UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

SHADING ANALYSIS FOR DESIGN OF PV POWER PLANT

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Bachelor in Electrical Engineering (Industrial Power)

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SHADING ANALYSIS FOR DESIGN OF PV POWER PLANT

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A report submitted

in partial fulfillment of the requirements for the Bachelor in Electrical Engineering

(Industrial Power)

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

DECLARATION

I declare that this report entitle "***Shading Analysis for Design of PV Power Plant***" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature : ....

Name : VINODH A/L ANNATHURAI

Date : ....

APPROVAL

I hereby declare that I have read through this report entitle “**Shading Analysis for Design of PV Power Plant**” and found that it has complied the partial fulfillment for awarding the Bachelor in Electrical Engineering (Industrial Power)

Signature : ....

Supervisor’s Name : DR. GAN CHIN KIM

Date : ....

DEDICATION

Dedicate to my beloved parents and family

ACKNOWLEDGEMENT

First of all, I would like to thank all the good people who have helped me in various ways to complete my Final Year Project.

My utmost gratitude goes to my main project supervisor Dr. Gan Chin Kim for continued patience and guidance, and for incredible expertise that he brings to all phases of the project. I highly appreciate his valuable time in giving me useful ideas to complete this project.

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ABSTRACT

PV system is environment friendly which is designed to reduce consumption of electricity from non-renewable energy sources. However, the PV system is exposed to weather conditions causing declination in power generation efficiency. Shading of photovoltaic modules is a widespread phenomenon which affects the performances of the PV system. In accordance to it, this research aims to improve the shading factors which will affect the performances of photovoltaic (PV) system in the solar power plant. Shading of solar cells not only reduces the cell power P_{MPP}, but also changes the open circuit voltage V_{OC}, short circuit current $I_{SC,}$ fill factor and its efficiency. The objective of this research is to design a PV power plant with a low or zero shading factor. This report has classified the shading into two aspects; the distance between buildings to PV power plant and height of the building. The Solar Pro software is used to analyze the shading and identification of the suitable ways to minimize the shading factor. The data obtained from the simulation were compared with the Meteonorm software, journals and experiment for the validity of the data. The findings from this research will give a clear view of the height of the buildings and the exact distance from the PV power plant to achieve zero shading factor. The exact specific distance can be calculated using the multiplier of the height of the building. The multiplier of the height is varied with different size of the PV power plant.

ABSTRAK

Sistem PV adalah mesra alam sekitar yang direka untuk mengurangkan penggunaan tenaga elektrik daripada sumber tenaga yang tidak boleh diperbaharui. Walau bagaimanapun, sistem PV yang terdedah kepada keadaan cuaca yang menyebabkan kemerosotan dalam kecekapan penjanaan kuasa. Teduhan modul fotovoltaic adalah satu fenomena yang meluas yang menjejaskan prestasi sistem PV. Selaras dengan itu, kajian ini bertujuan untuk memperbaiki faktor teduhan yang akan memberi kesan kepada prestasi photovoltaic (PV) sistem di loji janakuasa solar. Teduhan sel solar bukan sahaja mengurangkan kuasa PMPP, tetapi juga menukar voltan litar terbuka Voc, arus litar pintas ISC, Fill faktor dan kecekapannya. Objektif kajian ini adalah untuk mereka bentuk loji janakuasa PV dengan faktor yang rendah atau sifar teduhan. Laporan ini telah mengklasifikasikan teduhan kepada dua aspek; jarak antara bangunan untuk loji janakuasa PV dan ketinggian bangunan. Perisian Pro Solar digunakan untuk menganalisis teduhan dan mengenal pasti cara-cara yang sesuai untuk mengurangkan faktor teduhan itu. Data yang diperolehi daripada simulasi dibandingkan dengan perisian Meteonorm, jurnal dan ujikaji untuk kesahihan data. Penemuan daripada kajian ini akan memberikan gambaran yang jelas tentang ketinggian bangunan dan jarak yang tepat dari loji janakuasa PV untuk mencapai sifar faktor teduhan. Jarak tertentu yang tepat boleh dikira menggunakan penggandaan daripada ketinggian bangunan. Penggandaan ketinggian diubah dengan saiz yang berbeza loji janakuasa PV.

TABLE OF CONTENT

1 **INTRODUCTUION**

LIST TABLES

LIST FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
FF	Fill Factor
FKE	Fakulti Kejuruteraan Elektrik
I	Current
kW	KiloWatt
kWh	KiloWatt hour
MPPT	Maximum Power Point Tracking
PR	Performance Ratio
PSH	Peak Sun Hour
PV	Photovoltaic
RE	Renewable Energy
SEDA	Sustainable Energy Development Authority
SPF	Solar Path Finder
UTeM	Universiti Teknikal Malaysia Melaka
V	Voltage

CHAPTER 1

INTRODUCTION

1.1 Research Background

At present, electrical energy plays an important role in our daily life. Most of the electrical energy is produced by fossil fuels and nuclear energy. Since these kinds of energy sources are exhaustible, many countries have started to promote and practice the renewable energy. Among all the renewable energy, solar energy has higher demand than others. The photovoltaic (PV) system is installed to convert the solar energy to electrical energy. However; few main factors influences the performances of the PV system. The shading phenomenon is one of the main problems that decrease the PV performances. This research is carried out to study the analysis of shading effect of the nearby buildings in PV module by using Solar Pro simulation method. These findings will give a clear view for the PV system installer in setting up any solar power plant in Melaka area with the coordinate of 2.2^{o}N, 102.25^{o}E.

1.2 Problem Statement

The main aim of this research is to improve the shading factors which will affect the performances of photovoltaic (PV) system in the solar power plant. The major factor affecting the performance of this PV system is the shading phenomenon. There are several types of shading phenomenon in PV system; the front row PV array shading phenomenon, the height and distance of the surrounding buildings shading phenomenon and the nearby power distribution room and wire pole shading phenomenon. This research is carried out to ensure that the exact height and distance of surrounding buildings of the solar power plant which is free from shading that improves the performance of the PV system. The shading analysis and the system improvement are conducted by the simulation assisted by the Solar Pro software.

1.3 Objectives

The main objectives of this project are;

- To identify the suitable distance between the surrounding building and solar power plant which minimizes the shading factor.
- To verify the suitable height of the surrounding building which results in the zero shading factor.

1.4 Scope of Work

This research focuses on the shading analysis of the surrounding building towards the PV power plant which is situated in the flat ground base. The distance of the surrounding building from the power plant and the height of surrounding building are considered as the shading phenomenon. The main aim of the research is to improve the performance of PV system by minimizing the shading factor. The solar panel is facing towards south and designed in Melaka with the coordinate of 2.2^{o}N, 102.25^{o}E. The house-shape building size is 20m by 20m which is kept constant with the varied height and placed in east and west direction of the power plant. The PV power plant is only designed for the size of 400m^2, 1600m^2, 3600m^2, 6400m^2 and 10000m^2 with the maximum capacity of 16.2kW, 58.32kW, 126.36kW, 233.28kW and 356.40kW respectively. The Solar Pro software is used to simulate the shading analysis process.

1.5. Expected Project Outcome

At the end of the research, findings such as suitable distance of the surrounding building from the solar power plant which results in free shading is to be expected. Moreover, the suitable height of the surrounding building which causes the zero shading factor also is to be determined. Furthermore, the Solar Pro software simulates and produces shading analysis, which helps to improve the performances of the PV power plant is foreseeable.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss the theoretical background of the project. The theoretical background will explore the basic history, analysis of solar shading, and simulation software review, especially Solar Pro and Solar Pathfinder that were used in this project. In the basic principles part the types of shading, the effect of the photovoltaic shading array, influence of shading on the electrical parameters and methods to mitigate the shading problem were explained.

2.2 Theory and the Basic Principles

This part will be discuss the theory and the basic principles of the photovoltaic principles, types of shading, the effect of the photovoltaic shading array, influence of shading on the electrical parameters and methods to mitigate the shading problem.

2.2.1 Photovoltaic System

Photovoltaic is a technology of the solar energy which uses the unique properties of certain semi-conductors to directly convert solar radiation into electricity. A photovoltaic system is an electrical system, consisting of a PV module array and other electrical components needed to convert solar energy into electricity usable loads. The PV system is a distributed system, which generates the small amount of power to the consumers. A utility-connected PV system is the most common system design. Figure 2.1 and Figure 2.2 show the common system of PV configuration and its Grid-Connected system respectively.

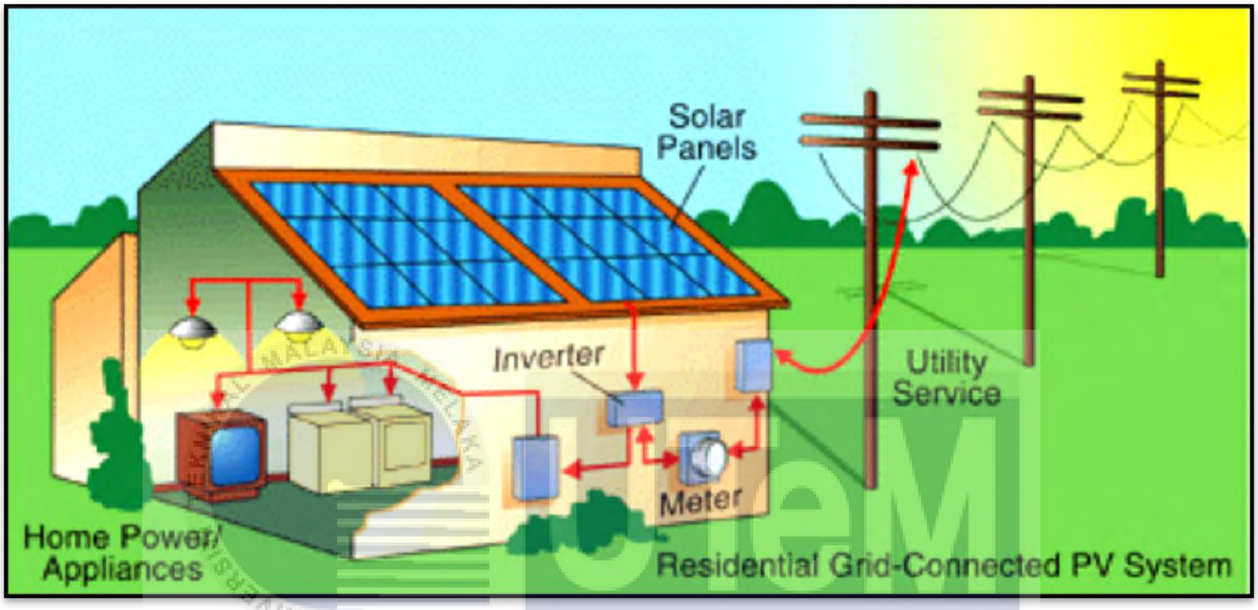


Figure 2.1: A Utility-Connected PV System

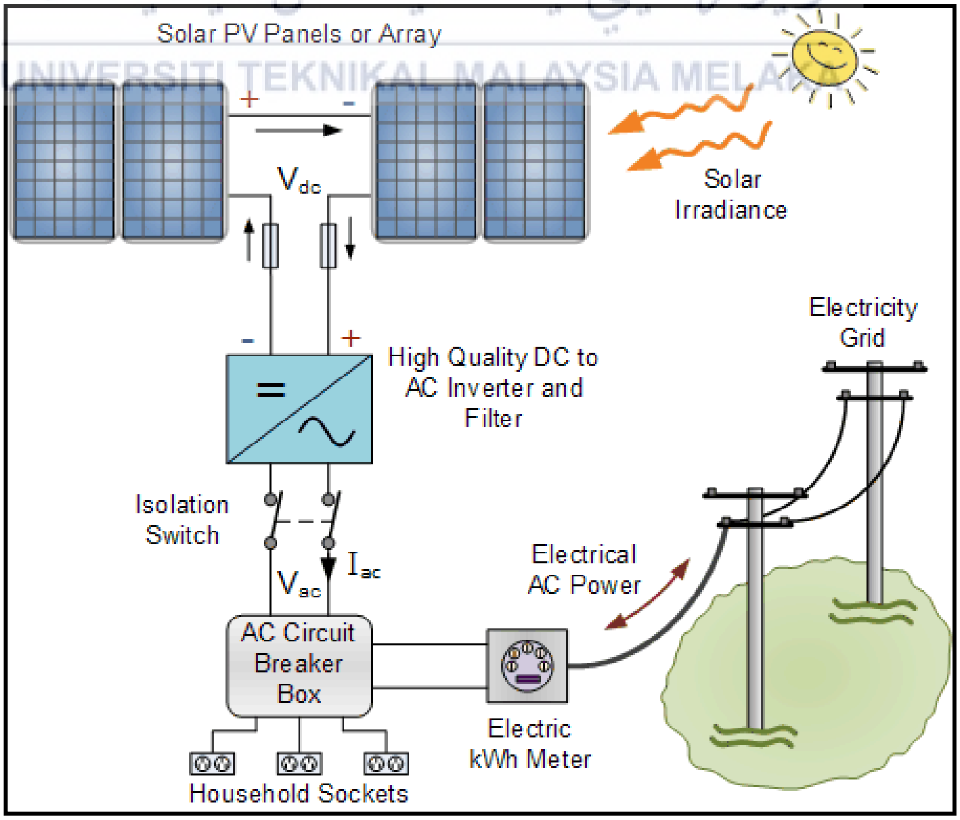


Figure 2.2: The Grid Connected PV System

2.2.2 Types of Shading

There are many factors influencing the performance of this system during the real installations of Photovoltaic (PV) system. Shading is one of the main factors which influence the performance of PV system. There are many types of shading phenomena in a PV system, and it can be divided into the following categories after long time surveys and observation on one large ground-based grid connected PV system [1].

1. The surrounding plant and guano (bird drop) shading phenomenon (Figure 2.3).
2. The front row shading phenomenon (Figure 2.4).
3. The nearby power distribution room and wire pole shading phenomenon (Figure 2.5).

