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OPTIMUM SIZING OF GCPV SYSTEM UNDER TROPICAL CONDITION

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ABSTRACT

Solar panel and photovoltaic (PV) inverter are the two elements that cost the most in a Grid-Connected Photovoltaic (GCPV) system installation. This research hence aims to determine the optimum sizing ratio between the two for the practice in the tropical climate condition. To do so, five minute average of year 2014 profile of tilted irradiance and back panel temperature data were gathered to be used in testing process. Testing was done by simulating the GCPV system by using DC simulator at three different sizing ratios: 1 to 1, 1 to 0.8 and 1 to 1.2by referring to the ratio between solar panel and inverter. Experimental results showed that the optimum sizing ratio is 1:0.8. This is because, at this setting, the simulation produced the highest system efficiency and the maximum value of system yield. In addition, this setting can also reduce the initial cost of GCPV system installation.

Keywords: GCPV system; optimum sizing ratio; system yield; efficiency; solar panel and inverter.

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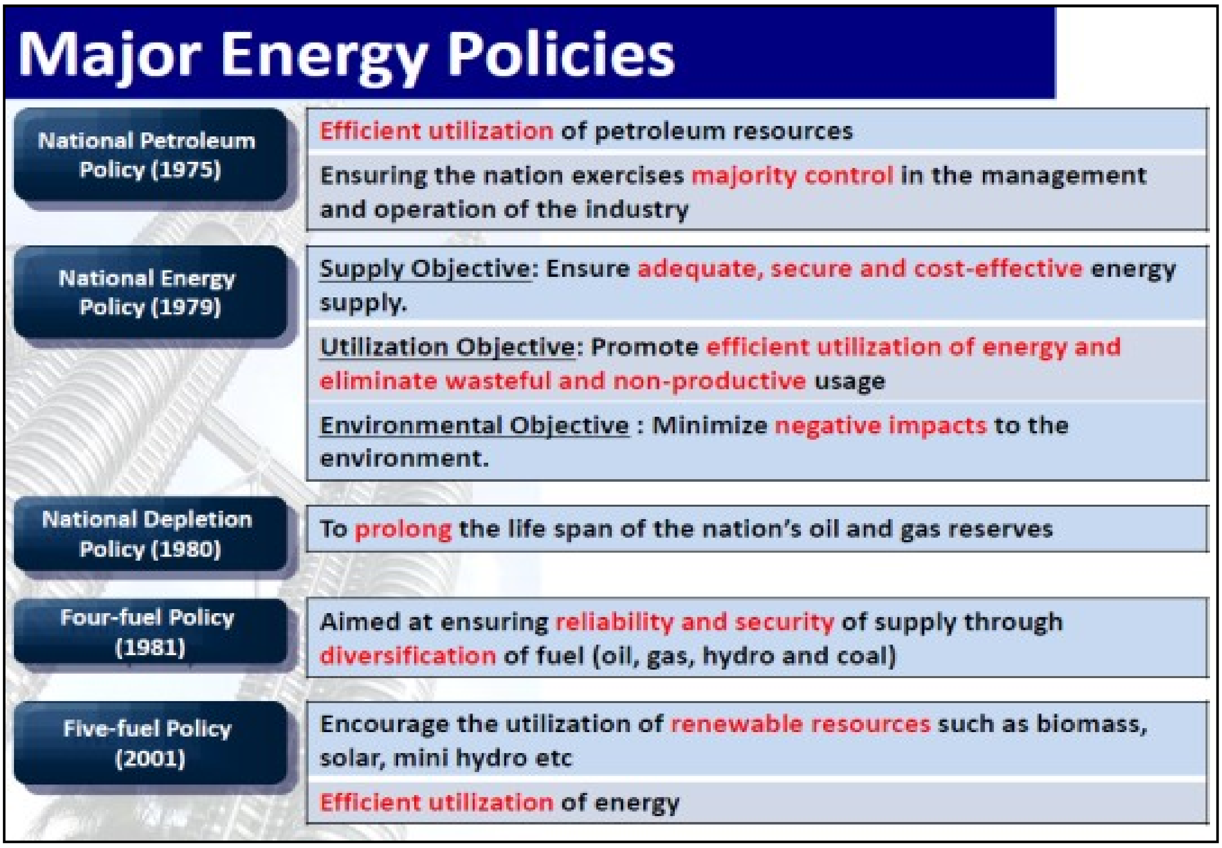
1. INTRODUCTION

1.1. Motivation

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 Fig. 1, according to National Energy Policy in 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 Fig. 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].



