array. Based on previous studies for example developed by Akihiro Oi [3], G. Walker [13] and F. M. Gonzalez-Longatt [9], the function developed to create the photovoltaic array by all authors is very similar. This function is based on Matlab Software, which needs three values to calculate the net current of the cell (Module operating current) [10]:

- In : V_a = Module operating voltage (V), vector or scalar
- G = Irradiance ($1G = 1000 \text{ W/m}^2$), scalar
- T_a = Module temperature in deg C, scalar

The body of the program is separated in three main parts which are:

- Constant's definition (electron charge, diode ideality factor, band gap)
- Variable's definition (calculation of I_{ph} , I_0 and R_s)
- Calculation of I_a

Constants and variables are defined (Appendix 1). The constant's values used present the real behavior of solar cell. The value of open-circuit voltage, $V_{OC} = 21.06V$ while the value of short-circuit current, $I_{SC} = 3.80A$. I_{SC} produced by short-circuit condition where the voltage, $V = 0V$ and it is the greatest value of current generated by a cell. V_{OC} is considered as the voltage drop across the diode (p-n junction) when it is transverse by the irradiant at the condition $I = 0A$ [9]. Appendix 1 shows I_a equation with five iterations. This is to get the accurate date of the output current. The result obtained from the programmed model as shown in Figure 24. The I-V characteristic curve obtained represents solar cells connected in series with the voltage is defined in increased fixed value.

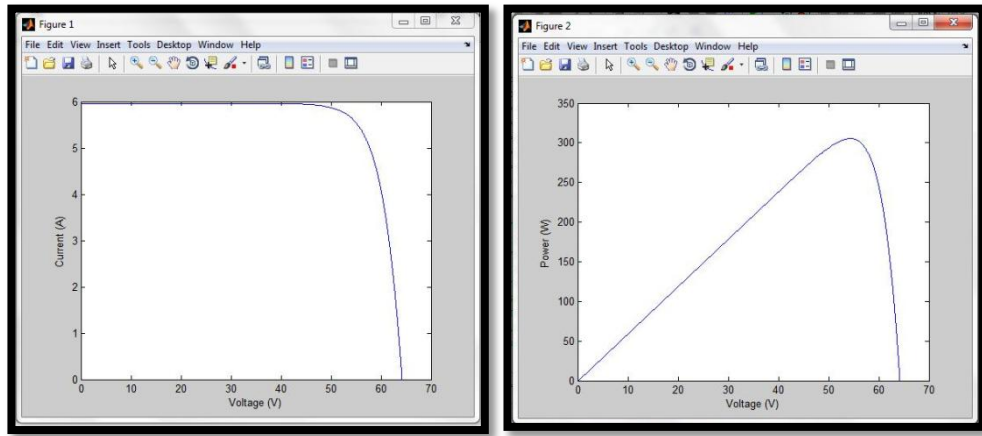


Figure 24: I-V and P-V Characteristic Curves

Therefore, to obtain the programmed PV array features, matrix configuration is used as shown Appendix 2. This procedure consists of defining groups, assemblies, and etc. The 'X' array shown in Figure 27 will describe how the shading pattern and configuration of the array used in illustration. The first column of 'X' array (m, m2, and m3), it defined as the number of unshaded modules in series with solar insolation = 1.0 ($1G = 1000 \text{ W/m}^2$). Second column of 'X' array (q, q1, and q3) is defined as the number of shaded modules in series assembly with solar insolation = 0.1. The last column (n, n1, and n2) is identified as number of series assemblies in a group. The shading pattern for a large array is very complex to model. In this procedure, only two different insolation levels are used for simplicity.

In order to describe various components of a PV array, a special categorization and terminology is used. As shown in figure 25, a "subassembly" is formed with several series connected PV modules receiving the intensity of irradiant.

Several such series-connected subassemblies, each with a different level of irradiant, form a series assembly [Figure 25(b)]. Series assemblies, having similar shading patterns, form a ‘group’ [Figure 25(c)]. Various groups (with i th group represented by ‘ G_i ’), having different shading patterns and connected in parallel, form a PV arrays, as shown in Figure 25(d)[1]. Illustration will explain the method and the format in which the input parameters are fed and the array configuration is described in the software to obtain the PV characteristics.

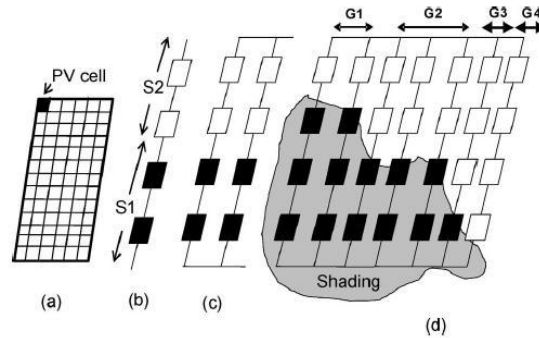


Figure 25: PV Array Terminologies. (a) PV module. (b) Series-Assembly with Two Series-connected Subassemblies S1 and S2. (c) Group. (d) PV Array with groups G1 to G4.

```

Command Window
unshaded modules in series G1: 5
shaded modules in series G1: 7
no of series in a group G1: 42
unshaded modules in series G2: 8
shaded modules in series G2: 4
no of series in a group G2: 40
unshaded modules in series G3: 11
shaded modules in series G3: 1
no of series in a group G3: 24

x =

     5     7    42
     8     4    40
    11     1    24

fx >> |

```

Figure 26: Matlab Matrix Command Window.,

Table 2: Shading Pattern and Configuration of the Array used in Illustration

Group	No. of unshaded modules in series assembly ($G = 1.0$)	No. of shaded modules in series assembly ($G = 0.1$)	No. of series assemblies in a group
G1	5	7	41
G2	8	4	40
G3	11	1	24

CHAPTER 5

CONCLUSION

As a conclusion, the I-V and P-V characteristic curves obtained are acceptable. It is recommended to use other design method approach for shading conditions. Project is smoothly progress according to pre-planned gantt chart. It is feasible for this project to be completed in this semester.

