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OPTIMUM SIZING OF GRID CONNECTED PHOTOVOLTAIC SYSTEM UNDER TROPICAL CONDITION

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OPTIMUM SIZING OF GRID CONNECTED PHOTOVOLTAIC (GCPV) SYSTEM UNDER TROPICAL CONDITION

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A Report submitted in partial fulfilment of the requirements for the degree of Electrical Engineering (Industrial Power)

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2017

I declared that this report entitle "Optimum Sizing of Grid Connected Photovoltaic (GCPV) System under Tropical Condition" 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 candidature of any other degree.

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BISMILLAHIRRAHMANIRRAHIM

In the name of Allah, the most Beneficent, the most Merciful

My humble effort in which I dedicate to my sweet and loving Father and Mother

Wan Mohd Kamil bin Wan Ibrahim and Zainon bt Omar

Whose affection, love, encouragement and prays of days and night enables me to complete the writing of these thesis successfully

Along with hard working and respected

Supervisor

And not to forget, all my fellow friends

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ABSTRACT

Initial investment for Photovoltaic system is expensive. Therefore, meticulous planning on the financial investment is needed. Usually, 60% from the total installation PV system cost went to solar panel and around 15% to 20% goes to the inverter. Currently, there are still no written standard or guidelines available yet on the optimum sizing between the solar panel and the inverter. Therefore, this research aims to determine the most optimum sizing ratio between solar panel and the inverter. To do so, an average of one year tilted irradiance and back panel temperature data are collected. Then, the collected data is simulated by PV simulator which is set at different sizing ratio which are 1:0.7, 1:0.8, 1:0.9, 1:1, 1.1.1, 1:1.2. The results show that the most optimum sizing ratio between solar panel and inverter is at 1:0.8. In terms of financial impact, this ratio shows that it saves cost around 4% for each 4kW system and will be greater if the PV system is expanded up to GigaWatts of size. Furthermore, this ratio also has the highest efficiency if compared to other ratios. When compare to 1:1 ratio, 1:0.8 ratio is higher in efficiency at 0.68%. This is due to the finding that at 20% smaller size than the panel, the inverter operated the closes to its full potential under tropical climate condition.

ABSTRAK

Pelaburan awal untuk sistem photovoltaic adalah mahal. Oleh itu, perancangan yang teliti terhadap kos pelaburan adalah diperlukan. Kebiasaannya, 60% daripada jumlah kos pemasangan sistem PV terdiri daripada panel dan kira-kira 15% hingga 20% terdiri daripada penyongsang. Sehingga kini, tiada garis panduan mahupun standard bertulis bagi nisbah optimum antara solar panel dan juga penyongsang. Oleh itu, kajian ini bertujuan untuk menentukan nisbah optimum diantara panel solar dan penyongsang. Untuk berbuat demikian, purata setahun bagi sinaran condong dan suhu belakang panel dikumpulkan. Kemudian, data yang dikumpul disimulasikan dengan simulator PV yang ditetapkan pada nisbah saiz yang berbeza iaitu 1:0.7, 1:0.8, 1:0.9, 1:1, 1:1.1, 1:1.2. Keputusan menunjukkan bahawa nisbah saiz yang paling optimum antara panel solar dan penyongsang adalah pada nisbah 1:0.8. Dari segi kesan kewangan, nisbah ini menunjukkan bahawa ia dapat menjimatkan kos kira-kira 4% bagi setiap sistem 4kW dan akan lebih tinggi penjimatan jika sistem PV dibesarkan sehinggan saiz gigawatt. Tambahan pula, nisbah ini juga mempunyai kecekapan tertinggi jika dibandingkan dengan nisbah yang lain. Apabila dibandingkan dengan nisbah 1:1, kecekapan nisbah 1:0.8 adalah 0.68% lebih tinggi. Ini adalah kerana keputusan bahawa pada saiz 20% lebih kecil daripada panel, penyongsang akan beroperasi pada tahap hampir maksimum keadaan iklim tropika.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TABLE OF CONTENTS	**iv**
	LIST OF FIGURES	**vii**
	LIST OF TABLES	**xi**
	LIST OF APPENDICES	**xii**
	LIST OF ABBREVIATIONS	**xiii**
1	**INTRODUCTION**	**1**
	1.0 Introduction	1
	1.1 Motivation	3
	1.2 Problem Statement	4
	1.3 Objectives	5
	1.4 Scope	6
2	**LITERATURE REVIEW**	**7**
	2.0 Overview	7
	2.1 GCPV System	7
	2.2 Solar Panel	11
	2.3 Solar Inverter	15
	2.4 Balance of System (BOS)	18
	2.4.1 Mounting Structure	18

		2.4.2 Cables	21
		2.4.3 Switches, Circuit Breaker and Fuses	22
		2.4.4 Protection Devices	22
	2.5	How GCPV Works	24
	2.6	Summary	26
3	**METHODOLOGY**		**27**
	3.0	Overview	27
	3.1	Gantt Chart	27
	3.2	Flow Chart of the System	29
		3.2.1 Literature Review of the Project	30
		3.2.2 Data Collection	30
		3.2.3 Data Processing	34
		3.2.4 Testing	36
		3.2.5 Analysis on the Output Testing	39
		3.2.6 Finding and Conclusion	41
		3.2.7 Thesis Writing	41
	3.3	Summary	41
4	**RESULT AND DISCUSSION**		**42**
	4.0	Overview	42
	4.1	Irradiance and Temperature Profiling	42
	4.2	Testing Result	49
	4.3	Testing Result Plotted On the Same Graph	67
	4.4	System Yield	72

	4.5	Financial Impact	73
	4.6	Summary	75
5	**CONCLUSION AND RECOMMENDATION**		**76**
	5.1	Conclusion	76
	5.2	Recommendation	77
	REFERENCES		78
	APPENDICES		83

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Energy Policies in Peninsular Malaysia and Sabah by KETTHA	2
1.2	Simple Operation Using Feed-In Tariff in Residential	3
1.3	Feed-In Tariff rates for solar PV on 2013 and 2014	4
2.1	Typical Grid-Connected Photovoltaic configuration	8
2.2	A 4.3kWp GCPV on the rooftop of the house at Bukit Beruang	9
2.3	A 12.2 kWp GCPV on the rooftop of the PBH Saujana Golf Resort	9
2.4	A 8MW GCPV on the Gading Kencana Solar Farm, Melaka	10
2.5	The process of Photovoltaic Effect	11
2.6	Solar Panel (a) HIT (b) Monocrystalline (c) Polycrystalline (d) Thin-Film	14
2.7	Single-phase half bridge inverter	15
2.8	Solar Inverter (a) SMA SB3000 (b) SMA SB3000 HF (c) ABB UNO-3.0-TL-OUTD	17
2.9	Main parts of Balance of System	18
2.10	Building Integrated Structure	19
2.11	Retrofitting structure	20

2.12	Free-standing structure	20
2.13	Solar module completed with accessories	21
2.14	Surge Protection Device (a) DC and (b) AC	24
2.15	IV curves varying temperatures	25
2.16	IV curves varying levels of irradiance	25
2.17	Typical Grid-Connected Photovoltaic configuration	26
3.1	Flowchart of whole system	29
3.2	Real Time Display (RTD)	32
3.3	Navigation to Query display	32
3.4	Query Display	33
3.5	Query result	33
3.6	Initial data from csv file opened with Microsoft excel	34
3.7	Convert Text to Column Wizard – Step 1 Window	34
3.8	Convert Text to Column Wizard – Step 2 Window	35
3.9	Rearranged data in 'Tab' style	35
3.10	One Year Average of Irradiance from 07:00 to 19:00	36
3.11	One Year Average of Back Panel Temperature from 07:00 to 19:00	36
3.12	Block diagram of testing process	37
3.13	Recorded Data from the Testing Process	40
4.1	Irradiance profile for (a) January (b) February (c) March (d) April (e) Mei (f) June	44
4.2	Irradiance profile for (a) July (b) August (c) September	

	(d) October (e) November (f) December	45
4.3	Temperature Profile for (a) January (b) February (c) March	
	(d) April (e) Mei (f) June	46
4.4	Temperature Profile for (a) July (b) August (c) September	
	(d) October (e) November (f) December	47
4.5	One year Irradiance Profile	48
4.6	One year Back Panel Temperature Profile	49
4.7	(a) Input Power (b) Output Power (c) Input Current (d) Output	
	Current (e)Input Voltage (f) Output Voltage	51
4.8	Efficiency of 1: 0.7 inverter to solar panel	52
4.9	(a) Input Power (b) Output Power (c) Input Current (d) Output	
	Current (e) Input Voltage (f) Output Voltage	54
4.10	Efficiency of 1: 0.8 inverter to solar panel	55
4.11	(a) Input Power (b) Output Power (c) Input Current (d) Output	
	Current (e) Input Voltage (f) Output Voltage	57
4.12	Efficiency of 1: 0.9 inverter to solar panel	58
4.13	(a) Input Power (b) Output Power (c) Input Current (d) Output	
	Current (e) Input Voltage (f) Output Voltage	60
4.14	Efficiency of 1: 1 inverter to solar panel	61
4.15	(a) Input Power (b) Output Power (c) Input Current (d) Output	
	Current (e) Input Voltage (f) Output Voltage	63
4.16	Efficiency of 1: 1.1 inverter to solar panel	64
4.17	(a) Input Power (b) Output Power (c) Input Current (d) Output	

	Current (e) Input Voltage (f) Output Voltage	66
4.18	Efficiency of 1: 1.2 inverter to solar panel	67
4.19	Input Current Graph of All Ratio	68
4.20	Output Current Graph of All Ratio	68
4.21	Input Voltage Graph of All Ratio	69
4.22	Output Voltage Graph of All Ratio	69
4.23	Input Power Graph of All Ratio	70
4.24	Output Power Graph of All Ratio	70
4.25	Overall Plotted Graph of Inverter to Solar Panel efficiency	71
4.26	Average Efficiency of Every Ratio	71

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	Comparison between four types of solar panel with different criteria	14
2.2	Comparison between three different topology of solar inverter with different criteria	17
3.1	Flowchart of whole system	29
3.2	Technical data of Pyranometer CM 11	31
3.3	Technical data of the CS220 surface-mount thermocouple	31
3.4	The Equipment used during Testing Process and their Image	38
3.5	Ratio Panel to Inverter	39
3.6	Description of every Column	40
4.1	System Yield of Every Ratio	72

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Contribution: Journal Paper to be submitted to International Journal of Renewable Energy Research (IJRER)	83
B	Datasheet of Inverter SB 3000HF from SMA Brand	95
C	Data of Solar Panel Plus SW 255 (MONO) from Solar World Brand	96

LIST OF ABBREVIATIONS

AC	-	Alternating Current
BIPV	-	Building Integrated Photovoltaic
BOS	-	Balance of System
CCC	-	China Compulsory Code
CSP	-	Concentrated Solar Power
DC	-	Direct Current
FiT	-	Feed-in-Tariff
GCPV	-	Grid Connected Photovoltaic
HIT	-	Heterojunction with Intrinsic Thin-layer
MPPT	-	Maximum Power Point Tracking
NEC	-	National Electrical Code
PV	-	Photovoltaic
ROI	-	Return of Investment
RTD	-	Real Time Display
SAPV	-	Stand Alone Photovoltaic
SEDA	-	Sustainable Energy Development Authority
SPD	-	Surge Protection Device
STC	-	Standard Test Condition

CHAPTER 1

INTRODUCTION

1.0 Introduction

By 2050, electrical energy supplies are targeted to multiply with a specific end goal to take care of energy demand of all household [1]. Fossil fuel sources like normal gas, coal, hydro and oil are some of the constrained normal sources which are expected to deplete in the future. Day by day, fossil fuel looked for from place to another. In the event that this procedure is proceeds with, these sources will become less and exclusive [2]. Based on Figure 1.1, According to National Energy Policy (1979), Malaysia aims to have a safe and ecological feasible supply as well as effective and clean use of energy in the future [3]. In order to fulfil this energy policy, in the year 1999 Malaysia has adopted the Five-Fuel Diversification Strategy as shown in Figure 1.1. This strategy adds a new source which is a renewable energy. The goal of this policy is to empower the use of renewable energy and to have a proficient and clean usage of energy [3] [4] .

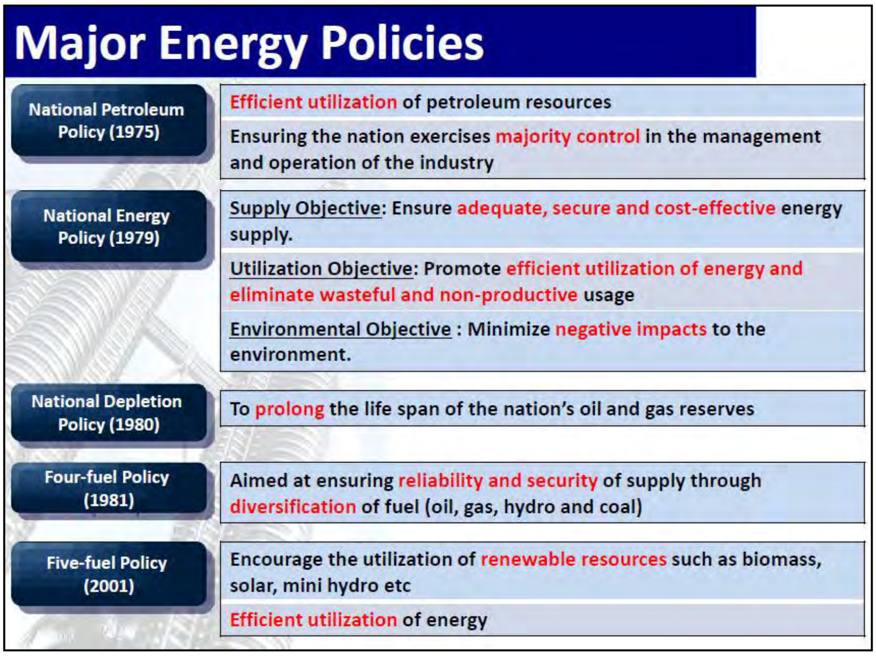


Figure 1.1: Energy Policies in Peninsular Malaysia and Sabah by KETTHA [3]

Renewable energy advancements can deliver reasonable and clean energy from their sources. Renewable sources which are commonly used are biomass which includes wood waste, municipal solid waste and biogas, hydropower, geothermal, wind and solar [5]. Solar energy is the most famous renewable energy among others in Malaysia. There are two main types of solar energy namely photovoltaic (PV) and concentrated solar power (CSP). Malaysia is likely the most acquainted with photovoltaic which is used by panels. For CSP innovations, regularly it will be utilized as a part of the vast power plant and is not proper for private utilize [6]. The reason why people are attracted to solar compared to other renewable sources is because it is free from pollution and placed near to the equator. As Malaysia is close to the equator, it receives 4,000 to 5,000 watt-per hour per square metre per day which is equivalent to sufficient energy from the sun to generate 11 years' worth of electricity.

1.1 Motivation

The motivation of this research is to make sure the customers who are interested to invest in solar energy to get the correct Return of Investment (ROI) for their investment. This research aims to reduce the installation cost of the solar system in addition to maintain the system efficiency. FITs is the one of the strategies to advance more prominent utilization of renewable energy in Malaysia. This strategy also allows user to sell the sources generated by renewable energy to the power utilities at a fixed premium price [7]. Figure 1.2 shows the simple operation of Feed-in Tariff in residential. First and foremost the solar panel generates DC electricity from the sunlight, and then the inverter converts DC-AC electricity for the own use. Besides, the meter is used to measure the amount of electricity generated from the solar system. The system is connected to utility grid to export the energy generated from the solar system [8].

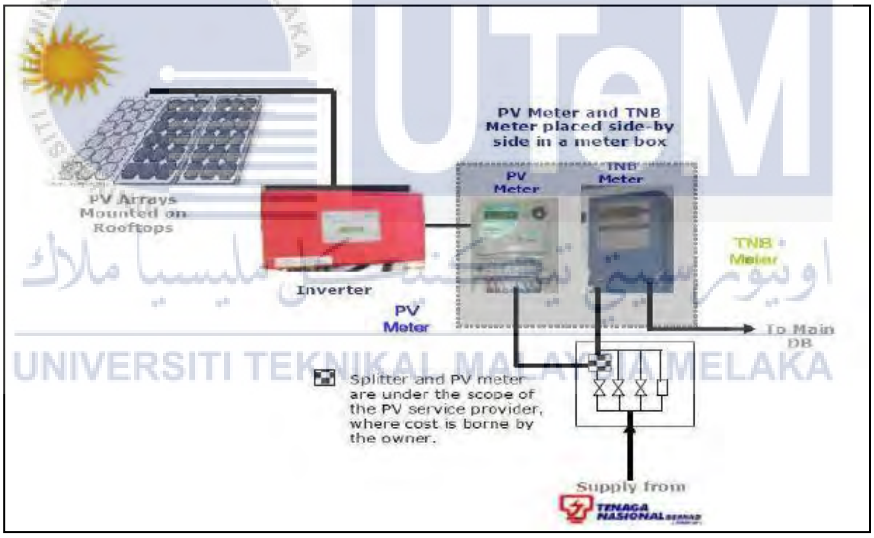


Figure 1.2: Simple Operation Using Feed-In Tariff in Residential [9]

By utilizing FITs, the client can make profits as well as making the investment. This is because if client is eligible to produce renewable energy, the energy is allowed to be sold to national security grid [10]. Figure 1.3 below shows the Feed-In Tariff rates for solar PV in 2013 and 2014 provided by Sustainable Energy Development Authority Malaysia (SEDA). By installing 4kW capacity of solar system, the income is generated as shown below:

$$\text{INCOME} = (\text{RM } 1.0411 + \text{RM } 0.2201 + \text{RM } 0.2116 + \text{RM } 0.0300 + \text{RM } 0.0100) \times 4\text{kW} \times 4.5 \text{ hour} \times 30 \text{ days} = \text{RM } 816.912 \text{ per month} \tag{1.1}$$

This program is known as the world's best strategy to implement the quick improvement of renewable energy besides creating an expansive and growing base of jobs and salary for the people involved.

FiT Rates for Solar PV (21 years from FiT Commencement Date)

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)	
(a) Basic FiT rates having installed capacity of :	2013	2014
(i) up to and including 4kW	1.1316	1.0411
(ii) above 4kW and up to and including 24kW	1.1040	1.0157
(iii) above 24kW and up to and including 72kW	0.9440	0.7552
(iv) above 72kW and up to and including 1MW	0.9120	0.7296
(v) above 1MW and up to and including 10MW	0.7600	0.6080
(vi) above 10MW and up to and including 30MW	0.6800	0.5440
(b) Bonus FiT rates having the following criteria (one or more) :	2013	2014
(i) use as installation in buildings or building structures	+0.2392	+0.2201
(ii) use as building materials	+0.2300	+0.2116
(iii) use of locally manufactured or assembled solar PV modules	+0.0300	+0.0300
(iv) use of locally manufactured or assembled solar inverters	+0.0100	+0.0100

Malaysia's Solar PV Feed-in Tariffs. *Source: SEDA*

Figure 1.3: Feed-In Tariff rates for solar PV on 2013 and 2014 [10].

1.2 Problem Statement

These days, the utilization of sun powered energy has increased. Still, not all individuals can possess this sunlight based PV framework because of its exorbitant establishment cost. The establishment of sunlight based PV framework is very costly toward the start. However, in the event that considering the benefit offered by Malaysia Feed-In Tariff program in the long term, the arrival must be ideal to the clients. According to thestar.com on 24 February 2014, the installation cost for complete system of 4kWp solar PV system costs around RM 40,000 compared to 50,000 to 60,000 on the year before 2014[11].

For a complete PV system, 60% from the total cost goes to the panel and around 15% to 20% goes to the inverter and the rest goes to Balance of system (BOS) which includes all other components that make the system provide the desired effect. Some of the examples of BOS are cables, breakers, protection device like SPD and fuses. The panel output power is not exactly the same to the output rated power. This is because photovoltaic PV system output depends on the environmental factors such as temperature and irradiance. The best condition to have a maximum output is at the Standard Test Condition (STC) in which the cell temperature is 25˚C, irradiance is 1000 W/m^2 and the air mass is 1.5 spectrums. In Malaysia climate, six out of more than 10 hours in a day receive direct sunlight with the irradiation between 800 W/m^2 and 1000 W/m^2 [12]. This is one of the factors which led the output of the panel, not to be at its maximum level. Since the panel output is not exactly the same to the rated output power, an inverter can undersize based on the panel output power. Under-sizing the inverter will not only result in the maximum performance of the system but can also reduce the cost [13]. Hence, the sizing ratio between panel and inverter needs to be optimized in order to deliver the maximum amount of energy at the lowest possible system cost.

Nowadays, in Malaysia there is no written standard for the optimum sizing between solar panel and inverter. Therefore, this research carries out a guideline so the optimum sizing ratio between solar panel and inverter can be achieved specifically for the requirement in the tropical condition.

1.3 Objectives

- To determine the average of one year profile of the tilted irradiance and back module temperature for Malaysia (to be used as raw data for GCPV system simulation).
- To perform simulations of GCPV system using DC Simulator to determine the optimum sizing ratio.
- To determine the most optimum sizing ratio of GCPV system between panels and inverters for the practice in the tropical climate condition.

1.4 Scope

- The study focuses on the optimum sizing of CGPV system under a tropical condition.
- The data sampling size used is based on five minutes average collected from the data in Malaysia from January to December 2014.
- The inverter tested is SB 3000HF and this experiment is carried out to determine the AC power, DC power and the efficiency.
- The tested ratios between panels and inverter in this experiment are 1:0.7, 1:0.8, 1:0.9, 1:10, 1:11 and 1:12.

CHAPTER 2

LITERATURE REVIEW

2.0 Overview

In this literature review part, it consists of several subtopics that related to optimum sizing of GCPV system. This chapter provides detailed explanation which is supported by facts, data and figures to enhance understanding about this research.

2.1 GCPV System

Grid Connected Photovoltaic (GCPV) system has increasingly become a prominent part as electrical supply resources and a basic part of an electrical utility grids. A GCPV power system is a set of equipment which includes Photovoltaic (PV) module, an inverter, and component connected to the utility grid. This system becomes famous among the users since it is very easy to install essentially. It does not require regular maintenance or replacement parts as well. In principle, this system does not need the battery as it is connected to the grid which absorbs the excess of electricity generated by the photovoltaic and exports the electricity to those in need [14]. Figure 2.1 shows a typical GCPV system configuration. It consists of PV array and grid inverter before connected to the AC grid.

Basically, PV array absorbs sunlight and converts it into DC power while the grid inverter will convert DC power into AC electricity [15].

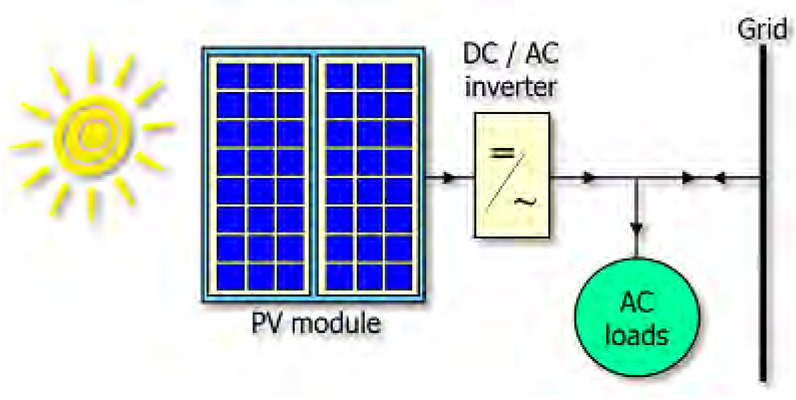


Figure 2.1: Typical Grid-Connected Photovoltaic configuration [16].

The GCPV system can be classified into two namely the Distributed System in which the energy is generated from many small scales of distributed PV system and Solar Farm. It consists of one centralised large scale of PV system [17]. Distributed system is divided into two parts, domestic or residential system and commercial system [18]. For domestic or residential system, the system is commonly constructed as a Building Integrated Photovoltaic (BIPV) system since the PV modules are installed as part of the building itself [17]. This system uses typically 1 to 5kWp and is constructed on the house's roof as shown in Figure 2.2. For indirect feed-in system, the power generated is consumed by user and the excess of it will be exported to the utility grid. However, for direct feed-in system the total energy generated by GCPV system will be exported directly to the grid at a single phase 230V, 50Hz. Next, Commercial system is a system which is typically used greater than 10kWp installed on the roof top of the commercial buildings or factories as shown in Figure 2.3. The power generated by this system will be consumed by the load in the buildings. Basically, the power generated by this system will not be exported to the grid [17].

Figure 2.2: A 4.3kWp GCPV on the rooftop of the house at Bukit Beruang[19].

Figure 2.3: A 12.2 kWp GCPV on the rooftop of the PBH Saujana Golf Resort[19].

Central System of GCPV system is the installation of large scale PV power generation as shown in Figure 2.4 in particular location. The power is distributed to end-users via the transmission network and distribution system. This system operation is similar to the traditional power generation station. The range of this system installation can be as small as 50kWp up to 60MWp and recently has been successfully installed in Europe [18]. This system is directly connected to the grid at high voltage network which is 11kV in Malaysia [17].

Figure 2.4: A 8MW GCPV on the Gading Kencana Solar Farm, Melaka [19]

Instead of Grid-Connected Photovoltaic (GCPV), there is Stand-Alone Photovoltaic (SAPV). GCPV system is connected straight to the grid so if users use more power than generated power from the solar PV, the power needed can be drawn automatically from the grid. But with SAPV system, it uses batteries to store power produced by the solar panels and the load will draw their electricity from these batteries. Basically, SAPV system is widely used in rural area which is not connected to the grid. Nowadays in urban area, GCPV system is widely used since the community residential is connected to the grid. Therefore, GCPV system is more convenience for them. Moreover, in terms of installation cost SAPV installation is more expensive compared to GCPV system installation as it is connected to the batteries[20].

2.2 Solar Panel

In 1893, a French scientist Alexandre Edmond Becquerel discovered the photovoltaic effect[21]. This research is continued by Charles Fritts and in 1883, he was able to create the first photovoltaic solar cell which was made by gold and selenium [21]. Nowadays, solar panel is widely used in a variety application. Solar panel functions to collect sunlight and convert it into the DC power. Solar panel is made up from individual solar cell which provides negative and positive charge such as silicon and boron respectively. When the photons strike the solar panel as shown in Figure 2.5, it will produce energy which enables the electrons to be eliminated from their atomic orbits and discharge into electric field produced by the solar cells which will drag these free electrons into a directional current. This process is called photovoltaic effect in which the sunlight is converted into electricity [22].

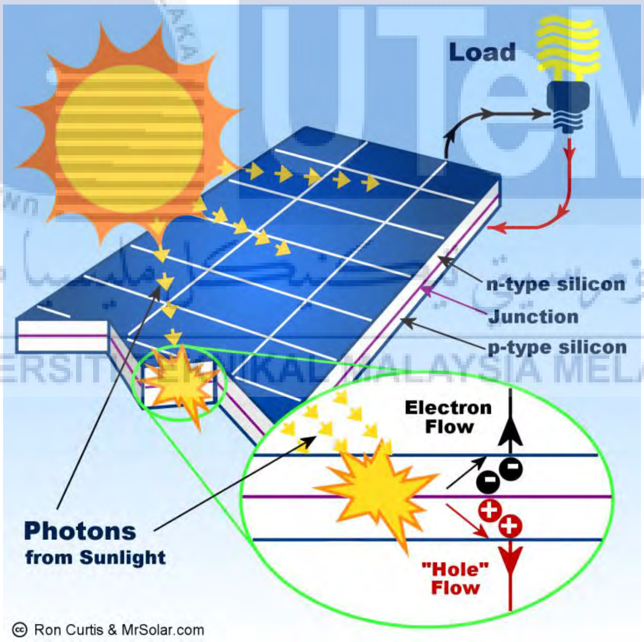


Figure 2.5: The process of Photovoltaic Effect [22].

