CHAPTER 1

INTRODUCTION

1.1 Background Of Study

The electricity supply to rural areas develops important social and economic benefits to remote communities throughout the world. Electrification in rural areas is difficult and is not economical because of enormous costs required to provide equipment and installation but also because the amount of losses along gridlines is extensive.

Basically, there are three options for supplying electricity to rural areas which are national gridlines, use of unsustainable resources such as diesel generators and also use of sustainable resources such as solar photovoltaic system. Renewable energy sources such as solar energy are among the least cost and most practical solutions, since they are coming from indefinite and available sources, they are sustainable (minimum maintenance needs) and will cause no impact towards fragile ecosystems. Further, renewable energies can help decrease CO^2 emissions, contributing to climate change improvement.

The potential of solar powered photovoltaic systems are huge. In Malaysia, the supply of electricity to rural areas was further improved during the ninth Malaysian Plan period as shown in Table 1. The implementation of rural electrification projects benefited 59,960 housing units, mainly in Sabah and Sarawak.

Table 1: Rural Electrification coverage by region, 2000-2010 [2]

Region	2000	2005	2010
Peninsular Malaysia	97.5	98.6	98.8
Sabah	67.1	72.8	80.6
Sarawak	66.9	80.8	89.6
Malaysia	89.5	92.9	95.1

Rural areas are suitable for solar energy applications due to their geographical location and the low return from high investment such as the installation of electricity gridlines. Solar PV systems also avoid greenhouse emissions, have low operation and maintenance costs, and allow production for the development of rural communities [3].

Furthermore, the high investment costs of installing solar energy systems are often incorrectly compared to the investment costs of conventional energy technologies. In many cases, particularly in rural locations, the low operation and maintenance costs as well as the non-existent fuel expenses and the improved reliability and the longer expected useful life of solar PV energy technologies, compensate high initial capital costs, but this kind of life cycle costing is not regularly used as a source for comparison.

1.2 Problem Statement

A sizeable proportion of the Malaysian’s poor live in rural areas such as in Sabah and Sarawak which are geographically isolated and are often too thinly populated or have a low potential electricity demand to justify the extension of the grid. Therefore, it is necessary to supply electricity through other way than the extension of the national grid. Solar energy is the most adaptable, flexible and easy to use technologies for rural areas.

1.3 Project Objectives

The objectives for the project are as follows:

1. To study the principles of Solar Energy and Photovoltaic Generation System
2. To design a Rural Electrification Photovoltaic Generation System
3. To study the economic aspect of Solar Photovoltaic System and compare it with other alternatives such as diesel generators and grid extension.
4. To evaluate and analyze the system proposed.

1.4 Scope Of Study

The scopes of study are as follows:

1. Study of solar energy and photovoltaic generation system.
2. To design and develop a rural photovoltaic electrification system
3. Few experiments will be conducted to gather the data such as:
    a) Solar radiation data
    b) Other related data such as weather, plants and others.
4. Economic comparison between solar PV system, diesel generators and grid extension will be studied.

The analysis of the system will be carried out to analyze the result after the completion of the project study

a) Rural electrification model will be designed

A result of the analysis and study will be presented and will be discussed and written. Recommendation of the system will be made after all the data and design have been analyzed and estimated.

1.5 The Relevancy and Benefits of The Project

The use of electricity in rural areas could give a lot of benefits to the rural communities such as:

1. Improve education by allowing studying at night, establishing good learning conditions such as computer facilities and internet.
2. To implement safety measures such as street lighting and signs.
3. Reduce isolation by the improvement of communication and information channel such us telephone, television, radio and computers.
4. To improve healthcare conditions
5. To prevent natural disasters by giving the opportunity of installing radio receivers and television by knowing the latest weather forecast.
6. To encourage productivity, since electricity also allows for irrigation, food preservation, water pumping and many others.

1.6 Feasibility of The Project

This project is expected to be completed within two semesters. The first semester is to explore and learn more about the solar energy, photovoltaic system and to study all theory involves in the system. The second semester will be used to model the rural electrification by the photovoltaic generation system and do the economic comparison between solar PV system, diesel generators, and grid extension.

CHAPTER 2

LITERATURE REVIEW

2.1 Fundamental of Solar Energy

Solar energy is one of the renewable energy that generates power by utilizing the energy from the sun. The sun basically provides energy in two forms which are light and heat. Solar thermal use heat to produce hot fluids or air while photovoltaic produce electricity.

Malaysia located near the equator, which has the average sunlight of 6 hours and monthly radiation between 4000 to 5500 Wh/m^2. Although the daytime is almost constant throughout the year, the global solar radiation on any particular day cannot be predicted. This is typical for any location situated in the equatorial climate [3]. The solar radiation pattern in Malaysia is shown in the **Table 2.**

Table 2: Distribution of Annual Solar Radiation Pattern [3]

Pattern	Definition	Distribution (%)
Clear	Days of clear sky with direct sunlight to the ground	15.7
Part Cloudy	Days with occasional cloud blocking direct sunlight	51
Afternoon Rain	Days with rain in the afternoon	16.5
Full Cloudy and Rain	Total overcast days with occasional rain	13.7
Special Case	Days occasional radiation due to cloud and atmosphere effect	2.8

2.2 Photovoltaic System

Photovoltaic cells work by photoelectric action. Light particles from the sun or other bright light source known as photons knock electrons loose from the solar cell's photovoltaic medium, which is usually silicon. Some of these released and energized electrons travel through an electrical circuit to power a device. On their return trip through the circuit, these now de-energized electrons can do one of these two things: they can repeat the process if sunlight is present or that can settle back into the available silicon molecules if the sun goes away and stops providing photons as fuels. The greater intensity of the light, the greater flow of electricity.

Many other parts including solar cells are required in PV system to generate electricity supply. Energy storage such as a battery bank is required in PV system to provide electricity at night and during the worst period of bad weather such as in monsoon climate. Solar cells generate direct current so some power conditioning and control equipment such as DC-AC inverter is required for alternate current appliances.

The PV system consists of a number of parts [4]:

a) The PV generator
b) Battery bank
c) Power conditioning and control equipment
d) Back-up generator (if needed)

A photovoltaic system does not need bright sunlight in order to operate. It also generates electricity on cloudy days, with its energy output proportionate to the density of the clouds.

2.2.1 The PV generator

Photovoltaic involves the direct generation of electricity from light by using a semiconductor material which can be adapted to release electrons. The most important parts of a PV system are the cells which form the basic building blocks, the modules, which bring together large numbers of cells into a unit, and, in some situations, the inverters used to convert the electricity generated into a form suitable for everyday use.

Solar cells represent the fundamental power conversion unit of a photovoltaic system. They are made from semiconductors and have a lot in common with other solid state electronic devices such as diodes, transistors and integrated circuits. There are few types of solar cells available in the market such as monocrystalline silicon, multicrystalline silicon and amorphous silicon.

1. Monocrystalline silicon

   Monocrystalline is made using cells saw-cut from a single cylindrical crystal of silicon; this is the most efficient of the photovoltaic (PV) technologies. The primary advantage of monocrystalline cells are their high efficiencies, typically around 15%, although the manufacturing process required to produce monocrystalline silicon is complex, resulting in slightly higher costs than other technologies [5].

2. Multicrystalline Silicon

   Multicrystalline is made from cells cut from an ingot of melted and recrystallised silicon. In the manufacturing process, molten silicon is cast into ingots of polycrystalline silicon. These ingots are then saw-cut into very thin wafers and put together into complete cells. Multicrystalline cells are cheaper to manufacture than monocrystalline ones, due to the simpler manufacturing process [5].