Figure 2.3: The Surrounding Plant and Guano Shading Phenomenon

Figure 2.4: Front Row Shading Phenomenon

Figure 2.5: The Nearby Power Distribution Room and Wire Pole Shading Phenomenon

2.2.3 The Effect of Photovoltaic Shading Array

A PV system comprises of many PV modules that are connected in series and parallel way. If the array layout is irrational or there are shades around the arrays, shading will occur in some modules [1]. In practical condition, a module with shading in a long series will not generate photovoltage, while other modules in the same series still produce voltage normally. So there is current going through this shaded module [2,3].

2.2.4 Influence of Shading on the Electrical Parameters

The shading in the photovoltaic can effect in disproportional high losses in performance. Shaded solar cells are frequently driven in the negative voltage range. The annual loss in a performance in some systems is more than 10% [4]. The influence of cell shading on electrical parameters are the short circuit current I_{sc}, open circuit voltage V_{oc}, fill factor, maximum power point P_{MPP} and efficiency [4,5]. Figure 2.6 is a simple example of the solar system which obtains all the electrical parameters.

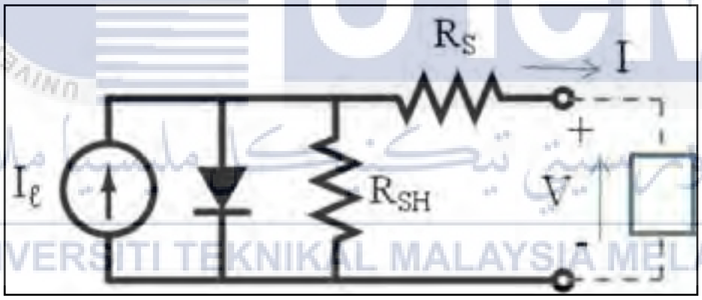


Figure 2.6: Solar system Circuit

i.) 2.2.4.1 Current-Voltage (I-V) Curves

The current-voltage (I-V) characteristic is the basic electrical output profile of PV device. The I-V characteristic represents all possible current-voltage operating point (and power output) for a given PV device (cell, module, or array) at a specified condition of incident solar radiation and cell temperature [4,5]. Figure 2.7 shows an I-V curve, which illustrates the electrical output profile of a PV cell, module or array at a specific operating condition [4,5, 6].

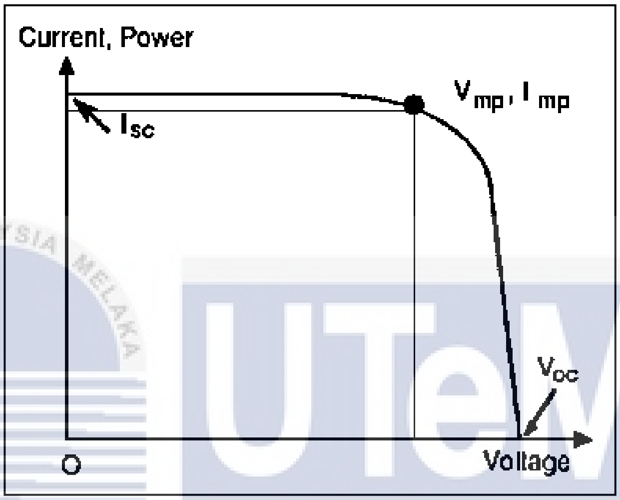


Figure 2.7: An I-V Curve Graph

A PV device can function at any place along its I-V curve, depending on the electrical load. At any specific voltage on an I-V curve there is an associated current, and this operating point is known as an I-V pair.

2.2.4.2 The Basic I-V Curve Parameters.

i.) Open circuit voltage

The open circuit voltage V_{oc} is the maximum voltage on an I-V curve and is the operating point of a PV device under infinite load or open circuit condition, and no current output [4].

$$V(\text{at } I=0) = V_{oc} \tag{2.1}$$

V_{oc} is also the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant [4-7].

$$V_{OC} = V_{MAX} \text{ for forward-bias power quadrant} \tag{2.2}$$

ii.) Short circuit current

The short circuit current I_{sc} is the maximum current on an I-V curve and is the operating point of a PV device under no load or short circuit condition, and no voltage output. Since the voltage is zero at the short-circuit current, the power output is also zero. I (at V=0) = I_{sc}. For an ideal solar cell, this maximum current value is the total current generated in the solar cell by photon excitation. $I_{sc} = I_{MAX} = I_{\ell}$ for forward-bias power quadrant [4-7].

iii.) Maximum power point

The operating point at which a PV device produces its maximum power output lies between the open-circuit and short circuit condition, when the device is electrically loaded at some finite resistance [2]. Figure 2.8 shows the voltage and current at this maximum power point which denoted as V_{MP} and I_{MP} respectively [4,6,7].

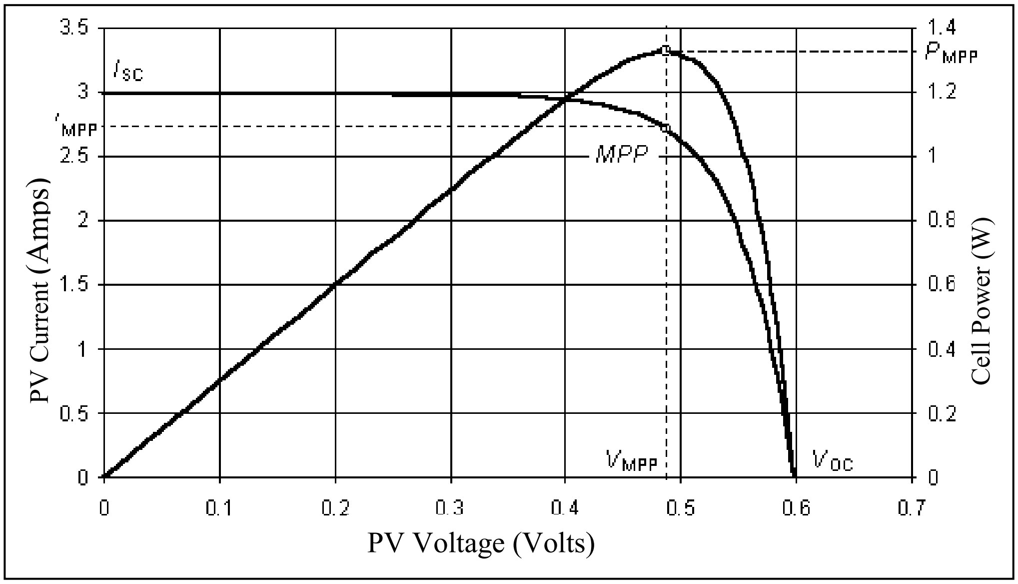


Figure 2.8: The Voltage and the Current at MPP

iv.) Fill Factor

The fill factor (FF) is essentially a measure of the quality of the solar cell. FF is the ratio of the maximum power of the product of the open –circuit voltage and short circuit voltage [4]. Figure 2.9 shows the high fill factor designated with the voltage and current at the maximum power point nearer to the open circuit voltage and short-circuit current respectively, producing a more rectangular shaped I-V curve. Fill factor is expressed as a percentage and is calculated using the following formula;

$$FF = \frac{P_{mp}}{V_{oc}\ x\ I_{sc}} \tag{2.3}$$

Where,

FF = fill factor

P_{mp}= maximum power (in W)

V_{oc} = open circuit voltage (in V)

I_{sc} = short circuit current (in A)

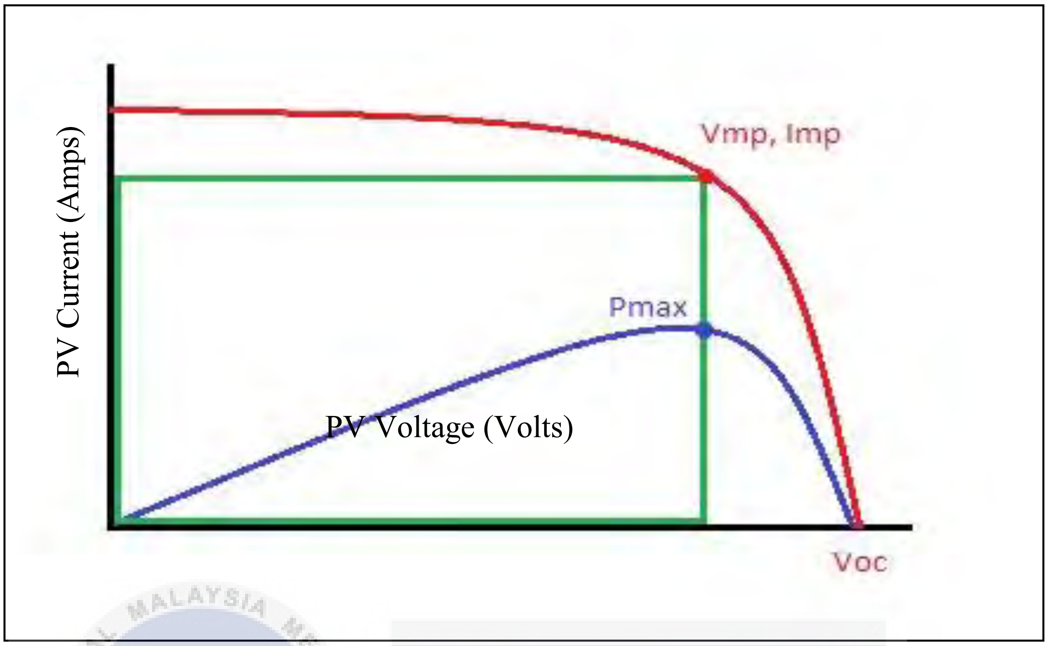


Figure 2.9: The Higher Fill Factor Graph

v.) Efficiency (η)

Efficiency is the ratio of electrical power output, P_{out} compared to the solar power input P_{in} into the PV cell [4]. Solar irradiance is multiplied by the area of the PV device to determine watts of solar power, which can then be directly compared to watts of electrical power. Efficiency is expressed as a percentage and is calculated with the following formula:

$$\eta = \frac{P_{mp}}{G \, X \, A} \tag{2.4}$$

Where,

η = efficiency

P_{mp}= maximum power (in W)

G = solar irradiance (in W/m^2)

A = area (in m^2)

2.2.5 Methods to Mitigate the Shading Problem

The method to overcome the shading is more significant to improve the performances of the PV system. There are plenty of techniques used to mitigate this shading problem. Various methods are applied to obtain the power generated from PV module while the shading effect occurs.

2.2.5.1 Single Diode Model

Single diode model is the basic model of PV module. This type of PV module consists of four elements described below [7,8].

- Current source of photoelectric
- Parallel diode current
- Series resistance
- Parallel resistance

This type of PV model has an advantage that it is not complicated and less parameters. However, when the solar irradiation is low, this model gives low accuracy [5,7,8].

2.2.5.2 Double Diode Model

The single diode model is successfully modified and upgraded to the double diode model by adding the second diode in parallel with the first diode. The second diode has compensated the Shockley-Read-hall recombination effect [5]. Figure 2.10 shows the equivalent circuit of this type of model.

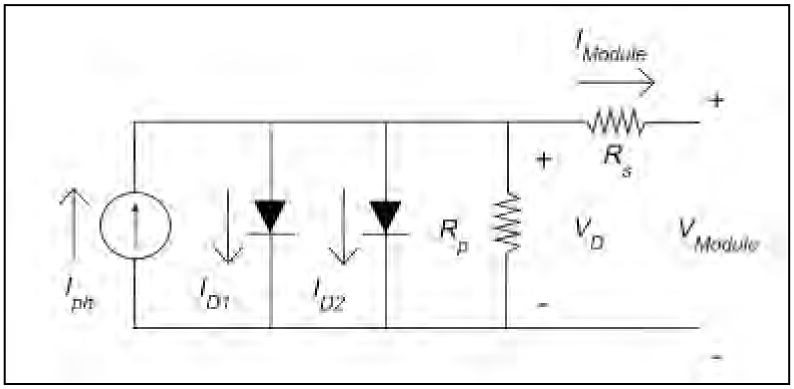


Figure 2.10: The Equivalent Circuit of the Double-Diode Model

This type of PV model has an advantage that it is more precise when the solar irradiation is less, such as in the morning and evening. Therefore, this type of model can be applied for longer duration throughout the day.

2.2.5.3 Bypass Diode

To overcome the effects of partial shading in a series string, a bypass diode is added in parallel with solar cell as in Figure 2.11.Under normal conditions, with no shading, each diode is reverse biases and all the cells generate power [7]. When the shading occurs in PV module, the photoelectric current becomes less than that in normal condition. Bypass diode is placed for forward bias [5, 7].

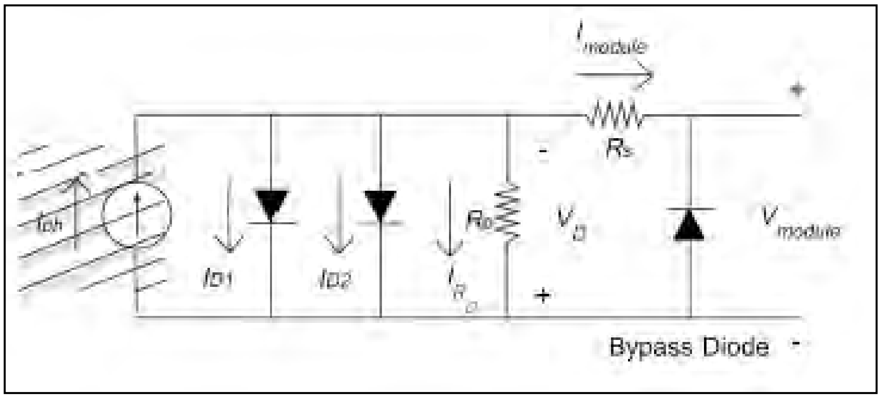


Figure 2.11: The Bypass Diode Model

2.2.5.4 Modified Maximum Power Point Tracking (MPPT) Techniques

MPPT techniques properly detect the global MPP. They include the power curve slope, load-line MPPT, dividing rectangles techniques, the power increment technique, instantaneous operating power optimization, Fibonacci search, neural networks, and particle swarm optimization [8,9,10]. The MPPT technique modified using Differential Evolution (DE) which is capable of finding global MPP under partial shading conditions. The performance of the proposed algorithm is verified by means of simulation in MATLAB/Simulink. The modified MPPT is applied to a grid-connected PV system in conjunction with DC-DC boost converter and DC-AC inverter. The simulation results prove that MPPT is able to track global MPP under partial shading condition accurately, fast and with zero oscillation [3,8,9,10].