The Photovoltaic (PV) module is made up by cells that compose the module itself. Before installing the solar panel, it is important to understand the types of solar panel technology offered. There are various types of solar panel and each of them has their own benefit to be considered depending on the users' need. There are four types of cell which are Monocrystalline, Polycrystalline, thin-film and Hybrid panel (HIT) [23].

Thin-Film technology is called as Thin-film since it uses a thinner level of photovoltaic material which is 10nm thick compared to other type of solar cell that use 200nm to 300nm thicker. In a hot temperature, thin film performs the best compared to other type of solar cell. Unfortunately, it has a very low efficiency and some of its material has demonstrated degradation of performance after some time and balanced out efficiencies can be 15 % to 35% lower than initial rates [24]. This technology is not suitable to be used in limited spaces. This is because it needs double spaces to achieve the same output with crystalline panel.

Next is Polycrystalline technology. Polycrystalline itself refers to “many crystal” of silicon in which it is designed, bluish in colour. This technology uses silicon material but for now the fragments of silicon are melted together to form the wafers for the solar panel[25]. This technology has less efficiency compared to Monocrystalline. This is because it produces more power in hot weather which usually out of its cell efficiency. In term of installation cost, this technology is less expensive compared to Monocrystalline. Since this solar cell is slightly less efficient than monocrystalline cells, it needs more spaces to produce the same output capacity [23].

Monocrystalline is the most seasoned solar cell technology among others but until today this technology is still used due to their high efficiency solar cell. Monocrystalline refers to “a single crystal” of silicon and it is designed, black in colour. Silicon is used instead of other materials because of its ability to achieve high degree of purity. In terms of efficiency, Monocrystalline has the highest efficiency compared to Polycrystalline and Thin-film according to standard operating conditions. This type of solar panel is suitable to install at limited space as users can maximize the output power in it[23].

Last but not least is the Hybrid technology, like Sanyo HIT cell. HIT refers to Heterojunction with Intrinsic Thin Layer, is a combination of crystalline and thin film technologies. This combination of two technologies results in the increasing efficiency of the solar cell. Today, this panel is the most expensive solar panel with the highest panel efficiency. In high temperature, this solar panel will produce 10% or more electricity (kWh) compared to other types of solar panel with the same temperature [26].

Table 2.1 below shows the comparison between four types of solar panel in terms of their brand, capacity, efficiency, temperature coefficient and size. Based on the table below, there are three types of modules which are HIT, Monocrystalline and

Polycrystalline and Thin-film technology. The capacity used to compare all these types of module is 325W for Monocrystalline, Polycrystalline and HIT technology and 120W for thin-film technology. In order to have thin-film at large capacity, the number of 120W panel must be double or triple. Hence, thin film will generate approximately 240W to 360W of maximum power. In terms of module efficiency, HIT technology has the highest efficiency of 19.4%, followed by monocrystalline and polycrystalline technology at 16.7% and the last one is Thin-film technology which has 9.8% of efficiency. By comparing all these technologies, it seems like HIT solar panel produce less losses as it has the highest temperature coefficient compared to other brands. In terms of panel size, HIT solar panel has the smallest dimension, followed by thin-film solar panel and lastly monocrystalline and polycrystalline solar panel.

In conclusion, HIT solar panel offers more advantages compared to other types of solar panel. HIT solar panel is the most expensive solar panel compared to others and it offers the highest efficiency as well. It can produce maximum power with smaller size of panel. Hence, this panel is suitable to be used at the limited space since it can generate maximum power in it. Also, it has the lowest power losses compared to others. The power losses of the panel can be calculated as shown below:

For example solar panel operated at 35 ºC

Temperature at STC is 25 ºC

Therefore, 5 C 25 C 10 C

Then, power loss for

IT: 10 C 0.2 2.

Therefore, panel losses = 2.9% × 325W = 9.425W

ax imum power produced by panel: 25W . 25W 15.5 W

Figure 2.6 below shows four types of solar panel technology. Figure 2.6 (a) (b) (c) (d) shows the HIT solar panel by Panasonic, Monocrystalline, and Polycrystalline by Yingli and Thin-Film technology by Kaneka respectively.

Table 2.1: Comparison between four types of solar panel with different criteria

Brand	Capacity	Module type	Module efficiency	Temperature coefficient	Panel size
Kaneka U-EA120	120W	Thin-Film	9.8%	-0.35% / ºC	1210×1008 ×40 mm
Yingli YLG 72 CELL	325W	Polycrystalline	16.7%	-0.42% / ºC	1960×990× 40 mm
Canadian Solar	325W	Monocrystalline	16.94%	-0.41% / ºC	1954×982× 40 mm
Panasonic VBHN325 SA 16	325W	HIT	19.4%	-0.29% /ºC	1590×1053 ×35 mm

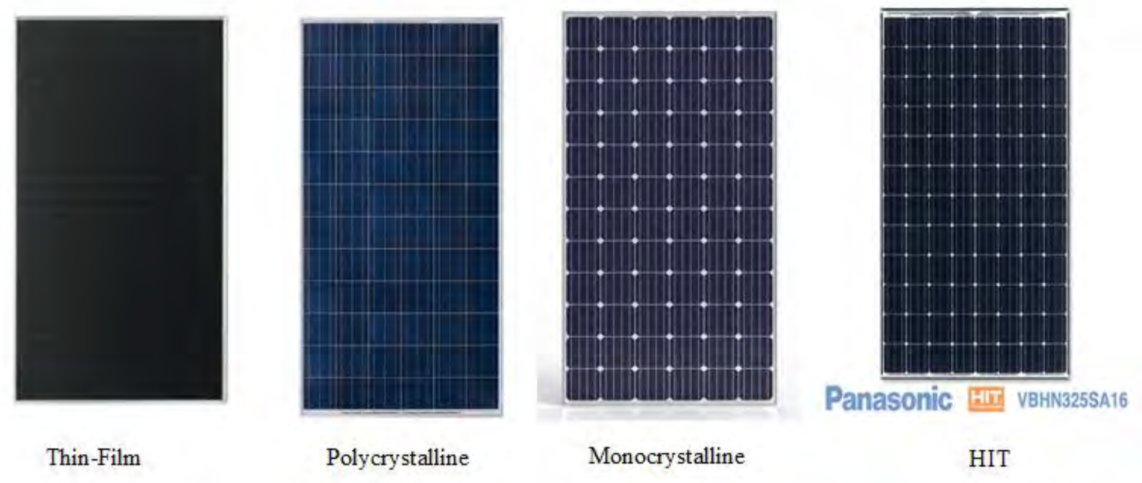


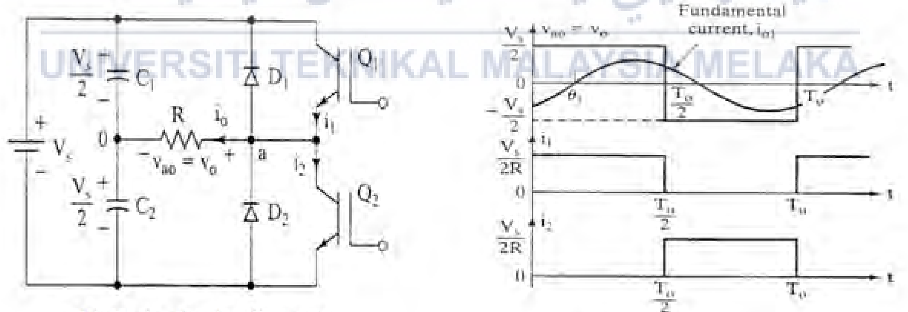
Figure 2.6: Solar Panel (a) HIT (b) Monocrystalline (c) Polycrystalline (d) Thin-Film[27][28][29]

2.3 Solar Inverter

Inverters are known as dc to ac converter. The function of inverter is to convert dc input voltage to a symmetric ac output voltage at desired magnitude and frequency. Inverters are widely used in industrial application such as variable-speed ac motor drives, induction heating, standby power supply and so on. The input sources may come from battery, fuel cell, solar or other dc source. Basically inverter can be classified into two types namely single-phase inverter and three-phase inverter [30].

Figure 2.7 (a) shows the basic principle of single phase inverter. The inverter circuit consists of two choppers and three DC source wires. When transistor Q1 is switch on at $\frac{T_o}{2}$, the instantaneous voltage across the load V_o is $V_S/2$ but when transistor Q2 is switch on at $\frac{T_o}{2}$, the instantaneous voltage across the load is $-V_S/2$. Figure 2.7 (b) shows the waveform with resistive load. Based on the output voltage in the, the rms value of output voltage is [30];

$$V_o = \left(\frac{2}{T_o}\int_0^{\frac{T_o}{2}} \frac{V_S^2}{4}\,dt\right)^{1/2} = \frac{V_S}{2}(2.1) \qquad (2.1)$$



(b) Basic circuit of inverter (a) Waveforms with resistive load

Figure 2.7: Single-phase half bridge inverter [30].

Inverter plays an important role in solar photovoltaic system. Generally, the power from the Photovoltaic panel is in DC power but most of electrical loads operate in AC. Therefore, the power generated by the solar panel needs to be converted first before supplying it to the active loads. Before choosing an inverter, the primary features that need to be considered are the type of inverter, AC output capacity, DC input voltage range, ambient temperature, efficiency and MPPT range. There are three types of inverter which are mostly used and they are Low-Frequency Inverter, High-Frequency Inverter and Transformerless inverter [31].

Low-frequency inverter offers the advantage in peak power capacity and reliability. Indeed, low-frequency inverter can operate at pinnacle power level up to 30% of their nominal power in several seconds. In terms of reliability, low-frequency inverter operates by utilizing powerful transformer contrast with different sorts of inverter. This inverter is suitable to be used for powerful appliances such as washing machines, air conditioners, refrigerators, and microwaves. Upgraded peak performance capacity and enhanced reliability of this inverter cause them more costly compared to other types of inverter [32].

High-frequency inverter technology joins the advantages from the past innovation. This technology has high level of efficiency by decreasing power losses of the transformer. It does also need more complex circuitry and is lighter compared to low-frequency inverter because of the usage of smaller transformer. This type of inverter provides safety through galvanic isolation amongst AC and DC side [33]. If there is any leakage current at the PV side, the current floats and will not spill to the neutral point through ground despite the fact that someone touches the panel. Therefore, it is safe to be used [17].

Transformerless inverter refers to the technology that generates power without using any transformer between AC side and DC side. These TL inverters utilize a computerized multi-step process and electronic segments to change over DC to high frequency AC output. Since this technology does not use transformer, this inverter becomes lighter, smaller in size, compact and relatively inexpensive [34]. Some of the major problems occur while using this type of inverter is that there is no electrical isolation between the DC and AC sides. When leakage current occurs at PV modules side, the current might flow through human body as a return path to the neutral point [17].

Table 2.2 shows the comparison of three topologies of inverter. These three topologies are Low-frequency inverter, High-frequency inverter and Transformerless inverter. The comparison uses 3000W of input capacity of inverter. For efficiency, transformerless inverter has the highest efficiency of 97.3%, followed by high-frequency inverter with 96.3% of efficiency and the last one is low-frequency inverter with 95% of efficiency. In terms of weight, transformerless inverter is the lightest compare to high and low frequency inverter. This is because transformerless inverter does not use the transformer and it uses computerized multi-step process and electronic segments to change over DC to high frequency AC output. Lastly, in terms of cost transformerless has the highest cost compared to high and low frequency inverter. Even though it is highly cost, it offers high efficiency of inverter which is not available at other types of inverter.

Figure 2.8 below shows three types of inverter topology. Figure 2.8 (a) (b) (c) shows the SMA SB3000 (Low-frequency transformer), SMA SB3000 HF (High frequency transformer) and ABB UNO-3.0-TL-OUTD (transformerless) respectively.

Table 2.2: Comparison between three different topology of solar Inverter with different criteria

Brand	Capacity	Topology	Inverter efficiency	Weight	Cost
SMA SB3000	3200W	Low-Frequency Transformer	95%	32kg	±RM5,698
SMA SB3000HF	3150W	High-Frequency Transformer	96.3%	17kg	±RM7,300
ABB UNO-3.0-TL-OUTD	3200W	Transformerless	97.3%	12kg	±RM7,400

Figure 2.8: Solar Inverter (a) SMA SB3000 (b) SMA SB3000 HF (c) ABB UNO-3.0-TL-OUTD[35][36]

2.4 Balance of System (BOS)

A solar photovoltaic Balance-of-system (BOS) includes all the components and the equipment in the photovoltaic system except for solar panel. BOS components are very sensitive and the sustainability of grid-connected photovoltaic system depends on the consistency of BOS components. BOS components include the inverter, DC and AC breakers, DC cable including string array and inter-array cables, AC cables, Ground Wire, Array Junction Box (DC combiner box), string over-current protection likes DC fuses or DC miniature circuit breaker (DC MCB) and Mounting structure [17].

Figure 2.9 shows the typical BOS components required for use in GCPV system. Basically, BOS components in grid-connected photovoltaic system include mounting structure for PV arrays or modules, cables, breakers, protection devices and Inverters.

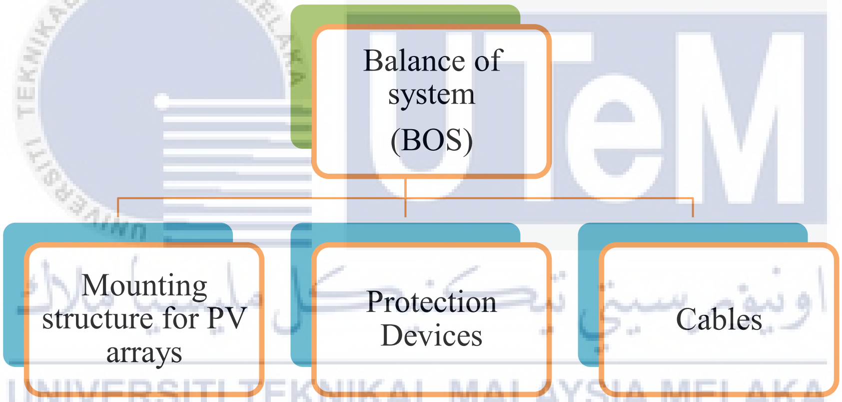


Figure 2.9: Main parts of Balance of System

2.4.1 Mounting Structure

Mounting structure is a special structure which is designed to hold the PV array or modules. Mounting structure should be designed strong enough to support the weight and strong wind loading. In GCPV system, almost all PV arrays are installed on the rooftop. Basically, there are three types of structure which are building integrated (BIPV), retrofitting, and free standing.

In BIPV system, the PV array is installed as the part of a building structure itself in which the roof tiles are replaced by PV array as shown in Figure 2.10. By implementing this type installation in Malaysia, there is one common problem that always occurs is water leakage. In order to overcome this problem, an exceptional and sturdy holding material must be utilized to fill up the gap between the arrays to prevent water leakage [17].

Figure 2.10: Building Integrated Structure [37].

For retrofitting structure, the PV array is installed on the top of existing roof tiles using a special bracket that hold the arrays as shown in Figure 2.11. The PV array must be installed at least 20cm from the roof to allow effective air ventilation under the array. A suitably-size gap between PV array and roof element may reduce the cell temperature and increase the power produced by the array. Sometimes, this installation covers the arrays at both sides to prevent water leakage however this might increase the cell temperature. As the cell temperature increase, the power produced by module will decrease [17].

Figure 2.11: Retrofitting structure [38].

Figure 2.12 shows the Free-standing structure mounted on the ground. Free-standing structure type is an independent solar panel that can be installed on the rooftop if the roof is concrete type or mounted on the ground. These types of structure need to be installed properly by using a strong material to support weight, storm or wind [39]. This type of structure has the higher power generated than retrofitted and BIPV type since it provides enough air ventilation under the PV array that consequently reduces the temperature [17]. Besides that, this type also can produce output efficiently since it can be easily adjusted according to the sun's rays.

Figure 2.12: Free-standing structure[39].

2.4.2 Cables

Solar cable is used in all photovoltaic system to connect solar module and AC/DC inverter. In GCPV system, cables is divided into three parts which is DC cables, AC cables and earthing cables. The cable installation must be sized correctly in order to prevent voltage drop and to ensure the cables operates safely [17].

Basically, DC cables of GCPV system required the following criteria; string cables will connect the PV modules in series and then to the array junction box, secondly is the array cable, where it is connecting from the array junction box to the DC main switch and lastly, DC inverter cables where is connected from the array DC main switch to the inverter. Normally the manufacturers supply their module complete with the cable and plug connected to the junction box on the back of the module. However, the cable and the plugs can be purchased individually [17]. Figure 2.13 shows the solar module completed with charge controller, solar cable adapter, mounting brackets and MC4 connectors.

Figure 2.13: Solar module completed with accessories [40].

AC cable is used to connect inverter to kWh meter; onto the AC main switch and then grid connection. Normally, the voltage produced by the inverter is typically 230V AC. Therefore, the cable required will be the same as the general building cabling. For the large system, the inverter can be in three-phase system which produces 400V AC output. For single-phase inverters the cable used will be three cores which is life (L), neutral (N) and earth (E) while for three-phase inverters it will be used five cores that is (Red, Yellow, Blue, neutral and earth). Earthing cables is the standard cable used in the wiring of building. Normally, these cables are installed from SPD's to the earthing system of the building. Based on the MS1837, the cable used for main PV array to the earth should be a minimum of $10mm^2$ [17].

2.4.3 Switches, Circuit Breaker and Fuses

Protection devices like switch, circuit breaker and fuse commonly used in dc section of PV systems and it must be rated for dc used. These components also is used in ac side and need to be rated for ac used. Switches consist of both of current and voltage rating. When it is used to control a motor, it must be rated to handle the horse power of the motor at the operating voltage of the motor.

The circuit breakers should be sized according to National Electrical Code (NEC) requirements. Basically, the breaker sizes must be larger than the maximum current rating. Larger wire sizes may be fused at their rated ampacities for example I_{max}.

For motors, the installation of fuses or circuit breaker may be necessary with ratings that exceed the circuit ampacity in order to accommodate the starting current of the motor. The motor must has the form of overload protection which will cut off the motor when the motor current exceeds approximately 125% of its rated running current, depending to the size and type of the motor.

2.4.4 Protection Devices

All circuit protection designed to protect the cable that is connected to it from overheating caused by overloads or short circuits. The size of the circuit protection must follow the CCC of the cable and the protection must be rated smaller than the rated value of the cable. PV module is known as the current limited devices, therefore it will not produce currents greater than the short circuit rating. String cables do not need to be protected from the over current from the modules in that string because it is not possible. If fault occur within a string, the current from the other strings could then feed into the faulty string, therefore protection is needed in each string. Based on the MS1837, the string cable protection can be determined by [17];

$$1.5 \times I_{sc\_mod\_stc} \leq I_{trip} \leq 2 \times I_{sc\_mod\_stc} \quad (2.2)$$

Where;

$$I_{trip} = rated\ trip\ current\ of\ over\ current\ protection\ (A)$$

$$I_{sc_{mod_{stc}}} = short\ circuit\ current\ module\ at\ stc\ (A)$$

For array cable protection, it has been sized to carry 1.3 rimes the array current. Therefore, no over current array protection is required. By-pass diode is used to provide the solar module become overheated. These components must be included in system design if it is not installed by manufacturer. As minimum, the diodes should be installed at each module, but if possible across each sub-string within the module. Based on MS1837, the rating of By-pass diode can be determined by [17];

$$V_{diode\_bypass} \geq 2 \times V_{oc\_module\_stc} \quad (2.3)$$

$$I_{diode\_bypass} \geq 1.3 \times I_{sc\_module\_stc} \quad (2.4)$$

Where;

$$V_{diode\_bypass} = voltage\ rating\ of\ bypass\ diode\ (V)$$

$$I_{diode_{bypass}} = current\ rating\ od\ bypass\ diode\ (A)$$

Next, Lightning protection is a common occurrence in Malaysia GCPV system should be protected. The requirements for lightning protection, surge protection, over voltage and earthing shall be in accordance to MS1837. Based on MS1837, they recommend that the SPD protection need to be installed between each of the array DC cables and earth and in between the inverter output cables and earth [17]. A surge Protective device (SPD) is the device that is used to protect the valuable electrical and electronic equipment against transient, originating from the lightning and also from switching sources [41]. Figure 2.14 (a) and (b) shows the DC and AC SPD. The green indicator indicates that the SPDs are in good condition.

Figure 2.14: Surge Protection Device (a) DC and (b) AC[42]

2.5 How GCPV System Works

The IV curve graphically represents the relationship between current and voltage of the solar module. Increasing the value of module's voltage will increase the cell temperature. Figure 2.15 shows the typical photovoltaic module's IV curve varying temperature. The curve shows the value of voltage become decrease as the temperature increase. The movement in the curve affected the moving of MPP along with the voltage and the temperature changes directly affect the output voltage, which in turn directly affects the power outputs. The amount of current will increase when the temperature increase but in small value that make it no need to consider during the design process [17].

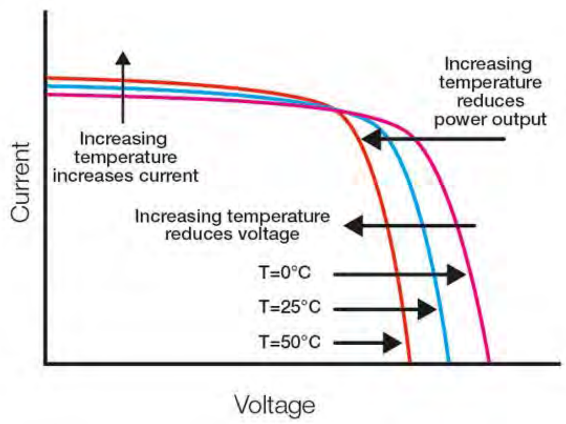


Figure 2.15: IV curves varying temperatures [43]

The amount of irradiance that strikes a photovoltaic module directly affects the current of the module. Figure 2.16 shows the IV curve varies with changes in irradiance. It can be seen that, the curve move vertically much more than move horizontally. This is due to the voltage is not affecting much towards changes in irradiance. The current is affected dramatically along with MPP when there is a change in irradiance [17].

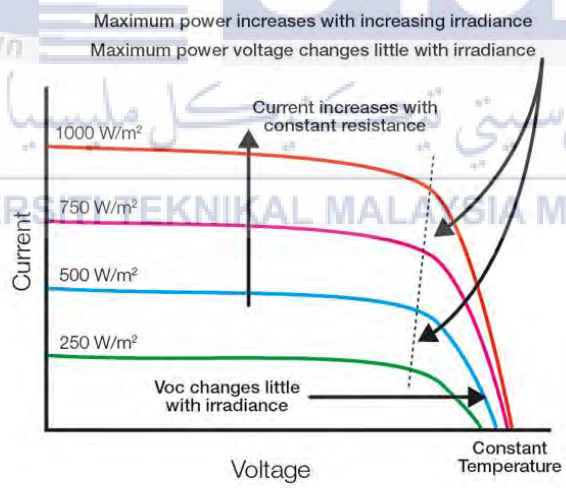


Figure 2.16: IV curves varying levels of irradiance[43]

Figure 2.17 shows the typical Grid Connected Photovoltaic system configuration. This system consists of the solar panels, inverter, electrical panel such as a breaker box, utility meter and utility grid [44]. When the irradiance strikes the solar panel, the semiconductor material absorb as much as sunlight as possible and converted it into DC electricity. After that, the DC electricity flows through the DC cable to the inverter. Inverter functioned to convert DC electricity to AC electricity but in this system it converts electricity to grid compatible AC which is equal to 50Hz and 240V. This inverter is known as synchronous inverter since it produces electricity in sync with the grid. Next, the 240V AC electricity flows to the electrical panel which is breaker box. This breaker box is connecting to the grid and all the loads like home appliances. From this breaker box, the AC electricity is supplied to all the active loads. If there are the excess of electricity generated by solar system, it will automatically export to the grid. However, if the electricity is not sufficient for all the active loads, the grid will automatically supply the electricity to the active load[45] .

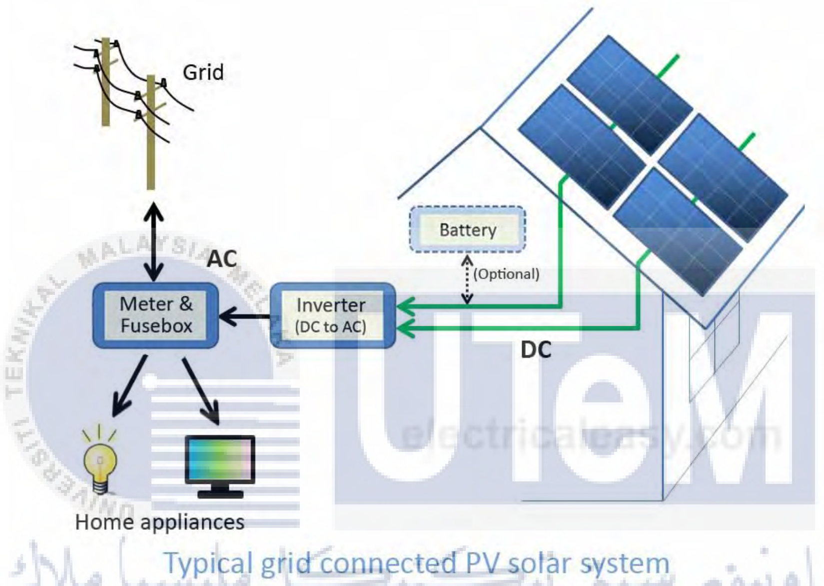


Figure 2.17: Typical Grid-Connected Photovoltaic configuration [44]

2.6 Summary

This chapter include a review on the relevant background readings and resources is carried out and presented. A range of topics are discussed from the general Grid-Connected Photovoltaic (GCPV) system and the components used in this system. The information gathered has been used to not only gain and understanding on the ‘ ow System Works’ but it is used to create a proposed solution to be implemented and simulated in the next sections of the report.

CHAPTER 3

METHODOLOGY

3.0 Overview

This chapter provides detailed explanation about the flow and the method that has been used in order to achieve the project's objective. This chapter consists of Gantt chart to show the timeline of the project and the flow chart of the whole system. The detailed explanation has been provided and explained clearly in this chapter.

3.1 Gantt Chart

Figure 3.1 shows the Gantt chart for timeline of the project. This project consists of five chapters. The project is started with the literature review research and it takes the whole semester to complete the study. This project is divided into two sections, PSM 1 and PSM 2. In PSM 1, the project focuses on data collecting and data analysing while in PSM 2, this project will continue with testing process and analysing an output.