3. Amorphous Silicon

Amorphous silicon cells are composed of silicon atoms in a lean homogenous layer rather than a crystal structure. Amorphous silicon absorbs light more efficiently than crystalline silicon, so the cells can be thinner. Amorphous silicon can be placed on a wide range of substrates, both rigid and flexible, which makes it perfect for curved surfaces and "fold-away" modules. However, Amorphous are less efficient than crystalline based cells, with typical efficiencies of around 6%, but they are simpler and cheaper to produce. Their low cost makes them perfectly suited for many applications where high efficiency is not essential and low cost is important [5].

The module is the element that generates the electricity. It is formed by a cluster of PV cells incorporated into a unit, usually by soldering them together under a sheet of glass. Modules can be adapted in size in order to fit the proposed site and are quickly and easily installed. They are also strong, dependable and waterproof. Modules produce electricity in DC and are available in sizes from a few watts to 300 watts.

PV array is for larger systems. Modules are attached in series or parallel. The installation should be fixed at a certain pre-determined angle to collect the maximum solar irradiation over a year or during the season of the highest demand and may be adjusted seasonally.

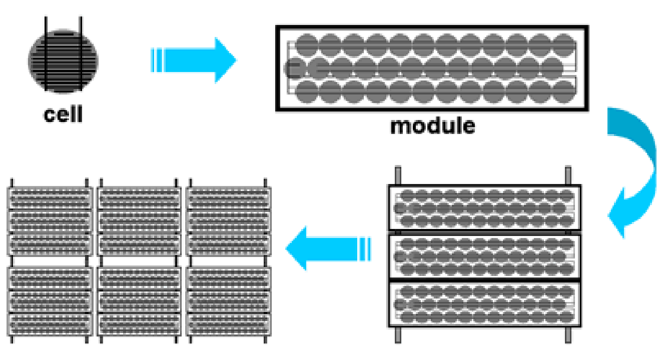


Figure 2.1: PV generator

2.2.2 *Battery Bank*

One of the crucial parts in this project is the battery bank. It is used to store up energy from the PV generator and can be used to power appliances during night or days without sunlight. There are 2 battery technologies which are generally found in PV system: lead-acid and nickel-cadmium [4]. Both can be found in a variety of sizes and capacity. Nickel-cadmium batteries present some technical advantages over lead-acid and are preferred for some applications. However, they are 3-4 times more expensive per unit of energy stored and as a result lead-acid batteries are more commonly used.

Battery is an electrochemical cell that can be charged electrically to provide a static potential for power or released electrical charge when needed. A battery generally consists of an anode, a cathode and an electrolyte.

1. The cathode or positive electrode consisting of a mass of electron-receptive chemical held in intimate contact with a metallic plate through which the electrons arrive from an external circuit
2. The anode or negative electrode, which consists of another chemical, which gives up electrons or electron donor held a close contact with a metallic member through which electrons can be conducted to the external circuit.
3. The electrolyte is usually a liquid that permits the transfer of mass necessary to the overall reaction. This movement takes place by migration of ions from an anode to a cathode or vice versa.

Figure 2.2: Battery bank

2.2.3 Power Conditioning and Control Equipment

1. Charge Regulator

A charge regulator is an electrical regulator designed to automatically maintain a constant level of voltage. A charge regulator monitors the battery bank state of charge to insure that when the battery needs charge current, it gets it. It also secures the battery from overcharged. Connecting a solar panel without a regulator may seriously risks and damages the battery. Therefore, could potentially lethal and causing a safety concern.

2. DC/AC Inverter

Inverters transform the DC electricity produced by your PV modules into the alternating current (AC) electricity commonly used in most homes for powering lights and appliances. The efficiency of the inverters usually depends on the load current being a maximum at the nominal output power. It can be as high as 95% but will be lower if the inverter is running under load.

2.2.4 Backup Generator

Solar PV generation systems can be sized to provide electricity during cloudy periods when the sun does not shine. However, sizing a system to cover a worst-case scenario, like during a monsoon season, can result in a very large, expensive system that will rarely get used to its capacity. The PV generation system has to be sized moderately, but include a backup generator in the system to get through monsoon season.

Engine generators can be fueled with biodiesel, petroleum diesel, gasoline, or propane, depending on the design. These generators produce AC electricity that a battery charger converts to DC energy, which is stored in batteries. Like most internal combustion engines, generators tend to be loud but a well designed Solar PV generation system will require running them only 50 to 200 hours a year.

Figure 2.3: Generator Set

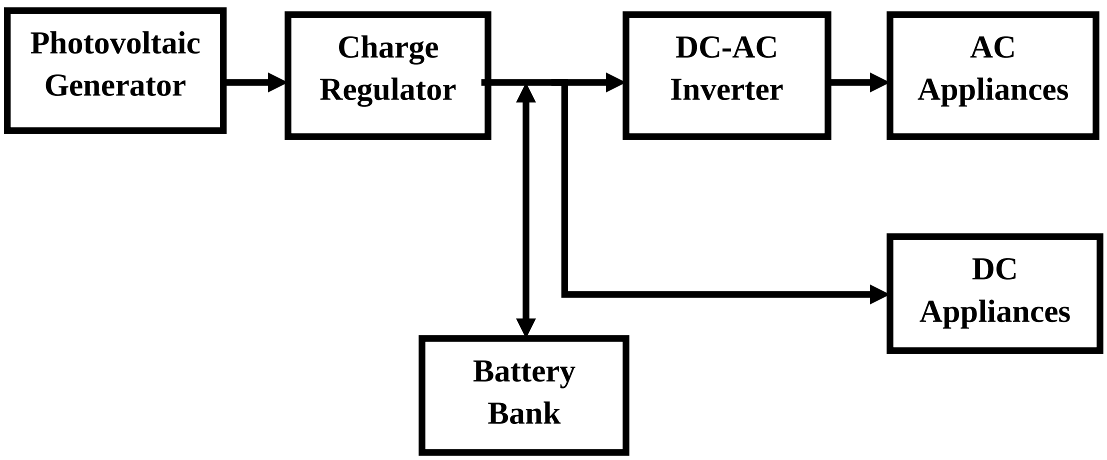


Figure 2.4: Configuration of a stand-alone PV system [4]

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

a) *Project Identification/ Problem Statement*

The project has been identified and the problem statement involves in this project is taken into account. All the features and constraints such as cost, time, energy and probability are also to be considered

b) *Literature Review and Theory*

A literature review aims to review the critical points of current knowledge on a particular topic. Several topics such as photovoltaic effect, battery efficiency and others need to be studied and to have deeper understanding of theory involves in this project.

c) *Research*

Research is done to get some information for the project. The research is done by surfing the internet, interviewing people and reading the books and journals. This is for obtaining a better understanding and technical explanation for the design.

d) *Data Gathering and Analysis*

All the research data and ideas are gathered and compiled to analyze and put together for the model development.

e) *Model Designing and Development*

Model designing process is started based on the conceptual and technical understanding and engineering calculations. All the designing and model development aspects are put under continuously ideas and careful observation.

f) *Problem Identification and Solving*

Any problems that occur during the model designing and development are taken into serious view at this stage. All works have to be reviewed all over again to overcome the problem and solve it.

g) *Final design*

At this stage, all the modeling is tested. The function of the model proposed needed to run the simulation and other important things that will ensure the workability of the final design. During this stage, all the altering was made to encounter the problems that occur and to fulfill the design specifications.

h) *Model Proposed and Result*

A model will be proposed and recommended at the end of the project. Final report will be submitted also at the end of the project.