Major Energy Policies

National Petroleum Policy (1975)	Efficient utilization of petroleum resources Ensuring the nation exercises majority control in the management and operation of the industry
National Energy Policy (1979)	Supply Objective: Ensure adequate, secure and cost-effective energy supply. Utilization Objective: Promote efficient utilization of energy and eliminate wasteful and non-productive usage Environmental Objective : Minimize negative impacts to the environment.
National Depletion Policy (1980)	To prolong the life span of the nation's oil and gas reserves
Four-fuel Policy (1981)	Aimed at ensuring reliability and security of supply through diversification of fuel (oil, gas, hydro and coal)
Five-fuel Policy (2001)	Encourage the utilization of renewable resources such as biomass, solar, mini hydro etc Efficient utilization of energy

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 meter per day which is equivalent to sufficient energy from the sun to generate 11 years' worth of electricity.

1.2. Literature Review

1.2.1.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].

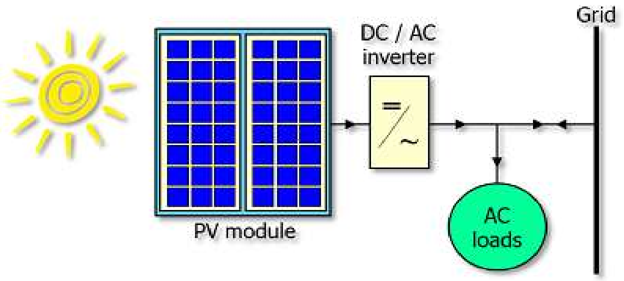


Fig.2. Typical grid-connected photovoltaic configuration [9]

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].

1.2.2. 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 polycrystalline, monocrystallinesolar 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 criteria.

Table1. 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

1.2.3.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 transformerlessinverter [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 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]. Table2 shows the comparison of the three different topology of inverter with different criteria. The different types of inverter efficiency are as described in [22].

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 SB3000 HF	3150W	High-Frequency Transformer	96.3%	17kg	±RM7,300
ABB UNO-3.0-TL-OUTD	3200W	Transformerless	97.3%	12kg	±RM7,400

1.2.4.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]:

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

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

2. RESULTS AND DISCUSSION

2.1. 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. 3 until Fig.12 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.