Table 3.1: Gantt Chart

Year	2016																2017																							
	PSM 1																PSM 2																							
Month	Sept				Oct				Nov				Dec				Jan				Feb				Mar				April				May				June			
Week / Project Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Literature review research																																								
Data collection																																								
Data processing																																								
Thesis writing																																								
Slide preparation																																								
PSM 1 Seminar																																								
Data testing																																								
Analysis on output testing																																								
PSM 2 Seminar																																								
Submission of full complete report																																								

3.2 Flow Chart of the System

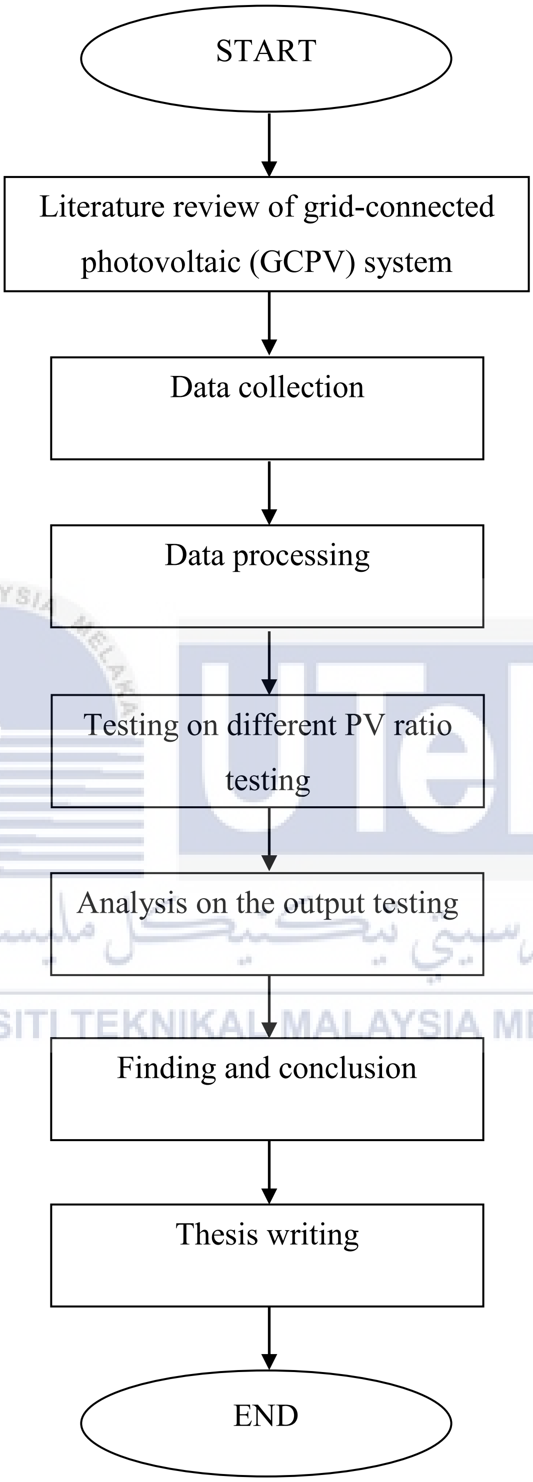


Figure 3.1: Flowchart of whole system

3.2.1 Literature Review of the Project

The literature review of the project starts with the basic of the solar energy. This research focuses on the study of Grid-connected Photovoltaic (GCPV) system. Literature review part includes some important subtopics which are Solar Panel, Solar Inverter, Balance of System (BOS) and how this system works. The characteristic of every subtopic is being studied in depth to enhance the knowledge about this project.

The main references used to gather all the information and knowledge about this project come from library research, Journals, books and online database.

3.2.2 Data Collection

Data collection which is used for this research is irradiance and back panel temperature. The irradiance data is measured by using Pyranometer CM 11 which is designed to measure the irradiance (radiant-flux, Watt/m^2) on plane surface, which results from the direct solar radiation and from the diffuse radiation incident from the hemisphere above. While for back panel temperature, the CS220 surface-mount thermocouple is used to measure the temperature on the back panel of a solar panel. Table 3.2 and Table 3.3 shows the technical data for the pyranometer CM 11 and CS220 surface-mount thermocouple which is used to measure irradiance and back panel temperature in this research respectively.

Table 3.2: Technical data of Pyranometer CM 11

Technical Data	
Spectral range	310-2800 nm (50% points) 340-2200 nm (95% points)
Sensitivity	Between 4 and 6 $\mu V/Wm^2$
Response time	< 15s (95% response) < 24s (99% response)
Temperature dependence of sensitivity	< 1% (-10^oC to $+40^oC$)
Directional error	< 10 W/m^2 (beam 1000 W/m^2)
Tilt error	< 0.25% (beam 1000 W/m^2)
Operating temperature	-40^oC to $+80^oC$
irradiance	0 – 1400 W/m^2 (max 4000 W/m^2)

Table 3.3: Technical data of the CS220 surface-mount thermocouple

Technical Data	
Type	Chromel-Constantan
Typical output	60 $\mu V/^oC$
Maximum temperature	Adheres for up to 260^oC
Thermocouple Tolerances (reference junction at 0^oC)	Special limits of 1.0^oC or 0.4% (0^o to 900^oC)

These irradiance and back panel temperature data will be used to obtain the value of P_{DC}, P_{AC}, I_{DC}, I_{AC}, V_{DC}, V_{AC} and efficiency during testing process. Both data have been collected from weather station monitoring system at SGPV laboratory. Figure 3.2 to Figure 3.5 shows the procedure on how to get both irradiance and back module temperature module. Figure 3.2 shows the Real Time Display (RTD) which is the main display of the system. In RTD, one can view the real time next data derived by several of sensors.

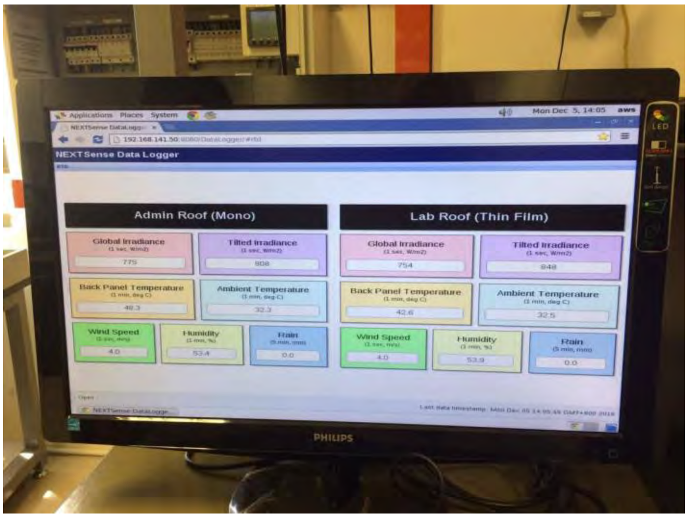


Figure 3.2: Real Time Display (RTD)

By selecting "Real-Time Display Query" on the left side on the Real Time Display (RTD) as shown in Figure 3.3. Query module in Figure 3.4 is provided to view and downloaded the data after query the data.

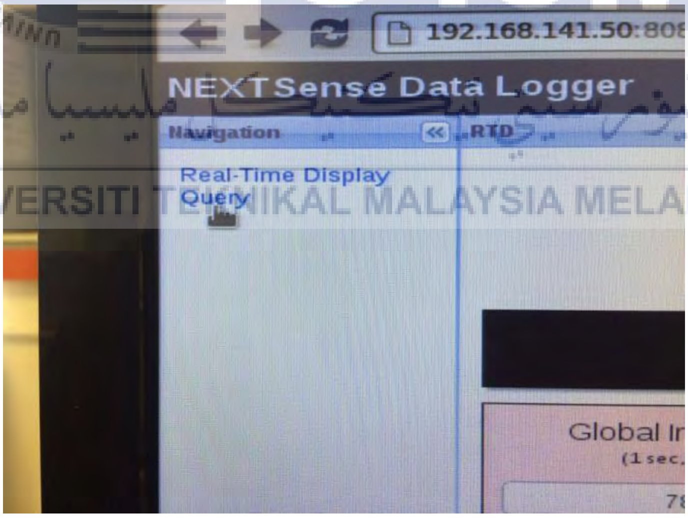


Figure 3.3: Navigation to Query display

The data can be query into four options which are; every second data, every minute's data, hourly data and daily data. For this research, the data has been query in every minute. The step to query this data is;

1. The station ID 1 was selected
2. Type of Query was set to 5minutes data
3. The begin date was set to 01-01-2014
4. The end date was set to 31-12-2014
5. Fetch button was clicked.

After that, the query result will be displayed on the Panel.as shown in Figure 3.5. The download button was clicked to download the data in csv file.

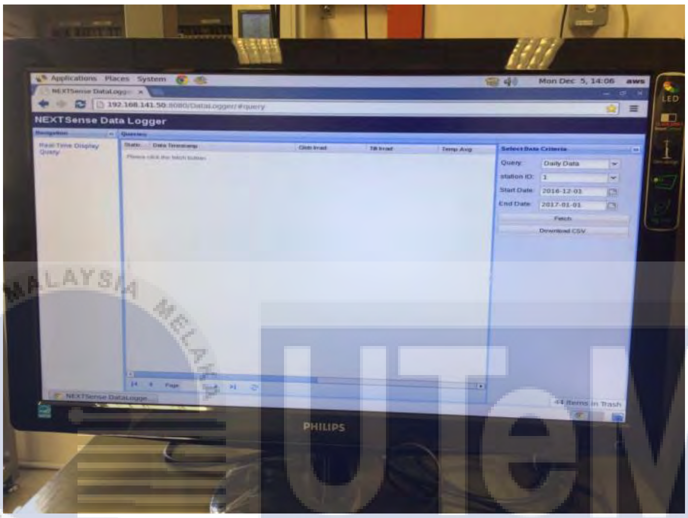


Figure 3.4: Query Display

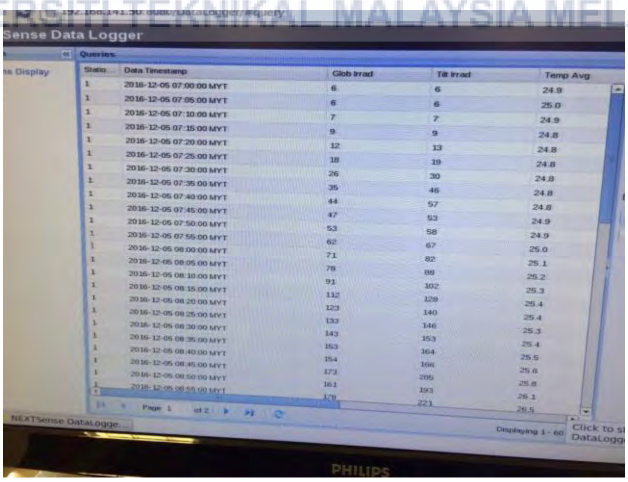


Figure 3.5: Query result

3.2.3 Data Processing

Initially the data which has been downloaded are in csv file and Figure 3.6 shows the csv data which is opened by using Microsoft Excel. This data is rearranged in order to separate each fields.

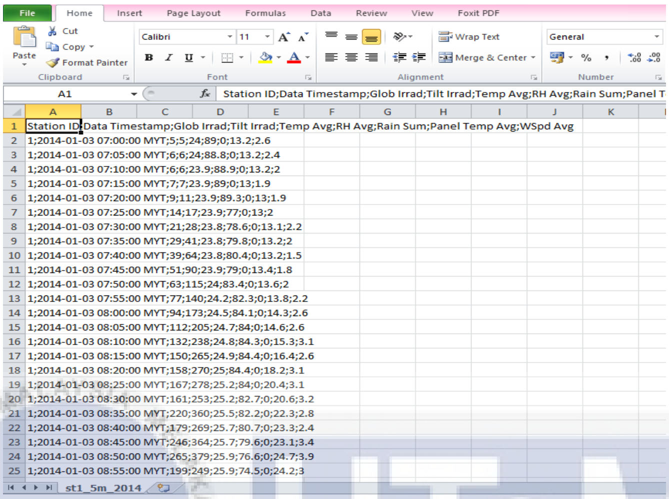


Figure 3.6: Initial data from csv file opened with Microsoft excel

Figure 3.7 to Figure 3.10 shows the step by step procedure to rearrange the data. Firstly, the 'Text to Column' tab on the toolbar is selected. After that, the window as shown in Figure .7 is displayed. The file type is changed to 'Delimited' type.

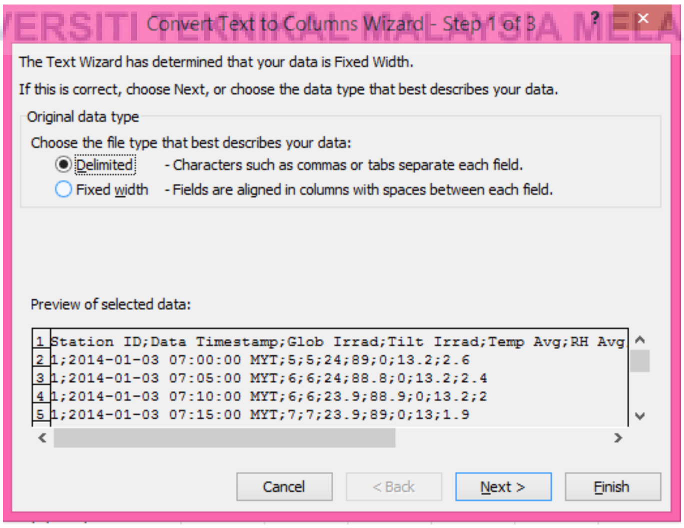


Figure 3.7: Convert Text to Column Wizard – Step 1 Window

After selecting 'Next' button on step one, the window as shown in Figure . will be displayed. The delimiters change from 'Tab' to 'Semicolon'. Figure . s hows the result where the data is rearranged in 'Tab' style.

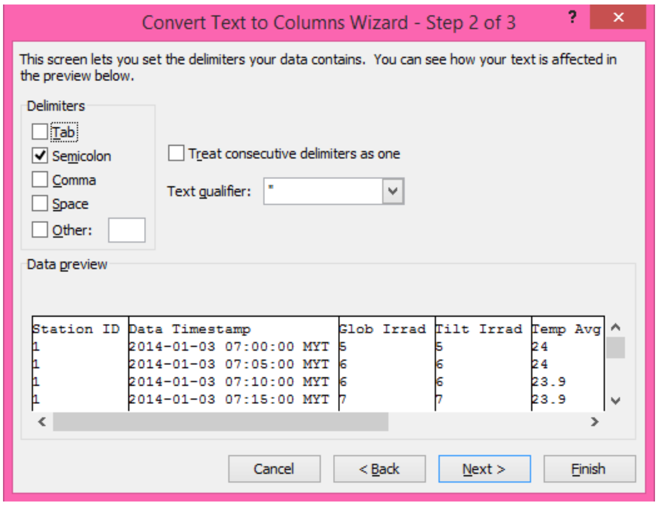


Figure 3.8: Convert Text to Column Wizard – Step 2 Window

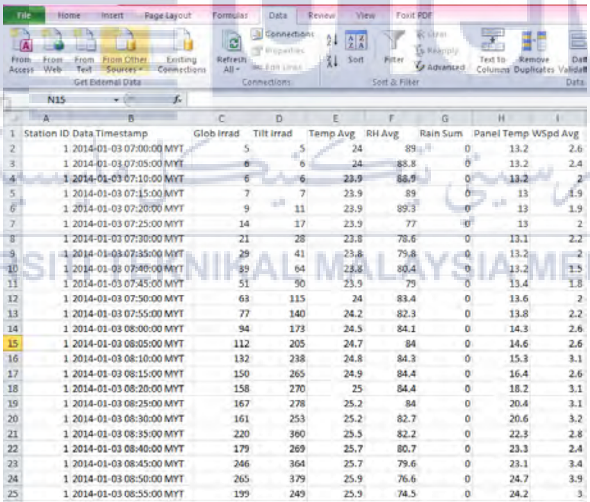


Figure . : R earranged data in 'Tab' style

After that, the one year average of irradiance and back panel temperature from 07:00 until 19:00 is calculated as shown in Figure 3.10 and Figure 3.11 respectively. Besides, the graph of one year average of irradiance and back panel temperature is plotted and discussed in chapter 4.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Time	January	February	March	April	May	June	July	August	September	October	November	December	**Average**
2	7:00	5.03	3.75	5.06	6.77	7.74	6.83	5.13	5.52	5.37	8.58	8.83	6.32	**6.24**
3	7:05	5.10	3.86	5.26	8.10	9.77	8.23	5.52	5.90	6.47	12.45	12.73	7.00	**7.53**
4	7:10	5.29	3.89	6.13	10.60	13.71	10.77	6.42	7.26	9.07	17.87	18.27	8.55	**9.82**
5	7:15	6.13	4.29	7.52	14.57	19.58	14.70	8.23	10.00	12.90	24.94	25.47	11.13	**13.29**
6	7:20	7.42	5.43	9.97	21.07	26.97	20.13	11.42	14.48	17.87	33.74	35.73	16.71	**18.41**
7	7:25	10.16	6.68	15.03	28.23	35.52	26.97	15.26	20.90	24.67	43.32	46.70	22.55	**24.67**
8	7:30	14.87	10.43	22.23	36.90	45.19	34.40	20.71	28.71	32.27	53.61	60.80	28.61	**32.39**
9	7:35	21.10	15.93	31.71	47.97	54.29	42.10	27.52	37.39	39.63	66.52	75.30	35.84	**41.27**
10	7:40	30.52	22.82	44.23	57.17	66.77	51.07	35.13	47.19	45.50	81.03	92.73	48.32	**51.87**
11	7:45	41.10	32.39	59.68	67.70	80.16	61.93	43.77	56.90	55.07	94.94	106.63	60.39	**63.39**
12	7:50	52.00	44.75	75.52	79.63	90.45	75.00	52.74	66.71	65.80	111.06	123.47	75.87	**76.08**
13	7:55	64.26	59.04	92.23	91.77	105.71	88.40	58.74	76.90	74.30	124.94	142.03	94.03	**89.36**
14	8:00	77.97	83.93	110.42	105.57	124.58	103.47	68.84	89.61	86.63	138.90	154.47	108.06	**104.37**
15	8:05	97.74	100.07	128.94	125.33	141.23	115.63	76.87	107.39	98.33	155.52	173.57	129.42	**120.84**
16	8:10	109.71	116.71	149.03	142.00	160.55	128.93	86.52	117.71	106.40	167.84	185.27	148.10	**134.90**
17	8:15	116.65	133.79	168.13	157.63	187.58	137.97	97.61	126.90	117.53	183.06	207.00	160.94	**149.57**
18	8:20	127.45	147.57	191.10	171.17	202.74	146.50	102.00	141.87	131.57	201.55	231.87	176.23	**164.30**
19	8:25	151.65	161.89	213.52	185.20	212.42	162.63	115.84	158.61	144.60	216.71	243.50	209.90	**181.37**
20	8:30	170.19	179.96	238.32	207.80	221.39	177.63	123.68	176.45	151.47	238.10	263.17	235.42	**198.63**
21	8:35	196.68	209.43	264.19	224.90	232.84	191.83	137.19	190.94	161.30	257.58	287.00	250.84	**217.06**
22	8:40	212.55	228.43	289.77	232.80	251.29	204.30	139.23	204.71	168.83	280.23	313.97	261.26	**232.28**
23	8:45	233.77	248.21	310.87	247.13	271.48	213.43	153.55	216.52	190.57	306.39	334.83	275.61	**250.20**
24	8:50	266.94	273.89	331.97	266.20	295.03	229.77	170.97	243.32	215.17	321.13	358.07	287.65	**271.67**
25	8:55	276.58	288.39	351.35	293.37	316.71	250.20	189.61	265.77	234.87	343.52	388.50	309.45	**292.36**

Figure 3.10: One Year Average of Irradiance from 07:00 to 19:00

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	time/month	january	february	march	april	may	june	july	august	septembe	october	novembei	decembei	**AVERAGE**
2	7:00	16.42	15.91	21.14	21.71	21.91	22.67	21.85	21.11	17.63	21.73	20.70	21.49	**20.36**
3	7:05	16.40	15.85	21.11	21.71	21.94	22.71	21.81	21.11	17.64	21.75	20.72	21.50	**20.35**
4	7:10	16.35	15.85	21.08	21.73	22.01	22.74	21.80	21.10	17.65	21.83	20.76	21.50	**20.37**
5	7:15	16.35	15.83	21.10	21.76	22.11	22.76	21.80	21.15	17.71	21.93	20.87	21.53	**20.41**
6	7:20	16.34	15.86	21.12	21.85	22.20	22.82	21.82	21.23	17.79	22.05	20.99	21.61	**20.47**
7	7:25	16.38	15.88	21.16	22.01	22.32	22.95	21.88	21.29	17.91	22.16	21.15	21.71	**20.57**
8	7:30	16.45	15.93	21.24	22.16	22.49	23.10	21.96	21.44	18.06	22.33	21.29	21.80	**20.69**
9	7:35	16.60	16.00	21.35	22.33	22.68	23.34	22.14	21.56	18.22	22.50	21.46	21.92	**20.84**
10	7:40	16.79	16.10	21.52	22.55	22.89	23.51	22.32	21.77	18.39	22.73	21.65	22.03	**21.02**
11	7:45	16.96	16.20	21.76	22.73	23.14	23.77	22.54	21.98	18.54	23.00	21.82	22.18	**21.22**
12	7:50	17.15	16.30	21.97	23.02	23.42	24.08	22.78	22.25	18.76	23.35	22.02	22.35	**21.45**
13	7:55	17.42	16.46	22.16	23.34	23.74	24.46	23.08	22.53	19.05	23.88	22.33	22.52	**21.75**
14	8:00	17.69	21.73	22.50	23.67	24.20	24.87	23.41	22.80	19.29	24.31	22.73	22.69	**22.49**
15	8:05	17.94	21.98	22.98	24.04	24.74	25.32	23.73	23.18	19.62	24.83	23.34	22.97	**22.89**
16	8:10	18.22	22.29	23.51	24.55	25.33	25.79	24.05	23.63	19.95	25.42	23.93	23.44	**23.34**
17	8:15	18.51	22.66	24.14	25.12	26.13	26.25	24.40	24.05	20.34	26.14	24.54	24.08	**23.86**
18	8:20	18.85	23.17	24.75	25.80	26.96	26.82	24.74	24.55	20.78	26.92	26.06	24.72	**24.51**
19	8:25	19.46	23.72	25.34	26.45	27.74	27.45	25.08	25.15	21.27	27.68	26.66	25.52	**25.13**
20	8:30	20.06	24.28	26.00	27.26	28.58	28.23	25.56	25.79	21.79	28.42	27.34	26.46	**25.81**
21	8:35	20.71	24.91	26.78	28.13	29.41	28.95	26.07	26.52	22.39	29.20	28.07	27.21	**26.53**
22	8:40	21.37	25.54	27.61	28.80	30.25	29.66	26.44	27.29	22.93	30.08	29.05	27.88	**27.24**
23	8:45	21.94	26.18	28.33	29.47	31.15	30.37	26.87	27.95	23.62	31.04	30.16	28.53	**27.97**
24	8:50	22.63	26.91	29.01	30.16	32.08	30.98	27.49	28.81	24.46	31.87	31.28	29.07	**28.73**
25	8:55	23.28	27.59	29.71	30.98	33.13	31.64	28.37	29.81	25.30	32.67	32.35	29.72	**29.55**

Figure 3.11: One Year Average of Back Panel Temperature from 07:00 to 19:00

3.2.4 Testing

Figure 3.12 shows the setup of equipment during testing process to determine the most optimum sizing ratio between inverter and solar panel. Table 3.4 shows the image of equipment used during the testing process. This testing process uses DC Simulator (Single-

String PV-Array Simulator PVAS2) to represent the solar panel. The DC simulator is connected to the High Frequency Inverter (SB 3000HF). An inverter is connected directly to the grid (Chroma Programmable AC Source) and AC/DC 240V 11kW load bank. The value of P_{DC}, P_{AC}, I_{DC}, I_{AC}, V_{DC}, V_{AC} and efficiency is obtained and recorded from power meter. This testing process uses the one year irradiance, G data and back module temperature, T.

The testing process starts by inserting the value of irradiance and back module temperature to the DC simulator. DC simulator will convert irradiance and temperature values into current and voltage respectively, according to the setting of module technology to be used. The voltage and current produced are in DC electricity. After that, the DC electricity will flow to the inverter through DC cable. Inverter converts DC electricity into AC electricity and at the same time the power meter will display the value of input and output of power, current and voltage.

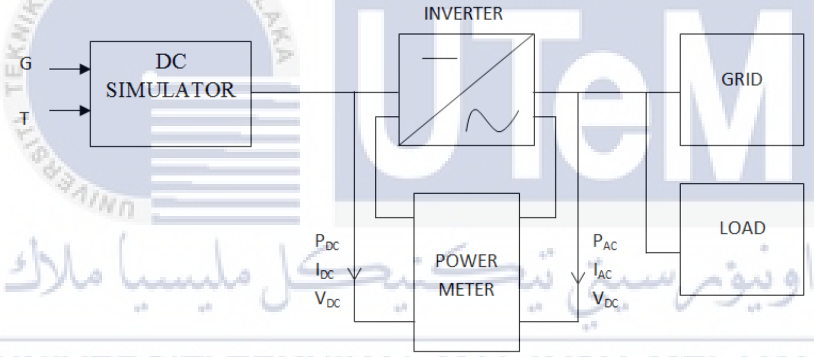


Figure 3.12: Block diagram of testing process

Table 3.4: The Equipment used during Testing Process and their Image

Equipment	Image
DC Simulator (Single-String PV-Array Simulator PVAS2)	
High Frequency Inverter (SB 3000HF)	
Grid (Chroma Programmable AC Source)	
Load (AC/DC 240V 11kW load bank)	
Power Meter	

Table 3.5 shows the ratio between the panel and inverter to be used in obtaining the optimum sizing of the panel and inverter during this experiment are as listed below.

Table 3.5: Ratio Panel to Inverter

No.	Ratio Panel to Inverter	Power Panel to inverter, (W)
1	1.0:0.7	4,095:3,150
2	1.0:0.8	3,780:3,150
3	1.0:0.9	3,465:3,150
4	1.0:1.0	3,150:3,150
5	1.0:1.1	2,835:3,150
6	1.0:1.2	2,520:3,150

3.2.5 Analysis on the Output Testing

Figure 3.13 shows one of the recorded data from the testing process. The output parameter and performance of every ratio are the same as Figure 3.13.The output data consist of 7 columns which are;

Table 3.6: Description of every Column

COLUMN	OUTPUT DATA
A	Irradiance, G
B	Output Current, I_{AC}
C	Output Voltage, V_{AC}
D	Output Power, P_{AC}
E	Input Current, I_{DC}
F	Input Voltage, V_{DC}
G	Input Power, P_{DC}
H	Efficiency

The efficiency has been calculated by using the following formula;

$$Efficiency = \frac{P_{OUT}}{P_{IN}} \tag{3.1}$$

	A	B	C	D	E	F	G	H
1	Irradiance [G]	I1rms [A]	U1rms [V]	P1 [W]	I4rms [A]	U4rms [V]	P4 [W]	Efficiency
2	422	1.04861	229.4729	196.9248	1.708344	569.5519	972.6204	0.202
3	446	4.630627	230.1072	1060.216	2.011848	544.9137	1094.219	0.969
4	464	4.883235	230.1517	1118.993	2.381851	508.1136	1203.625	0.930
5	476	5.08839	230.1873	1166.781	2.43498	509.338	1233.603	0.946
6	497	5.319355	230.2263	1220.484	2.557717	506.8814	1289.969	0.946
7	508	5.595054	230.2722	1284.116	2.698627	505.8176	1358.859	0.945
8	522	5.800863	230.3065	1331.519	2.814938	503.472	1411.115	0.944
9	526	6.001819	230.3396	1378.201	2.92526	501.9267	1462.599	0.942
10	541	6.193876	230.3729	1422.909	3.001935	505.3844	1511.54	0.941
11	562	6.343134	230.3986	1457.445	3.079744	504.9136	1549.382	0.941
12	575	6.44859	230.4164	1481.91	3.152593	502.0087	1577.178	0.940
13	577	6.568705	230.4372	1509.834	3.223267	503.0192	1616.066	0.934
14	590	6.803221	230.4764	1564.274	3.321384	505.4018	1673.346	0.935
15	591	6.960307	230.5027	1600.749	3.386804	506.5511	1710.385	0.936
16	600	7.022805	230.5133	1615.312	3.39859	509.5201	1726.375	0.936
17	604	7.129697	230.5303	1640.15	3.468311	506.8127	1752.607	0.936
18	599	7.182538	230.539	1652.503	3.501321	506.0903	1766.898	0.935
19	613	7.242349	230.5494	1666.433	3.507328	509.3863	1781.495	0.935
20	623	7.238928	230.5488	1665.513	3.504846	509.3408	1780.01	0.936
21	628	7.249541	230.5508	1667.922	3.522866	508.3024	1785.556	0.934
22	634	7.452303	230.5853	1715.068	3.656216	503.9915	1837.498	0.933
23	632	7.578466	230.6058	1744.409	3.732549	501.5257	1867.068	0.934

Figure 3.13: Recorded Data from the Testing Process

3.2.6 Finding and Conclusion

Finding and conclusion will be described in detail in chapter 4 and 5.