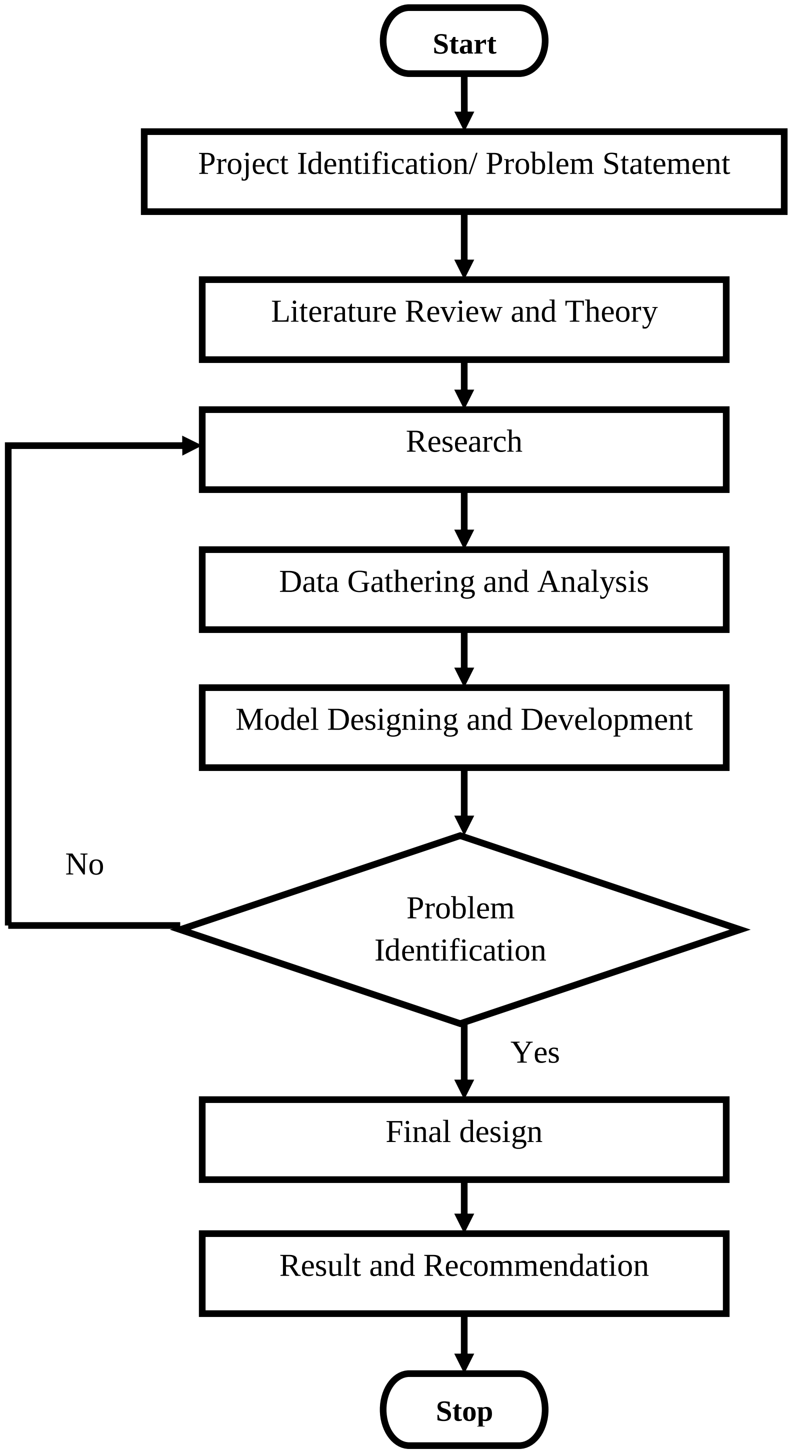


Figure 3.1: The Flow Chart of the Project

3.2 Project Activities

The project activities are as follows:

a) Literature Review

A literature review aims to review the critical points of current knowledge on a particular topic. Several topics such as photovoltaic effect, battery bank and others need to be studied and fully understood

b) Theory Understanding

Before conducting a project, the most important thing is to fully understand the theory. In this particular project, fundamental of solar energy, photovoltaic system and the full system needs to be theoretically understood.

c) Data Gathering

All the research data and ideas are gathered and compiled to analyze and put together for the model development.

d) Model Development

A rural electrification model will be developed and analyzed. A few experiments will be conducted to get a result.

e) Fine-tune and finalizing model system

At this stage, all the modeling is tested. The function of the model proposed needed to run the simulation and other important things that will ensure the workability of the final design.

f) Report writing

After analyzing all the result and finalizing the model proposed, a report is written and submitted

3.3 Tools and Equipment Required

3.3.1 Hardware

In this project, a pyranometer or sometimes we called a solar meter, is used to compute broadband solar irradiance on a surface and is a sensor which is designed to measure the solar radiation flux density in W/m^2 (watts per meter square) from a field of view of 180 degrees.

Not all of the solar energy reaching Earth's outer atmosphere reaches the surface of the Earth. Some of this energy is reflected back out into space and some of it is absorbed in the atmosphere itself. On a typical sunny day in Malaysia, about 1000 W/m2 actually reaches surface. This is a quite a lot of energy, enough to power 10x100 Watt light bulbs.

A typical pyranometer does not need any power to operate and are frequently used in meteorology, climatology, solar energy studies and building physics. They can be seen in many meteorological stations, often installed horizontally and next to solar panels, and the sensor is mounted in the surface plane of the panel. The pyranometer, has a glass dome shaded from the Sun's beam and the shading is accomplished either by an occulting (concealing) disc or a shading arm [7].

Figure 3.2: Pyranometer

3.3.2 Softwares

HOMER Software

HOMER Software is the micro power optimization model, it simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications.

The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations [8].

NI Multisim

Multisim equips educators, students, and professionals with the tools to analyze circuit behavior. The intuitive and easy-to-use software platform combines schematic capture and industry-standard SPICE simulation into a single integrated environment. Multisim abstracts the complexities and difficulties of traditional syntax-based simulation, so you no longer need to be an expert in SPICE to simulate and analyze circuits. Multisim is available in two distinct versions to meet the teaching needs of educators or the design needs of professionals [9].

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Modeling of Photovoltaic System for Rural Electrification

The evaluation criteria for rural electrification consist of several points such as [10]:

1. Population of the village
2. Number of houses
3. Geographical position, solar radiation intensity and average sunlight per day
4. Weather condition of the village
5. Electrical demand and power capacity

4.1.1 Estimation of Electric Power Consumption

There are 2 techniques considered for the PV rural electrification;

a) A stand alone individual PV generation system
b) Complex PV generation system

For an individual PV system, a battery bank is required to supply necessary power for each house. For complex PV generation system, total capacity of electrical demand is calculated for 10 and 20 houses and it will be the base for PV complex generation system.