2.2.5.5 An Energy Recovery Circuit

An energy recovery circuit is added to recover the energy from the solar. This function simple circuit is that, during partial shading, parts of the current from the nonshaded modules are harvested by an energy recovery circuit using power electronic switches and storage components. There is no need to short circuit the shaded module; as a result, it can still generate the output power (despite being partially shaded). Figure 2.12 shows the connection of the energy recovery circuit in the PV grid-connected system [11].

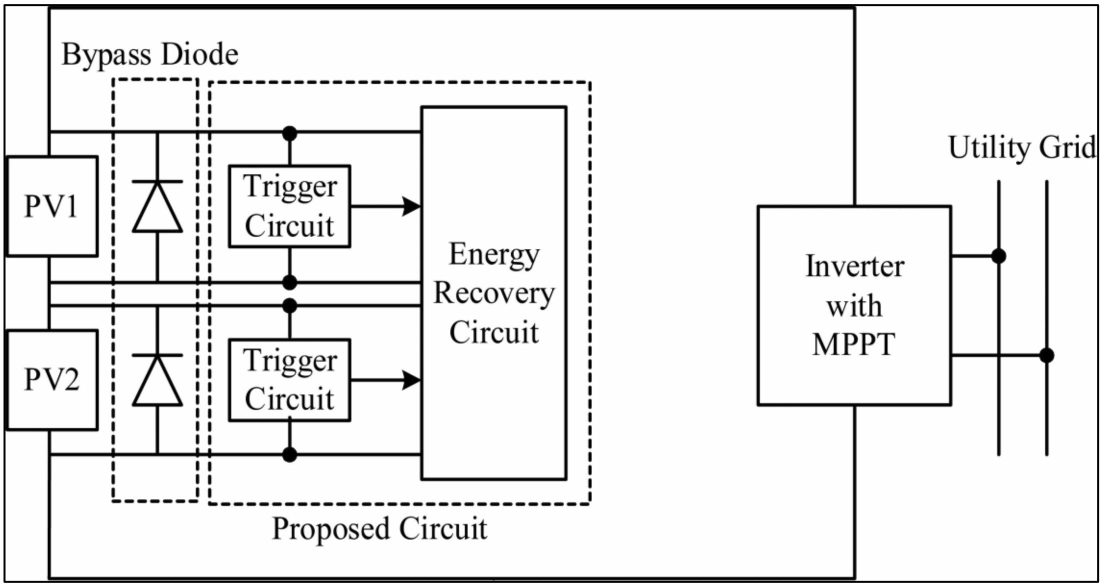


Figure 2.12: A Simple Energy Recovery Circuit

2.2.5.6 Different Array configuration

There are different array configurations for interconnecting PV modules, namely series-parallel, total cross-tie and bridge-link configuration [8]. SP, TCT, and BL configuration are shown in Figure 2.13. The interconnection between the PV strings enable different current flowing through the PV strings in TCT and BL configuration. This may decrease the current that flows through the shaded cells and keep them in the forward bias region, thus blocking the operation of bypass diodes [8].

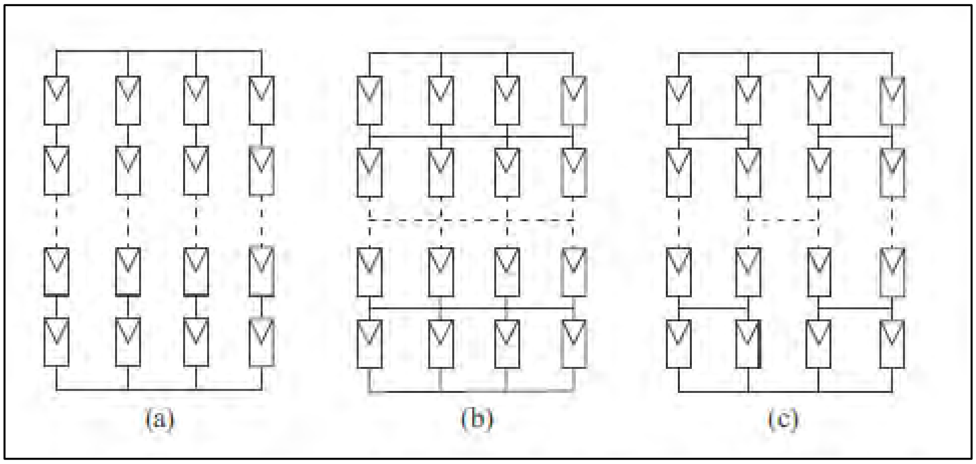


Figure 2.13: Array Configuration for Alleviating the Power Loss Under the Partial Shading Conditions. (a) SP, (b) TCT, and (c) BL.

2.2.5.7 Adding circuit in a bypass diode

The bypass diode is activated when the module is shaded, to protect the module from hotspot damages. Figure 2.14 and Figure 2.15 shows a simple bypass diode circuit and a modified bypass circuit respectively. The main purpose is to increase the output power of PV system during partial shading. The aim is to recover the energy from the shaded module, divert it to a power electronic circuit and process it to become a part of the output power [12,13,14].

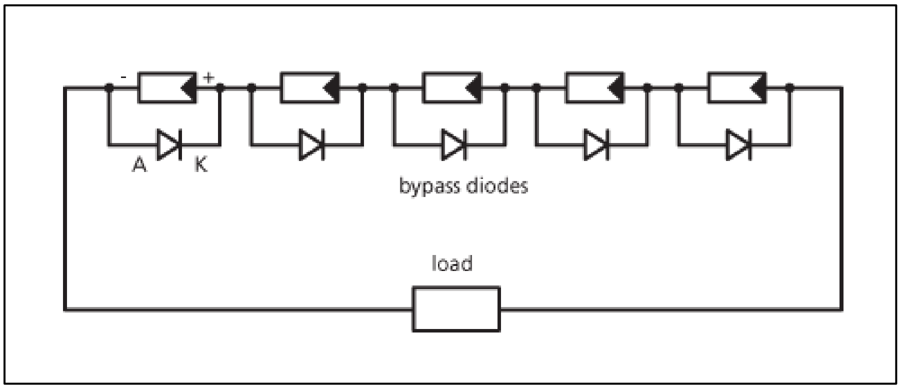


Figure 2.14: The Series-parallel PV System with Bypass Diode

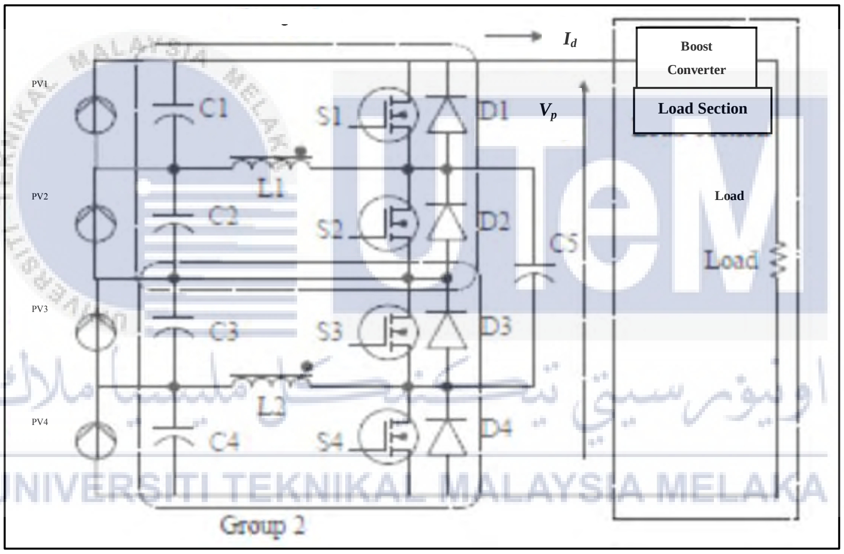


Figure 2.15: The New Added Circuit

CHAPTER 3

METHODOLOGY

3.1 Introduction

This section contains the methodology that was used in this research and project. The main purpose of this section is to collect information related to the methods and techniques that have been used in this project development, such as the process of research, process of identifying, measuring activities and results. By using the appropriate methodologies for the research and development, all data and information needed was acquired in accordance with time. The research and development process is divided into several parts. In section 3.2, principles of the methods or techniques used in the project were discussed. The principle analysis method, which is the Solar Pro software was used to analyze the shading and electrical parameters, together with solar pathfinder. In Section 3.3, description of the work for this paper is explained in the form of flow chart .

3.2 Methods or Techniques

This part will be discussing the methods used and the features of the Solar Pro Software. Besides, the basic principle of the solar pathfinder is also discussed in this section.

3.2.1 Layout of the Solar Power Plant

Photovoltaic systems use solar panels for converting the sun irradiance power into electricity in the form of DC power. Each solar power application is uniquely designed, taking into consideration specific influences such as climate condition, system capacity, and installation location and shading analysis. The main aim for considering these factors is to enhance the performance.

3.2.2 PV Panel Orientation

A solar power generation depends on the amount of radiation received by the PV panel. Power plant design should include direction of the PV panel for the purpose of collecting largest possible amount of sun radiation. PV systems can be categorized into tracking and fixed systems. Since tracking PV systems are more expensive, complex and require higher maintenance than fixed system, the tracking system has been excluded in the current design. This study considers fixed PV system: nevertheless, the PV modules should be installed at a direction that can receive the highest possible sunshine. PV module directing is determined by two angles, namely azimuth and tilt angle.

3.2.3 Position at the Target Site

The position of the sun ominously changes in the sky at any time of the day and any day in the year. Additionally, the path of the sun in the sky varies depending on the location on the earth. Sun position is identified by two parameters, namely azimuth and tilt angle. as shown in Figure 3.1.

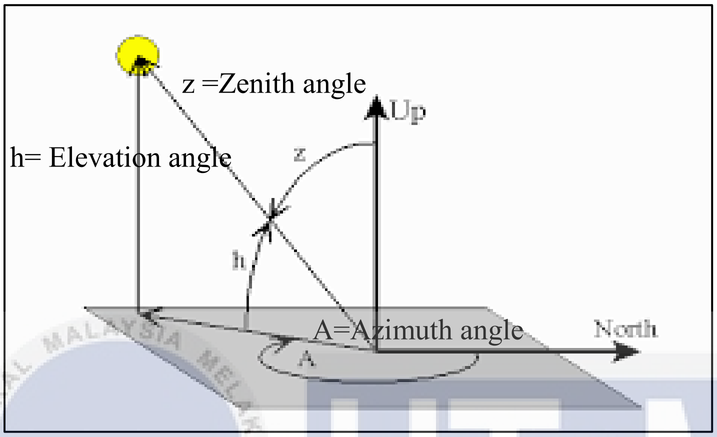


Figure 3.1 Azimuth Angle and Tilt Angle

3.2.4 Module Azimuth Angle Selection

Azimuth angle(y) for the PV panel is the angular displacement from south to the horizontal projection of the solar panel direction, as shown in Figure 3.2. Displacements east of south are considered negative value and west of south are positive values [15].

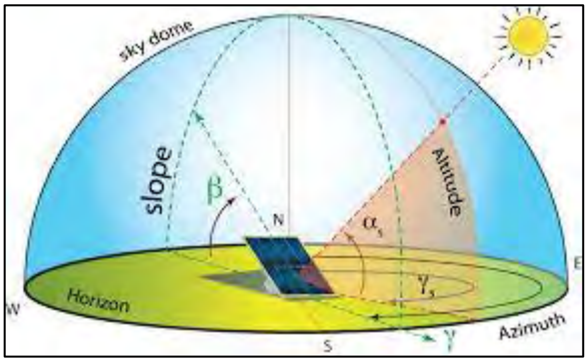
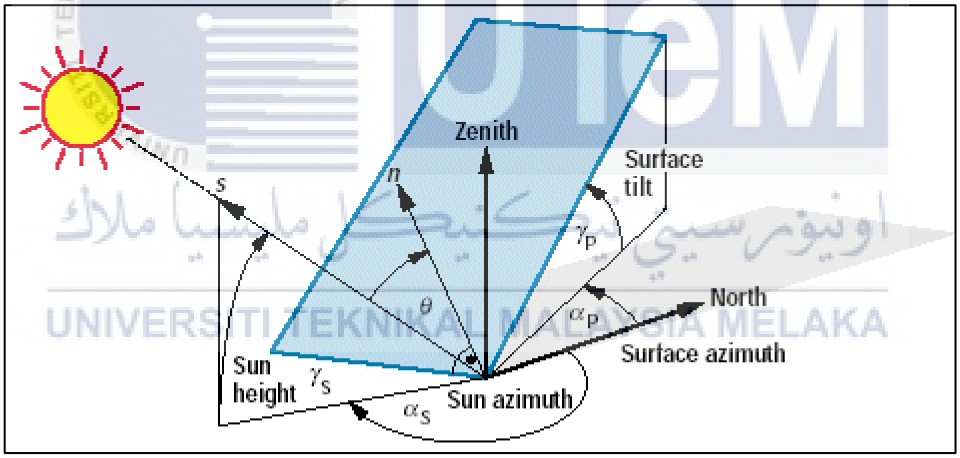


Figure 3.2: Angular Displacement

The optimum azimuth angle for solar power panel is usually 0° in the northern hemisphere or 180° in the southern hemisphere [15]. Therefore, the azimuth angle of the PV panels in the plant was determined to be equal to 0°.

3.2.5 Module Tilt Angle Selections

Tilt angle is the angle between the surface of the module and the horizontal line on the ground, also called as inclination angle, as shown in Figure 3.3. Tilt angle is responsible for determining the amount of solar energy received by the surface of the PV panel. In order to intercept high irradiance, the sun shine has to be perpendicular on the surface of the PV panel [16]. The optimum tilt angle is within a range of +15° or -15° [17]. Therefore, it is recommended to use the minimum tilt angle of 10° to let the water and dust slide [18]. Therefore, the minimum tilt angle of the PV panels in the plan was set to 10°.