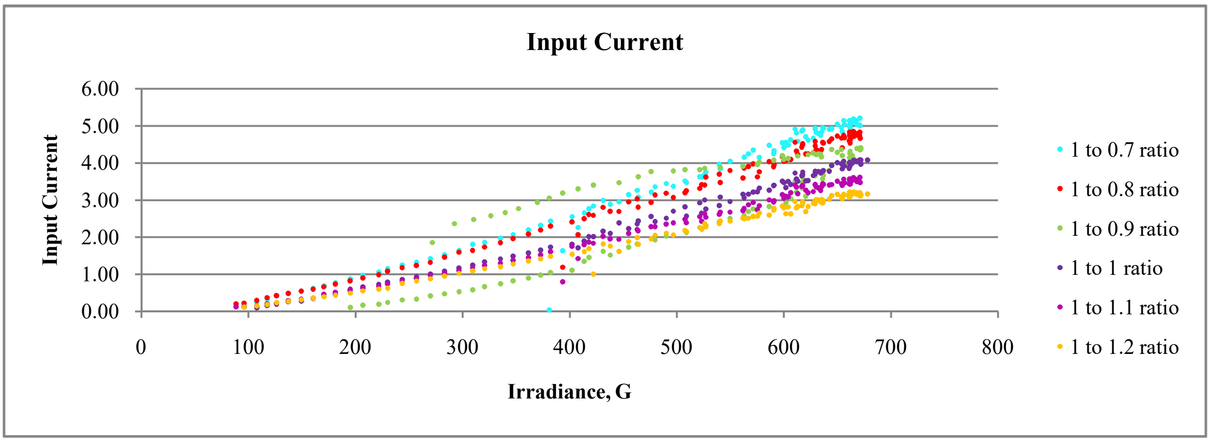


Fig.3. Input current graph of all ratio

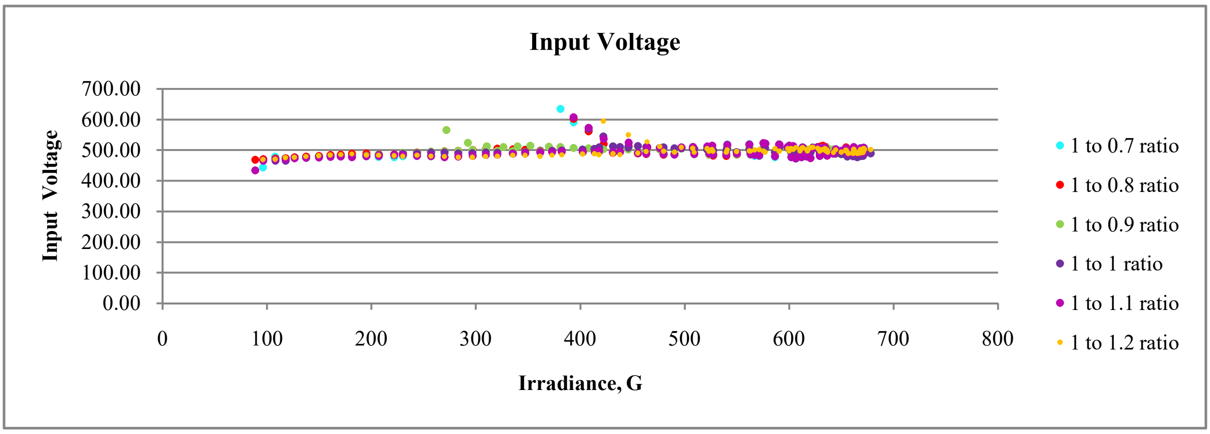


Fig.4. Input voltage graph of all ratio

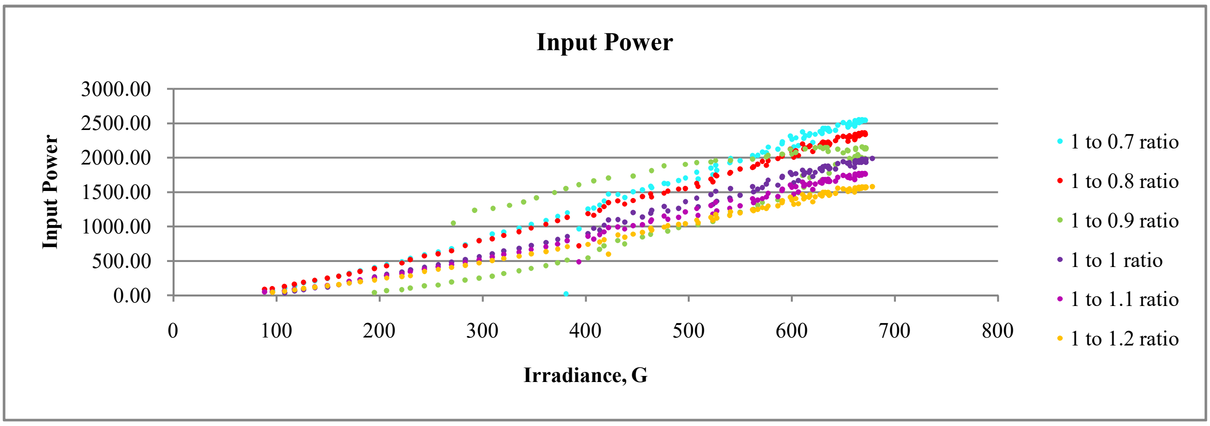


Fig.5. Input power graph of all ratio

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. 4 and Fig. 7 shows the graph of input and output voltage of every ratio plotted on the same axes. Based on the input voltage graph in Fig. 4, 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 Fig. 7, 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.