Table 3: Estimation of Electrical Energy Consumption for Rural House

Items	**Number of Items (Estimated)**	**Consuming Power (w)**	**Duration of Use per Day (h/d)**	**Consuming Energy (wh/d)**
Lamps	5	100	10	1000
Television	1	100	10	1000
Mini Fridge	1	100	24	2400
Table Fan	2	100	6	600
Total (1 house)	9	400	50	5000

Table 4: Estimation of Electrical Energy Consumption for village with 10 and 20 houses

Number of Houses	**10**	**20**
House	50,000	100,000
Mosque	400	800
School	400	600
Water Pump	1500	3000
Streets	2000	2000
Total (wh/d)	54,300	106,400

4.1.2 Estimation of PV System Size

a) Determination of Electrical Energy Consumption

Every daily load is calculated and summed to get an average daily load. Total energy estimated for each house, is shown in the table 3 above, whereas, table 4 show the estimated electrical energy consumption for 10 and 20 houses villages.

b) Determination of Available Sunlight

To determine available sunlight per day, it is always useful to take a reading on an average day during the worst month of year. It is to ensure the system can operate for the whole year. In Malaysia the average sunlight per hour is around 6 hours.

c) Determination of PV Array Size

To determine the size of the PV array system, the daily consumption divided by the sun-hours per day. This is for PV system powering loads that will be used every day. Table 3 shows the PV system capacity for a house, 10 and 20 houses.

Table 5: Capacity of PV Generation System

Number of Houses	**1**	**10**	**20**
Calculated PV System Capacity (kW)	0.834	9.05	17.8
Recommended PV System Capacity (kW)	1	10	20

d) Determination of Battery Bank Size

To determine the capacity of the battery, it depends on daily consuming energy, battery characteristics and number of days of which it can provide power without recharging [10]. In this case, it will last longer if the battery operates 20-30% of their capacity. We design it to use 20% of their capacity so that it will last about 5 days without recharging. Multiply the daily energy by 5 and divided the result by battery voltage will determine the amp hour rating of the battery bank.

Table 6: Battery sizing for Rural Electrification

	Number of Houses		
Battery Voltage (V)	1	10	20
12	2,084	22,625	44,334
24	1,042	11,313	22,167
48	521	5.657	11,084

** All values of batteries are in amp-hour (Ah)*

4.2 Solar Radiation Readings

4.2.1 Solar Radiation in Malaysia

Generally, most places in Malaysia recorded normal solar radiation throughout this period. In Figure 4.1 as shown below, most places in Malaysia receive 17 to 21 MJm^{-2} of daily solar radiation per day. Central & tips of southern Sarawak together with an area in southern Johor had the lowest solar radiation throughout this period ranged from 16.0 to 16.3 MJm^{-2}. Meanwhile, higher solar radiation was recorded in northern Kelantan with 22.3 MJm^{-2} of solar radiation per day [3].

Being a maritime country close to the equator, Malaysia naturally has plentiful sunshine and as a result solar radiation. However, it is extremely rare to have a full day with completely clear sky even in periods of drought. The cloud cover cuts off a substantial amount of sunshine and thus solar radiation. On the average, Malaysia receives about 6 hours of sunshine per day. There are, however, seasonal and spatial variations in the amount of sunshine received. Alor Setar and Kota Bharu receive about 7 hours per day of sunshine while Kuching receives only 5 hours on the average. On the extreme, Kuching receives only an average of 3.7 hours per day in the month of January. On the other end of the scale, Alor Setar receives a maximum of 8.7 hours per day on the average in the same month [3].

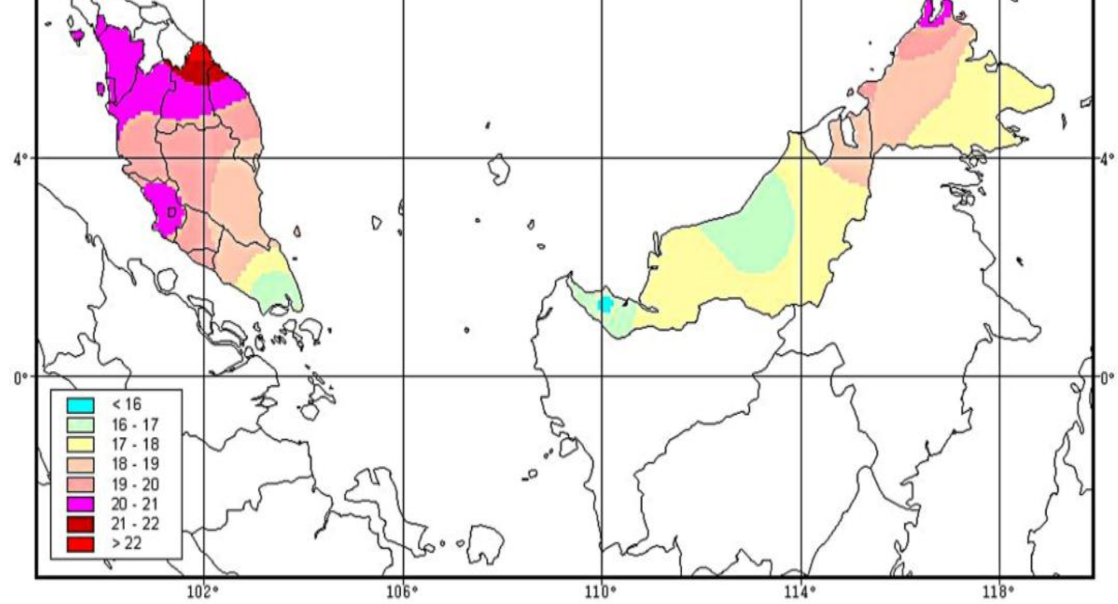


Figure 4.1: Mean Daily Solar Radiation (MJm^{-2}) [3]

4.2.2 Solar Radiation in Tronoh

Solar radiations in Tronoh below are taken from Universiti Teknologi Petronas Solar Lab from 26th February 2010 until 4th March 2010. The data were taken every 5 minutes by pyranometer. The X-axis is the time of the day while the Y-axis is the solar radiation value in W/m². Refer Appendix 1 for the value of Solar Radiation in Tronoh.