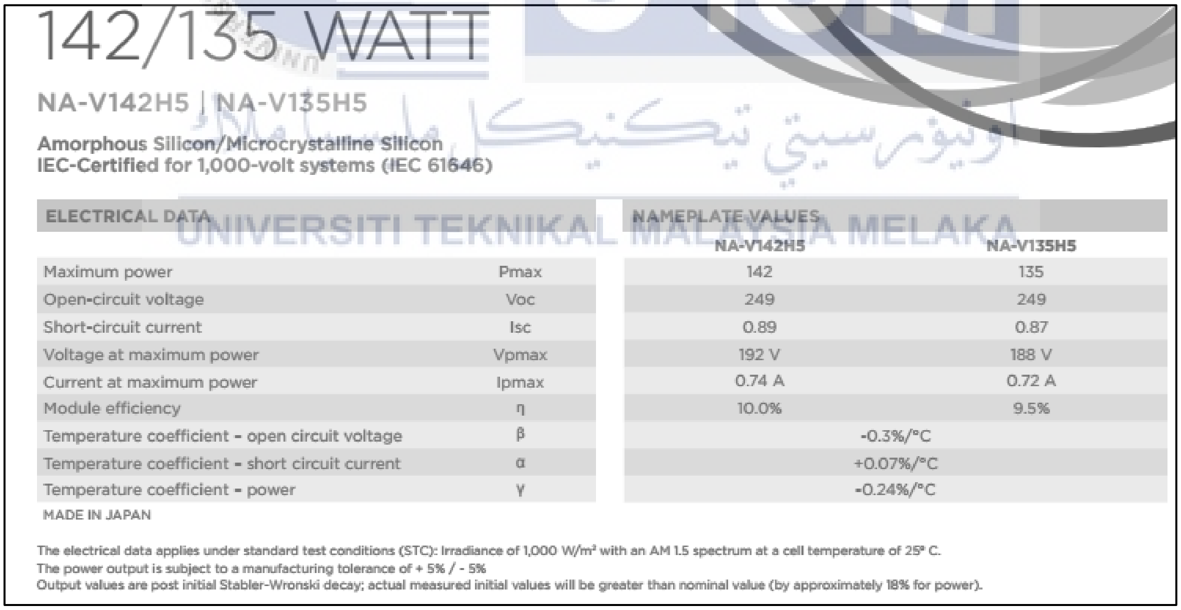
3.3 : Tilt Angle

3.2.6 PV Module

The Solar Pro software is used to obtain the data for analysis throughout the research. The solar power plant is designed using the Solar Pro software. Initially, PV module is selected where the manufacturer is Sharp with model number NA-V135H5. For experiment purpose, thin-film module is used. This NA-V135H5 model has a 135W capacity of power for each module.

I. Electrical characteristics

Electrical characteristics are determined by the manufacturer based on the result of production line test. Each module has particular characteristic described in the name plate label. Name plate label of NA-V135H5 [19] is shown in Figure 3.4.



142/135 WATT

NA-V142H5 | NA-V135H5

Amorphous Silicon/Microcrystalline Silicon
IEC-Certified for 1,000-volt systems (IEC 61646)

ELECTRICAL DATA		NAMEPLATE VALUES	
		NA-V142H5	NA-V135H5
Maximum power	Pmax	142	135
Open-circuit voltage	Voc	249	249
Short-circuit current	Isc	0.89	0.87
Voltage at maximum power	Vpmax	192 V	188 V
Current at maximum power	Ipmax	0.74 A	0.72 A
Module efficiency	η	10.0%	9.5%
Temperature coefficient - open circuit voltage	β	-0.3%/°C	
Temperature coefficient - short circuit current	α	+0.07%/°C	
Temperature coefficient - power	γ	-0.24%/°C	

MADE IN JAPAN

The electrical data applies under standard test conditions (STC): Irradiance of 1,000 W/m² with an AM 1.5 spectrum at a cell temperature of 25° C.
The power output is subject to a manufacturing tolerance of + 5% / - 5%
Output values are post initial Stabler-Wronski decay; actual measured initial values will be greater than nominal value (by approximately 18% for power).

Figure 1.4: Name Plate Label of NA-V135H5

3.2.7 Size of PV Module

The 135W with model number NA-V135H5 manufactured with the size of length 1409mm and the width of 1009mm. The thickness of this thin-film module is 46mm. The array arrange with the gap of 1100mm with the beside array. The gap with the front line array is 4500mm. The figure below shows the arrangement of the modules.

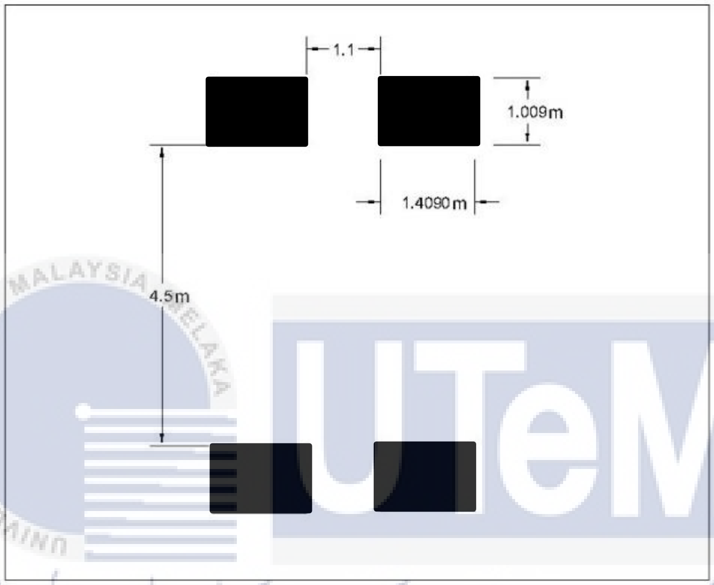


Figure 3.5: Arangment of PV Module

3.2.8 Layout of the Power Plant

Figure 3.6 shows the design of 20m by 20m solar power plant with the maximum capacity of 16.2kW was designed in the coordinate of 2.2^{o}N, 102.25^{o}E using the Solar Pro software. The Sharp brand solar module was used in this designing process. where PV module faces towards the south direction. The surface area of the power plant is 400m^2 which is around 0.0988 acres (approximate 0.1 acres). The same method is used to design different sizes of solar power plant. This experiment was carried out during 5am-8pm.

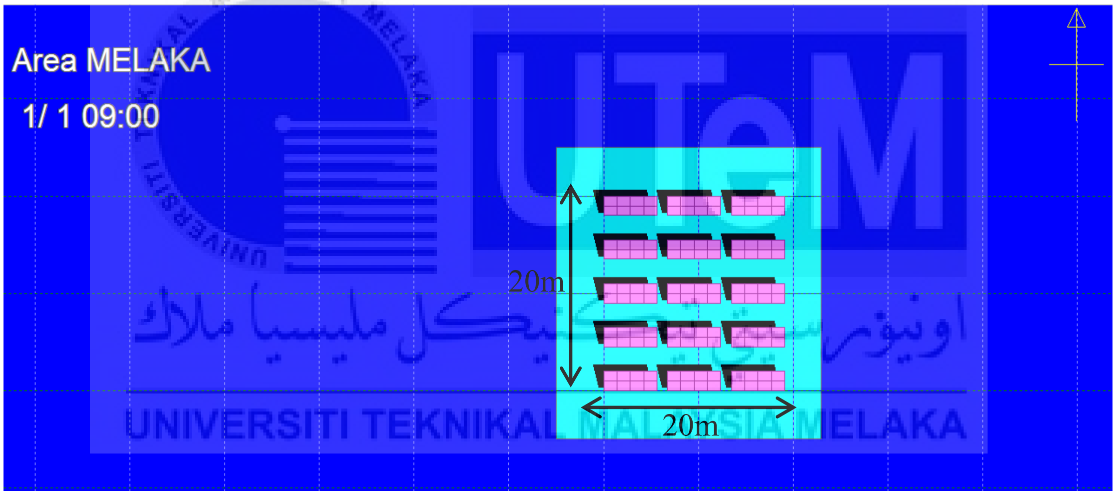


Figure 3.6: Top View of the 20m by 20m PV Power Plant

3.2.9 Solar Power Plant

Table 3.1 shows the size of the solar power plant and total number of PV modules required with total capacity of the plant. The length and width increases constantly in unit metre. The maximum numbers of PV modules where Sharp brand with model number NA-V135H5 (135W) are arranged in the different area of the power plant.

Table 3.1: Size of Power Plant with the Parameters

Length	Width	Area,m^2	Area, acre	No. PV Modules	Total Capacity, kW
20	20	400	0.10	120	16.20
40	40	1600	0.40	432	58.32
60	60	3600	0.89	936	126.36
80	80	6400	1.58	1728	233.28
100	100	10000	2.47	2640	356.40

3.2.10 Designed Building beside the Power Plant (Varied Distance)

Figure 3.7 and Figure 3.8 shows the house shaped building with a coordinate of (-10m, 60m) is designed beside the power plant. The size of the building which is 20 meter by 20 meter was kept constant throughout the analysis. The distance between the PV power plant and the building was increased constantly.

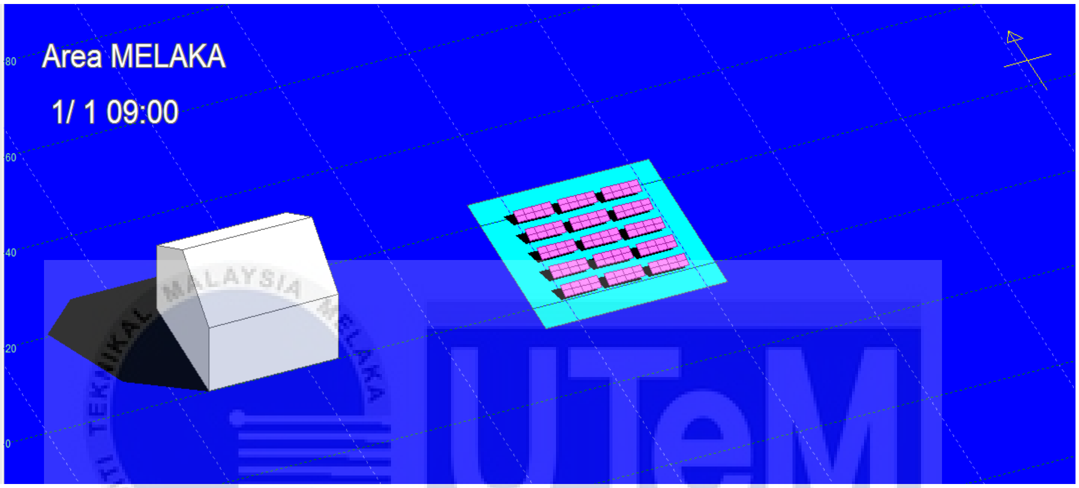


Figure 3.7: A House Shaped Building beside the 20m by 20m PV Power Plant

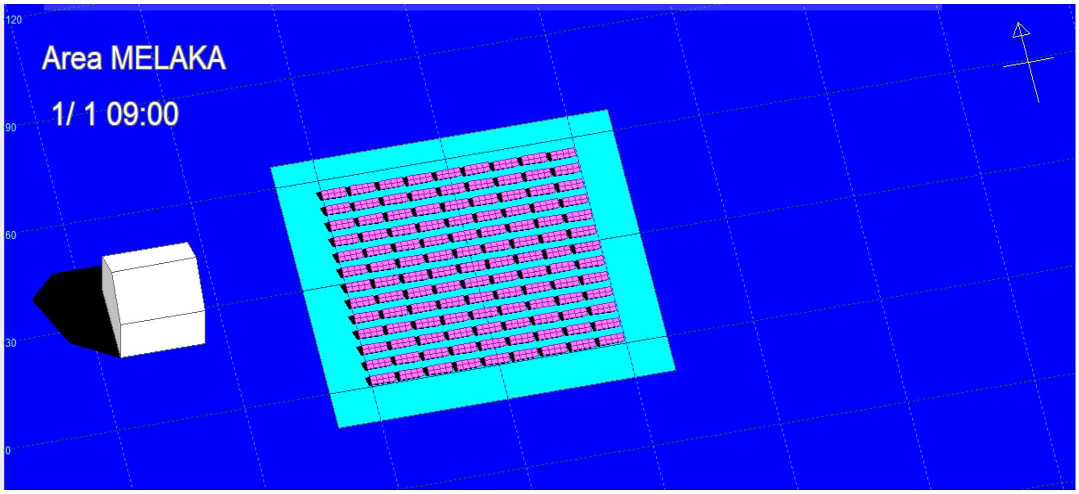


Figure 3.8 : A House Shaped Building beside the 80m by 80m PV Power Plant

3.2.11 Solar Pro Software

Solar Pro is sophisticated simulation software for a PV system. The software is able to simulate electricity generation under different condition which is varied by each system so that it allows system designing based on precise data. Additionally, since the calculated data come out with the persuasive and graphical look, it can be also utilized for presentations and education related to PV system generation.

i.) 3D CAD

The 3D CAD in the Solar Pro simulation allows to draws the varius height of the 20m by 20m buildings. This simulation also includes the influence of shadow from the surrounding buildings of the Solar power plant and objects allows to check optimal settings and module designs before the system installation. The software is also able to import meteorological database of TMY3. The 3 dimensions (3D) give clear view of the position and shape of the 20m by 20m building from the solar power plant.

Figure 3.9: 3D CAD and Designing of the Building

ii.) I-V Curve

The software calculates the I-V curve of solar modules accurately and quickly based on the electrical characteristics of Sharp brand thin film.. Besides I-V curve, this software can also calculate the P_{MPP}, open circuit voltage V_{OC}, short circuit current $I_{SC,}$ fill factor and its efficiency.