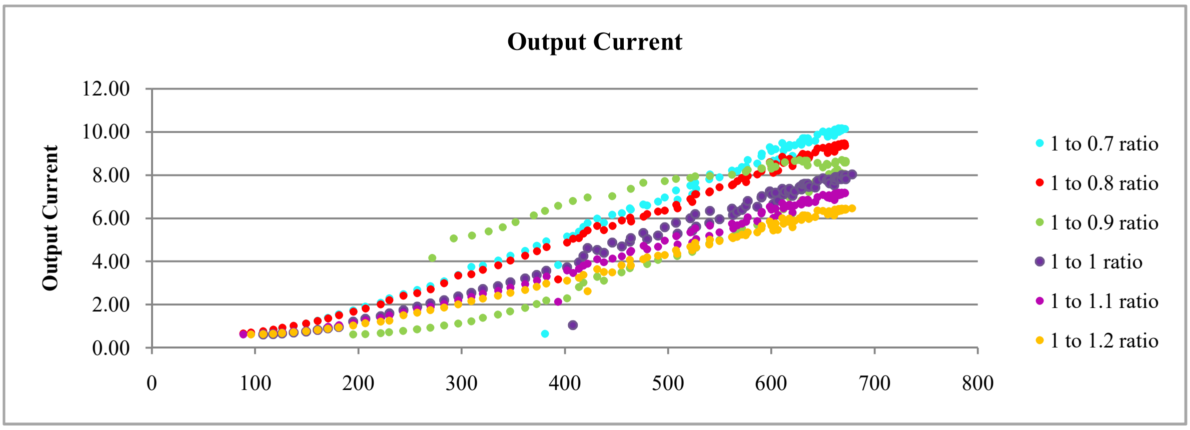


Fig.6. Output current graph of all ratio

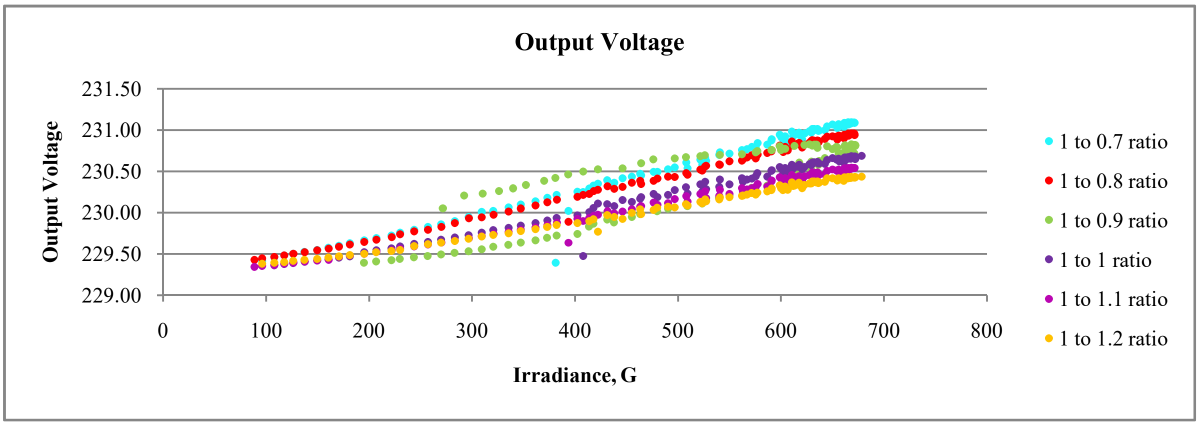


Fig.7. Output voltage graph of all ratio

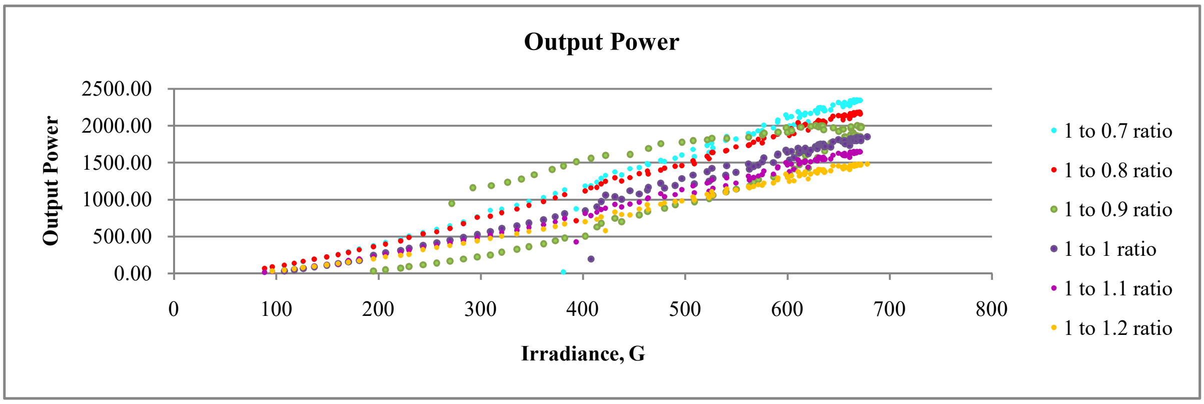


Fig.8. Output power graph of all ratio

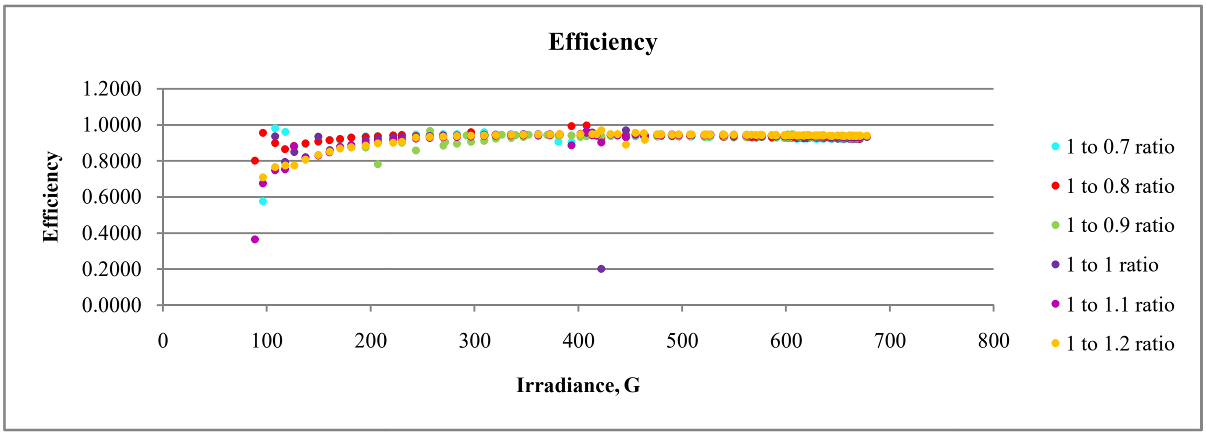


Fig.9. Efficiency of each ratio plotted on the same axes

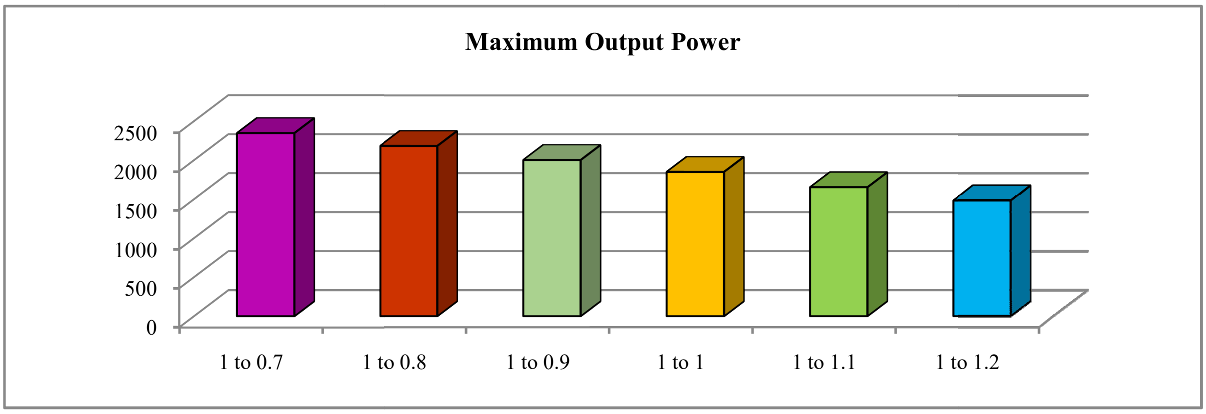


Fig.10. Maximum output power of each network

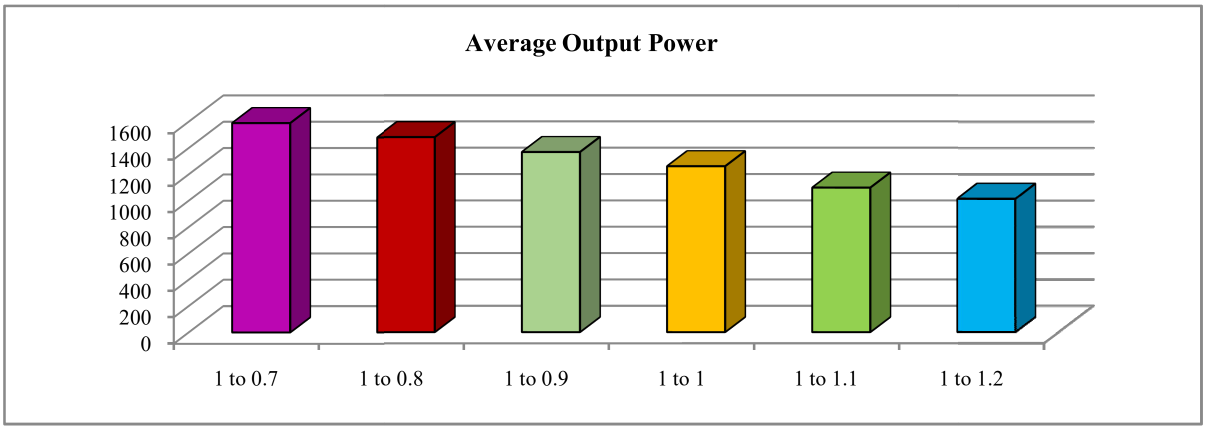


Fig.11. Average output power of each ratio of each network

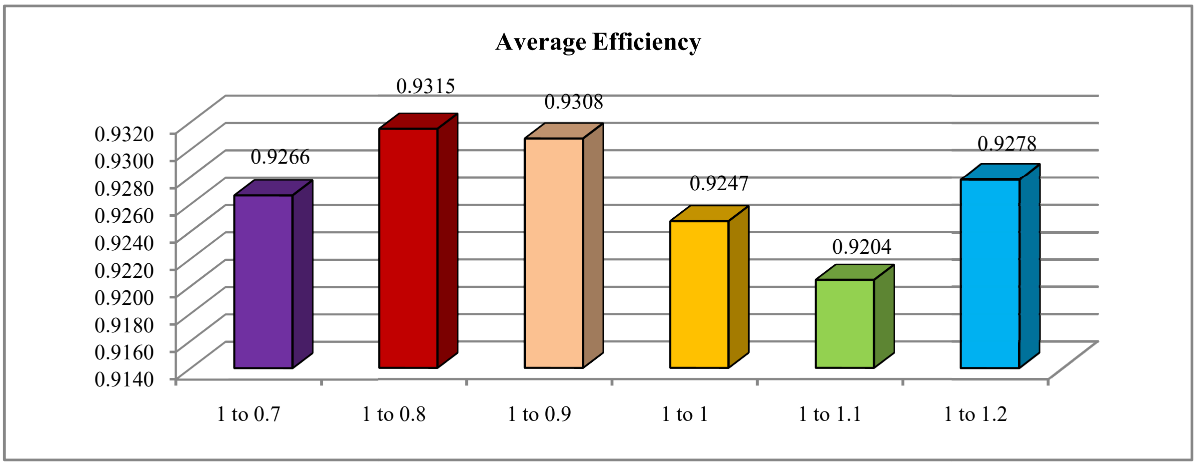


Fig.12. Average efficiency of each ratio

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. 6 is higher than input current. The value of power in Fig. 5 and Fig. 8 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. 11 and Fig. 12 show 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.

2.2. System Efficiency

The efficiency has been calculated by using the following formula:

$$Efficiency = \frac{P_{OUT}}{P_{IN}} \tag{2}$$

Fig. 9 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. 12 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.

2.3.Financial Impact

2.3.1.1:1 Ratio of Inverter to Solar Panel

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

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

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

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

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.

2.3.2.1:0.9 Ratio of Solar Panel to Inverter

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

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

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

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

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

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.