3.2.7 Thesis Writing

After fulfilling all the elements and procedures needed for this research, final thesis writing will be prepared to provide a clear, specific argument which will serve as guidance to the reader so they know what to expect from this thesis. This thesis combination will be prepared based on actual facts and collected field data. This thesis consists of several main elements, namely Introduction, Literature Review, Methodology, Result and Discussion, and Conclusion and Recommendation.

3.3 Summary

In this chapter, the methodology of the project is described clearly. Gantt chart is provided in this chapter to show the project timeline for two semesters. Also, flowchart of the project is provided to briefly explain the method used to obtain the result. Every step in the flowchart has been explained clearly in every subtopic in this chapter.

CHAPTER 4

RESULT AND DISCUSSION

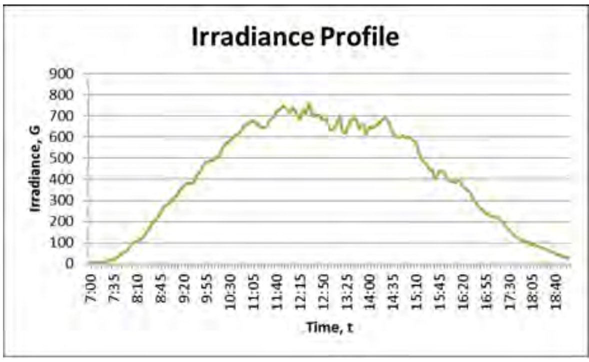
4.0 Overview

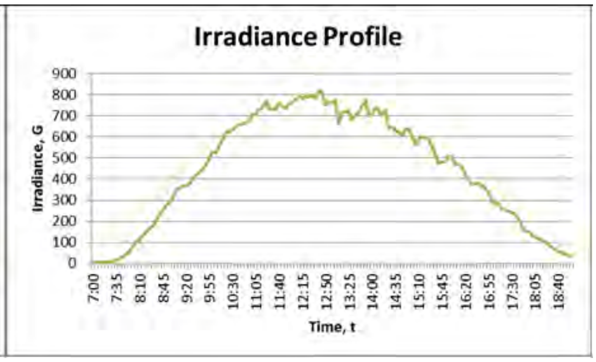
This chapter provides the preliminary result which has been discussed earlier in chapter 3. The preliminary result shows the data for irradiance and temperature in tropical condition which will be used in future testing process. This data will be used to determine the optimum sizing of GCPV system.

4.1 Irradiance and Temperature Profiling

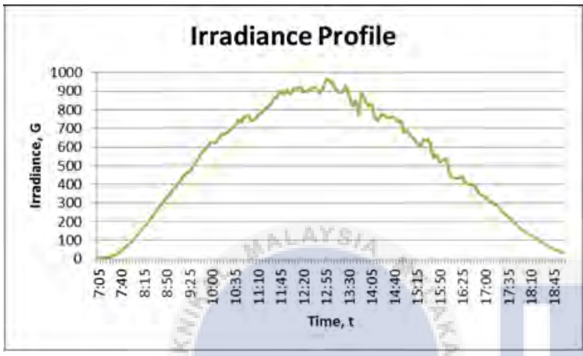
Figure 4.1(a) to (f) and Figure 4.2 (a) to (f) show the Irradiance profile from January 2014 until June 2014, and July 2014 until December 2014, respectively. Based on the figure below, the peak time to have the maximum value of irradiance is in between 10.00am to 2.00pm. Based on Figure.4.1, the highest value of irradiance can be obtained in March while the lowest irradiance recorded is in May. In March 2014, the value of irradiance is approximately 1000W/m^2. This is due to the clear skies and the sun position is in direct to the solar. However, in May 2014 the value is the lowest compared to the other 5 months value. Lower irradiance can be affected to several factors such as cloudy day, rainy day which lead to fewer amounts of sunlight strikes directly to the solar panel.

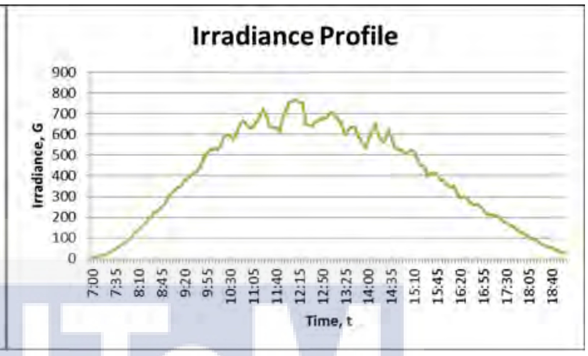
Figure 4.3 (a) to (f) and Figure 4.4 (a) to (f) show the Back panel Temperature profile. Based on the graph below, the temperature of the solar panel gives maximum reading between 11am to 2pm. The temperature of the solar panel will affect the output power. The higher the back module temperature, the lower the voltage will be. Therefore, the output power will decrease. Hence, it is important to keep the temperature of the solar panel as low as possible in order to maintain the output power at maximum and efficiency of the solar panel



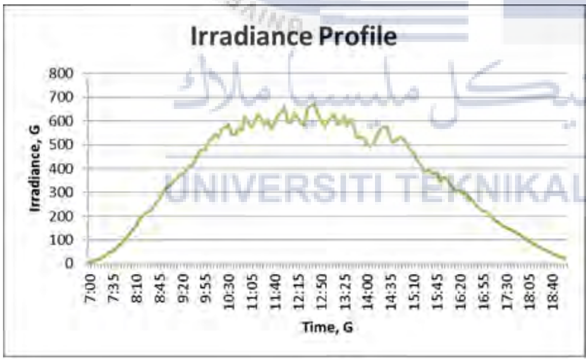


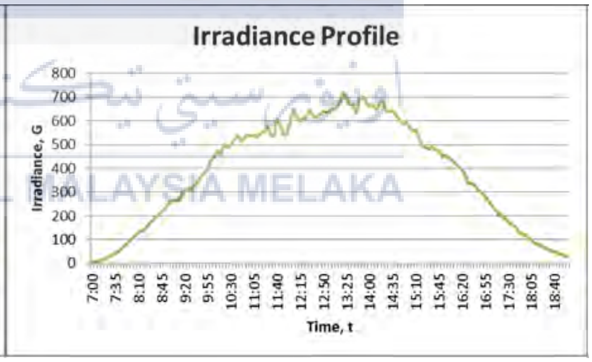
(a) (b)





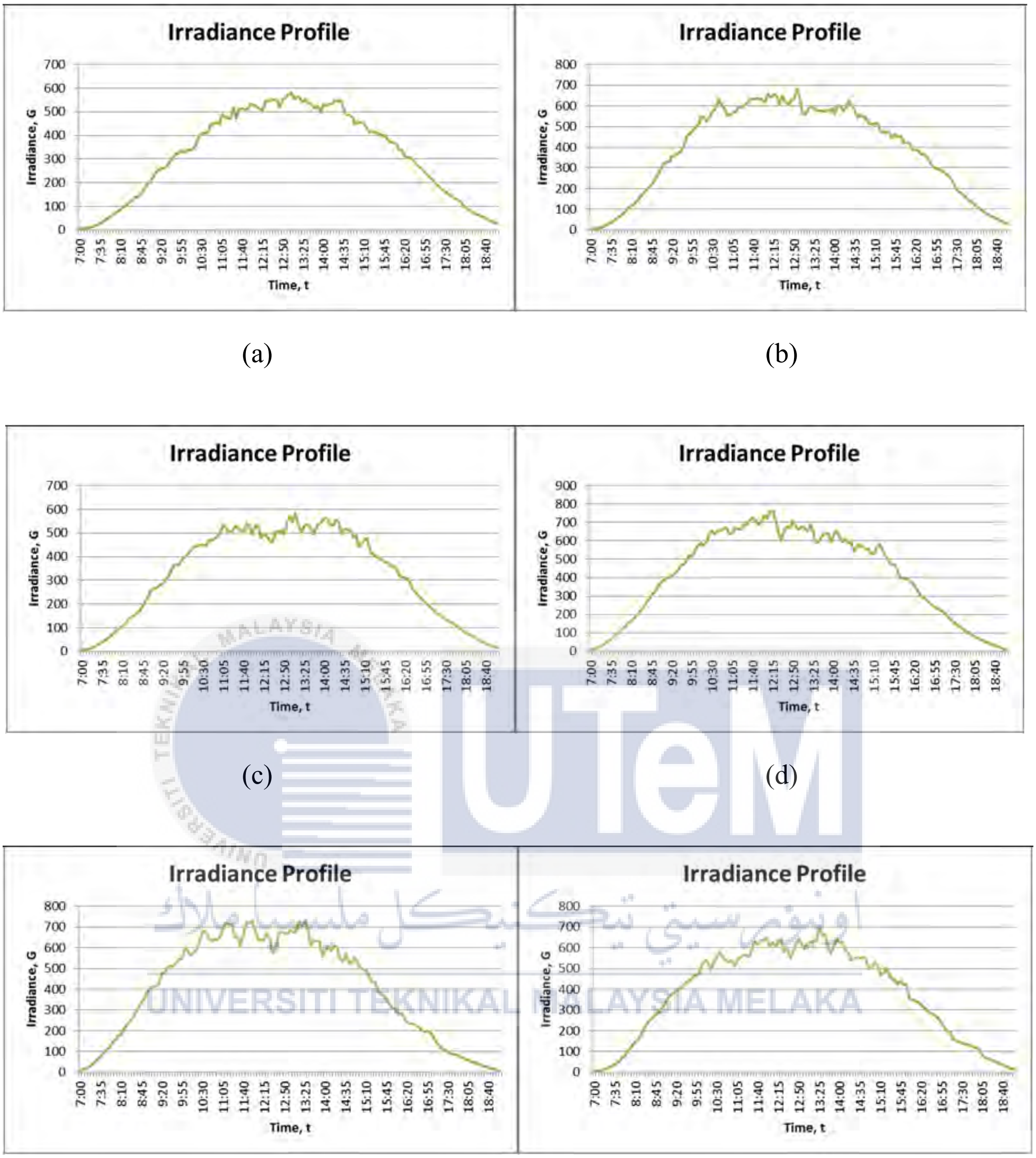
(c) (d)





(e) (f)

Figure 4.1: Irradiance profile for (a) January (b) February (c) March (d) April (e) Mei (f) June



(a) (b)

(c) (d)

(f) (g)

Figure 4.2: Irradiance profile for (a) July (b) August (c) September (d) October (e) November (f) December

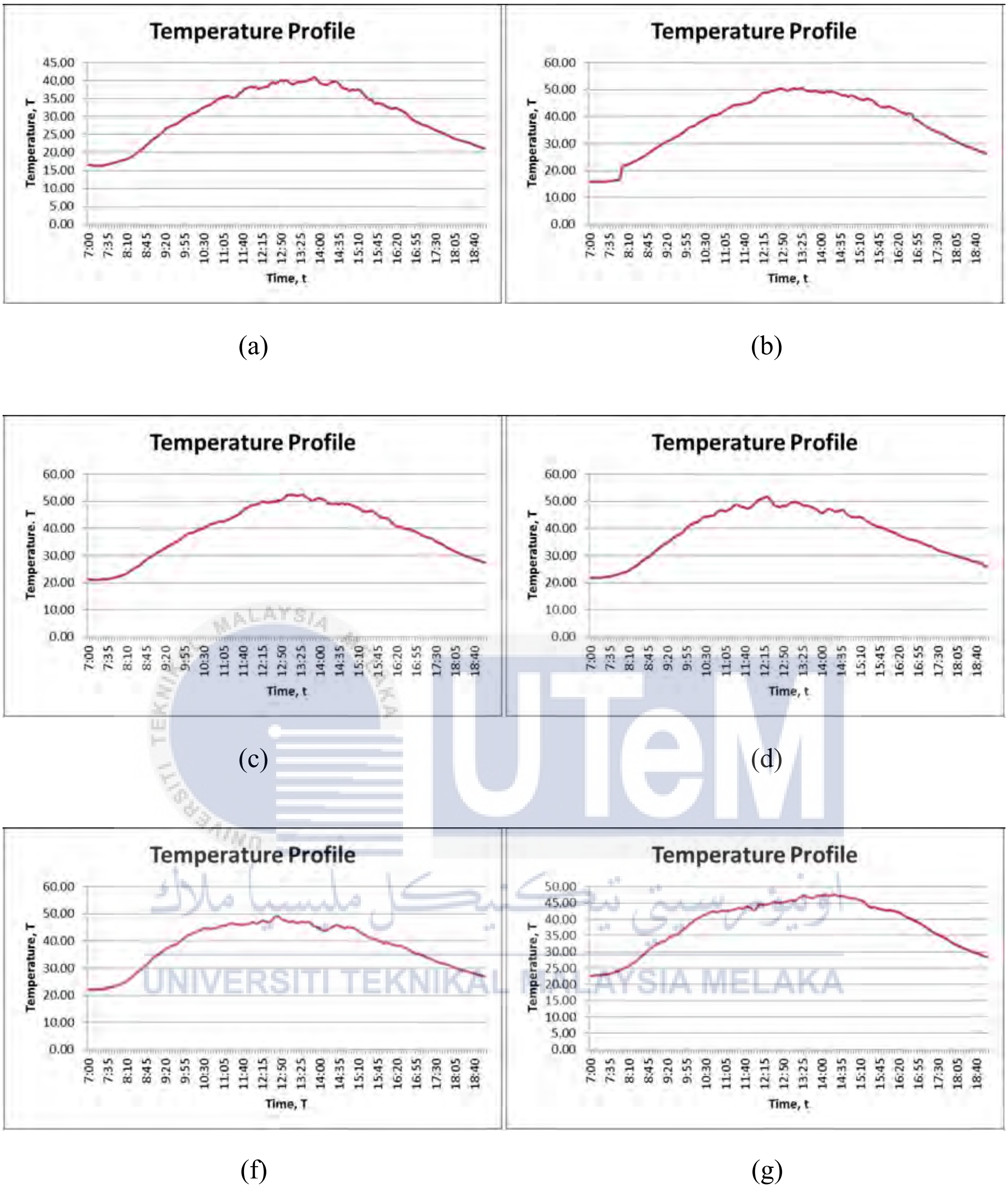


Figure 4.3: Temperature Profile for (a) January (b) February (c) March (d) April (e) Mei (f) June

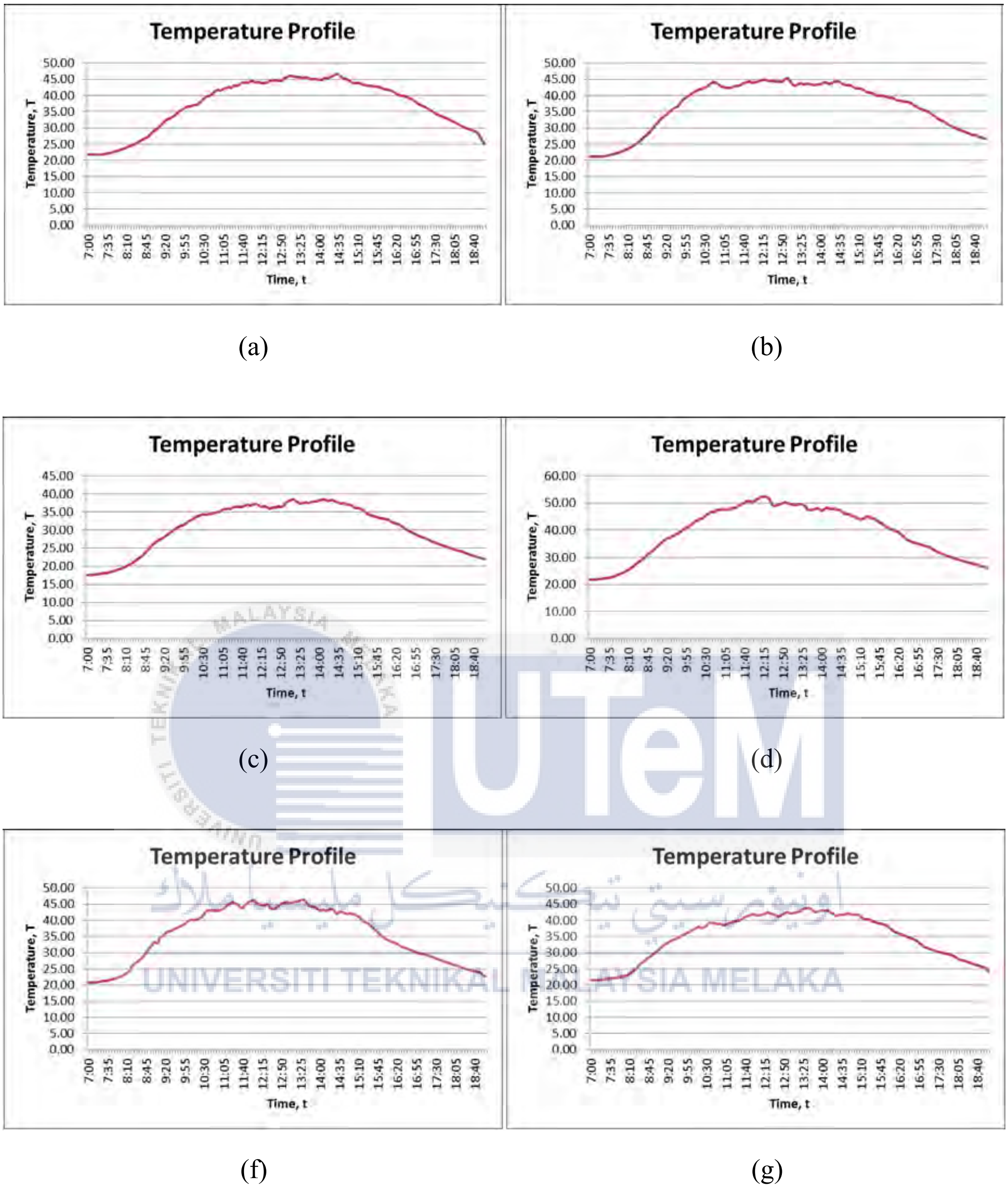


Figure 4.4: Temperature Profile for (a) July (b) August (c) September (d) October (e) November (f) December

Figure 4.5 shows the average irradiance profile in a year 2014. The average of the irradiance is in between 600 W/m^2 to 700W/m^2. This because of the query type used is 5 minutes data. If the data is sorted by one second of data, the irradiance should be higher than 5 minutes of data. The irradiance reading increases from morning to afternoon but then slowly drops in the evening. The peak time to have maximum value of irradiance is in between 11.00 to 14.30.

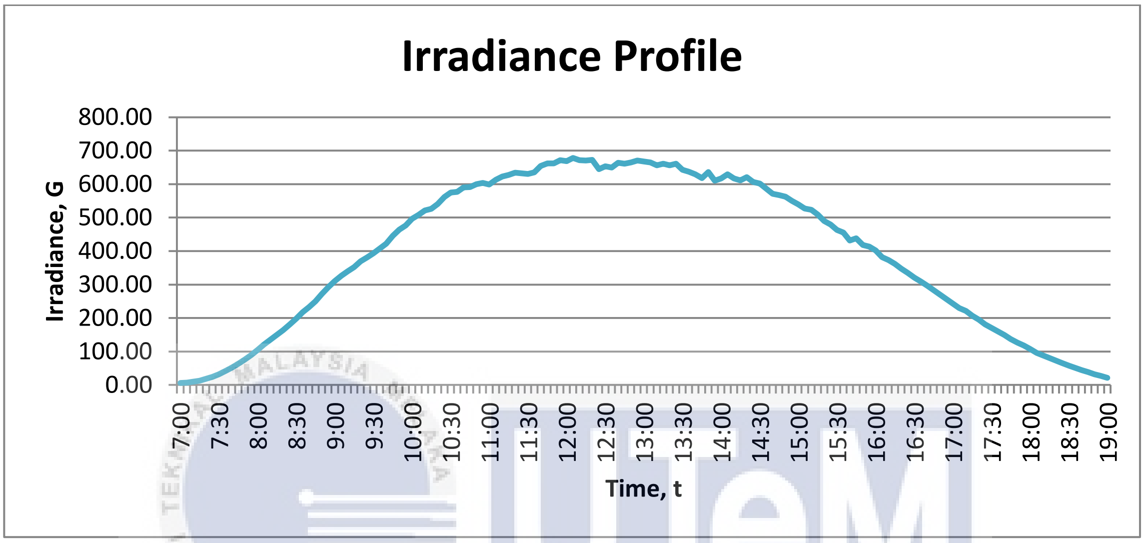


Figure 4.5: One year Irradiance Profile

Figure 4.6 shows the average back module temperature profile in a year 2014. The back panel temperature seems to be in average of ± 5˚C. This is because the back panel temperature is 10 to 20% higher than ambient temperature. Based on Figure 4.6, the temperature is low in the morning but then keeps on rising until afternoon and it slowly drops in the evening. This is due to the typical climate in Malaysia where the temperature is high in the afternoon.

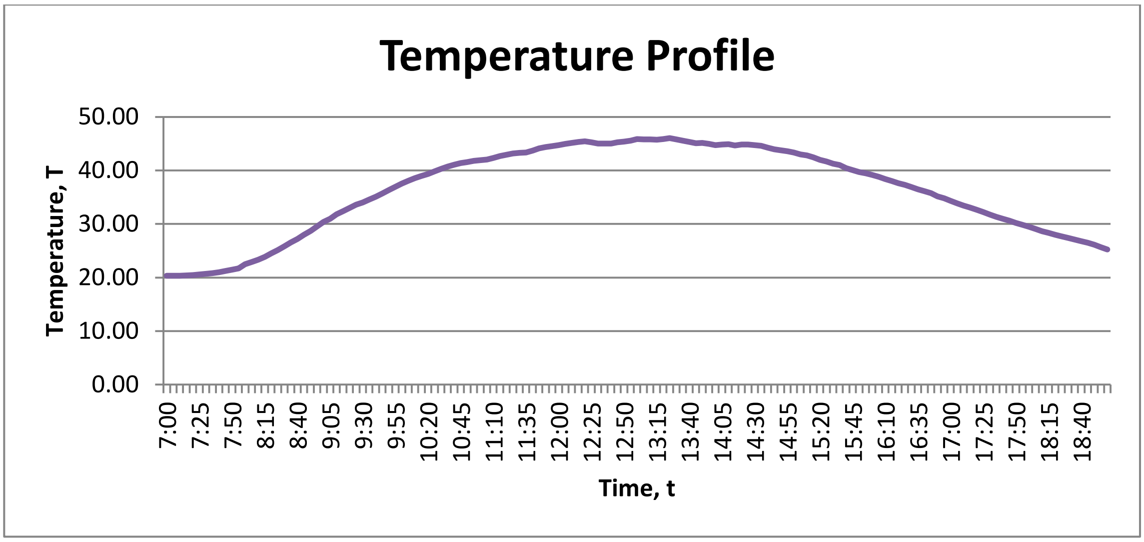


Figure 4.6: One year Back Panel Temperature Profile

4.2 Testing Result

1 : 0.7 Inverter to Solar Panel ratio

The value of irradiance that strikes the photovoltaic cell is affecting the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.7 below, the value of input and output current is increasing proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.03A and 5.21A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.63A and 10.17A respectively.

The temperature of the cell is affecting the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.7 below, the value of input voltage is constant for about 500V. This is due to the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant about 230V. This is because of the system is grid connected which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.7 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power of 20.08W and 2549W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 18.19W and 2347.71W.

In conclusion, the inverter functions to maintain the power so the input power is as close as possible to output power albeit in AC. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage become decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.7 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to inverter loss, the value of the power is quite lower on the AC side. Inverter losses refers to the switching factor in the inverter and the usage of transformer inside the inverter.

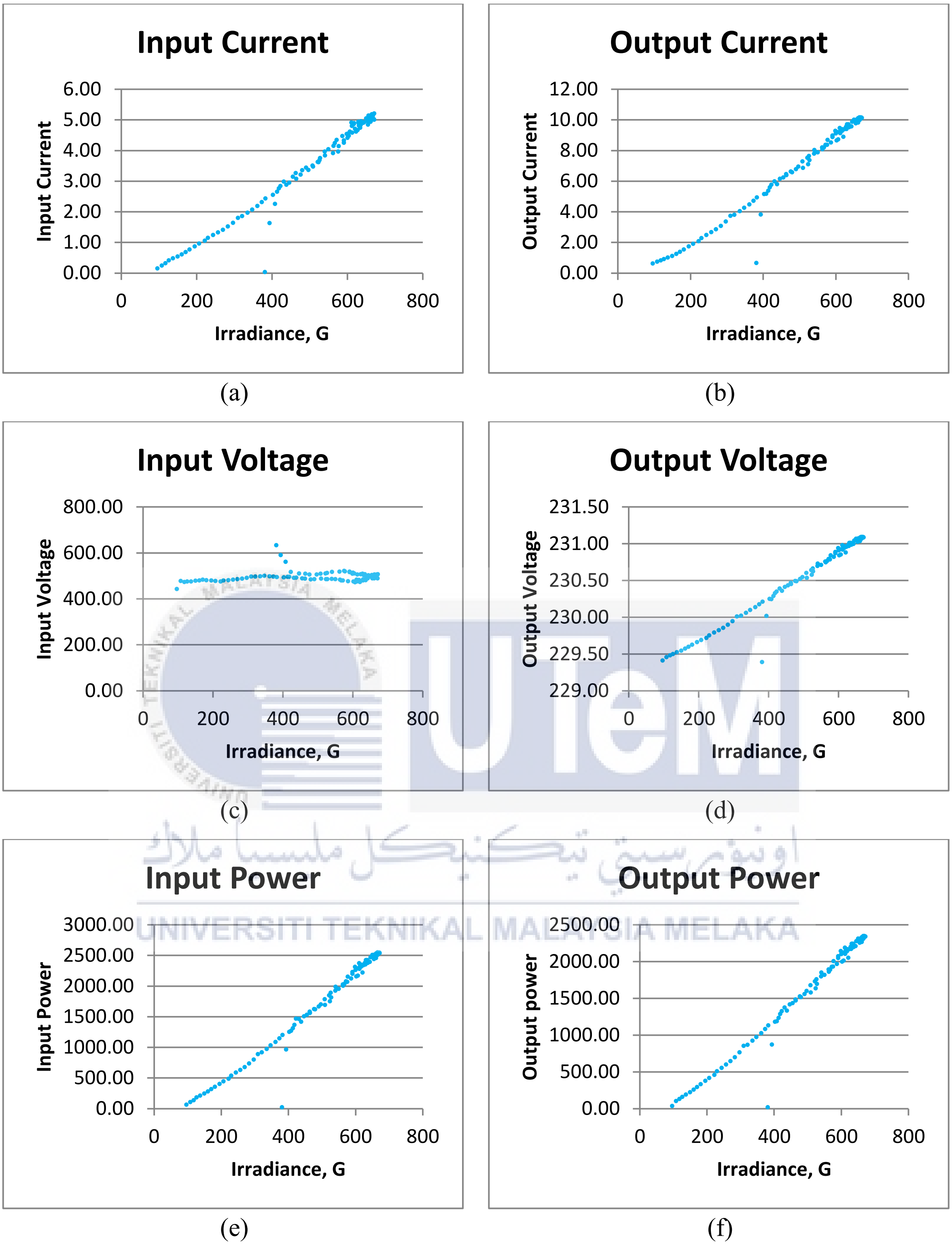


Figure 4.7: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e)Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.8 below shows the graph of Efficiency against Irradiance for 1: 0.7 inverters to solar panel. The minimum and maximum value of efficiency is 58% and 98% respectively.