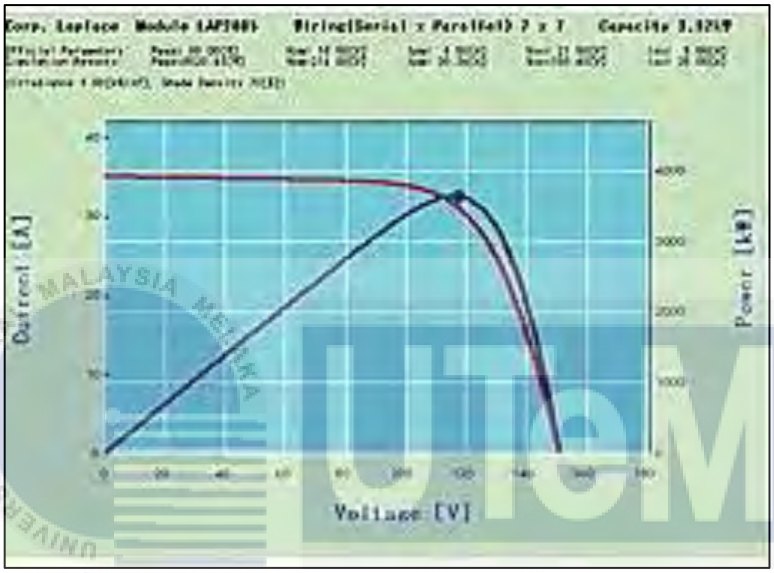


Figure 3.10: An I-V Curve

iii.) Electric Power Calculation

The Solar Pro calculates the amount of generated electricity based on the coordinates of 2.2^{o}N, 102.25^{o}E and the weather conditions of the area of Melaka. This leads precise simulation results. The energy of the inverter and series-parallel output also can be determined using this software. This software also represents the output in various forms of systematic way such as a line graph, bar graph and table form.

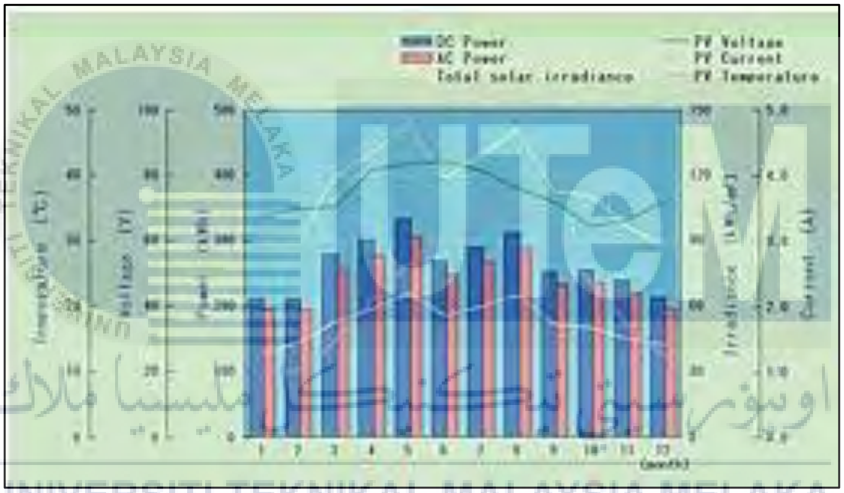


Figure 3.11: Electric Power Calculation

iv.) Support for Designing

The Solar Pro software determines necessary component for installing a PV system automatically based on the settings. Moreover, this software suggests the tilt angle of the PV modules to design the system depend on the coordinate of the 2.2^{o}N, 102.25^{o}E (Melaka).

3.2.12 Solar Pathfinder

The Solar Pathfinder is used for shade analysis to calculate the solar irradiance performance on any coordinate for a year. Any trees, buildings or other objects that could cast shadows are reflected in the plastic dome, clearly showing shading patterns at the site. The underlying diagram is latitude specific and engineered with data for the entire year. A wax pencil can be used to trace around the reflected shadows on the sun path diagram, providing a permanent record of each reading. A compass and a bubble level are built into each Pathfinder (Figure 3.12), making it easy to keep the instrument level and facing right direction. The rubber tipped legs on the tripod telescope out, allowing a person to use the Pathfinder on sloping roofs and other rough sites.

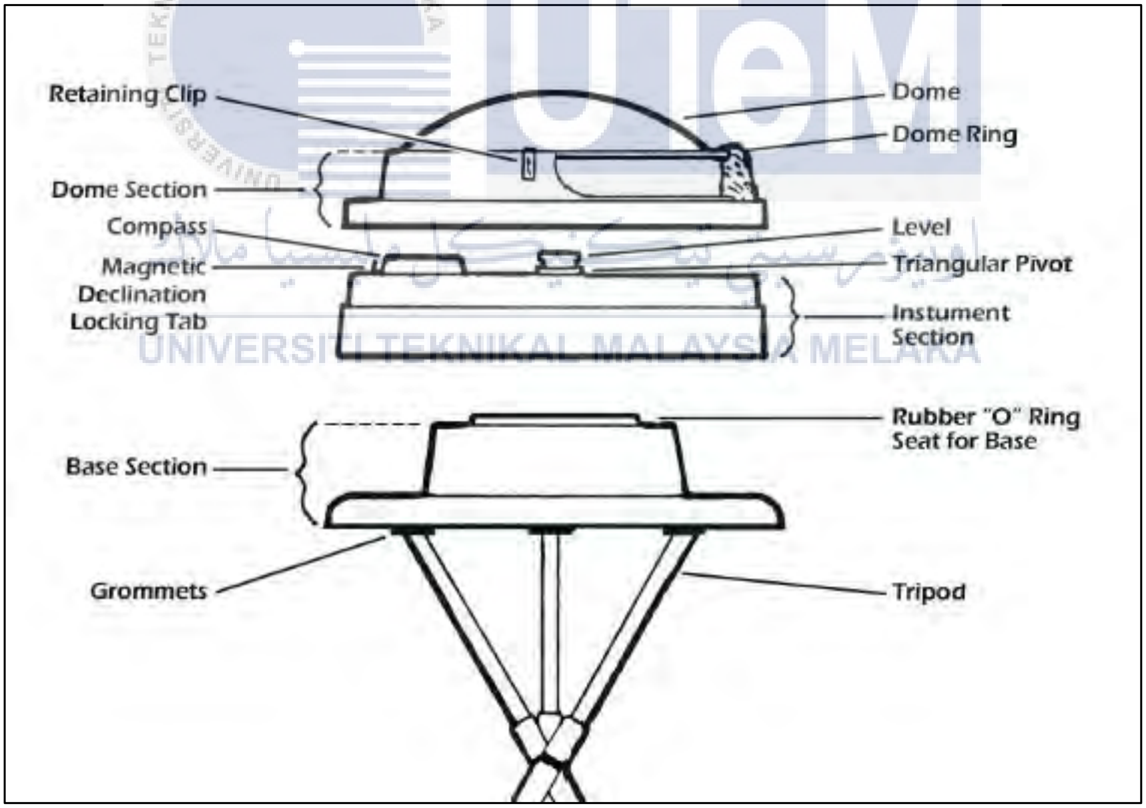


Figure 3.12: A Solar Pathfinder

3.3 Description of the Work to be Undertaken

This project is completed in the duration of 20 weeks. This project is divided into three major tasks where task 1 is to design solar power plant, task 2 is to complete the building of PV system with the shading factors and task 3 is to finalize the data. Figure 3.13 shows the flow chart of the work to be undertaken throughout the project.

Task 1: Layout of a solar power station.

This project starts with gathering information by doing some searching and studying the journals. 22 journals had been referred to study about PV system, shading analysis and its electrical parameters. After about a month, the Solar Pro software was explored and designing of PV system was begun. Eventually, the designing of solar power plant system with different sizes and capacities was also started.

Task 2: Completing the built of the PV system with the shading factors

The designing of PV system was completed using Solar Pro software. After the designing was done, analysis and simulation are carried out. The analysis focuses on the shading of the surrounding buildings. The different height of the building was used with the different size of the solar power plant.

Task 3: Finalizing the data

The height of the building and the distance of the building were analysing to obtain zero shading factor or optimum capacity of PV energy at the solar power plant. The result obtained from the data was displayed in the form of the table and graph. The final report is done with the aid of the result of the analysis.

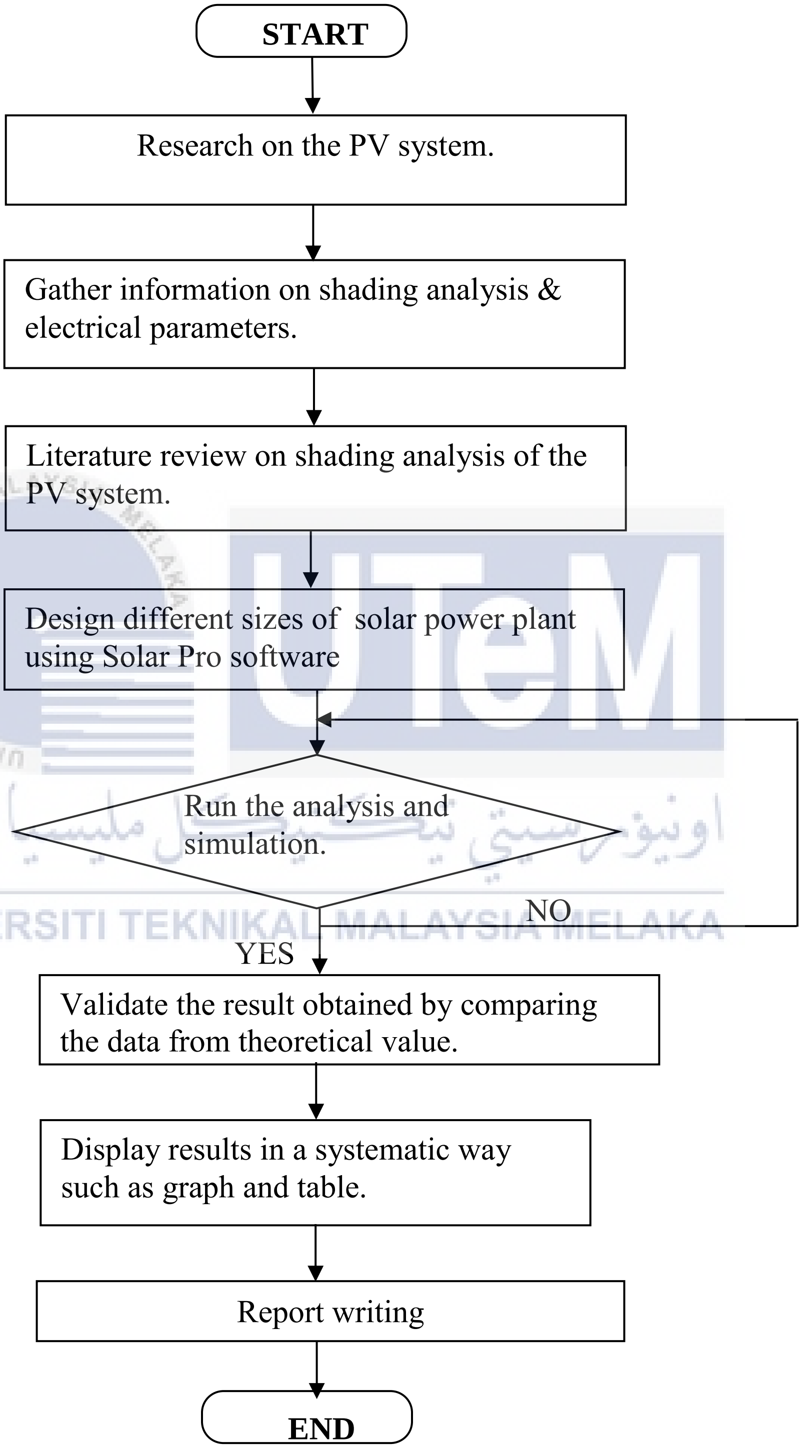


Figure 3.13 : Flow Chart of Work to be Undertaken

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this chapter will discuss the data obtain from the Solar Pro simulation. The result of specific PV energy and the energy reduction will shows in the form of the graph. The next part is analysis and the data validation is will be discussed. The parameters like total irradiation, peak sun hour and performance ratio will be compared with Solar Pro simulation, Meteonorm software, solar pathfinder and other journals. Last part of this section is the discussion and finalization of the data where the exact size of the building with the proper distance from the solar power plant which results in zero shading factor will be identified.

4.2 Specific PV Energy

The general definition of yield factors of power plants, expressed in simplified terms, describes how many times energy generated during plant operation covers the energy used for constructing the plant [20]. An exact definition would be: 'The yield factor is the ratio of net energy production during plant life and the cumulative energy used for construction, operation and operating supply items'. These parameters are the performance ratio, final PV system yield and reference yield [20]. The simulation is carried out to obtain the optimum PV energy with the height and distance of the surrounding building from the PV power plant.