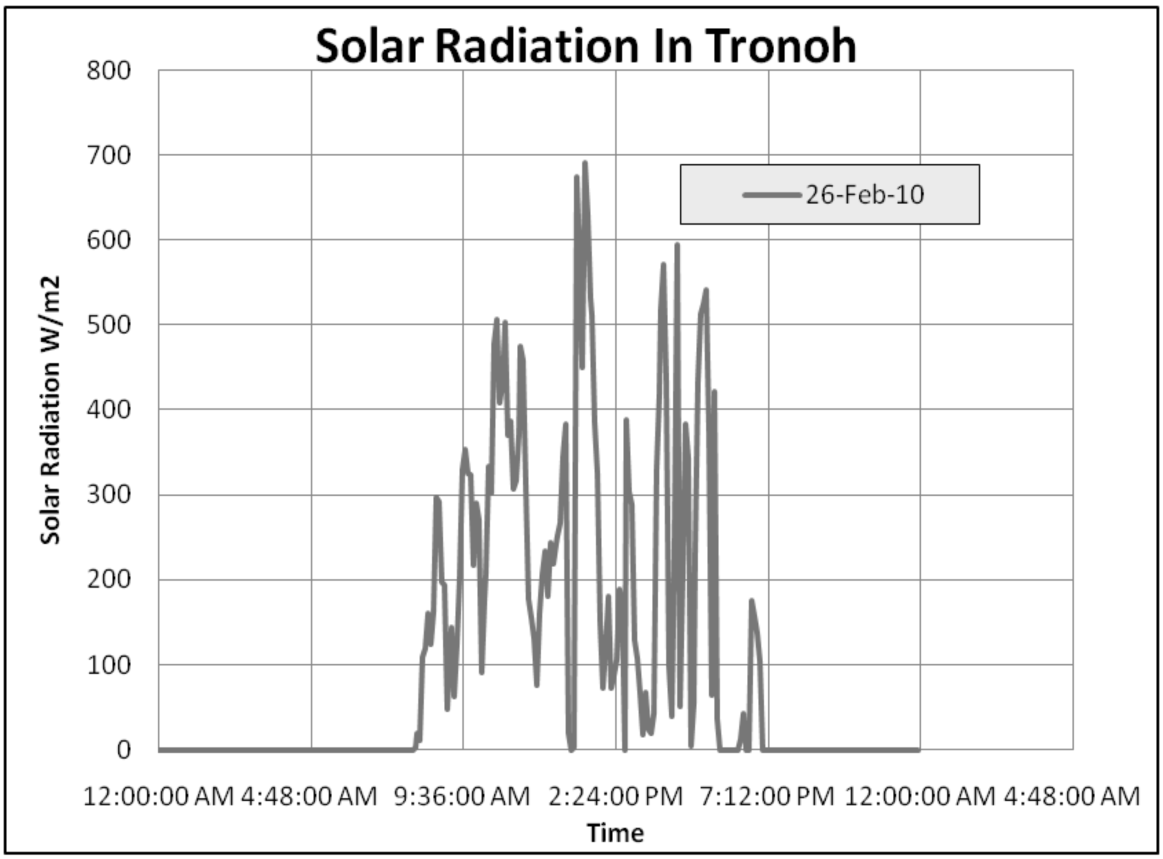


Figure 4.2: Graph Solar Radiation in Tronoh on 26th February 2010

From the graph above, we can conclude that the day is an afternoon rain pattern. It was raining at afternoon with partly clear in the morning and afternoon.

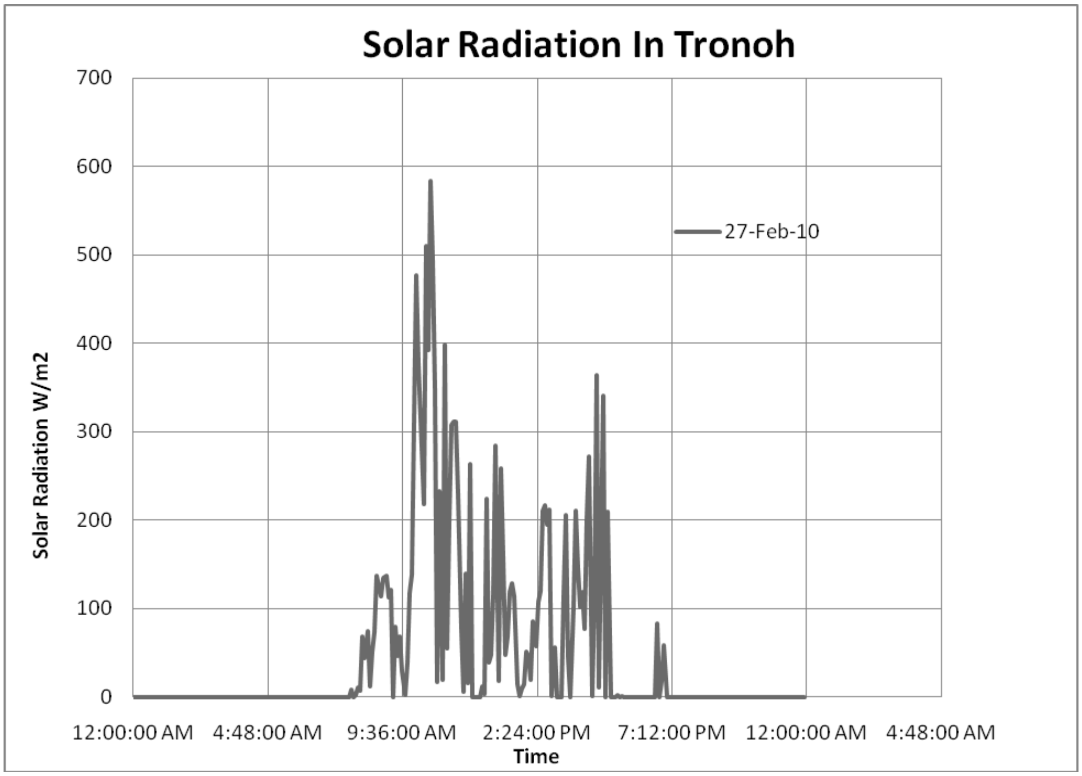


Figure 4.3: Graph Solar Radiation in Tronoh on 27th February 2010

Based on the graph above, the day is full cloudy and rain pattern. It was raining heavily at afternoon and it was blocking the radiation from reaching pyranometer until it stopped at evening around 5:30 PM.

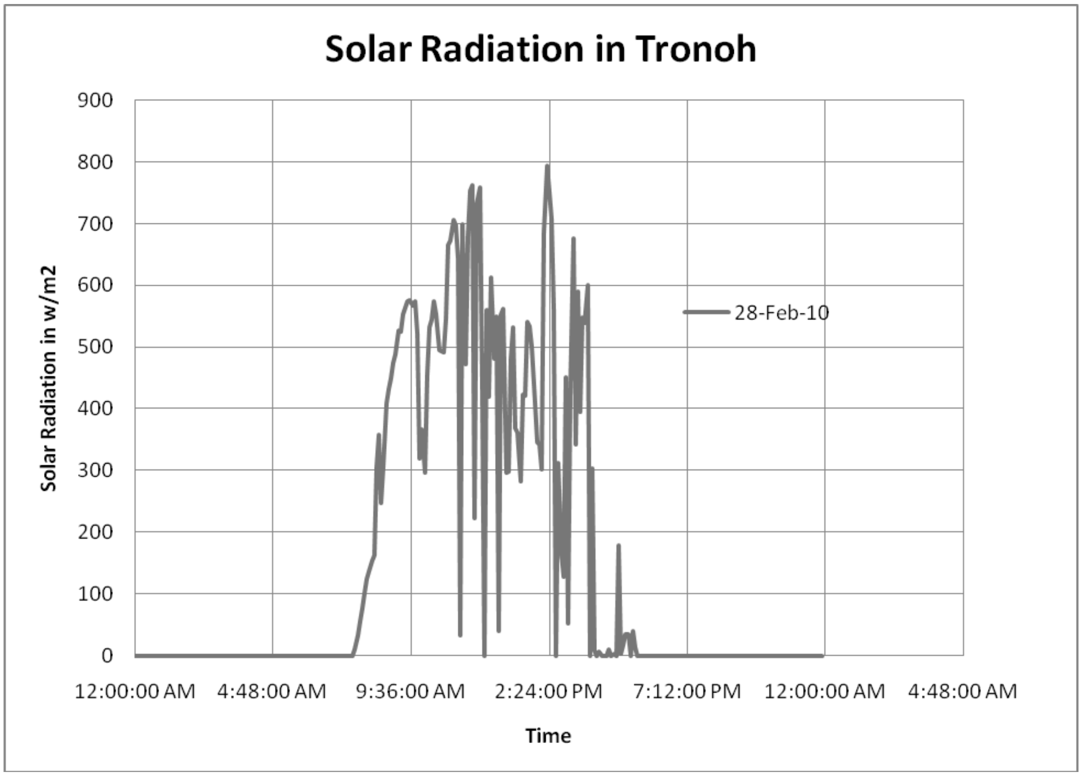


Figure 4.4: Graph Solar Radiation in Tronoh on 28th February 2010

Based on the graph above, it was a part cloudy day which occasional clouds were blocking the direct sunlight. However, in the morning, it was clear sky until around 12:00 PM.