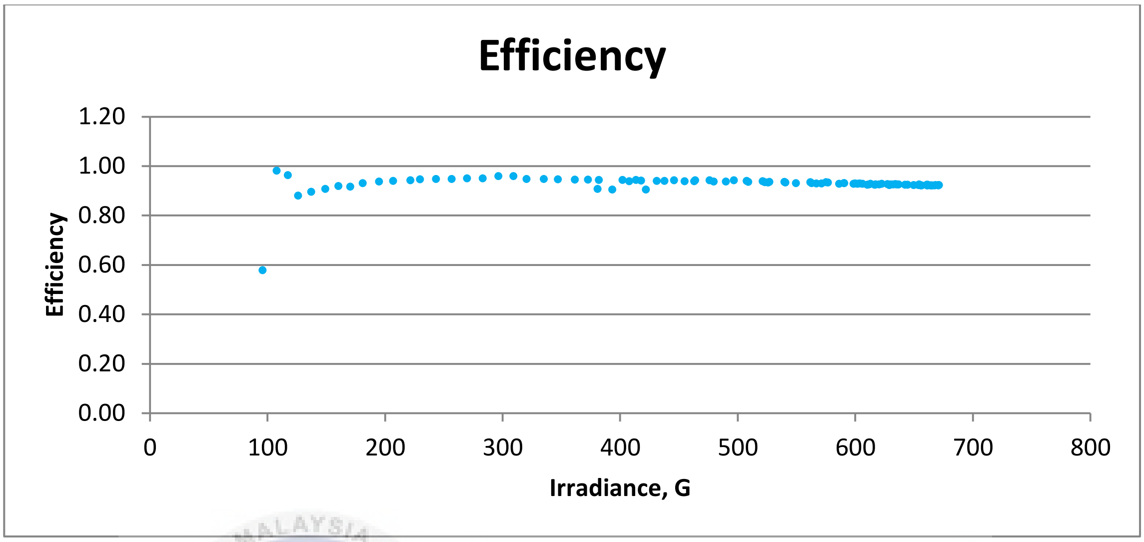


Figure 4.8: Efficiency of 1 : 0.7 inverter to solar panel

1 : 0.8 Inverter to Solar Panel ratio

The value of irradiance which strikes the photovoltaic cell affects the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.9 below, the value of input and output current increases proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.20A and 4.85A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.66A and 9.46A respectively.

The temperature of the cell affects the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.9 below, the value of input voltage is constant, about 500V. This is because of the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant, about 230V. This is because of the system is grid connected in which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.9 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power 83.20W and 2360.93W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 66.70W and 2183.29W.

In conclusion, the inverter functions to maintain the power so the input power is as close as possible to output power albeit in AC. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.1 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter losses, the value of the power is quite lower on the AC side. Inverter loss refers to the switching factor in the inverter and the usage of transformer inside the inverter.

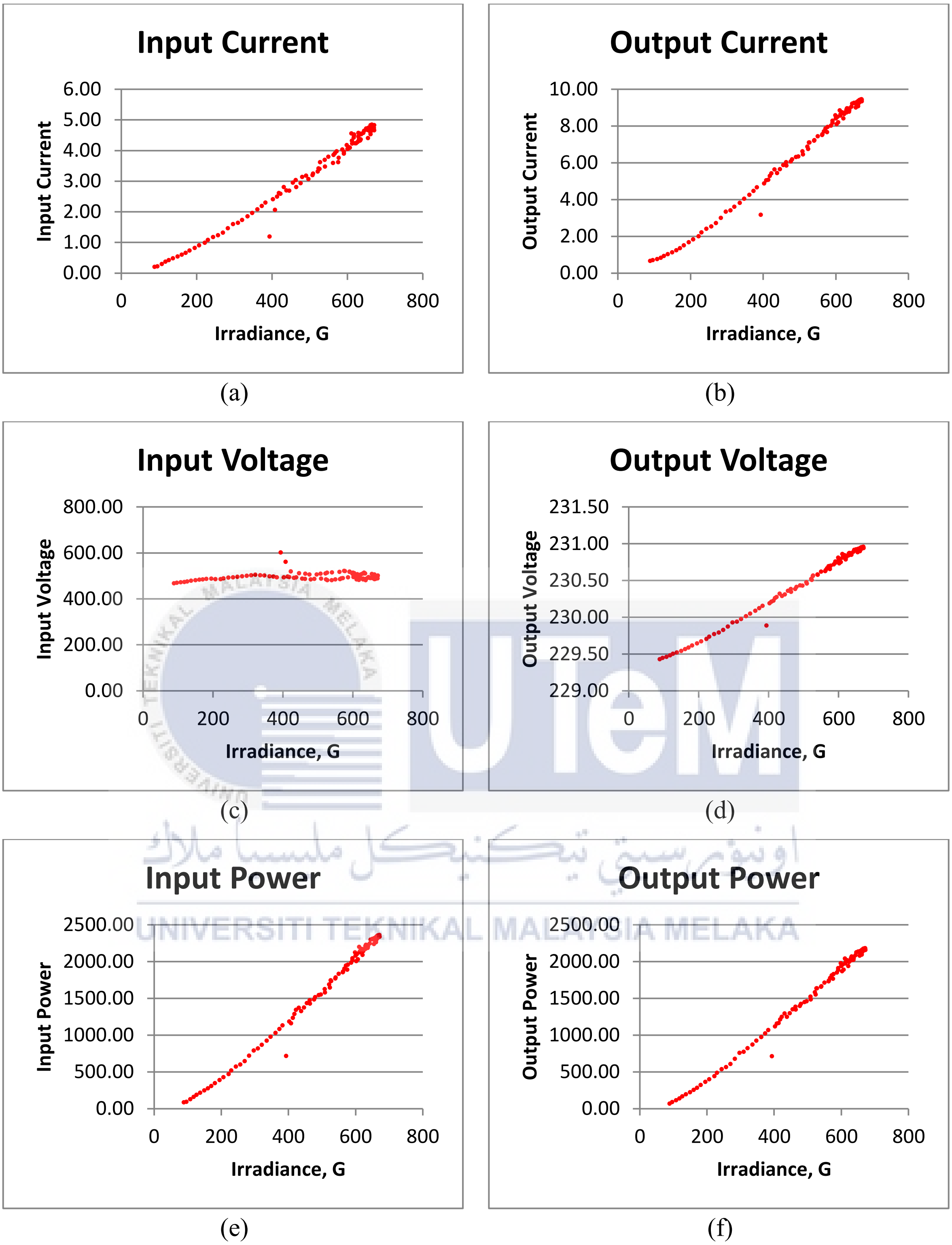


Figure 4.9: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e) Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.4 below shows the graph of Efficiency against Irradiance for 1: 0.8 inverters to solar panel ratio. The minimum and maximum value of efficiency is 80% and 100% respectively.

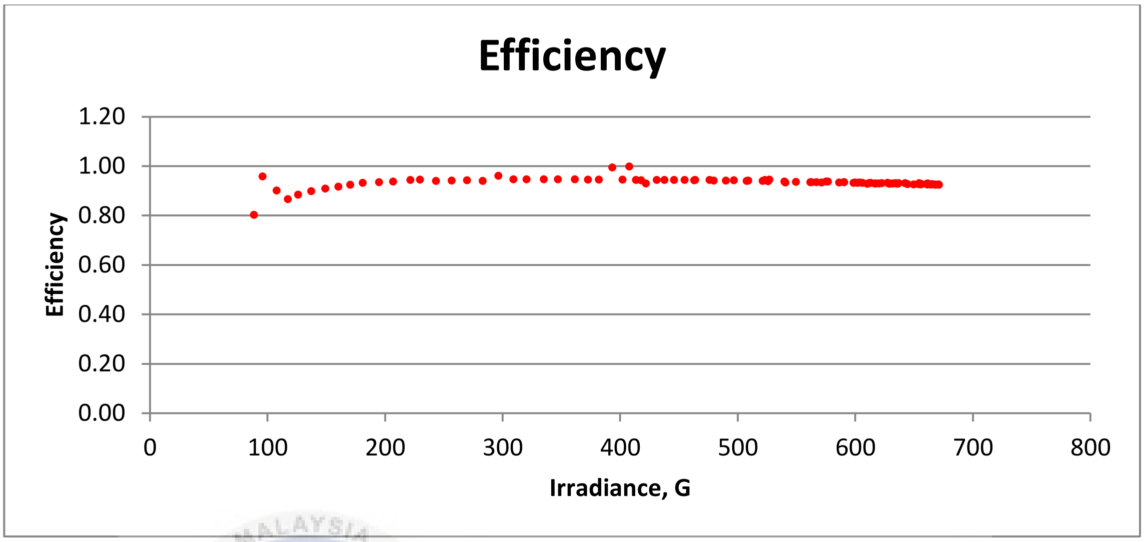


Figure 4.10: Efficiency of 1 : 0.8 inverter to solar panel

1 : 0.9 Inverter to Solar Panel ratio

The value of irradiance which strikes the photovoltaic cell affects the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.11 below, the value of input and output current increases proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.10A and 4.41A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.62A and 8.69A respectively.

The temperature of the cell affects the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.11 below, the value of input voltage is constant, about 500V. This is due to the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant, about 230V. This is because of the system is grid connected in which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.11 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power 37.92W and 2157.40W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 33.15W and 2003.42W.

In conclusion, the inverter functions to maintain the power is as close as possible to output power albeit in AC. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.1 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter losses, the value of the power is quite lower on the AC side. Inverter loss refers to the switching factor in the inverter and the usage of transformer inside the inverter.

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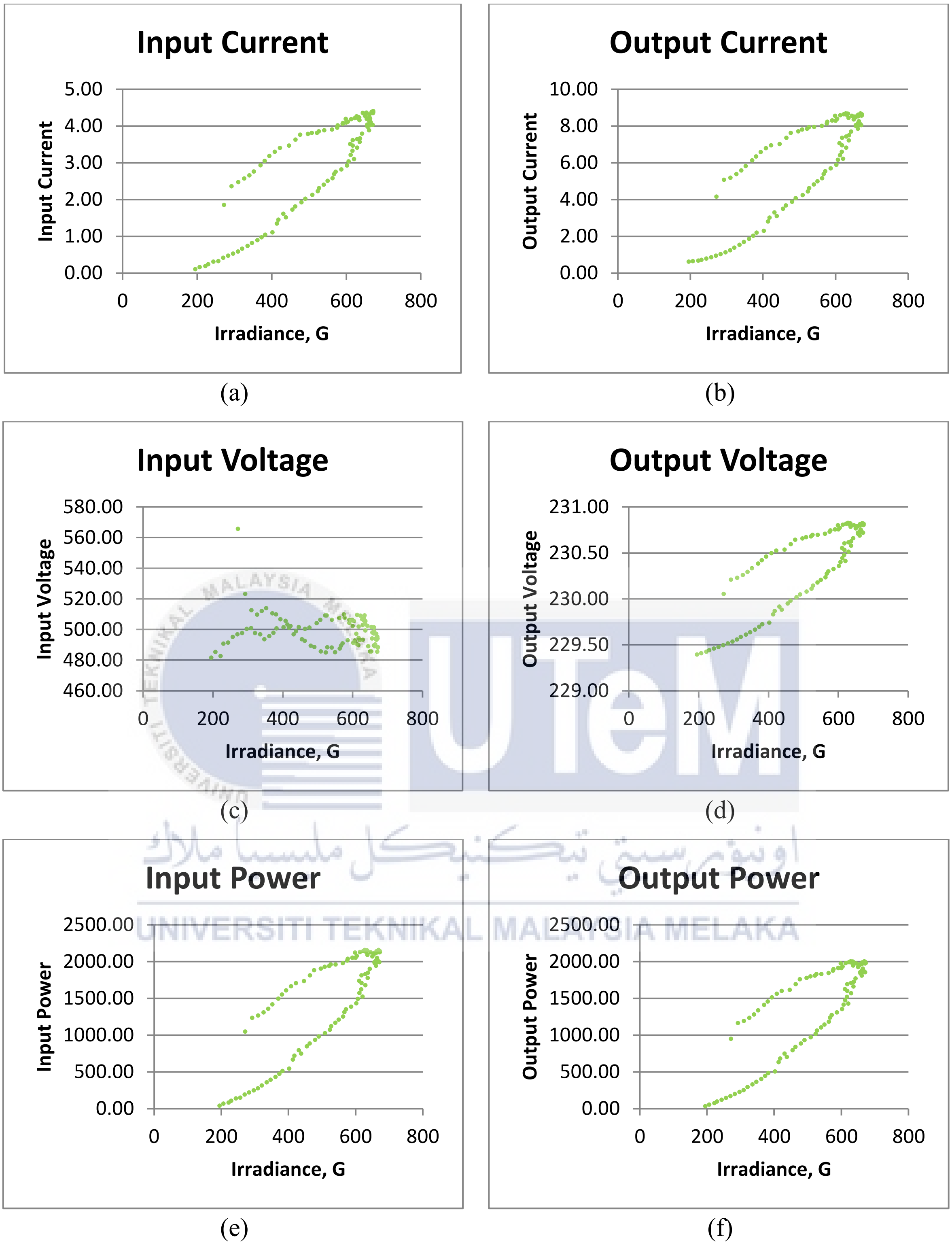

Figure 4.11: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e) Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.12 below shows the graph of Efficiency against Irradiance for 1: 0.9 inverters to solar panel ratio. The minimum and maximum value of efficiency is 78% and 97% respectively.

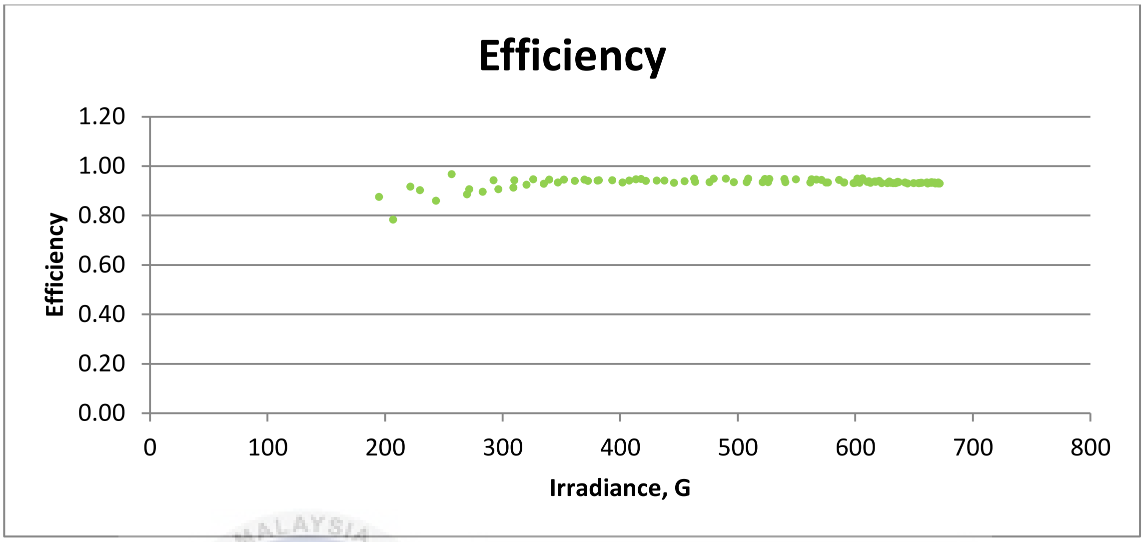

Figure 4.12: Efficiency of 1 : 0.9 inverter to solar panel

1 : 1 Inverter to Solar Panel ratio

The value of irradiance which strikes the photovoltaic cell affects the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.13 below, the value of input and output current increases proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.10A and 4.08A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.62A and 8.03A respectively.

The temperature of the cell affects the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.13 below, the value of input voltage is constant, about 500V. This is due to the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant, about 230V. This is because of the system is grid connected in which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.13 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power 35.77W and 1987.79W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 33.48W and 1850.47W.

In conclusion, the inverter functions to maintain the power is as close as possible to output power albeit in AC .When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.13 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter losses, the value of the power is quite lower on the AC side. Inverter loss refers to the switching factor in the inverter and the usage of transformer inside the inverter.

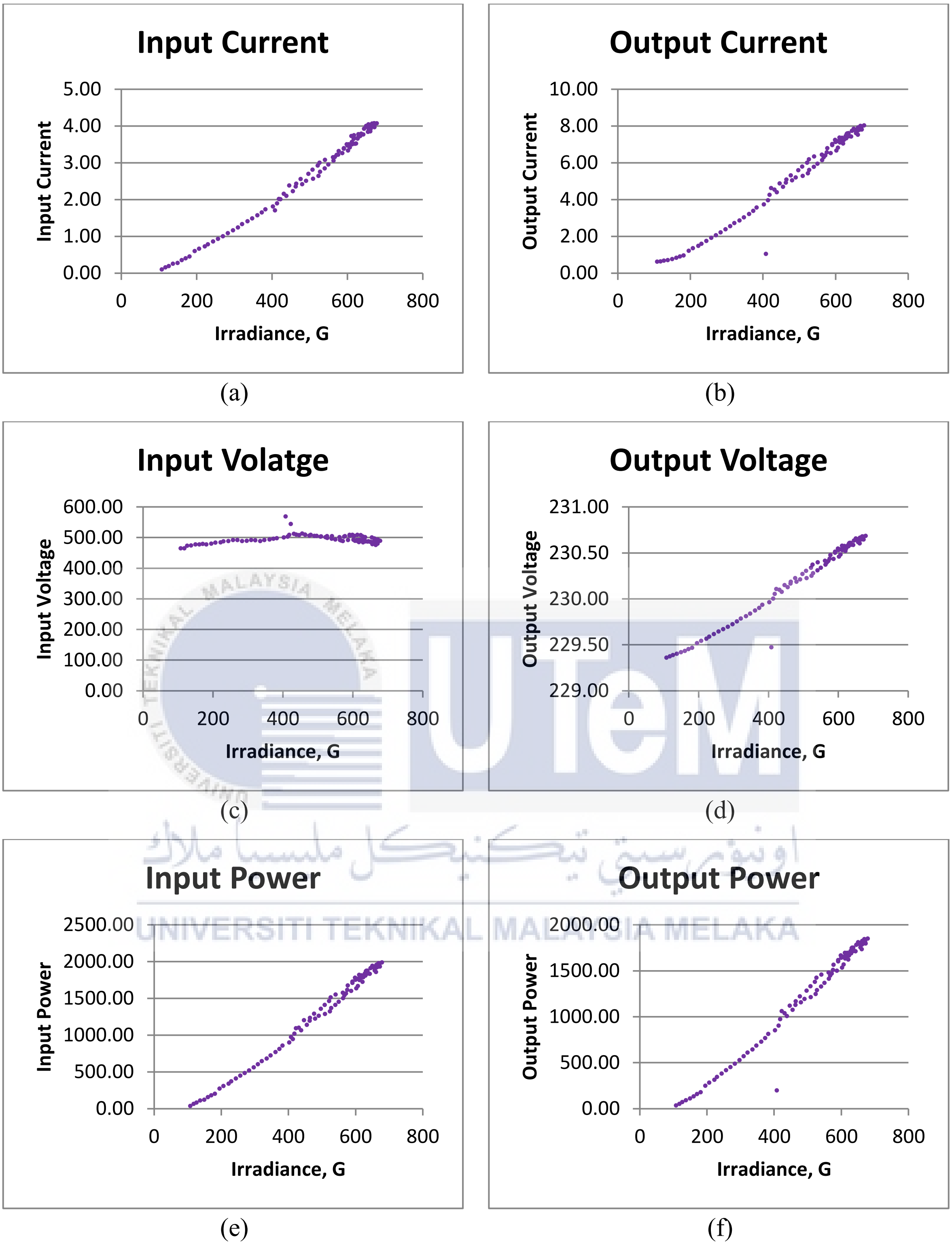

Figure 4.13: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e) Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.14 below shows the graph of Efficiency against Irradiance for 1: 1.0 inverters to solar panel ratio. The minimum and maximum value of efficiency is 20% and 97% respectively.

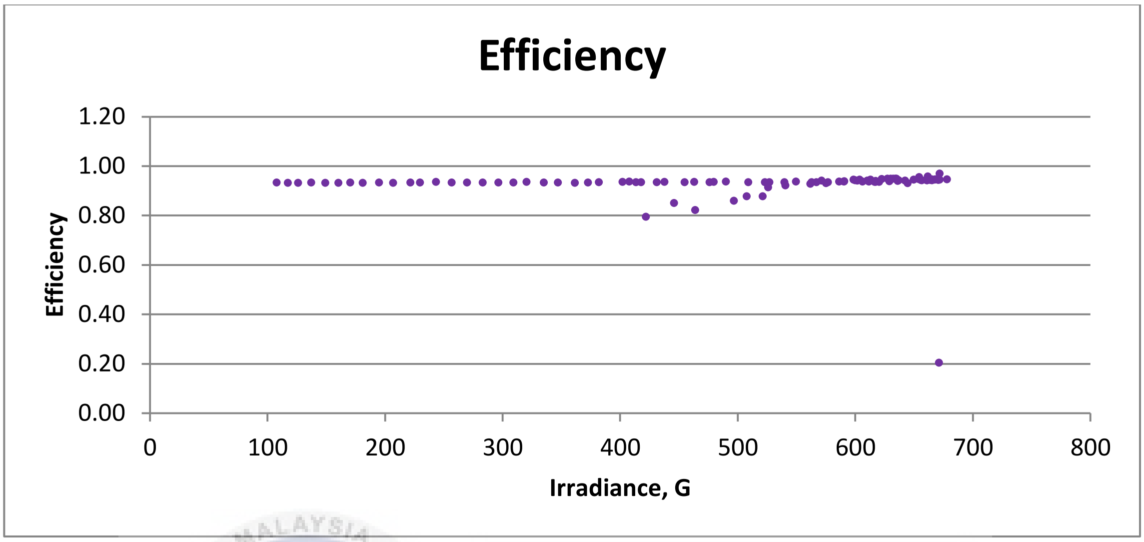

Figure 4.14: Efficiency of 1 : 1 inverter to solar panel

1 : 1.1 Inverter to Solar Panel ratio

The value of irradiance which strikes the photovoltaic cell affects the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.15 below, the value of input and output current increases proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.12A and 3.61A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.61A and 7.19A respectively.

The temperature of the cell affects the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.15 below, the value of input voltage is constant, about 500V. This is due to the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant, about 230V. This is because of the system is grid connected in which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.15 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power 47.48W and 1767.55W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 17.44W and 1653.60W.

In conclusion, the inverter functions to maintain power is as close as possible to output power albeit in AC. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.15 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter losses, the value of the power is quite lower on the AC side. Inverter loss refers to the switching factor in the inverter and the usage of transformer inside the inverter.

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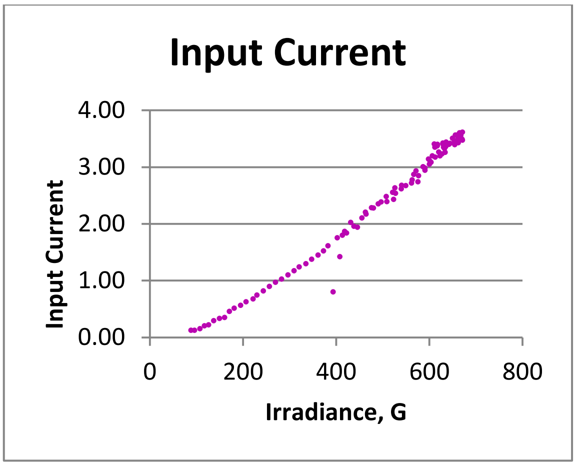
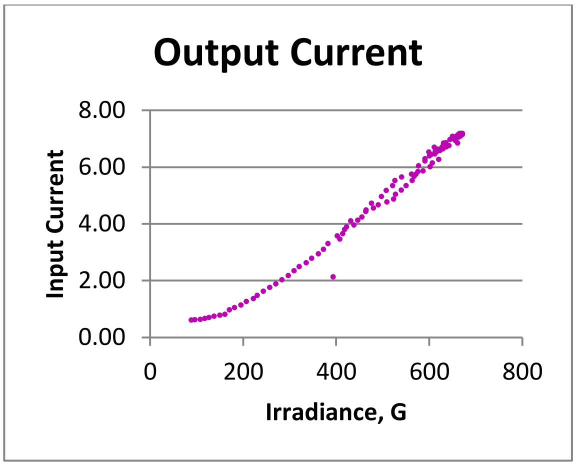
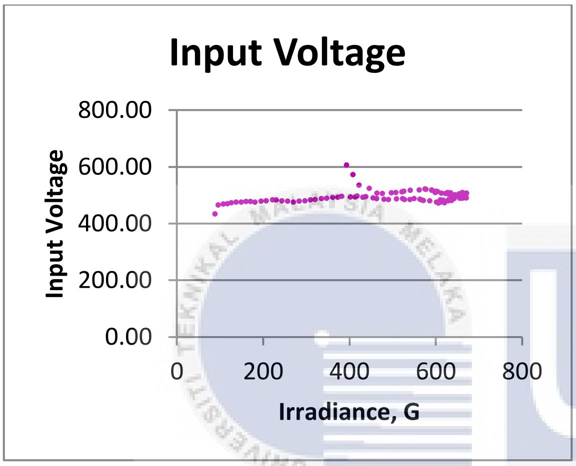


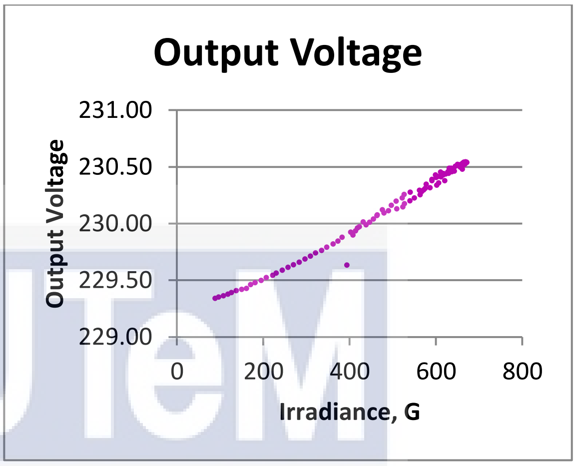
(a)



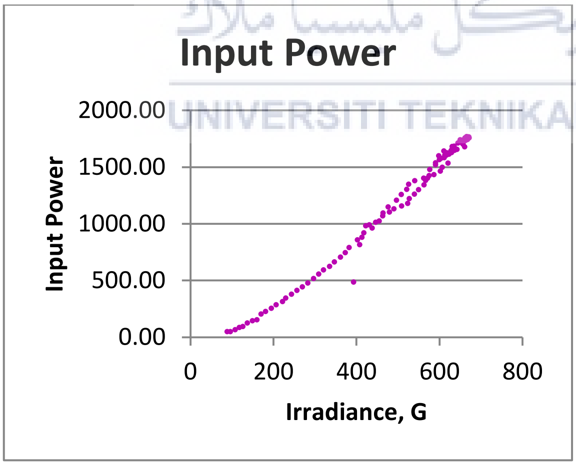
(b)



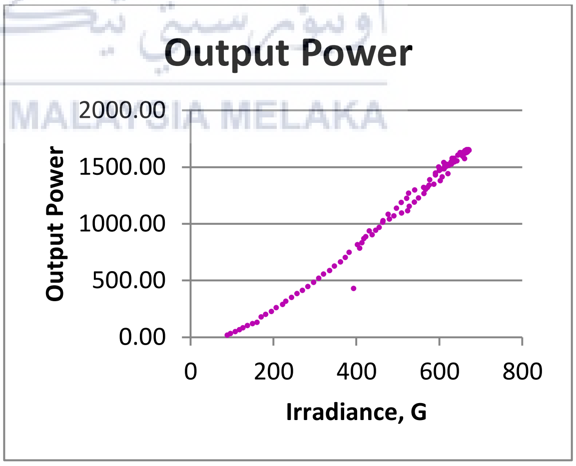
(c)



(d)



(e)



(f)

Figure 4.15: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e) Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.16 below shows the graph of Efficiency against Irradiance for 1: 1.1 inverters to solar panel ratio. The minimum and maximum value of efficiency is 36% and 96% respectively.