4.2.1 20m by 20m PV Power Plant

The Figure 4.1 shows the graph with specific PV energy in 20m by 20m size of PV power plant with the distance of building from power plant. The specific PV energy for free shading is 1248.46kWh/kWp. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

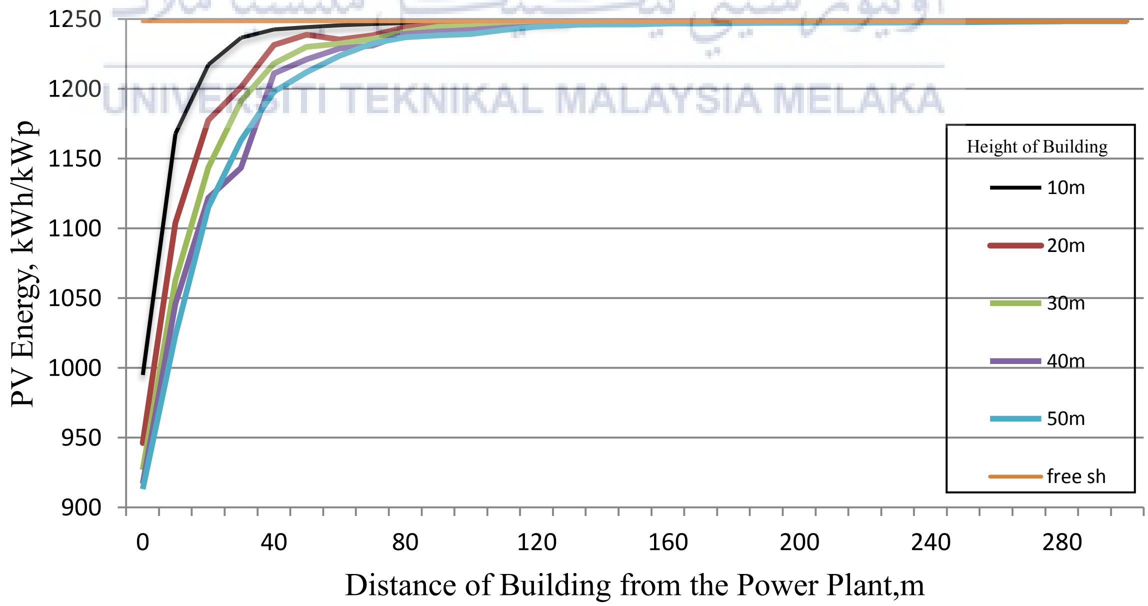


Figure 2.1: PV Energy versus Distance of Building from the 20m by 20m Power Plant

4.2.2 40m by 40m PV Power Plant

The Figure 4.2 shows the graph with specific PV energy in the 40m by 40m size of PV power plant with the distance of the building from the power plant. The specific PV energy for free shading is 1248.28kWh/kWp. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

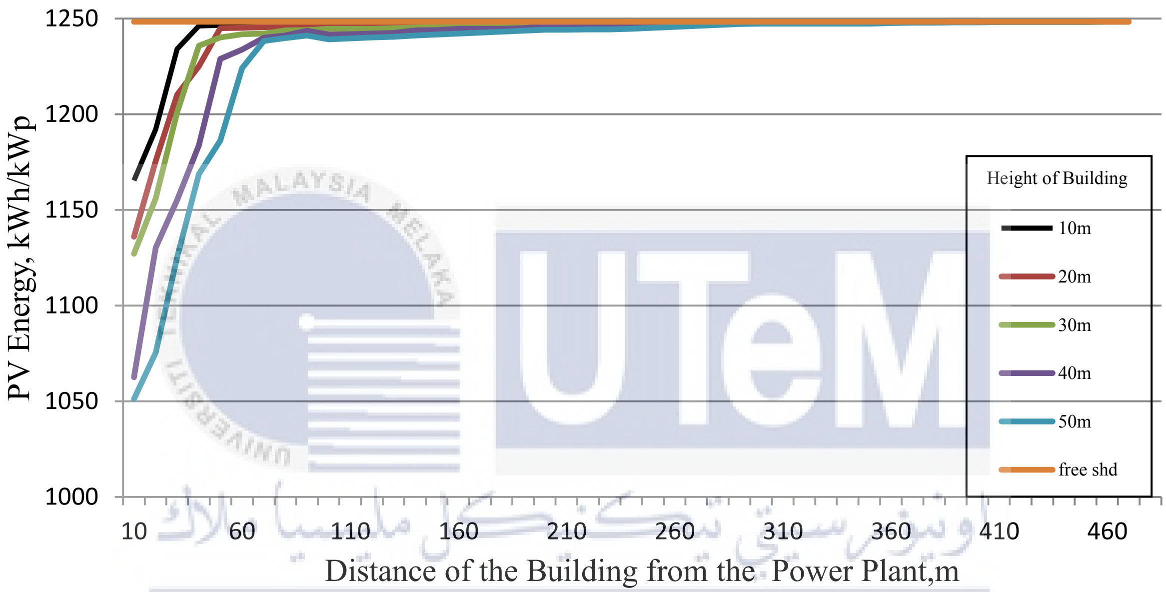


Figure 4.2: PV Energy versus Distance of Building from the 40m by 40m Power Plant

4.2.3 60m by 60m PV Power Plant

The Figure 4.3 shows the graph with specific PV energy in the 60m by 60m size of PV power plant with the distance of the building from the power plant. The specific PV energy for free shading is 1248.22kWh/kWp. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

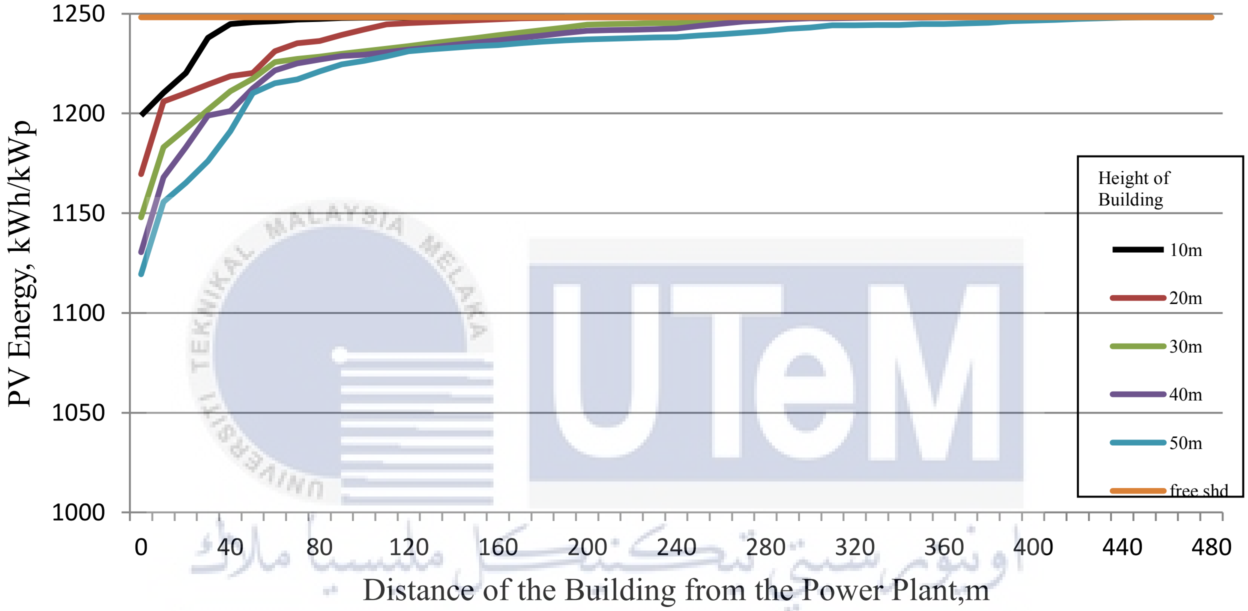


Figure 4.3: PV Energy versus Distance of Building from the 60m by 60m Power Plant

4.2.4 80m by 80m PV Power Plant

The Figure 4.4 shows the graph with specific PV energy in the 80m by 80m size of PV power plant with the distance of the building from the power plant. The specific PV energy for free shading is 1248.29kWh/kWp. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

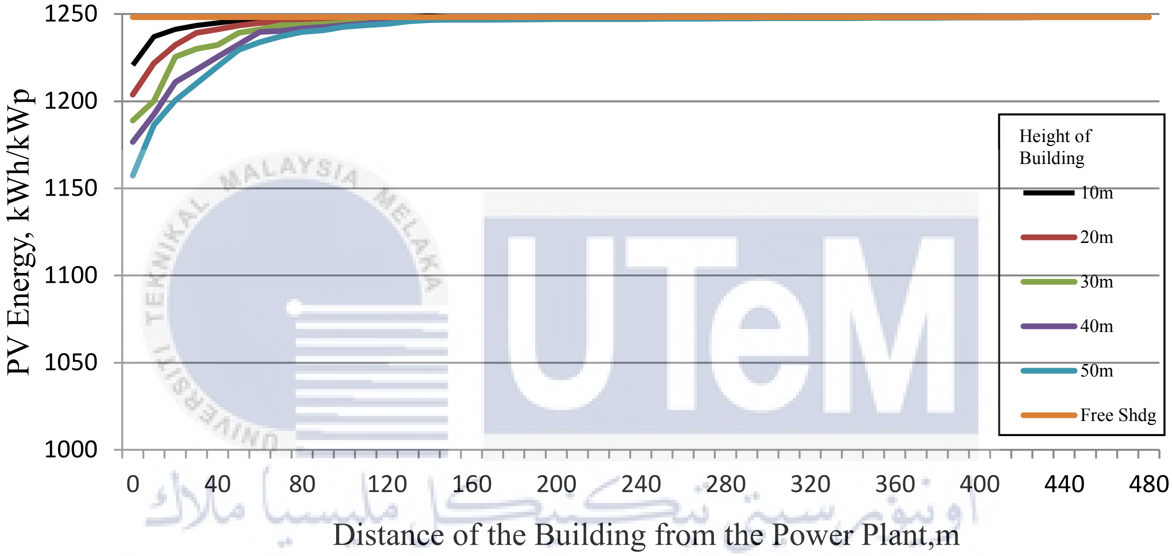


Figure 4.4: PV Energy versus Distance of Building from the 80m by 80m Power Plant

4.2.5 100m by 100m PV Power Plant

The Figure 4.5 shows the graph with specific PV energy in the 100m by 100m size of PV power plant with the distance of the building from the power plant. The specific PV energy for free shading is 1248.46kWh/kWp. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

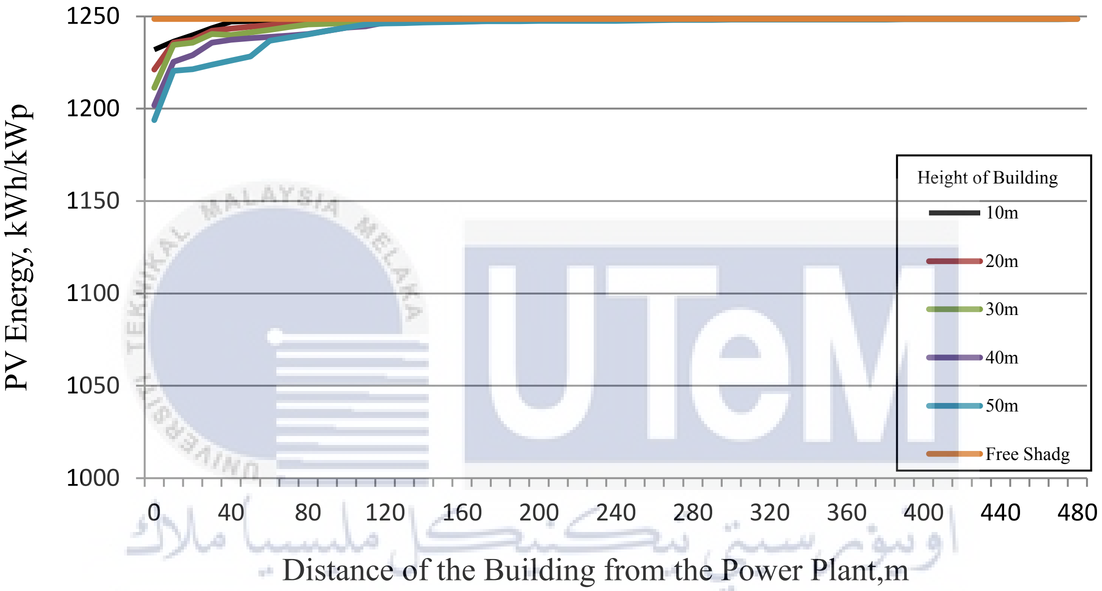


Figure 4.5: PV Energy versus Distance of Building from the 100m by 100m Power Plant

4.3 Photovoltaic (PV) Energy Reduction

4.3.1 20m by 20m PV Power Plant

The Figure 4.6 shows the graph with PV energy reduction, % in the 20m by 20m size of PV power plant with the distance of the building from the power plant. The PV energy reduction for free shading is 0%. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

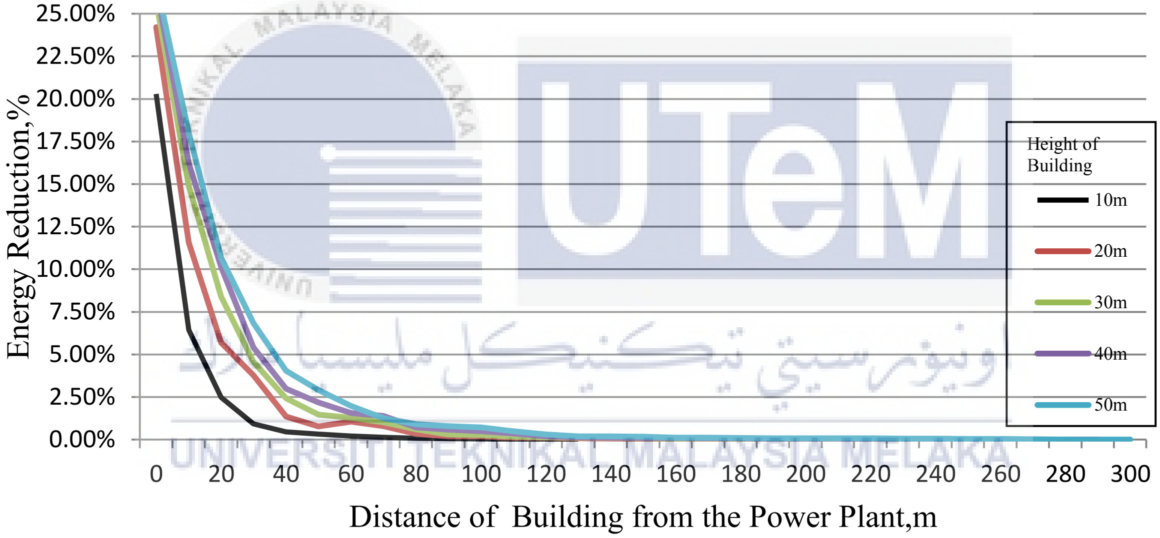


Figure 4.6: Energy Reduction versus Distance of Building from the 20m by 20m Power Plant

4.3.2 40m by 40m PV Power Plant

The Figure 4.7 shows the graph with PV energy reduction, % in the 40m by 40m size of PV power plant with the distance of the building from the power plant. The PV energy reduction for free shading is 0%. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