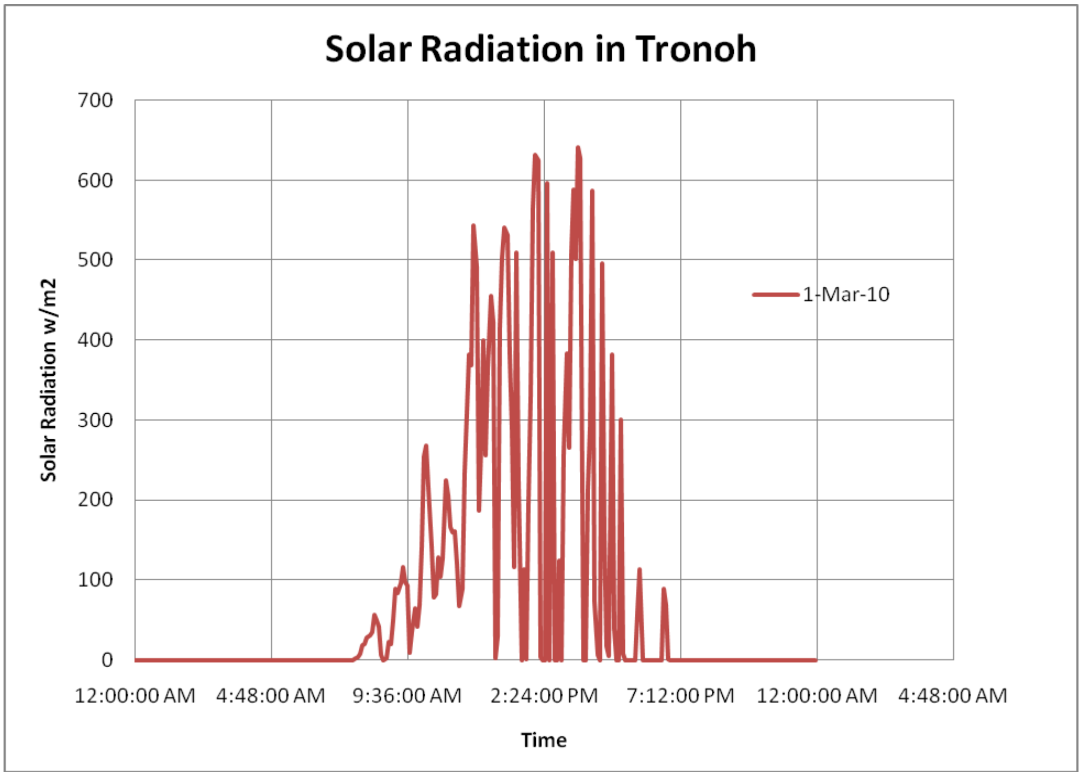


Figure 4.5: Graph Solar Radiation in Tronoh on 1st March 2010

Based on the graph above, it was a part cloudy day from morning until evening. The striking effects show that the day is not very clear because of the clouds often shielding the sun radiation.

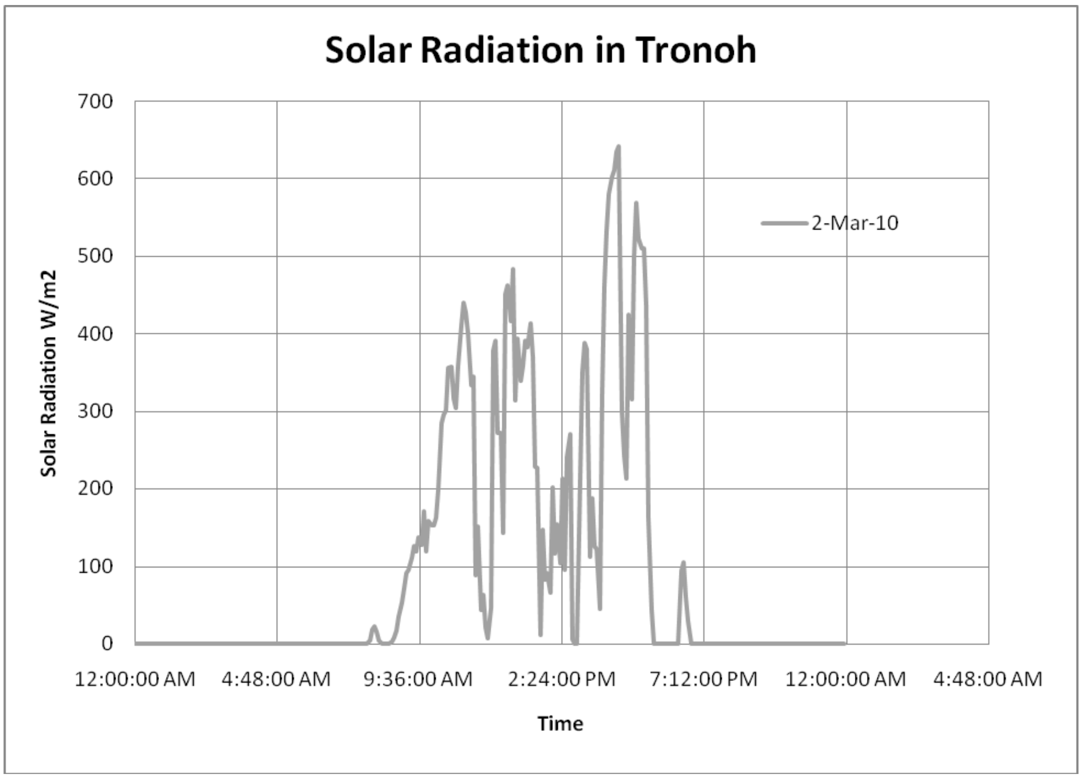


Figure 4.6: Graph Solar Radiation in Tronoh on 2nd March 2010

Based on the graph above, it was an afternoon rain pattern day. It was raining heavily for about 2 hours from 2:00 PM until about 4:00 PM. Then, it turned clear until sunset.