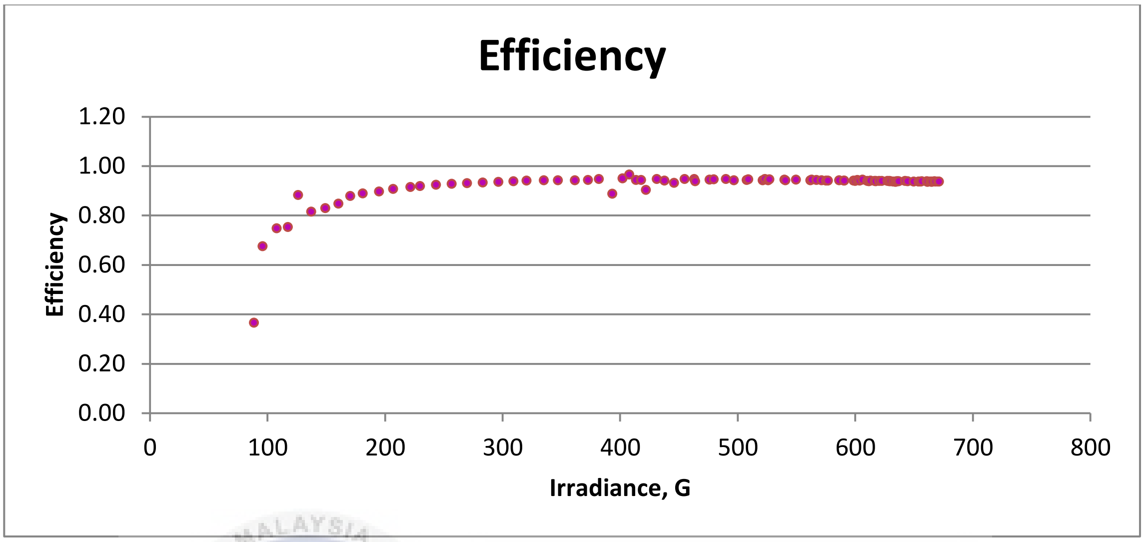


Figure 4.16: Efficiency of 1 : 1.1 inverter to solar panel

1 : 1.2 Inverter to Solar Panel ratio

The value of irradiance which strikes the photovoltaic cell is affecting the current dramatically. As the value of irradiance increases, the value of current will also increase. Based on the graph of input current and output current in Figure 4.17 below, the value of input and output current increases proportionally to irradiance. The input current shows the value of minimum and maximum current is 0.11A and 3.21A respectively. Meanwhile, the value output current seems to be double to the input current. This is because of the lower value of the output voltage. The value of minimum and maximum current of the output current is 0.62A and 6.46A respectively.

The temperature of the cell affects the voltage. As the value of temperature increases, the value of voltage decreases which in turn will directly affect the power outputs. Based on the graph of input and output voltage in Figure 4.17 below, the value of input voltage is constant, about 500V. This is due to the constant value of average back panel temperature used during the testing process. For the output voltage, the value of the voltage is also constant, about 230V. This is because of the system is grid connected which it will maintain the voltage at 230V and 50Hz frequency.

Power depends on the voltage and current. Based on the Figure 4.17 below, the graph of input and output power increases proportionally to irradiance. The input power has the minimum and maximum power 43.13W and 1581.08W respectively. For output power, the value of minimum and maximum is slightly lower than input power due to the inverter losses. The value of minimum and maximum output power is 30.61W and 1484.18W.

In conclusion, the inverter functions to maintain the power is as close as possible to output power albeit in AC. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side because this is GCPV system. When the values of the voltage decrease at AC side, this will result in higher value of AC current. Because of that, the output current in in Figure 4.17 is higher than input current. The power depends on the voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter losses, the value of the power is quite lower on the AC side. Inverter loss is refers to the switching factor in the inverter and the usage of transformer inside the inverter.

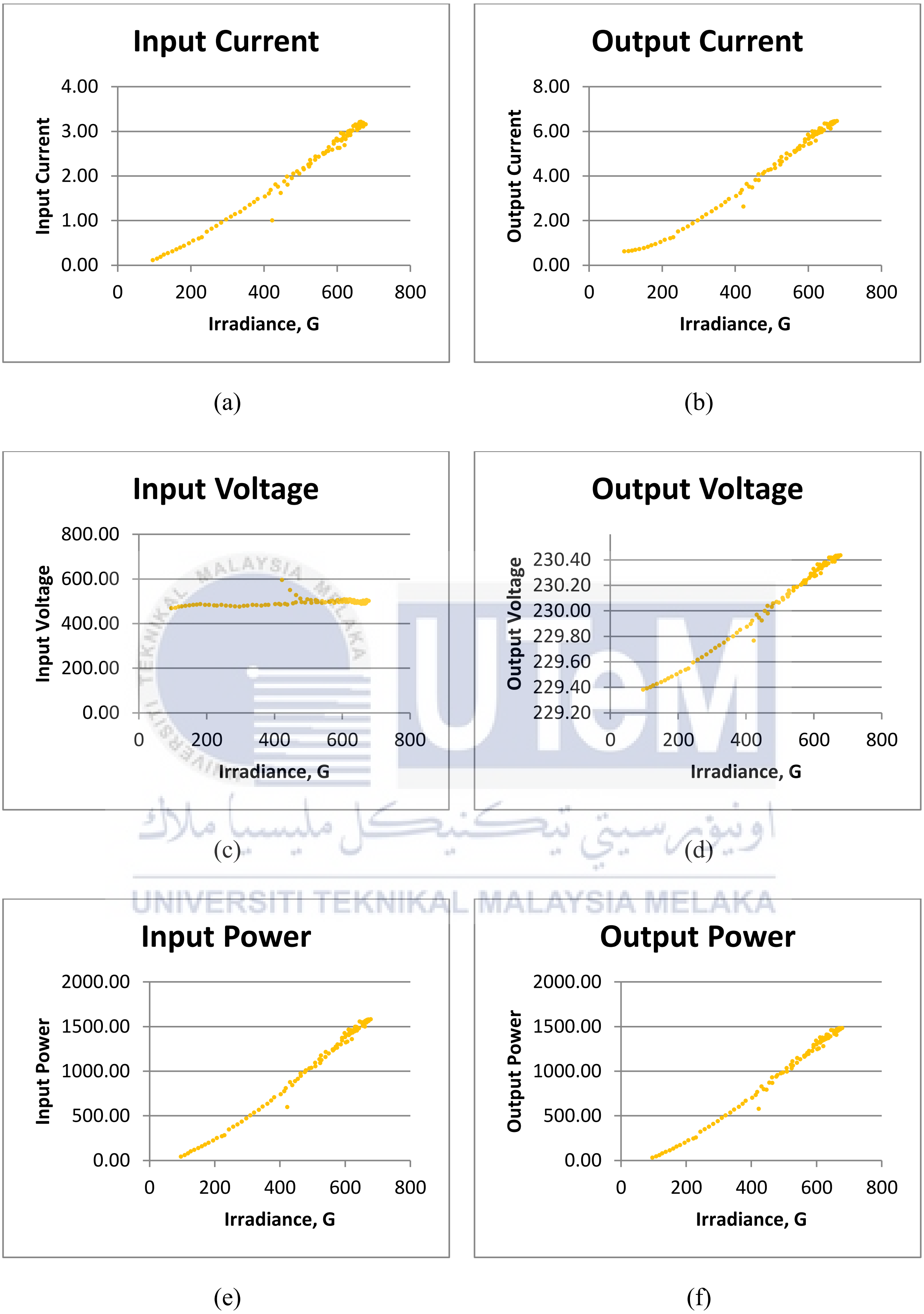


Figure 4.17: (a) Input Power (b) Output Power (c) Input Current (d) Output Current (e) Input Voltage (f) Output Voltage

Efficiency is defined as the ratio between output power and input power. Figure 4.18 below shows the graph of Efficiency against Irradiance for 1: 1.2 inverters to solar panel ratio. The minimum and maximum value of efficiency is 71% and 97% respectively.

Figure 4.18: Efficiency of 1 : 1.2 inverter to solar panel

4.3 Testing Result Plotted On the Same Graph

Figure 4.19 and 4.20 show the graph of input and output current of all ratio plotted on the same axes. Based on the graph below, ratio of 1:0.7 shows the highest reading value of input and output current while the ratio that shows the lowest reading of input and output current 1:1.2 ratio. The input current records the highest value of current exceeds 5A while the lowest value is less than 1A. Meanwhile, the output current records the highest value exceeds than 10A and the lowest value is less than 2A. Output current records high value of current compared to input current due to the decreasing value of the output voltage. This is because of this system is grid connected system. In grid connected system, the inverter tries to maintain the output voltage at 230V and 50Hz. In order to make the output voltage is comparable to input voltage, the inverter will increase the value of output current. Therefore, the output current is higher than input current.

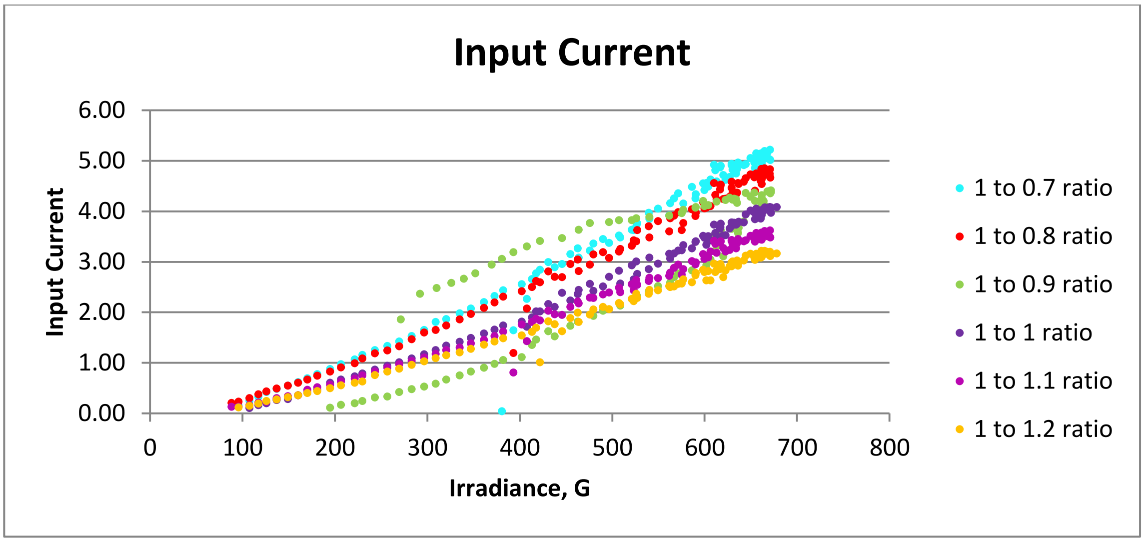


Figure 4.19: Input Current Graph of All Ratio

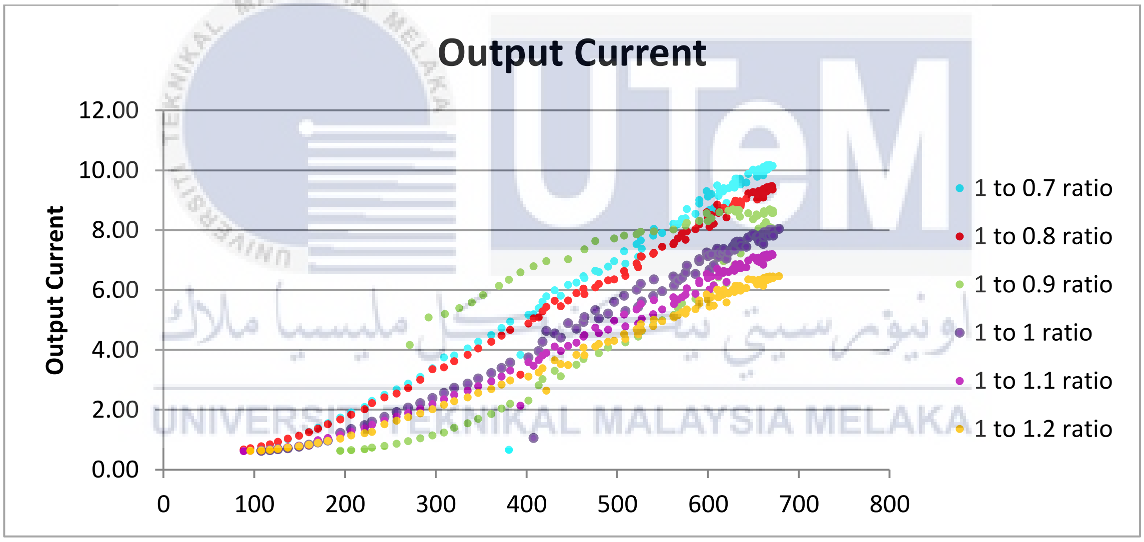


Figure 4.20: Output Current Graph of All Ratio

Figure 4.21 and 4.22 show the graph of input and output voltage of every ratio plotted on the same axes. Based on the input voltage graph in Figure 4.20, the graph shows that the value of input voltage is constant. This is because of the consistence nature of temperature in Malaysia. For the output voltage, the value is in between 229V to 231V. This is because of this system is a grid connected system. In grid connected system, the inverter will try to maintain the output voltage at 230V and 50Hz frequency.

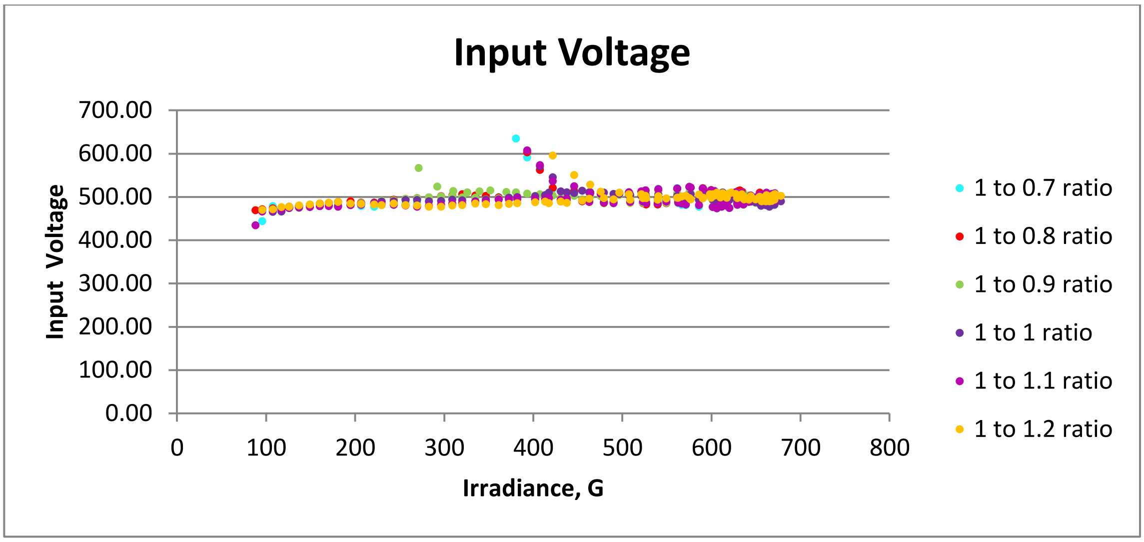


Figure 4.21: Input Voltage Graph of All Ratio

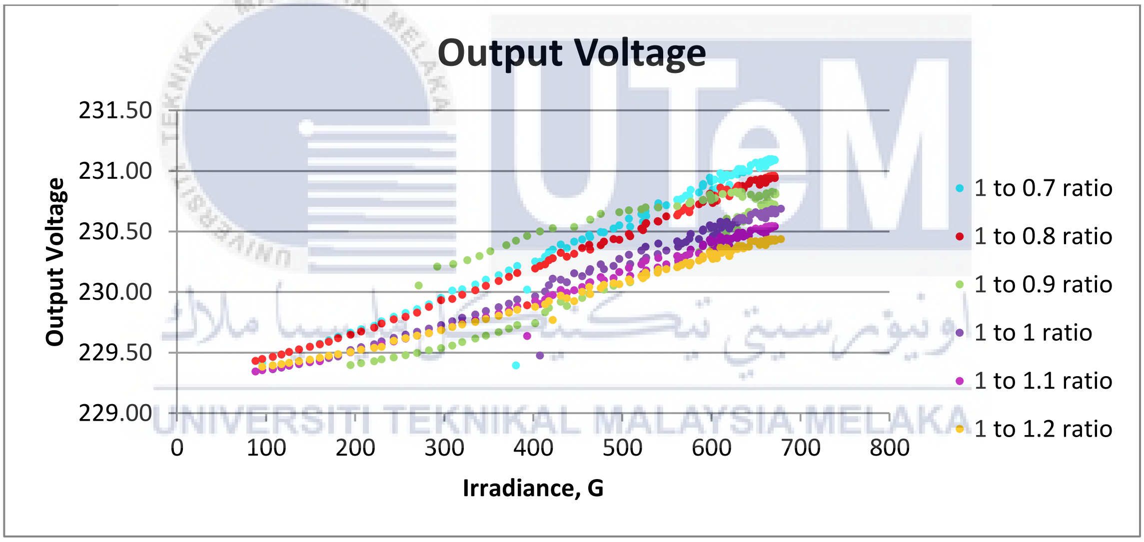


Figure 4.22: Output Voltage Graph of All Ratio

Figure 4.23 and 4.24 show the graph of input and output power of all ratios plotted on the same axes. Based on the graph below, ratio of 1:0.7 shows the highest and the lowest reading value of input and output power. For input power, the power shows the highest value which exceeds 2500W while the lowest value is less than 500W. Meanwhile, for output power the highest value exceeds 2000W and the lowest value is less than 500W. Based on the figure below, the value of output power is slightly lower than input power due to the inverter losses and the usage of transformer inside the inverter. Some of the losses in the inverter are copper loss which is caused by the resistive heating losses in the primary and secondary winding of the transformer.

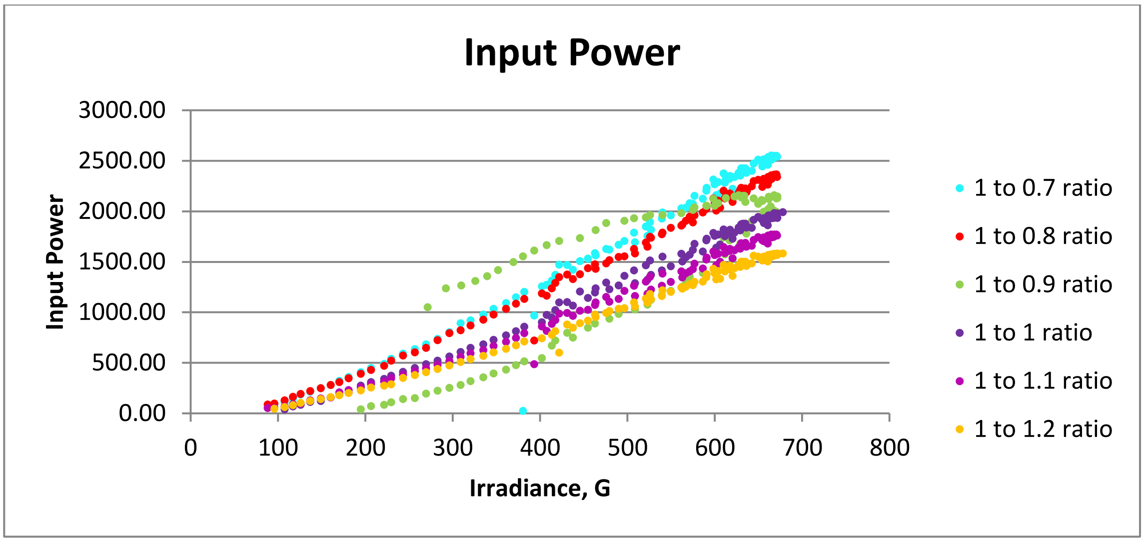


Figure 4.23: Input Power Graph of All Ratio

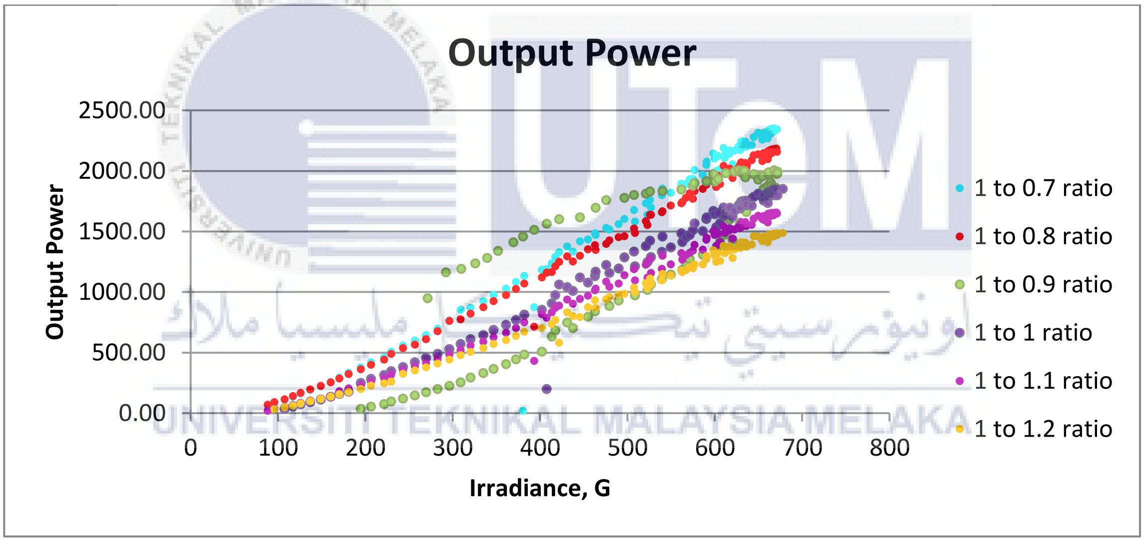


Figure 4.24: Output Power Graph of All Ratio

Figure 4.25 shows the graph of efficiency versus irradiance of all ratio plotted on the same axes. Based on the graph below, ratio of 1:0.8 records the highest value of efficiency which is approximately to 100%. Meanwhile, ratio which has the lowest efficiency is 1:1 ratio which has the efficiency approximately to 20%.

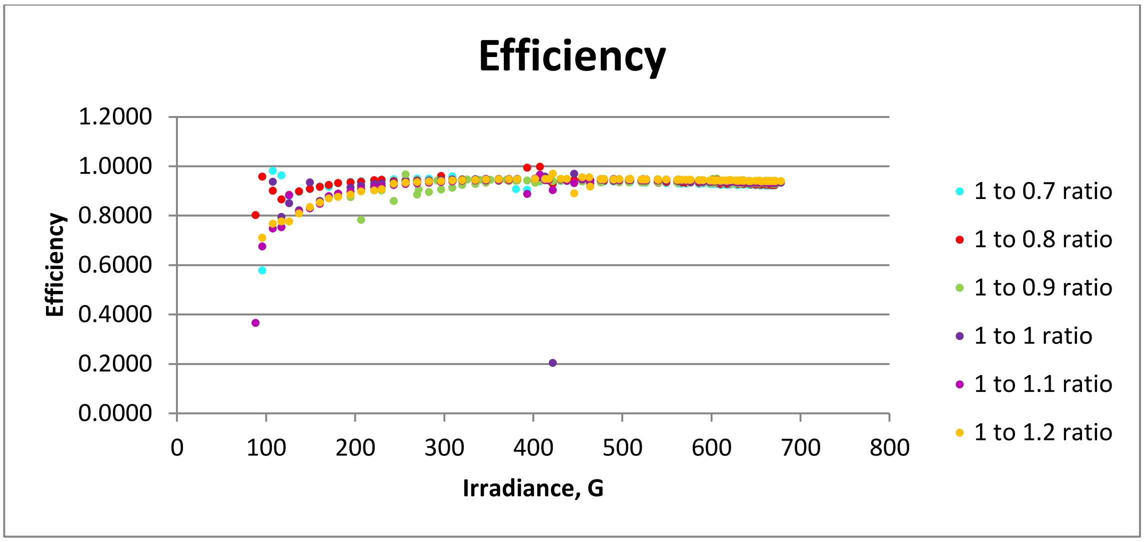


Figure 4.25: Overall Plotted Graph of Inverter to Solar Panel efficiency

Figure 4.26 shows the bar chart of the average efficiency of every ratio. Based on figure below, ratio 1:0.8 has the highest efficiency compared to other ratios. Ratio 1:0.8 records the value of efficiency at 93.15%. Ratio 1:0.9 has the second highest ratio with 93.08% after ratio 1:0.8. Ratio of 1:0.7, 1:1 and 1:1.2 give the efficiency reading of 92.66%, 92.47% and 92.78% respectively. Ratio that records the lowest value of efficiency is 1:1.1 with the recorded efficiency value of 92.04%. Therefore, ratio 1:0.8 has the most efficient system compared to other systems.