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- [12] Solar Cell Voltage – Current Characterization retrieved at April 25, 2012 at <http://www.californiascientific.com/resource/Solar%20Cell.pdf>
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APPENDICES

Appendix 1

```
clc
clear

VOC=64.2; %open circuit voltage (V)
ISC=5.96; %short circuit current (A)
VR=54.7; %reference voltage for maximum power
IR=5.58; %reference current for maximum power
TR=298; %reference temperature (K)
GR=1000; %reference irradiance (W/m^2)
NS=96; %number of cells per module
AM0=1.631; %area of one module (m^2)
mi=0.0035; %temperature coefficient for short circuit current (A/K)

% VOC=44.8; %open circuit voltage (V)
% ISC=8.33; %short circuit current (A)
% VR=35.2; %reference voltage for maximum power
% IR=7.95; %reference current for maximum power
% TR=298; %reference temperature (K)
% GR=1000; %reference irradiance (W/m^2)
% NS=72; %number of cells per module
% AM0=1.94; %area of one module (m^2)
% mi=0.00045; %temperature coefficient for short circuit current
% (A/K)

%-----CELL PARAMETERS-----
EG=1.124; %energy gap (eV)
A=1.3; %ideality factor
k=1.38*10^-23; %Boltzmann's constant (J/K)
q=1.6*10^-19; %charge of electron (C)
```

```

%-----INPUT-----

TA=input('Temperature (oC): ');
T1=TA+273; %convert from Celcius to Kelvin
%T1=input('Temperature (K): ');
G1=input('Solar irradiance (W/m^2): ');

% MS1=input('Number of modules in series (0 for single): ');
% MP1=input('Number of modules in parallel (0 for single): ');
MS1=0;
MP1=0;

%-----CALCULATION OF V BY VARYING I FOR A SINGLE MODULE-----

IL1=(ISC+(mi)*(T1-TR))*(G1/GR); %light generated current
IRS1=ISC/(exp((VOC*q)/(NS*A*k*TR))-1); %reference saturation current
IS1=IRS1*((T1/TR)^3)*exp((q*EG/(A*k))*((1/TR)-(1/T1))); %saturation
current
RS1=((NS*A*k*TR/q)*log(((ISC-IR)/IRS1)+1)-VR)/IR; %series resistance
h1=IL1/1000; %setting increment
IA=0:h1:IL1; %range of I with increment h
N1=length(IA); %number of data points
VA(N1)=0; %setting final value of V
for i=1:(N1-1)
VA(i)=(NS*A*k*T1/q)*log(1+(IL1-IA(i))/IS1)-IA(i)*RS1; %computing V
end
%
% -----DETERMINATION OF OUTPUT BASED ON NUMBER OF MODULES-----
ifMS1==0 %determining number of modules connected in series
MSA=1; %single module
else
MSA=MS1; %multiple modules connected in series
end

ifMP1==0 %determining number of modules connected in parallel
MPA=1; %single module

```



```

else

MPA=MP1; %multiple modules connected in parallel

end

V1=MSA*VA; %new voltage limit
I1=MPA*IA; %new current limit
P1(N1)=0; %setting final value of P
for i=1:(N1-1)
P1(i)=I1(i)*V1(i); %computing P
end

%-----MAXIMUM POINT DETERMINATION-----

[PMAX1,i]=max(P1); %maximum P
VMAX1=V1(i); %V at maximum P
IMAX1=I1(i); %I at maximum P

%-----FILL FACTOR DETERMINATION-----

FF1=(VMAX1*IMAX1)/(V1(1)*I1(N1));

%-----EFFICIENCY DETERMINATION-----

AM1=MSA*MPA*AM0; %area based on number of modules
n1=(PMAX1/(AM1*GR))*100;

%-----I-V CHARACTERISTIC PLOT-----

figure(1)
plot(V1,I1), xlabel('Voltage (V)'), ylabel('Current (A)');
%

% %-----POWER AGAINST VOLTAGE PLOT-----

figure(2)
plot(V1,P1), xlabel('Voltage (V)'), ylabel('Power (W)');

```

Appendix 2

```
function output = matric

m = input('unshaded modules in series G1: ');
q = input('shaded modules in series G1: ');
n = input('no of series in a group G1: ');

m1 = input('unshaded modules in series G2: ');
q1 = input('shaded modules in series G2: ');
n1 = input('no of series in a group G2: ');

m2 = input('unshaded modules in series G3: ');
q2 = input('shaded modules in series G3: ');
n2 = input('no of series in a group G3: ');

x = [ m    q    n    ;
      m1   q1   n1   ;
      m2   q2   n2  ]
```