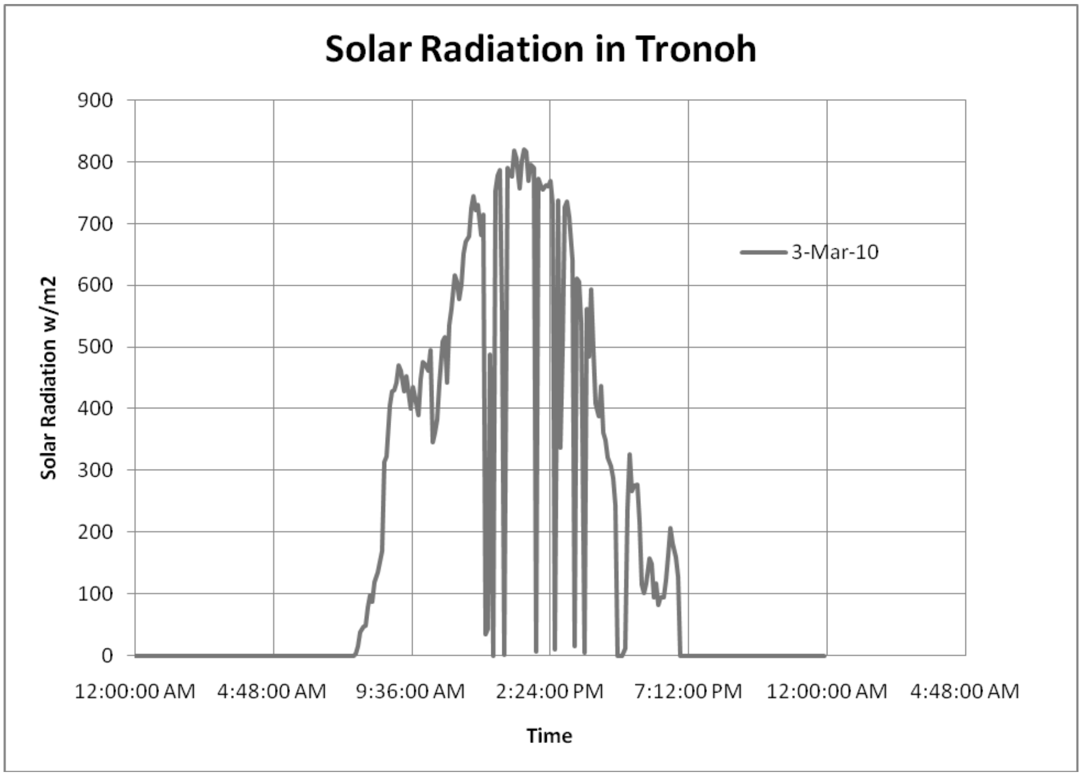


Figure 4.7: Graph Solar Radiation in Tronoh on 3rd March 2010

Based on the graph above, it was a clear day with occasional clouds in the evening. The cloud in the evening slightly affected the reading as the sun intensity decrease because of the clouds shielding the sun.

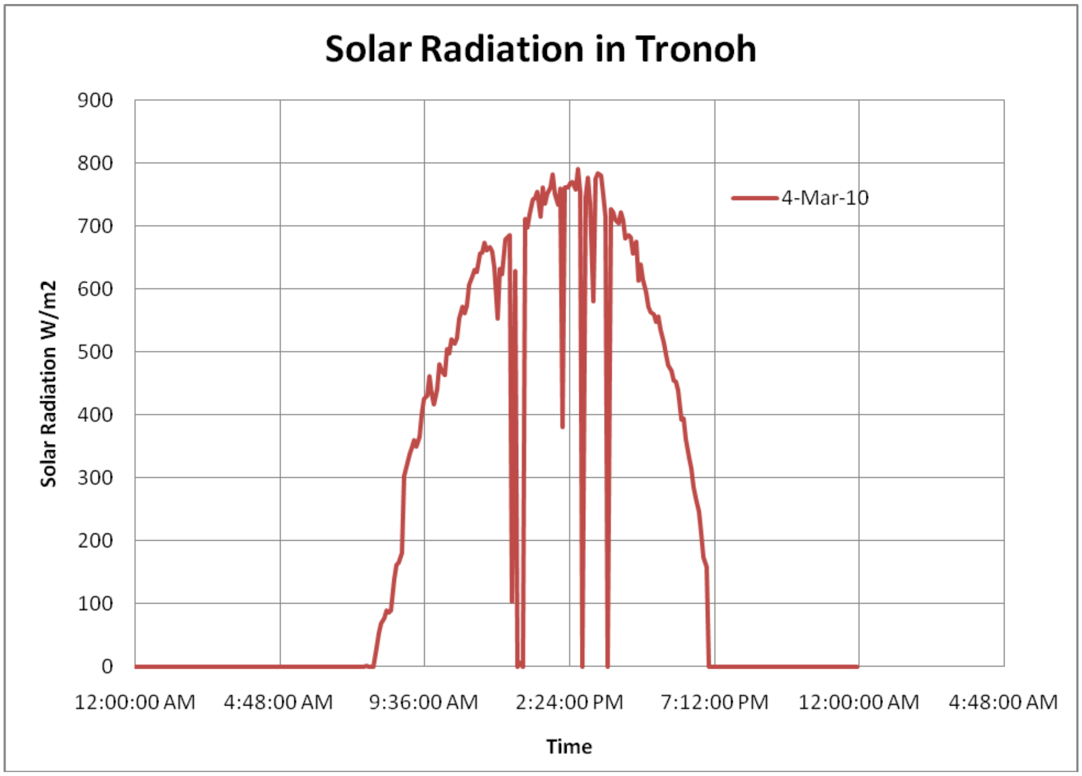


Figure 4.8: Graph Solar Radiation in Tronoh on 4th March 2010

Based on the graph above, it was clear day from early morning until evening. This is typical for most days in Malaysia.

Based on a week of solar radiation in Tronoh, Perak, it is safe to assume that Malaysia climate and weather are suitable for the implementation of Solar PV system. Average of solar hours in Malaysia is around 6 hours. Although the daytime is almost constant throughout the year, the global solar radiation on any particular day cannot be predicted. This is typical for any location situated in the equatorial climate [3].

4.3 Photovoltaic Systems Design

4.3.1 PV Array Design

Modules must be connected into arrays to get higher voltages or currents. Series connection result in higher voltages, while parallel connections result in higher currents when modules are connected in series, it is desirable to have each module's maximum power production occur at the same current. When modules are connected in parallel, it is desirable to have each module's maximum power production occur in same voltage.

Figure below shows several common module configurations. In figure 4.9a, modules are connected in series parallel. Note that for the series connection of modules, it is common practice to install bypass diode across each module so that if one module in the string should fail, the output of the remaining modules will bypass the failed module. In the parallel connection of figure 4.9a, blocking diodes are connected in series with each series string of modules, so that if any string should fail, the power output of the remaining series string will not be absorbed by the failed string [13].

In the figure 4.9b, the modules are connected to produce both positive and negative voltages with respect to ground. If three sets of modules are connected in this manner, the combined output conveniently feeds the input of 3-phase inverter systems [13].

A PV array is mounted in a fixed position at an appropriate tilt angle facing towards the equator or south for Malaysia. The main advantage of this is it minimizes the human intervention but it also limits the performance. There are several ways of improving the performance such manual tilt adjustment, tracking arrays and concentrator technologies. However, the most suitable ways for standalone systems is fixed array.

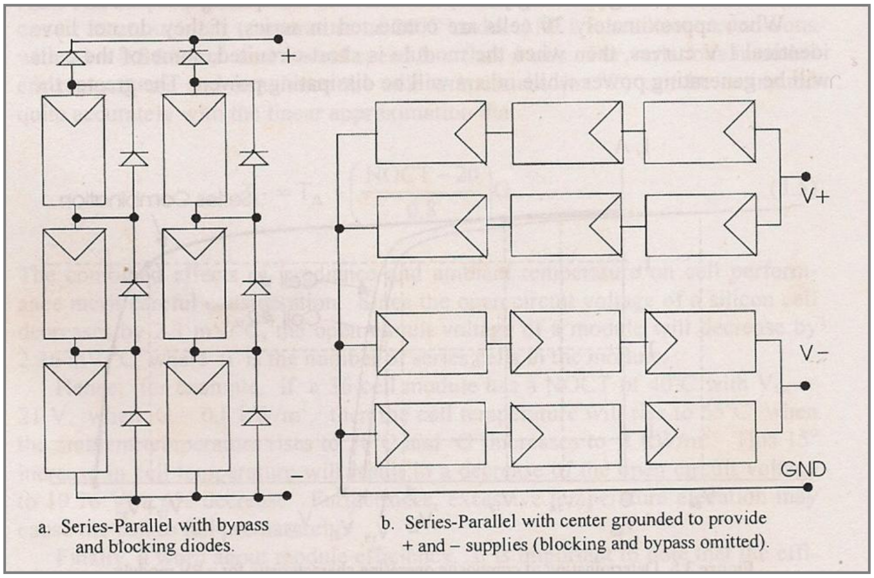


Figure 4.9: PV Array common configuration [12]

4.3.2: Battery bank design

The size of the battery is directly dependent on 4 main factors which are the autonomy desired, the depth of discharge, the temperature and also the power demand. The autonomy desired is the number of days the battery could provide the loads without input from PV array. The depth of discharge is how much the total capacity of battery is used. Low temperatures greatly reduced the storage capacity of batteries and high temperatures are dangerous to the battery. The ideal temperature of the battery is in the range of 25 to 35 degrees Celsius. The power demand means the battery capacity decreases with increasing discharge current.