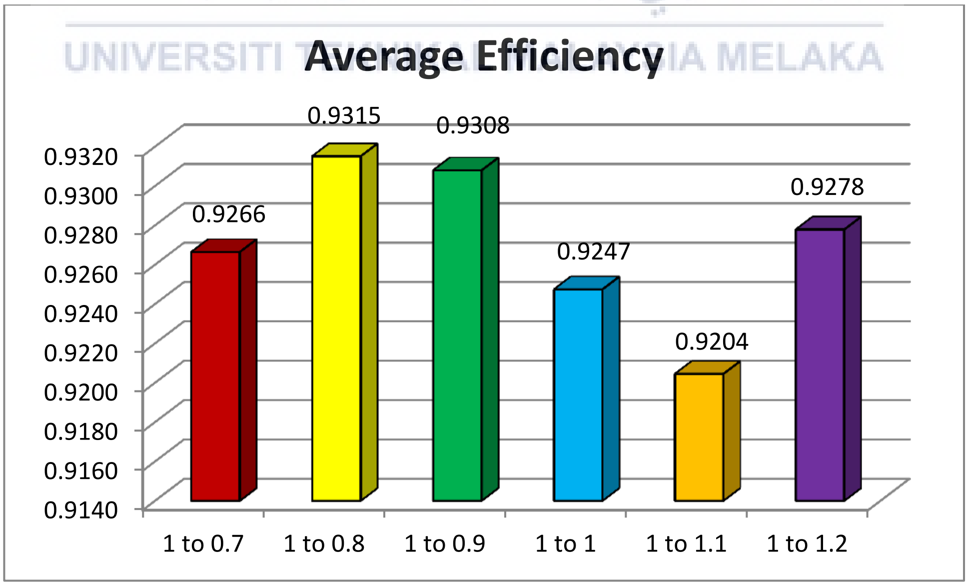


Figure 4.26: Average Efficiency of Every Ratio

4.4 System Yield

Ideal System Yield for One Year

$$System\ Yield = P_{array} \times PSH \times No.of.days \times Losses \times Efficiency$$

$\boldsymbol{where}$;

$P_{array} = Power\ array$

$PSH = Peak\ Sun\ Hour$

Losses = $f_{temp\_ave}, f_{dirt}, f_{mm}, \eta_{pv\_inv}$ = 0.8

$\boldsymbol{therefore}$; $S.Y = 4kW \times 5\ hour \times 365\ days \times 0.8 \times 0.963 = 5623.92kW/h$

System Yield Of Every Ratio

$$\boldsymbol{System\ Yield = Efficiency \times Ideal\ System\ Yield}$$

Table 4.1: System Yield of Every Ratio

1: 0.7	$0.9266 \times 5623.92kW/h = \mathbf{5211.12kw/h}$
1 : 0.8	$0.9315 \times 5623.92kW/h = \mathbf{5238.68kw/h}$
1 : 0.9	$0.9308 \times 5623.92kW/h = \mathbf{5234.74kw/h}$
1 : 1.0	$0.9247 \times 5623.92kW/h = \mathbf{5200.44kw/h}$
1 : 1.1	$0.9204 \times 5623.92kW/h = \mathbf{5176.26\ kw/h}$
1 : 1.2	$0.9278 \times 5623.92kW/h = \mathbf{5217.87kw/h}$

In conclusion, the ratio which has the highest efficiency among the others is 1:0.8 while the lowest efficiency is 1:1.1. Nowadays, the installation of solar panel to inverter uses 1:1 ratio in which the power of solar panel is equal to the power of inverter. This research proves that the ratio of solar panel to inverter at 1:0.8 is the most optimum sizing ratio of GCPV system under tropical condition. This is because of it has the highest system efficiency compared to other systems. Therefore, the system will operate efficiently and the inverter can operate at the maximum power. Besides, this system can save up to RM 1,600 for installation of 4kW system. In addition, this system also has the system yield of 5238.68kW which is close to the ideal system yield.

4.5 Financial Impact

1:1 Ratio of Inverter to Solar Panel

$Total\ Installation\ Cost\ for\ 4kW\ system = RM\ 40{,}000$

$Price\ for\ 4kW\ inverter = (4kW \times 2) + 1 = RM9{,}000$

$$Therefore; \frac{RM\ 9{,}000}{RM\ 40{,}000} \times 100\% = 22.5\%$$

$Inverter\ cost\ is\ 22.5\ \%\ from\ the\ total\ cost\ of\ installation$

Based on the calculation above, it shows that by using 1:1 ratio of inverter to solar panel in 4kW system, the total cost of installation is approximately RM 40,000. The price for 4kW is RM 9,000 which is equal to 22.5% from the total installation cost.

1:0.9 Ratio of Solar Panel to Inverter

$Price\ for\ 3.6kW\ inverter = (3.6kW \times 2) + 1 = RM\ 8{,}200$

$$Therefore; \frac{RM\ 8{,}200}{RM\ 40{,}000} \times 100\% = 20.5\%$$

$Inverter\ cost\ is\ 20.5\ \%\ from\ the\ total\ cost\ of\ installation.$

$Saving\ Cost = RM9{,}000 - RM8{,}200 = RM\ 800$

$New\ total\ installation\ cost = RM\ 40{,}000 - RM\ 800 = RM\ 39{,}200$

For this case, the inverter has been undersized from 4kW to 3.6Kw but it will be implemented in 4kW system. By implementing 3.6kW inverter in 4kW system, the price of inverter reduces from RM 9,000 to RM 8,200 which is equal to 20.5% from the total cost of installation. Under sizing the inverter capacity will save cost about RM 800 and the new total installation cost will reduce to RM 39,200.

<u>1:0.8 Ratio of Solar Panel to Inverter</u>

$$Price\ for\ 3.2kW\ inverter = (3.2kW \times 2) + 1 = RM\ 7{,}400$$

$$Therefore; \frac{RM\ 7{,}400}{RM\ 40{,}000} \times 100\% = 18.5\%$$

$$Inverter\ cost\ is\ 18.5\ \%\ from\ the\ total\ cost\ of\ installation.$$

$$Saving\ Cost = RM9{,}000 - RM7{,}400 = RM\ 1{,}600$$

$$New\ total\ installation\ cost = RM\ 40{,}000 - RM\ 1{,}600 = RM\ 38{,}400$$

In this case, the inverter has been undersized to 3.2kW and will be implemented in 4kW system. By implementing 3.2kW inverter in 4kW system, the price of inverter reduces from RM 8,200 to RM 7,400 which is equal to 18.5% from the total cost of installation. Under sizing the inverter capacity will save cost about RM 1600 and the new total installation cost will reduce to RM 38,400.

<u>1:0.7 Ratio of Inverter to Solar Panel</u>

$$Price\ for\ 2.8kW\ inverter = (2.8kW \times 2) + 1 = RM\ 6{,}600$$

$$Therefore; \frac{RM\ 6{,}600}{RM\ 40{,}000} \times 100\% = 16.5\%$$

$$Inverter\ cost\ is\ 16.5\ \%\ from\ the\ total\ cost\ of\ installation.$$

$$Saving\ Cost = RM9{,}000 - RM6{,}600 = RM\ 2{,}400$$

$$New\ total\ installation\ cost = RM\ 40{,}000 - RM\ 2{,}400 = RM\ 37{,}600$$

For this case, the inverter has been undersized to 2.8kW and will be implemented in 4kW system. By implementing 2.8kW inverter in 4kW system, the price of inverter reduces from RM 7,400 to RM 6,600 which is equal to 16.5% from the total cost of installation. Under sizing the inverter capacity will save cost about RM 2400 and the new total installation cost will reduce to RM 37,600.

In conclusion, the ratio which has the highest efficiency among the others is 1:0.8 while the lowest efficiency is 1:1.1. Nowadays, the installation of solar panel to inverter uses 1:1 ratio in which the power of solar panel is equal to the power of inverter. This research proves that the ratio of solar panel to inverter at 1:0.8 is the most optimum sizing ratio of GCPV system under tropical condition. This is because of it has the highest system efficiency compared to other systems. Therefore, the system will operate efficiently and the inverter can operate at the maximum power. Besides, this system can save up to RM 1,600 for installation of 4kW system. In addition, this system also has the system yield of 5238.68kW which is close to the ideal system yield.

4.6 Summary

This chapter provides all the result for this project. This includes the one year result for irradiance and back panel temperature in 2014, the input and the output current, voltage and also power and some calculation for system yield and financial impact.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

The purpose of this research is to determine average of one year profile of the tilted irradiance and back panel temperature for Malaysia climate and then performing simulation of GCPV system by using DC simulator to obtain the most optimum sizing ratio of GCPV system between solar panel and inverter for the practice in the tropical climate condition. The average of one year tilted irradiance shows that the irradiance has maximum value approximately to 700 W/m^2 due to the query type used is 5 minutes data. The peak sun hour is in between 11am until 2pm. Next for back panel temperature profile, the temperature is consistence at approximately 5˚C. This is due to the consistence nature of temperature in Malaysia. In GCPV system, an inverter cost around 15% to 20% from the total cost of installation and it gives huge impact in return of investment (ROI). Therefore, the simulation of GCPV system has been conducted in order to determine the optimum sizing ratio between solar panel and inverter. This simulation is achieved by simulating average of one year tropical profile of irradiance and back panel temperature into a DC simulator which is connected to the high frequency inverter (SB 3000HF), grid and AC load. The results shows that the most optimum sizing ratio between solar panel and inverter is at 1:0.8 since it has the highest efficiency with 93.15% compare to other ratio. Compared to 1:1 sizing ratio, this system can save 4% of the installation cost since the inverter has been undersized. Therefore, the most optimum sizing ratio for solar panel and inverter is 1:0.8 since it gives benefits it return of investment as well as maintaining the system efficiency.

5.2 Recommendation

As for the recommendation, in future research the optimum sizing can be tested on different types of inverter such as Low-Frequency inverter and Transformerless inverter. During the testing process, an inverter sizing should be adjusted instead of panel sizing so that the value of output power can be more accurate. Besides, in future the ratio can be tested up to 1:0.5 in order to have more accurate result on sizing ratio between solar panel and inverter.

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APPENDIX A

CONTRIBUTION: JOURNAL PAPER TO BE SUBMITTED TO INTERNATIONAL JOURNAL OF RENEWABLE ENERGY RESEARCH (IJRER)

Optimum Sizing of GCPV System Under Tropical Condition

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Abstract- Initial investment for Photovoltaic system is expensive. Therefore, meticulous planning on the financial investment is needed. Usually, 60% from the total installation PV system cost went to solar panel and around 15% to 20% goes to the inverter. Nowadays, there is no written standard or guideline yet on the optimum sizing of solar panel and inverter. Therefore, this research aims to determine the optimum sizing ratio between solar panel and the inverter. To do so, average of one year tilted irradiance and back panel temperature data are collected. Then, the collected data is simulated by PV simulator which is set at different sizing ratio which are 1:0.7, 1:0.8, 1:0.9, 1:1, 1.1.1, 1:1.2. The results show that the most optimum sizing ratio between solar panel and inverter is at 1:0.8 since it has 0.73% higher than 1:1 sizing ratio. Next, financial impact study shows that sizing ratio at 1:0.8 saves RM 1, 600 for 4kW system. By utilize this ratio, the total installation cost for solar system can be reduce from RM 40, 000 to RM 38, 400 for 4kW system. This is due to the fact that at an inverter sizing smaller than the panel, the inverter cannot operate the closes to its full potential.

Keywords GCPV System, Optimum Sizing Ratio, System Yield, Efficiency, Solar Panel and Inverter.

1. Introduction

By 2050, electrical energy supplies are targeted to be multiplied with a specific end goal to take care of energy demand of all household [1]. Fossil fuel sources like normal gas, coal, hydro and oil are constrained normal sources that will be depleted in future. Day by day, fossil fuel looked for from place to another. In the event that this procedure is proceeds with, these sources will get to be less and exclusive [2]. Based on Figure 1.1, According to National Energy Policy (1979), Malaysia aimed to have a safe and ecological feasible supply and to have an effective and clean use of energy in future [3]. In order to fulfil this energy policy, in the year 1999, Malaysia has adopted the Five-Fuel Diversification Strategy as shown in Figure 1.1. This strategy added new source which is renewable energy. The goal of this policy is to empower the use of renewable energy and to have a proficient and clean usage of energy [3] [4] .

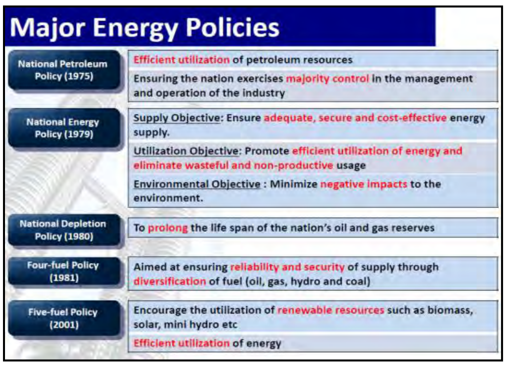

Fig. 1. Energy Policies in Peninsular Malaysia and Sabah by KETTHA [3]

Renewable energy advancements can deliver reasonable and clean energy from their sources. Renewable sources that are commonly used are Biomass which includes wood waste, Municipal solid waste and biogas, Hydropower, Geothermal, Wind and solar [5]. Solar energy is the most famous renewable energy among others in Malaysia. Solar energy has two main types which are photovoltaic (PV) and concentrated solar power (CSP). Malaysia likely most acquainted with photovoltaic which is uses by panels. For CSP innovations, regularly it will be utilized as a part of the vast power plant and is not proper for private utilize [6]. The reason why people are attracted to solar compare to others renewable sources because it is pollution free and placed near to the equator. Being close to the equator, Malaysia receive between 4,000 to 5,000 watt-per hour per square metre per day which is equivalent to sufficient energy from the sun to generate 11 years' worth of electricity.

2. Literature Review

2.1. GCPV System

Grid Connected Photovoltaic (GCPV) system has become increasingly prominent part as an electrical supply resources and a basic part of an electrical utility grid. A GCPV power system is a set of equipment that includes Photovoltaic (PV) module, an inverter and component that are connected to the utility grid. This system become famous among the user since it is very easy to install essentially does not require regular maintenance or replacement parts. In principle, this system does not need the used of battery since it is connected to the grid which absorb the excess of electricity generated by the photovoltaic and export the electricity to the needed [7]. Fig. 2 shows a typical GCPV system configuration. This system consists of the solar panels, inverter, electrical panel such as a breaker box, utility meter and utility grid [8]

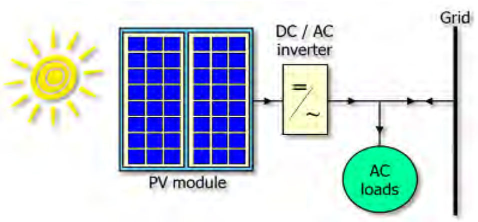

Fig. 2. Typical Grid-Connected Photovoltaic configuration [9].

GCPV system consists of the solar panels, inverter, electrical panel such as a breaker box, utility meter and utility grid [8]. When the irradiance strikes the solar panel, the semiconductor material absorb as much as sunlight as possible and converted it into DC electricity. After that, the DC electricity flows through the DC cable to the inverter. Inverter functioned to convert DC electricity to AC electricity but in this system it converts electricity to grid compatible AC which is equal to 50Hz and 240V. This inverter is known as synchronous inverter since it produces electricity in sync with the grid. Next, the 240V AC electricity flows to the electrical panel which is breaker box. This breaker box is connecting to the grid and all the loads like home appliances. From this breaker box, the AC electricity is supplied to all the active loads. If there are the excess of electricity generated by solar system, it will automatically export to the grid. However, if the electricity is not sufficient for all the active loads, the grid will automatically supply the electricity to the active load[10]

2.2. Solar Panel

Solar panel is functioning to collect the sunlight and convert it into the DC power. The Photovoltaic (PV) module is made up by the cells that compose the module itself. There four types of solar panels which are Monocrystalline, Polycrystalline, thin-film and Hybrid panel (HIT) [11]. Thin-Film technology is called Thin-film since it used a much thinner level of photovoltaic material. In a hot temperature, thin film performs the best compare to other type of solar cell. Unfortunately, this solar cell has a very low efficiency and some of its material has demonstrated degradation of performance after some time and balanced out efficiencies can be 15 % to 35% lower than initial rates [12]. Next, for Polycrystalline technology it used silicon material but for now many fragment of silicon is melted together to form the wafers for the solar panel[13]. This technology has less efficiency compared to monocrystalline. This is because it produces more power in hot weather which usually out of its cell efficiency. Besides Polycystalline, Monocrystalline solar panel is the most seasoned solar cell technology among others. Till today, this technology is being used due to their high efficiency solar cell. Monocrystalline refers to "a single crystal" of silicon and it is designed black in colour. Silicon is used instead of other material since it is able to achieve high degree of purity. In term of efficiency, Monocrystalline has the highest efficiency compare to Polycrystalline and Thin-film under standard operating conditions[11]. Last but not least is the Hybrid technology. HIT which is refers to Heterojunction with Intrinsic Thin Layer is a combination of crystalline and thin film technologies. This combination of two technologies resulted to the increasing the efficiency of the solar cell. Nowadays, this panel is the most expensive solar panel with the highest panel efficiency. In high temperature, this solar panel will produce 10% or more electricity (kWh) compare to other types of solar panel with the same temperature [14]. Table 1 shows the comparison between four types of solar panel in several criteri

Table 1. Comparison between four types of solar panel with different criteria

Brand	Capacity	Module type	Module efficiency	Temperature coefficient	Panel size
Kaneka U-EA120	120W	Thin-Film	9.8%	-0.35% / ºC	1210×1008×40 mm
Yingli YLG 72 CELL	325W	Polycrystalline	16.7%	-0.42% / ºC	1960×990×40 mm
Canadian Solar	325W	Monocrystalline	16.94%	-0.41% / ºC	1954×982×40 mm
Panasonic VBHN325SA 16	325W	HIT	19.4%	-0.29% /ºC	1590×1053×35 mm

2.3. Solar Inverter

Inverter plays an important role in solar photovoltaic system.Generally, inverter is functioning to convert DC supply into AC supply. There are three types of inverter that is frequently used which is Low-Frequency Inverter, High-Frequency Inverter and Transformerless inverter [15]. Low-frequency inverter offers the advantage in peak power capacity and reliability. Indeed, it can operate at pinnacle power level up to 30% of their nominal power in several seconds. In term of reliability, this inverter operated by utilizing powerful transformer contrast with different sorts inverter. This inverter is suitable to be used for powerful appliances such as washing machine, air conditioner, refrigerators, and microwaves[16]. Next is High-frequency inverter technology. This technology has high level of efficiency by decreasing power losses of the transformer. It also does need more complex circuitry but it is lighter compare to low-frequency inverter because of the smaller transformer is used. This type of inverter provides safety through galvanic isolation amongst AC and DC side [17]. If there is any leakage current at the PV side, the current floats and will not spill back to the neutral point through ground despite the fact that somebody touches the panel. Therefore, it is safe to be used [18]. Last but not least, Transformerless inverter refers to the technology that generates power without using any transformer between AC side and DC side. These TL inverters utilized a computerized multi-step process and electronic segments to change over DC to high frequency AC output. Since this technology is not using transformer, these inverter become lighter, small in size, compact and relatively inexpensive [19]. Some of major problem occurs while using this type of inverter is; there is no electrical isolation between the DC and AC sides. When there is leakage current occurs at PV modules side, the current might flow through human body as a return path to neutral point [18]. Table 2 shows the comparison of the three different topology of inverter with different criteria.

Table 2. Comparison between three different topology of solar Inverter with different criteria

Brand	Capacity	Topology	Inverter efficiency	Weight	Cost
SMA SB3000	3200W	Low-Frequency Transformer	95%	32kg	±RM5,698
SMA SB3000HF	3150W	High-Frequency Transformer	96.3%	17kg	±RM7,300
ABB UNO-3.0-TL-OUTD	3200W	Transformerless	97.3%	12kg	±RM7,400

2.4. System Yield

Energy Yield is the energy output over a whole year for a specified peak power rating (kWp) solar array[20]. The factors that influence the solar system energy yields is the rated power. The higher the installation size will produce more electrical energy. Through in-depth study, the amount of energy yield of the solar cell is produce depending on their irradiance. The higher the value of irradiance strikes the photovoltaic cell will result the higher value of energy yield[21].

Mathematically, the yearly average energy yield equation can be express as[20]:

$$E_{sys} = P_{array\_STC} \times f_{temp} \times f_{mm} \times f_{dirt} \times H_{tilt} \times \eta_{pv\_inv} \times \eta_{inv} \times \eta_{inv-sb} \qquad \text{Eq. (1)}$$

Where;

P_{array_STC} = Rated output power of the array under standard test condition

f_{temp} = Temperature de-rating factor, dimensionless

f_{man} = De-rating factor for manufacturing tolerance, dimensionless

f_{dirt} = De-rating factor for dirt, dimensionless

H_{tilt} = Yearly irradiation value (kWh/m^2) for the selected site (allowing for tilt, orientation and shading)

η_{inv} = Efficiency of the inverter dimensionless

η_{pv_inv} = Efficiency of the subsystem (cables) between the PV array and the inverter

η_{inv-sb} = Efficiency of the subsystem (cables) between the inverter and the switchboard

3. Methodology

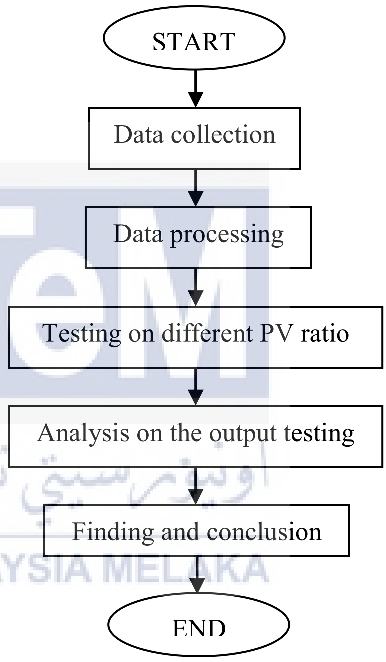

Fig. 3. Flowchart of the Research Project

3.1. Data Collection and Processing

Data collection that is used for this research is irradiance and back panel temperature. The irradiance data is measured by using Pyranometer CM 11 which is designed to measure the irradiance (radiant-flux, Watt/m^2) on plane surface, which results from the direct solar radiation and from the diffuse radiation incident from the hemisphere above. While for back panel temperature, the CS220 surface-mount thermocouple is used to measure the temperature on the back panel of a solar panel. Fig. 4 shows the image of pyranometer CM 11 on the left side and CS220 surface-mount thermocouple on the right side which is used to measure irradiance and back panel temperature in this research .

Fig. 4. Pyranometer CM 11 (left) and CS220 surface-mount thermocouple (right)

Both of the irradiance and back panel temperature data will be used to obtain the value of P_{DC}, P_{AC}, I_{DC}, I_{AC}, V_{DC}, V_{AC} and efficiency during testing process. These data has been collected from weather station monitoring system at SGPV laboratory University Technical Malaysia Melaka.Fig. 5 shows the Real Time Display (RTD) which is the main display of the system. In RTD, one can view the real time next data derived by several of sensors. Alternatively, there is an option to view the real time running graph for some some of the sensors data.

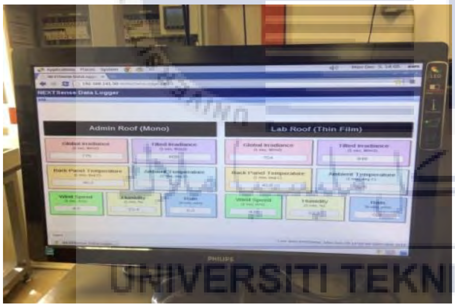

Fig. 5. The Real Time Display (RTD)

3.2. Testing Process

Fig. 6 shows the experimental setup during testing process. The main purpose of this testing is to determine optimum sizing ratio between panel and inverter. The main component used in this process is DC simulator, inverter that is connected to the load and grid and power meter. DC simulator is used to represent solar panel. This testing process used raw data of irradiance, G and back module temperature, T. The outputs to be obtained from this process are P_{DC}, P_{AC}, I_{DC}, I_{AC}, V_{DC}, V_{AC} and efficiency.

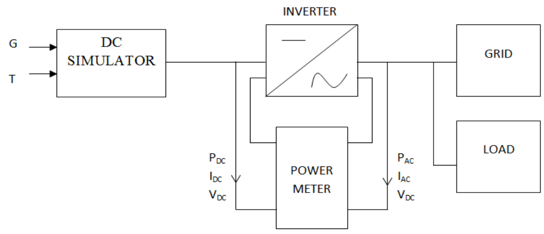

Fig. 6. Block diagram of testing process

The process begins by inserting the value of irradiance and back module temperature to the DC simulator. DC simulator will convert irradiance and temperature values into current and voltage respectively according to the setting of module technology to be used. The voltage and current produces are in DC electricity. After that, the DC electricity will flow to the inverter through DC cable. Inverter used in this testing process is SB3000 HF and it functioned to convert DC electricity into AC electricity. At the same time, the power meter will display the value of produce the value of P_{DC}, P_{AC}, I_{DC}, I_{AC}, V_{DC}, V_{AC}.

Table 3 shows the ratio between the panel and inverter to be used in obtaining the optimum sizing of GCPV system under tropical conddition.

Table 3. Ratio Panel to Inverter

No.	Ratio Panel to Inverter	Power Panel to inverter, (W)
1	1.0:0.7	4,095:3,150
2	1.0:0.8	3,780:3,150
3	1.0:0.9	3,465:3,150
4	1.0:1.0	3,150:3,150
5	1.0:1.1	2,835:3,150
6	1.0:1.2	2,520:3,150

4. Result

4.1. Testing Result

The value of irradiance that strikes the photovoltaic cell is affecting the current dramatically. As the value of irradiance increase, the value of current also will be increase. Fig. 7 and Fig.10 shows the graph of input and output current of all ratio plotted on the same axes. Based on the graph below, ratio of 1:0.7 shows the highest reading value of input and output current while the ratio that shows the lowest reading of input and output current 1:1.2 ratio. The input current record the highest value of current exceeds 5A while the lowest value less than 1A. Meanwhile, the output current record the highest value exceed than 10A and the lowest value less than 2A. Output current recorded high value of current compare to input current due to the decreasing value of the output voltage.

The temperature of the cell is affecting the voltage. As the value of temperature is increase, the value of voltage become decrease which in turn will directly affects the power outputs. Based on the graph of input and output voltage in Fig. 8 and Fig. 11 shows the graph of input and output voltage of every ratio plotted on the same axes. Based on the input voltage graph in Fig. 8, ratio of 1:0.7 shows the highest reading value of input voltage which is exceed 600V while ratio 1:1.1 shows the value less than 500V. For output voltage, ratio of 1:0.7 records the highest and the lowest value which is exceeding 230V and less than 229.5V respectively. Based on the figure below, the value of output voltage is lower than input because of the system is grid connected which it will maintain the voltage and frequency at 230V and 50Hz respectively.

Inverter functioned to maintain the power so that the input power is equal to output power. When the input voltage (DC) is set at 500V, the grid connected will maintain the voltage at 230V, 50Hz frequency at AC side. When the values of the voltage become decrease at AC side, this will result the higher value of AC current. Because of that, the output current in in Fig. 10 is higher than input current. The value of power in Fig. 9 and Fig. 12 is depending on the input and the output of voltage and current. At DC side, the power is equal to the product of voltage and current, $P = I \times V$ while for AC side $P = I \times V\ COS\ \theta$. Due to the inverter loss, the value of the power is quite lower on the AC side (Output). Inverter loss is referring to the switching factor in the inverter.