2.3.3. 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.

2.3.4.1:0.7 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.

2.3.5.Ideal System Yield for One Year

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

where$\text{P}_{\text{array}} = \text{Power array}$ and $\text{PSH} = \text{Peak Sun Hour}$.

Therefore;

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

2.3.6.System Yield of Each Ratio

$$\text{System Yield} = \text{Efficiency} \times \text{Ideal System Yield} \tag{4}$$

Table 3 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.

Table 3. System yield of every ratio

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

3. METHODOLOGY

3.1.Project Flow

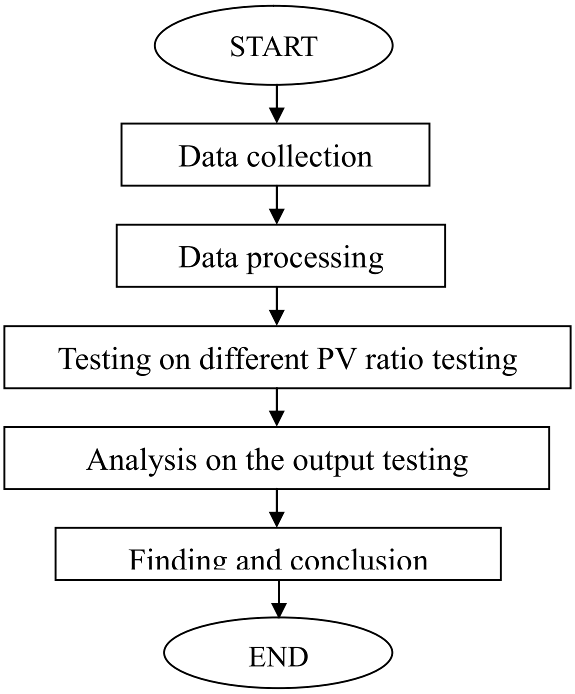


Fig.13. Flowchart of the research project

3.2.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 that 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. 14 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.14. 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. 15 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 of the sensors data.

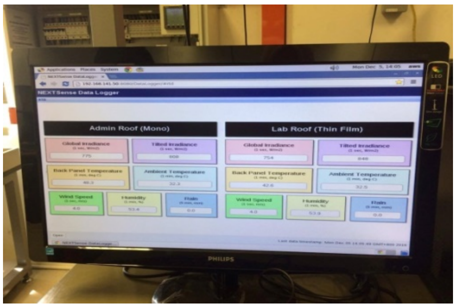


Fig.15. Real Time Display (RTD)

3.3.Testing Process

Fig. 16 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.

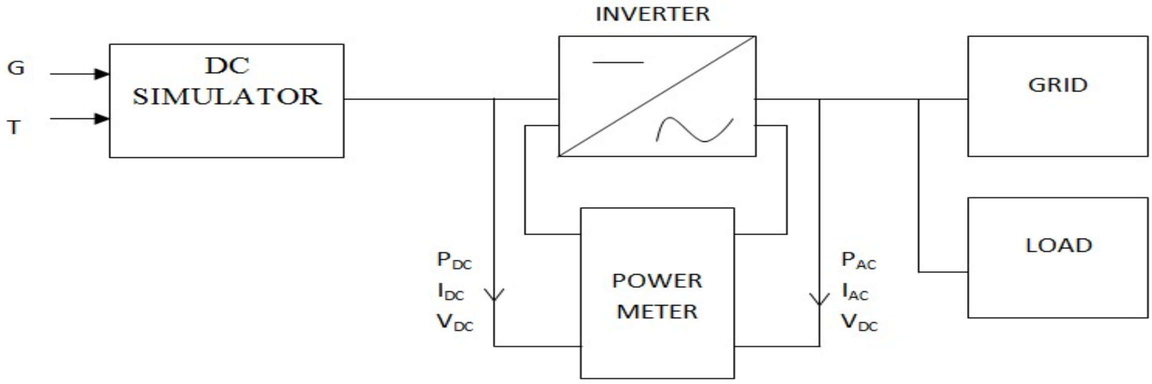


Fig.16. Block diagram of testing process

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} and V_{AC}. Table4 shows the ratio between the panel and inverter to be used in obtaining the optimum sizing of GCPV system under tropical condition.

Table 4. 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. 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.

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