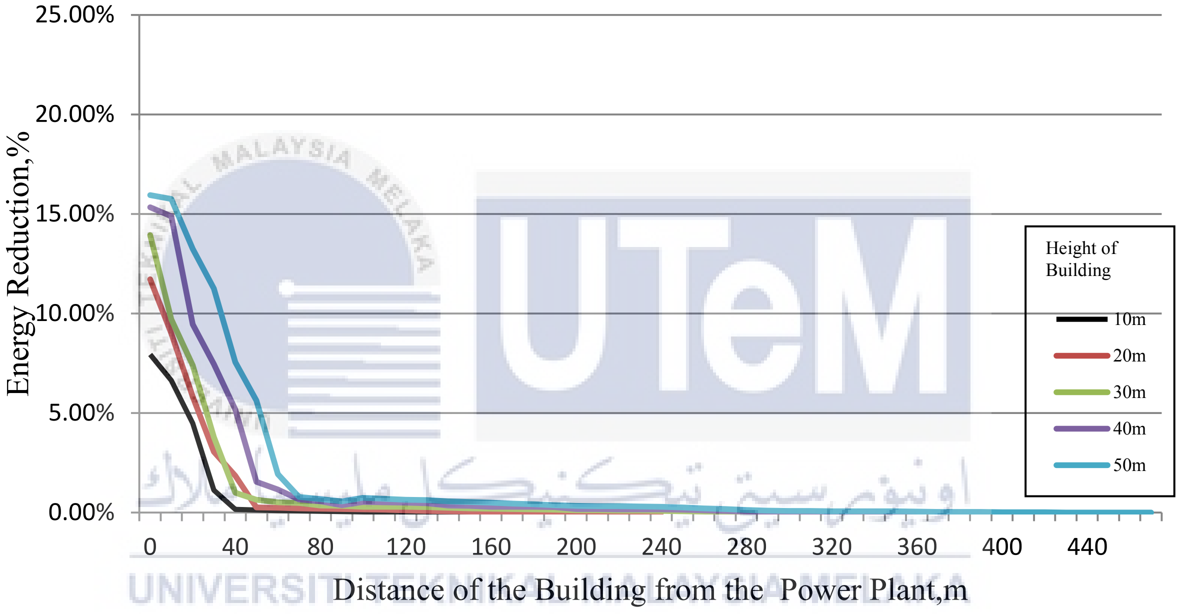


Figure 4.7: Energy Reduction versus Distance of Building from the 40m by 40m Power Plant

4.3.3 60m by 60m PV Power Plant

The Figure 4.8 shows the graph with PV energy reduction,% in the 60m by 60m size of PV power plant with the distance of the building from the power plant. The PV energy reduction for free shading is 0%. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

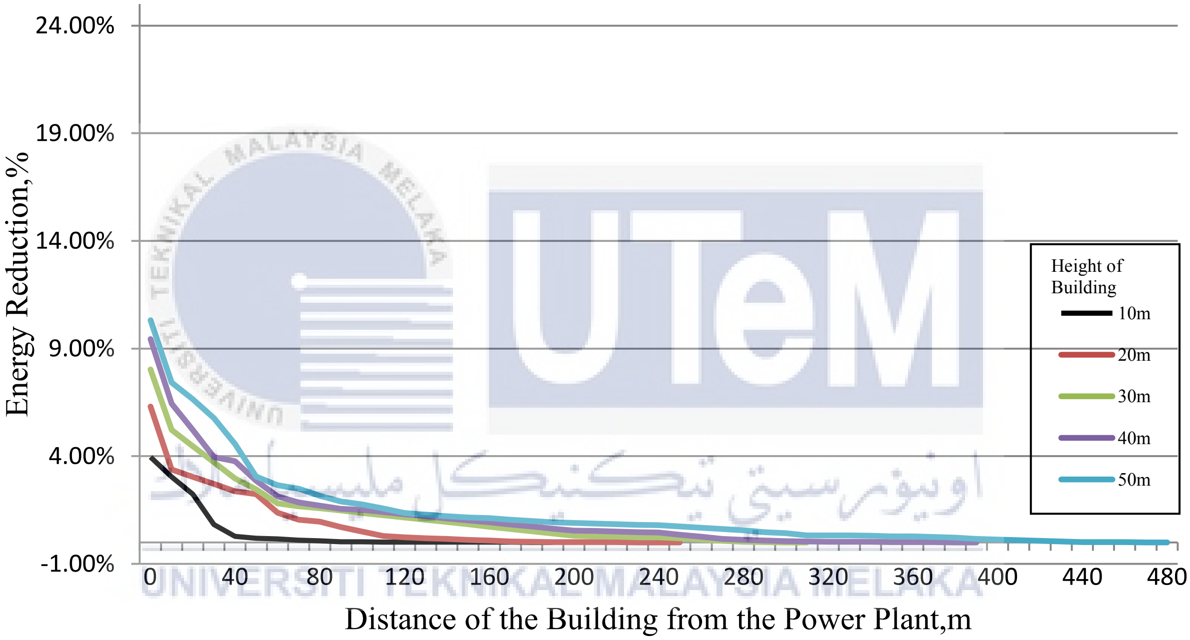


Figure 4.8: Energy Reduction versus Distance of Building from the 60m by 60m Power Plant

4.3.4 80m by 80m PV Power Plant

The Figure 4.9 shows the graph with PV energy reduction,% in the 80m by 80m size of PV power plant with the distance of the building from the power plant. The PV energy reduction for free shading is 0%. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

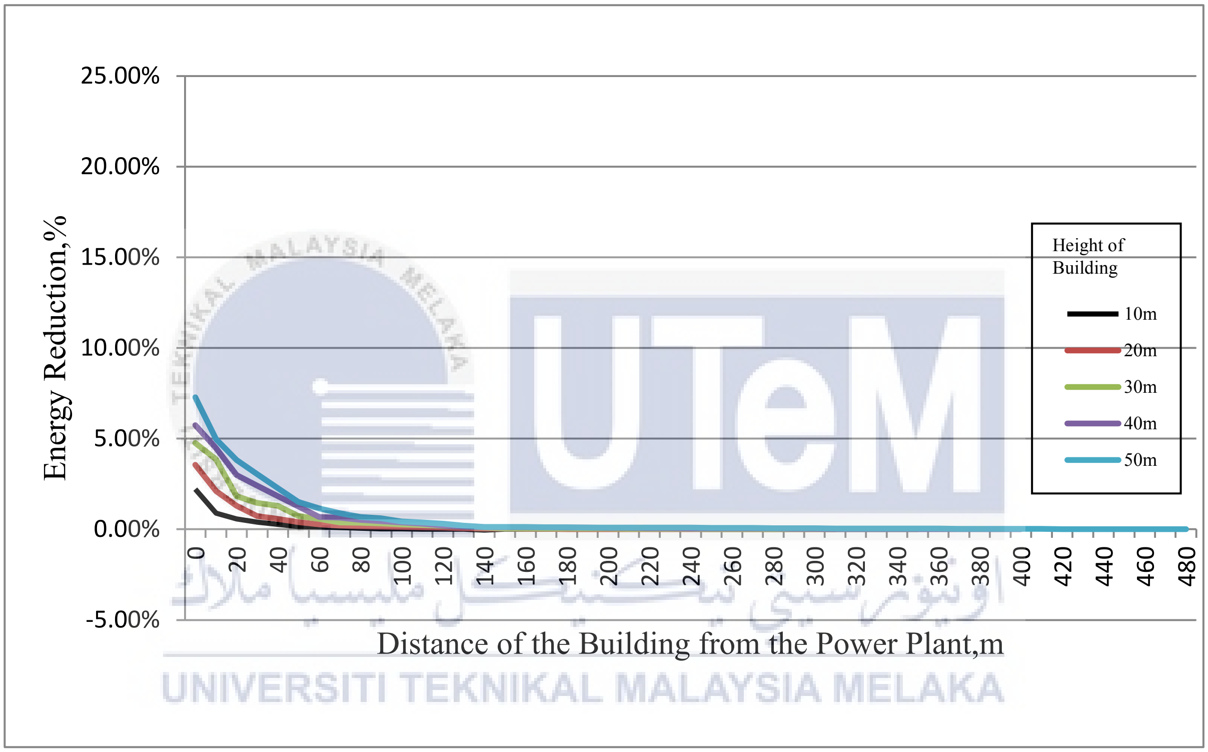


Figure 4.9: Energy Reduction versus Distance of Building from the 80m by 80m Power Plant

4.3.5 100m by 100m PV Power Plant

The Figure 4.10 shows the graph with PV energy reduction,% in the 100m by 100m size of PV power plant with the distance of the building from the power plant. The PV energy reduction for free shading is 0%. The simulation was carried out for five different heights of building with the distance which results in zero shading factor or the amount of free shading PV energy.

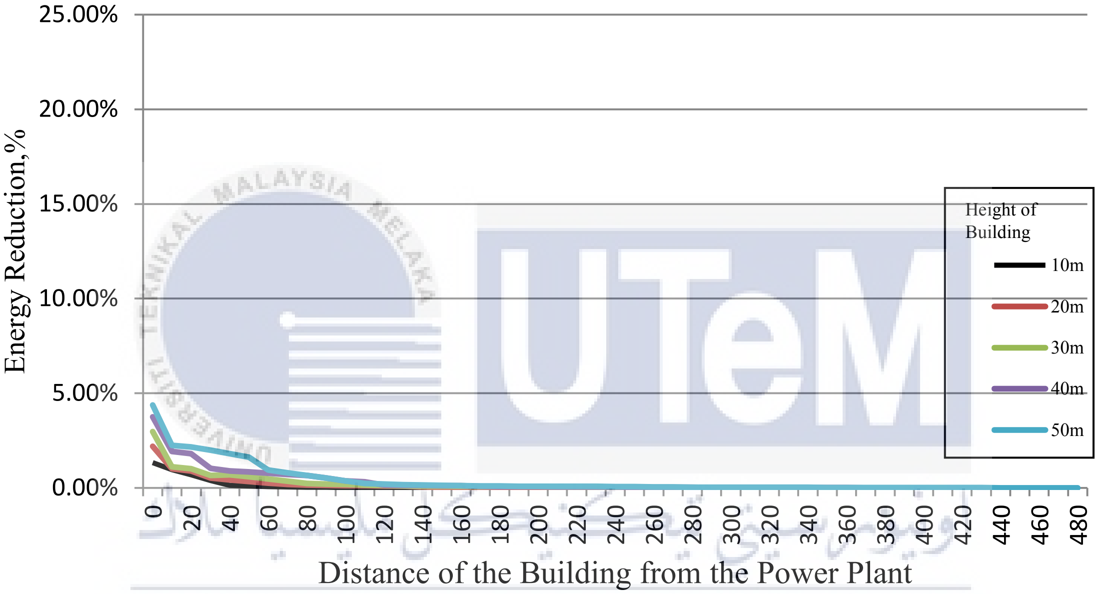


Figure 4.10: Energy Reduction versus Distance of Building from the 100m by 100m Power Plant

4.4 Analysis and Data Validation

The measurement of the exact height and distance of surrounding buildings from the PV power plant has not been analysed by any experts. Most of the experts use the Rules of Thumbs to state the exact height and distance of the buildings. From the Sustainable Energy Development Authority, SEDA in the module Grid-Connected PV Power System Design, “Rule-of-Thumb is to locate the array at distance that is at least twice the height of the object, this will ensure that the object will not cast a shadow” [21]. There are no official standards or papers that are related to the shading factors which involves the surrounding buildings sizes. Hence, this Solar Pro software is used to simulate the performances of the PV power plant by measuring the irradiation and PV energy when there is an effect of the shading factors.

Since there is no proper standard and papers regarding the size of the building beside the PV power plant other factors such as Peak Sun Hour, PV energy, irradiation, sun path diagram, performance ratio are take into account to prove and verify that the data from the simulation of the Solar Pro software is valid and nearly equivalent to the real one.

4.4.1 Total Irradiation

Solar irradiation is an intensity of solar energy. Total irradiation is a sum up from the direct irradiation, diffuse irradiation and reflected irradiation. Table 4.1 shows the total irradiation obtained from the simulation is 1674.94kWh/m2 per year and the Peak Sun hour. The Table 4.2 is a comparison of the total irradiation from the Solar Pro software and the Meteonorm software. The Meteonorm obtained the irradiation of global radiation (Melaka) is 1657kwh/m2 on the year of 2014. Meteonorm contains worldwide weather data which can be retrieved in over 35 data formats**.** Meteonorm contains 8325 weather stations**,** five geostationary satellites and 30 years of experience**.**

Table 4.1: Total Irradiation (Solar Pro Software)

Size,m	Total irradiation, kWh/m2	PV Energy,kwh	Specific PV Energy, kwh/kwp	PSH
20m X 20m	1674.94	20224.98	1248.46	4.59
40m X 40m	1674.94.	72799.89	1248.28	4.59
60m X 60m	1674.94	157725.05	1248.22	4.59
80m X 80m	1674.94.	291200.50	1248.29	4.59
100m X 100m	1674.94	444951.65	1248.46	4.59
	1674.94.			

Table 4.2: Comparison of the Total Irradiation from the Solar Pro and the Metonorm

	Solar Pro	**Meteonorm**	
Month	**Total Irradiation, kWh/m^2**	**Total Irradiation, kWh/m^2**	**Differences,%**
Jan	147.26	134	9%
Feb	147.47	137	7%
Mar	155.97	153	2%
Apr	137.68	144	5%
May	130.17	145	11%
Jun	123.46	135	9%
July	127.54	140	10%
Aug	136.07	139	2%
Sep	139.96	142	1%
Oct	148.79	127	15%
Nov	135.82	135	1%
Dec	144.75	124	14%
	1674.94	**1657**	**1%**

The data obtained from Solar Pro software is parallel with the Meteonorm software with the difference of 1% per year. Hence, the data obtained from the simulation is valid with the real metrological data.

4.4.2 Peak Sun hour

Peak sun hour describes the amount of solar energy that is available during a day. The daily amount of solar radiation striking any location on earth varies from sunrise to sunset due to clouds, the sun's position in the sky, and what's mixed into the atmosphere. From the simulation the total irradiation is 1674.94kWh/m2 per year.

$$\sum year = 1674.94$$

$$PSF = \frac{1674.94\, kWh/m^2}{1000W/m^2}$$

$$PSF/year = 1674.94 \tag{4.1}$$

$$PSF/Day = 4.59\ hour$$

The simulation of the Solar Pro software gives the data of peak sun hour, PSH is 4.59 hour for one day. The journal of sustainable and Environment 3 which entitled Evaluation of Solar and Metrological Data relevant to Solar energy Technology Performance in Malaysia produces the data which shows the PSH in Melaka on year 2012 is 4.5hour which is the nearest to the simulation[22]. The Figure 4.11 shows the graph of daily solar radiation from the journal. Therefore, the simulation and the experiment values are almost the same. Hence, the data obtained from Solar Pro simulation can be verified and assumed to be the real one.