Fig. 14 and Fig. 15 shows the bar chart for the maximum and average output power respectively for all ratio. Based on the graph, ratio that has the highest output power is 1:0.7. This is because of during the testing process, the panel size used for this ratio is bigger than other ratio. Whıle, ratio of 1:1.2 has the lowest output since the panel size is undersize 20% from the actual size. Since the different size of solar panel used for each ratio, output power cannot be considered in order to consider the most optimum ratio between solar panel and inverter. To be fair, the efficiency will be considered in order to determine the most optimum of solar panel and inverter.

4.2. System Efficiency

The efficiency has been calculated by using the following formula;

$$Efficiency = \frac{P_{OUT}}{P_{IN}} \qquad \text{Eq. (2)}$$

Fig. 13 shows the graph of efficiency versus irradiance of all ratio plotted on the same axes. Based on the graph below, ratio of 1:0.8 recorded the highest value of efficiency which is approximately to 100%. Meanwhile, ratio that has the lowest efficiency is 1:1 ratio which has the efficiency approximately to 20%.

Fig. 16 shows the bar chart of the average efficiency of every ratio. By referring figure below, ratio 1:0.8 has the highest efficiency compared to other ratios. Ratio 1:0.8 recorded the value of efficiency at 93.15%. Ratio 1:0.9 has the second highest ratio with 93.08% after ratio 1:0.8. Ratio of 1:0.7, 1:1 and 1:1.2 gives the efficiency reading of 92.66%, 92.47% and 92.78% respectively. Ratio that recorded the lowest value of efficiency is 1:1.1 with the recorded efficiency value of 92.04%. Therefore, ratio 1:0.8 has the most efficient system compared to other system.

5. Financial Impact

<u>1:1 Ratio of Inverter to Solar Panel</u>

Total Installation Cost for 4kW system
$$= \text{RM } 40{,}000$$

Price for 4kW inverter $= (4\text{kW} \times 2) + 1$
$$= \text{RM}9{,}000$$

$$\text{Therefore; } \frac{\text{RM } 9{,}000}{\text{RM } 40{,}000} \times 100\% = 22.5\%$$

Inverter cost is 22.5 % from the total cost of installation

The calculation shows that the total cost of 4kW installation by using 1:1 ratio of inverter to solar panel is RM 40,000. The price for 4kW inverter is RM 9,000 which is equal to 22.5% from the total installation cost.

<u>1:0.9 Ratio of Solar Panel to Inverter</u>

$$\text{Price for 3.6kW inverter} = (3.6\text{kW} \times 2) + 1 = \text{RM } 8{,}200$$

$$\text{Therefore; } \frac{\text{RM } 8{,}200}{\text{RM } 40{,}000} \times 100\% = 20.5\%$$

Inverter cost is 20.5 % from the total cost of installation.

$$\text{Saving Cost} = \text{RM}9{,}000 - \text{RM}8{,}200 = \text{RM } 800$$

$$\text{New total installation cost} = \text{RM } 40{,}000 - \text{RM } 800 = \text{RM } 39{,}200$$

For this case, the inverter has been undersize to 3.6kW and will be implemented in 4kW system. The price of inverter is reducing to RM 8,200 which is equal to 20.5% from the total cost of installation. This system saves RM 800 and the new total cost of installation after under-sizing the inverter is RM 39,200.

1:0.8 Ratio of Solar Panel to Inverter

$$\text{Price for 3.2kW inverter} = (3.2\text{kW} \times 2) + 1 = \text{RM } 7{,}400$$

$$\text{Therefore; } \frac{\text{RM } 7{,}400}{\text{RM } 40{,}000} \times 100\% = 18.5\%$$

Inverter cost is 18.5 % from the total cost of installation.

$$\text{Saving Cost} = \text{RM}9{,}000 - \text{RM}7{,}400 = \text{RM } 1{,}600$$

$$New\ total\ installation\ cost = RM\ 40{,}000 - RM\ 1{,}600 = RM\ 38{,}400$$

In this case, the inverter has been undersized to 3.2kW and will be implemented in 4kW system. The price of inverter is reducing to RM 7,400 which is equal to 18.5% from the total cost of installation. This system saves RM 1600 and the new total installation cost reduce to RM 38,400.

1:0.7 Ratio of Inverter to Solar Panel

$$\text{Price for 2.8kW inverter} = (2.8\text{kW} \times 2) + 1 = \text{RM } 6{,}600$$

$$\text{Therefore; } \frac{\text{RM } 6{,}600}{\text{RM } 40{,}000} \times 100\% = 16.5\%$$

Inverter cost is 16.5 % from the total cost of installation.

$$\text{Saving Cost} = \text{RM}9{,}000 - \text{RM}6{,}600 = \text{RM } 2{,}400$$

$$\text{New total installation cost} = \text{RM } 40{,}000 - \text{RM } 2{,}400 = \text{RM } 37{,}600$$

For this case, the inverter has been undersized to 2.8kW and will be implemented in 4kW system. The price of inverter is reducing to RM 6,600 which is equal to 16.5% from the total cost of installation. Under-sizing the inverter saves cost about RM 2400 and the new total installation cost reduce to RM 37,600.

Ideal System Yield for One Year

$$\text{System Yield} = \text{P\_array} \times \text{PSH} \times \text{No. of. days} \times \text{Error} \times \text{Efficiency} \quad \text{eq. (3)}$$

where;

P_{array} = Power array

PSH = Peak Sun Hour

$$\textbf{therefore};\ \text{S.Y} = 4\text{kW} \times 5\text{ hour} \times 365\text{ days} \times 0.8 \times 0.963 = 5623.92\text{kW/h}$$

System Yield of Each Ratio

$$\text{System Yield} = \text{Efficiency} \times \text{Ideal System Yield} \quad \text{eq. (4)}$$

Table 4 shows the calculation of system yield for every ratio. By referring to the table below, the ratio that has the value of system yield approximately to the ideal system yield is 1:0.8 ratio. Therefore, it can be conclude that, ratio 1:0.8 has the highest output power rating (kWp) over a whole year.

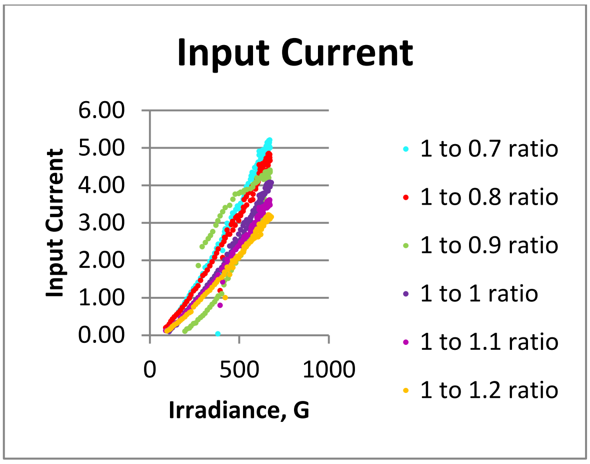

Fig. 7. Input Current Graph of All Ratio

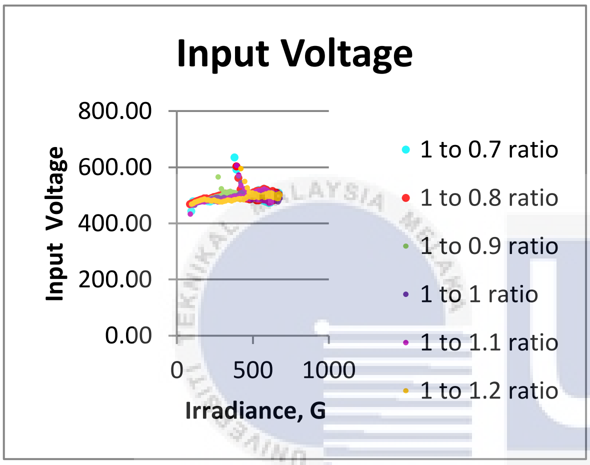

Fig. 8. Input Voltage Graph of All Ratio

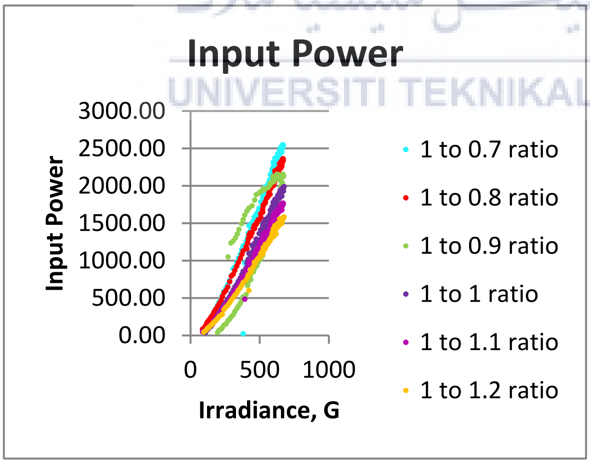

Fig. 9. Input Power Graph of All Ratio

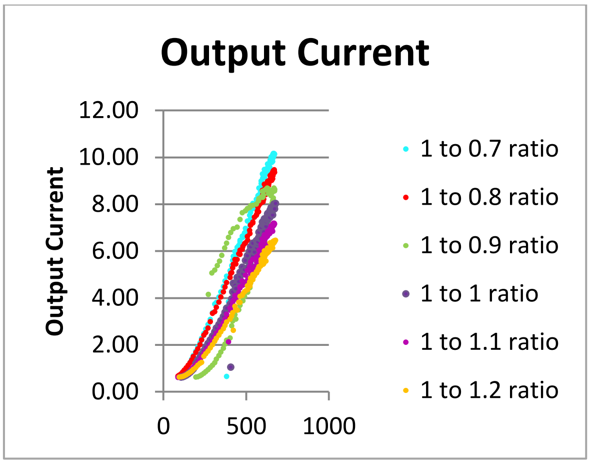

Fig.10 . Output Current Graph of All Ratio

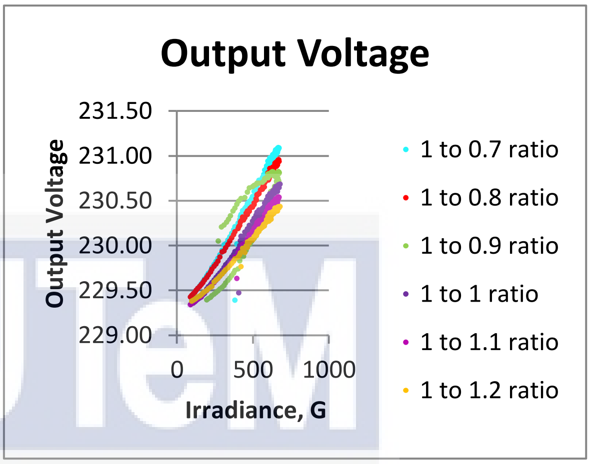

Fig. 11. Output Voltage Graph of All Ratio

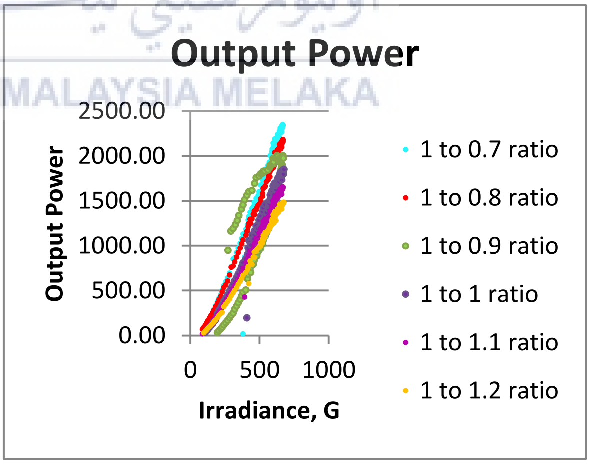

Fig. 12. Output Power Graph of All Ratio

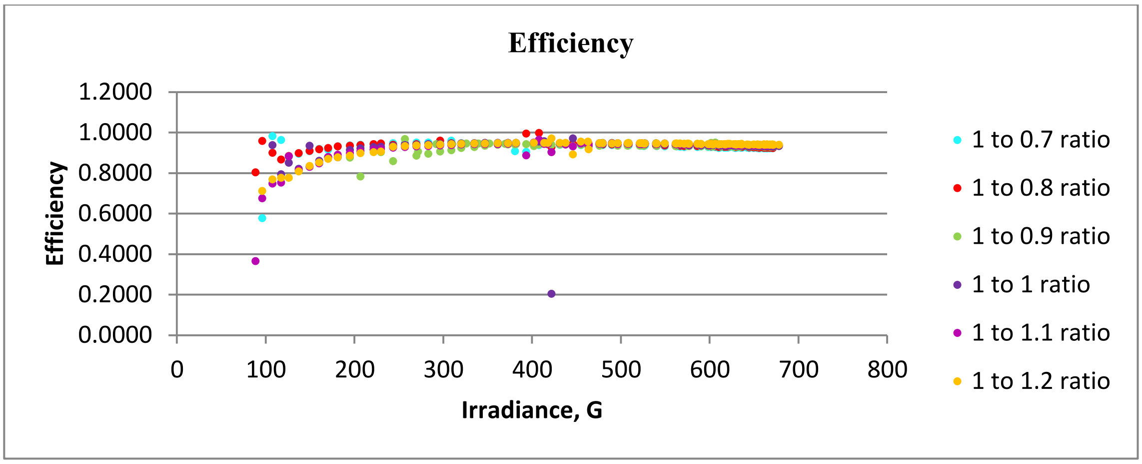

Fig. 13. Efficiency of each ratio plotted on the same axes

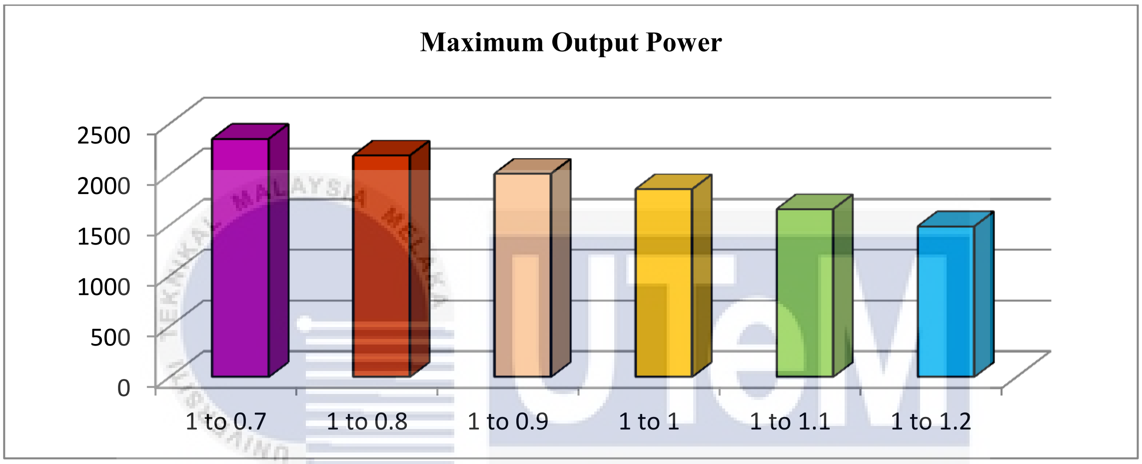

Fig. 14. Maximum Output Power of each network

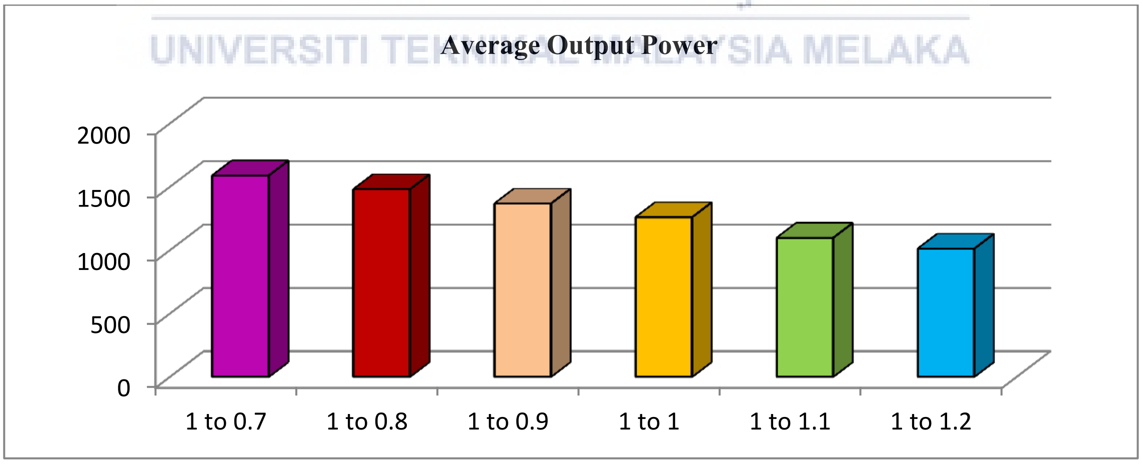

Fig. 15. Average Output Power of each ratio of each network

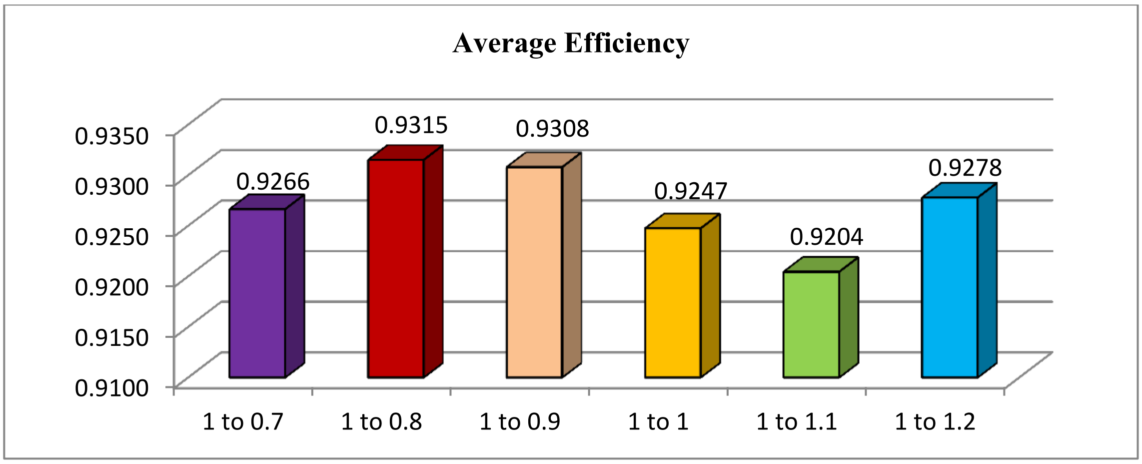

Fig. 16. Average Efficiency of each ratio

Table 4. System Yield of every ratio

1: 0.7	$0.9266 \times 5623.92kW/h = \mathbf{5211.12kw/h}$
1 : 0.8	$0.9315 \times 5623.92kW/h = \mathbf{5238.68kw/h}$
1 : 0.9	$0.9308 \times 5623.92kW/h = \mathbf{5234.74kw/h}$
1 : 1.0	$0.9247 \times 5623.92kW/h = \mathbf{5200.44kw/h}$
1 : 1.1	$0.9204 \times 5623.92kW/h = \mathbf{5176.26\ kw/h}$
1 : 1.2	$0.9278 \times 5623.92kW/h = \mathbf{5217.87kw/h}$

6. Conclusion

The purpose of this research is to determine the most optimum sizing ratio of GCPV system between solar panel and inverter for the practice in tropical climate condition. It is clear that ratio 1:0.8 is the most optimum sizing ratio compare to other ratio. This is because of it has the highest efficiency compare to other ratio. This system has 93.15% of efficiency. It is clear that by using this ratio, the inverter can operate at maximum power output. In addition to that, this system will decrease inverter losses. Besides that, this system can save RM1, 600 for 4kW system installation. By implementing this ratio in the installation of solar system will make the total installation cost for 4kW reduce to RM 38, 400. Last but not least, this system also has the highest system yield at 5238.68kW/h. This value is approaching the ideal system yield. Therefore, this is also one of the reason that ratio of 1:0.8 is the most optimum ratio between solar panel and inverter.

As for the recommendation, in future research the optimum sizing will be tested on different types of inverter such as Low-Frequency inverter and Transformerless inverter.

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APPENDIX B

Datasheet of Inverter SB 3000HF from SMA Brand

Technical data	Sunny Boy 2000HF	Sunny Boy 2500HF	Sunny Boy 3000HF
Input (DC)			
Max. DC power (@ cos φ = 1)	2100 W	2600 W	3150 W
Max. DC voltage	700 V	700 V	700 V
MPP voltage range	175 V – 560 V	175 V – 560 V	210 V – 560 V
DC nominal voltage	530 V	530 V	530 V
Min. DC voltage / start voltage	175 V / 220 V	175 V / 220 V	175 V / 220 V
Max. input current / per string	12 A / 12 A	15 A / 15 A	15 A / 15 A
Number of MPP trackers / strings per MPP tracker	1 / 2	1 / 2	1 / 2
Output (AC)			
AC nominal power (@ 230 V, 50 Hz)	2000 W	2500 W	3000 W
Max. AC apparent power	2000 VA	2500 VA	3000 VA
Nominal AC voltage; range	220, 230, 240 V; 180 – 280 V	220, 230, 240 V; 180 – 280 V	220, 230, 240 V; 180 – 280 V
AC grid frequency; range	50, 60 Hz; ± 4.5 Hz	50, 60 Hz; ± 4.5 Hz	50, 60 Hz; ± 4.5 Hz
Max. output current	11.4 A	14.2 A	16 A
Power factor (cos φ)	1	1	1
Phase conductors / connection phases	1 / 1	1 / 1	1 / 1
Efficiency			
Max. efficiency / Euro-eta	96.3 % / 95.0 %	96.3 % / 95.4 %	96.3 % / 95.5 %
Protection devices			
DC reverse-polarity protection	●	●	●
ESS switch-disconnector	●	●	●
AC short circuit protection	●	●	●
Ground fault monitoring	●	●	●
Grid monitoring (SMA Grid Guard)	●	●	●
Galvanically isolated / all-pole sensitive fault current monitoring unit	● / –	● / –	● / –
Protection class / overvoltage category	I / III	I / III	I / III
General data			
Dimensions (W / H / D) in mm	348 / 580 / 145	348 / 580 / 145	348 / 580 / 145
Weight	17 kg	17 kg	17 kg
Operating temperature range	-25 °C ... +60 °C	-25 °C ... +60 °C	-25 °C ... +60 °C
Noise emission (typical)	www.SMA-Solar.com	www.SMA-Solar.com	www.SMA-Solar.com
Internal consumption: (night)	0.8 W	0.8 W	0.8 W
Topology	HF transformer	HF transformer	HF transformer
Cooling concept	OptiCool	OptiCool	OptiCool
Electronics protection rating / connection area (as per IEC 60529)	IP65 / IP54	IP65 / IP54	IP65 / IP54
Climatic category (per IEC 60721-3-4)	4K4H	4K4H	4K4H
Features			
DC connection: SUNCLIX	●	●	●
AC connection: screw terminal / plug connector / spring-type terminal	– / ● / –	– / ● / –	– / ● / –
Display: text line / graphic	– / ●	– / ●	– / ●
Interfaces: RS485 / Bluetooth	○ / ●	○ / ●	○ / ●
Warranty: 5 / 10 / 15 / 20 / 25 years	● / ○ / ○ / ○ / ○	● / ○ / ○ / ○ / ○	● / ○ / ○ / ○ / ○
Certificates and permits (more available on request)	CE, VDE 0126-1-1, Enel-GUIDA ED. 1.1, RD 1663, G83/1-1, PPC, AS4777, EN 50438**, C10/C11, PPDS		
* Variants for France under preparation			
** Does not apply to all national deviations of EN 50438			
● Standard features ○ Optional features – not available			
Provisional data, as of March 2010 – data at nominal conditions			
Type designation	SB 2000HF-30	SB 2500HF-30	SB 3000HF-30

APPENDIX C

Data of Solar Panel Plus SW 255 (MONO) from Solar World Brand

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

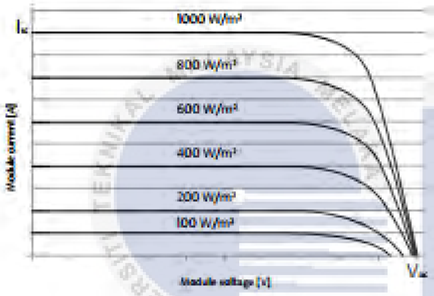
Maximum power	P_{max}	255 Wp
Open circuit voltage	V_{oc}	37.8 V
Maximum power point voltage	V_{mpp}	31.4 V
Short circuit current	I_{sc}	8.66 A
Maximum power point current	I_{mpp}	8.15 A

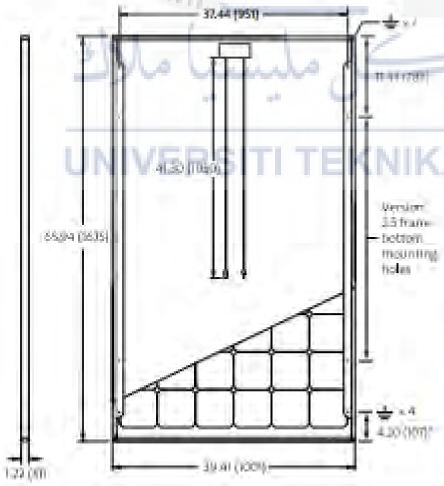
*STC: 1000 W/m², 25°C, AM 1.5

1) Measuring tolerance (P_{max}) traceable to TUV Rheinland: +/- 2% (TUV Power Controlled).

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.04 %/°C
TC V_{oc}	-0.30 %/°C
TC P_{mpp}	-0.45 %/°C
Operating temperature	-40°C to 85°C





PERFORMANCE AT 800 W/m², NOCT, AM 1.5

Maximum power	P_{max}	184.1 Wp
Open circuit voltage	V_{oc}	34.0 V
Maximum power point voltage	V_{mpp}	28.3 V
Short circuit current	I_{sc}	6.99 A
Maximum power point current	I_{mpp}	6.52 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m², 100% (+/-2%) of the STC efficiency (1000 W/m²) is achieved.

COMPONENT MATERIALS

Cells per module	60
Cell type	Mono crystalline
Cell dimensions	6.14 in x 6.14 in (156 mm x 156 mm)
Front	Tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)

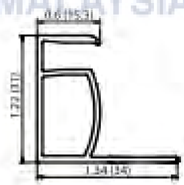
SYSTEM INTEGRATION PARAMETERS

Maximum system voltage SC II		1000 V
Max. system voltage USA NEC		1000 V
Maximum reverse current		16 A
Number of bypass diodes		3
*UL Design Loads**	*Two rail system*	113 psf downward 64 psf upward
*UL Design Loads**	*Three rail system*	170 psf downward 64 psf upward
*IEC Design Loads**	*Two rail system*	113 psf downward 50 psf upward

*Please refer to the Sunmodule installation instructions for the details associated with these load cases.

ADDITIONAL DATA

Power sorting[1]	-0 Wp / +5 Wp
J-Box	IP65
Module leads	PV wire per UL4703 with H4 connectors
Module efficiency	15.51 %
Fire rating (UL 790)	Class C
Glass	Low iron tempered with ARC



VERSION 2.5 FRAME

- Compatible with both "Top-Down" and "Bottom" mounting methods
- Grounding Locations:
  - 4 corners of the frame
  - 4 locations along the length of the module in the extended flange

NEW!

Independently created PAN files now available.
Ask your account manager for more information.