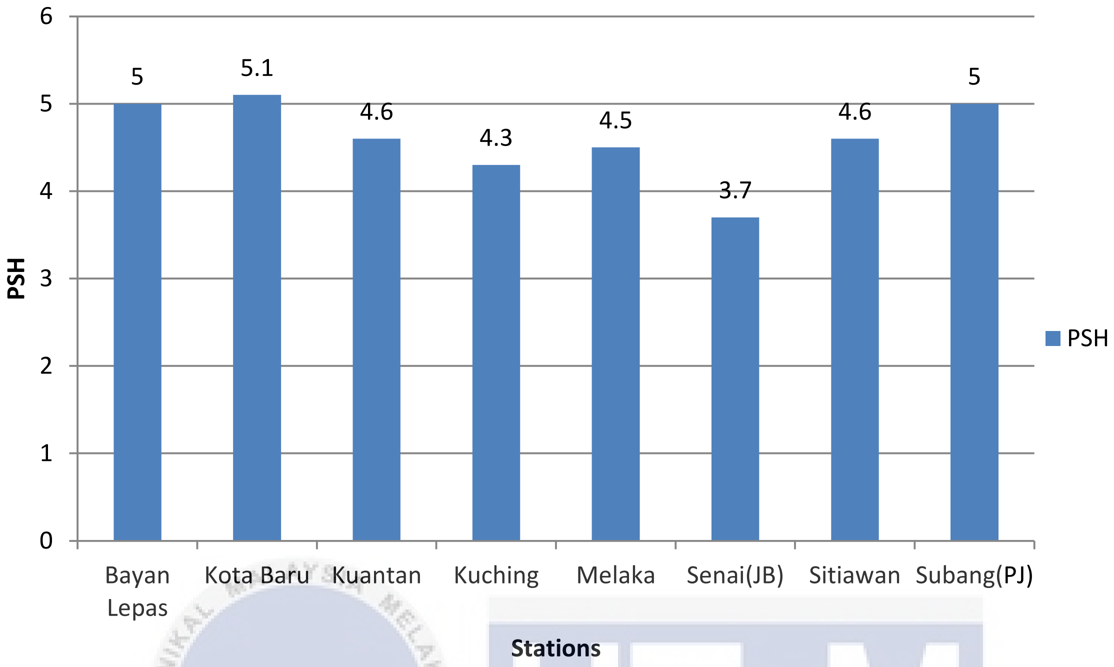


Figure 4.11: PSH in Malaysia's Stations [22]

4.4.3 Comparison of PSH Using the Solar Pathfinder

The solar Pathfinder is used for shade analysis and to calculate the solar irradiance performance on any coordinate for a year. The Figure 4.12 and Figure 4.13 shows a building with the height of the 15m and it's the sun path diagram respectively. The solar path finder is placed 10m distance from the building. The experiment carried out on May 2015**.** Table 4.3 shows the sun hours and the AC energy. Hence, it can be concluded that the peak sun hours in the coordinate of 2.2^{0}N, 102.3^{0}E (Melaka) is 4.70 hours.

Figure 4.12: The 15m FKE building

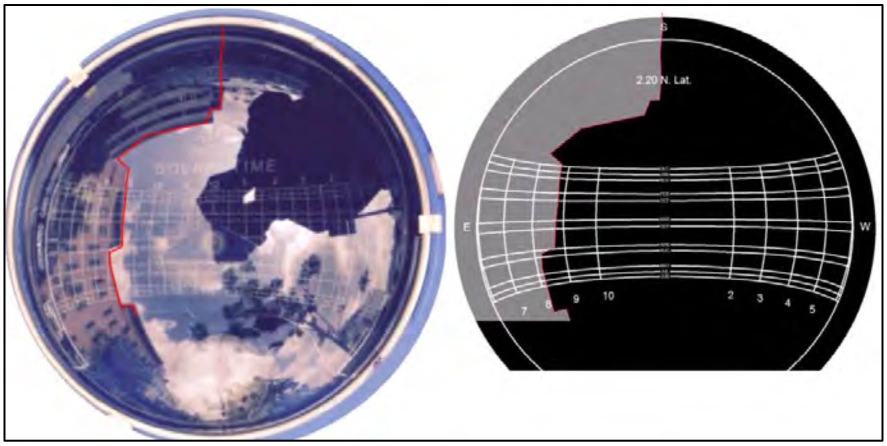


Figure 4.13: Sun Path Diagram of FKE Building

Table 4.3: The Sun Hours and the AC Energy(SPF)

Month	Unshaded % of Ideal Site Azimuth=180 Tilt=2.2	Actual Shaded Solar Radiation Azimuth=180.0 Tilt=10.0 kWh/m²	Actual Shaded AC Energy (kWh) Azimuth=180.00 Tilt=10.00	Actual Unshaded AC Energy (kWh) Azimuth=180.0 Tilt=10.00
January	95.11%	4.9	1,651.80	1,719.00
February	94.71%	5.23	1,589.41	1,659.00
March	92.45%	5.62	1,866.77	2,007.00
April	93.04%	5.17	1,675.06	1,791.00
May	94.18%	4.63	1,555.72	1,638.00
June	94.36%	4.62	1,530.32	1,607.00
July	94.71%	4.39	1,499.91	1,570.00
August	94.88%	4.06	1,381.58	1,444.00
September	90.90%	4.22	1,385.30	1,519.00
October	90.89%	4.13	1,408.21	1,544.00
November	91.57%	4.64	1,515.63	1,657.00
December	93.72%	4.75	1,613.80	1,709.00
Totals	93.38%	56.36	18,673.52	19,864.00
--	Unweighted	Effect: 93.31%	--	--
--	**Yearly Avg**	**Sun Hrs: 4.70**	--	--

Table 4.4 summarise the Peak Sun Hour, PSH from the Solar Pro software, Journal and from the experiment.

Table 4.4 : Summarise of Peak Sun Hour in Melaka (PSH)

Solar Pro (software)	Metrological Data(paper)	Solar path finder (experiment)
4.59 hours	**4.5 hours**	**4.7 hours**

4.4.4 Performance Ratio

The performance ratio is a measure of the quality of a PV plant that is independent of the location. The performance ratio is stated in percent and describes the relationship between the actual and the theoretical energy outputs of the PV plant.

$$PR = \frac{Y_f}{H}$$

Where, (4.2)

Y_f Final yield, kWh/kWp

H Solar irradiation, kWh/m2

From simulation (Solar Pro),

$$PR = \frac{1248.35}{1674.94}$$

$$PR = 0.7453$$

$$PR = 74.53\%$$

The average yield yearly final yield was found to be 1248.35kWh/kWp while the performance ratio (PR) is 74.53%.

According to Photovoltaic Monitoring Centre, University Teknologi MARA (UiTM) the performance ratio of the grid-connected photovoltaic (PV) system at Malaysia varies from 71.37% to 91.99% [23,24]. The PR of 74.53% from the Solar Pro software is in the range of standard which was released by PV Monitoring Centre [23,24].

4.5 Discussion and Finalisation of the Data

This research simulates using Solar Pro software version 4.1. The data obtained from the simulation are compared with the standards, published journals, papers and previous experiments. All the data gathered from the simulation such as PV energy, peak sun hour, total irradiation and performance ratio were declared as valid and compatible for the coordinates of Melaka.

The 20m by 20m building built in left of the power plant and the height and distance of the building is varied to obtain the zero shading factor in the PV power plant. The building height starts with 10m and zero metre distance which is nearest to the PV power plant. The height of the building is increased gradually and the distance were recorded when the shading factor is zero.

The simulation begins with the 20m by 20m PV power plant. Table 4.5 shows the height of the building with a distance of 20m by 20m PV power plant with no shading. When the height of the building is 10m, the distance from the PV power plant is 60m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 100m, 130m,160m, and 200m respectively.

Table 4.5: Height of the Building with a Distance of 20m by 20m PV Power Plant with No Shading

Size PV plant: **20m X 20m**					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	60	100	130	160	200

From the data obtained, for the size of 20m by 20m PV power plant with the capacity of 16.20kW, the distance from the power plant is four to six times of the height of 20m by 20m size of building.

Table 4.6 shows the height of the building with the distance of 40m by 40m from the PV power plant with no shading. When the height of the building is 10m, the distance from the PV power plant is 50m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 90m, 125m, 170m, and 190m respectively.

Table 4.6: Height of the Building with a Distance of 40m by 40m PV Power Plant with No Shading

Size PV plant: **40m X 40m**					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	50	90	125	170	190

From the data obtained, for the size of 40m by 40m PV power plant with the capacity of 58.32kW, the distance from the power plant is 3.8 to 5 times of the height of the 20m by 20m size of building.

Table 4.7 shows the height of the building with the distance of 60m by 60m PV power plant. When the height of the building is 10m, the distance from the PV power plant is 45m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 80m, 120m, 150m, and 160m respectively.

Table 4.7: Height of the Building with a Distance of 60m by 60m PV Power Plant with No Shading

Size PV plant: **60m X 60m**					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	45	80	120	150	160

From the data obtained, for the size of 60m by 60m PV power plant with the capacity of 126.36kW, the distance from the power plant is 3.2 to 4.5 times of the height of the 20m by 20m size of building.

Table 4.8 shows the height of the building with the distance from the 80m by 80m PV power plant with no shading. When the height of the building is 10m the distance from the PV power plant is 40m for the zero percent energy reduction. The distance from the PV power plant is increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 70m, 100m, 125m, and 130m respectively.

Table 4.8: Height of the Building with a Distance of 80m by 80m PV Power Plant with No Shading

Size PV plant: **80m X 80m**					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	40	70	100	125	130

From the data obtained, for the size of 80m by 80m PV power plant with the capacity of 233.28kW, the distance from the power plant is 2.6 to 4.0 times of the height of the 20m by 20m size of building.

Table 4.9 shows the height of the building with the distance of 100m by 100m PV power plant with no shading. When the height of the building is 10m the distance from the PV power plant is 35m for the zero percent energy reduction. The distance from the PV power plant increases when the height of the building is increased where for the height of the building 20m, 30m, 40m, 50m the distance from the power plant to obtain low shading factor is 70m, 95m, 115m, and 120m respectively.

Table 4.9: Height of the Building with a Distance of 100m by 100m PV Power Plant with No Shading

Size PV plant: **100m X 100m**					
Height of the building, m	10	20	30	40	50
Distance from the PV power plant, m	35	70	95	115	120

From the data obtained, for the size of 100m by 100m PV power plant with the capacity of 356.40kW, the distance from the power plant is 2.4 to 3.5 times of the height of the 20m by 20m size of building.

Table 4.10 shows the distance of the building from the PV power plant in terms of the multiplication of the height. When the size of the PV power plant increases, the distance of the building from the PV power plant in terms of the multiplication of the height is decreases. The building with the length of 20m and the width of 20m only give a huge impact to the smaller size of the power plant. The bigger size of the power plant like 60m by 60m, 80m by 80m and 100m by 100m is not affected much in its yield with the present of the building.

Table 4.10: Distance of the Building from the PV Power Plant in Terms of the Multiplication of the Height

Building size is 20m by 20m with varied height						
Size of the PV power plant, m	**Distance of the building from the PV power plant, multiply of the height**					
Height of Building **Size of PV Plant**	**10m**	**20m**	**30m**	**40m**	**50m**	**Range**
20m X 20m	6.0	5.0	4.3	4.0	4.0	**4 to 6**
40m X 40m	5.0	4.5	4.2	4.3	3.8	**3.8 to 5**
60m X 60m	4.5	4.0	4.0	3.8	3.2	**3.2 to 4.5**
80m X 80m	4.0	3.5	3.3	3.1	2.6	**2.6 to 4**
100m X 100m	3.5	3.5	3.2	2.9	2.4	**2.4 to 3.5**

CHAPTER 5

CONCLUSION

5.1 Conclusion

Shading of photovoltaic modules is a widespread phenomenon which affects the performances of the PV system. Shading of solar cells not only reduces the cell power P_{MPP}, but also changes the value of a open circuit voltage V_{OC}, short circuit current $I_{SC,}$ fill factor and its efficiency. The distance and height of the building besides the solar power plant cause some variation in the shading factors and affects the performances of PV system. The objective of this research is to design a PV power plant with a low or zero shading factor by identifying the suitable distance of the surrounding building and the suitable height of the building.

In a nutshell, the analysis of shading factors is done with the aid of Solar Pro software in order to obtain the output of solar cell. Solar Pro is sophisticated simulation software for a PV system. The software is able to simulate the PV system under different condition which is varied by each system so that it allows system designing based on precise data.

Since there is no proper standard and papers regarding the size of the building beside the PV power plant other factors such as Peak Sun Hour, PV energy, irradiation, sun path diagram, performance ratio are take into account to prove and verify that the data from the simulation of the Solar Pro software is valid and nearly equivalent to the real one. The data obtained from the simulation are compared with the standards, published journals, papers and previous experiments. All the data gathered from the simulation such as PV energy, peak sun hour, total irradiation and performance ratio were declared as valid and compatible for the coordinates of Melaka.

The result that was obtained will give an exact specific distance between the building and power plant together with the height of the building, producing a zero shading factor. The exact specific distance can be calculated using the multiplier of the height of the building. The multiplier of the height is varied with the different size of the PV power plant. Compare to the smaller size power plant, the bigger size of the power plant is not affected much in its yield with the present of the 20m by 20m building.

In a nutshell, the result that was obtained will give an exact specific distance between the building and power plant together with the height of the building, producing a zero shading factor. The exact specific distance can be calculated using the multiplier of the height of the building. The multiplier of the height is varied with the different size of the PV power plant.

5.2 Recommendation

In light of the evaluation of the PV plant, the following future works are recommended:

i.) A new research should take into account different shapes and sizes of buildings and different positions from the PV power plant.

ii.) The Solar Pro is recommended to collaborate with Meteonorm software or Metrological department to ensure all the metrological data are valid. Hence, no verification by other relevant source will be required.

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