Battery can be connected in several configurations. Battery are connected in series to get higher voltages and connected in parallel to draw higher current from the battery. Battery can be connected in parallel-series configuration to gain higher current and also higher voltages. The figures below show several connections of battery to attain 12V and 24V.

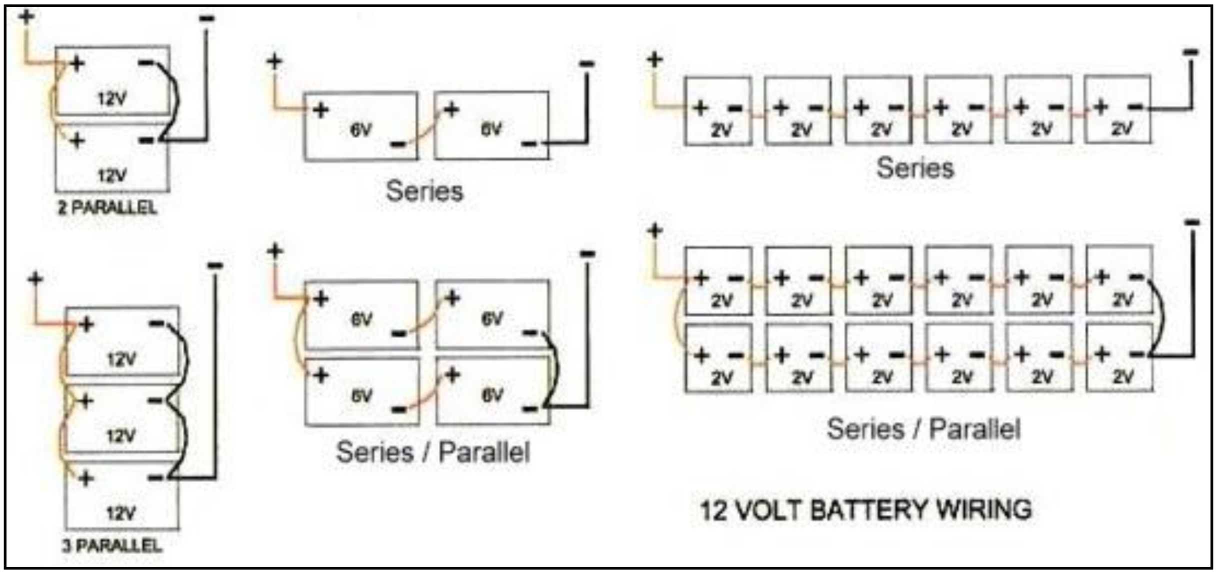


Figure 4.10: Several configuration for 12V Battery [14]

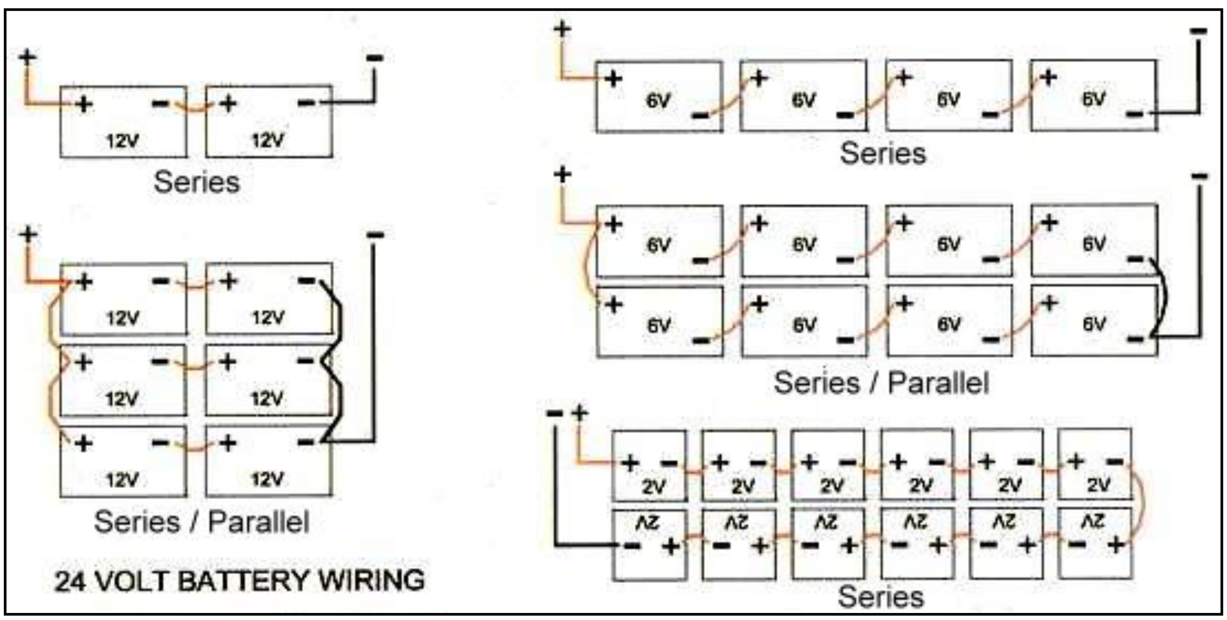


Figure 4.11: Several Configurations for 24V Battery [14]

4.3.3 Inverter Design

Inverter is required in systems that supply power to AC loads. The inverter converts DC output from the battery or the array to standard AC supply. The inverter must be able to meet the maximum demand including the surge produced by loads such as motors. There are number of different types of inverter depending of the waveform. In general, the square ware inverter is the least expensive and quite efficient but has limitation on its application [13].

Two ratings are of particular importance for the selection of the inverter which is the rating in the continuous mode and the rating in the surge mode. To prevent unnecessary losses, special attention should be made to the fact that the inverter is rather inefficient when the load is typically less than 10% of its nominal rating.

Table 7: Summary of Inverter Performance Parameters

Parameter	Square Wave	Modified Sine Wave	Pulse Width Modulated	Pure Sine Wave
Output Power range (Watts)	Up to 1,000,000	300 – 2,500	Up to 20,000	Up to 2,000
Surge Capacity (multiple of rated output power)	Up to 20x	Up to 4x	Up to 2.5%	Up to 4x
Typical Efficiency Over Output Range	70 – 98%	70 – 85%	>90%	Up to 80%
Harmonic Distortion	Up to 40%	≈5%	<5%	<1%

1. Example of Simple Square Wave Inverter

In the example of square wave inverter below, the battery is supplying 12Vdc which is the same rated voltage supplied by the PV array. It also used a 1:20 ratio step up centre-tapped transformer which is needed to step up the voltage to 240 Vac.

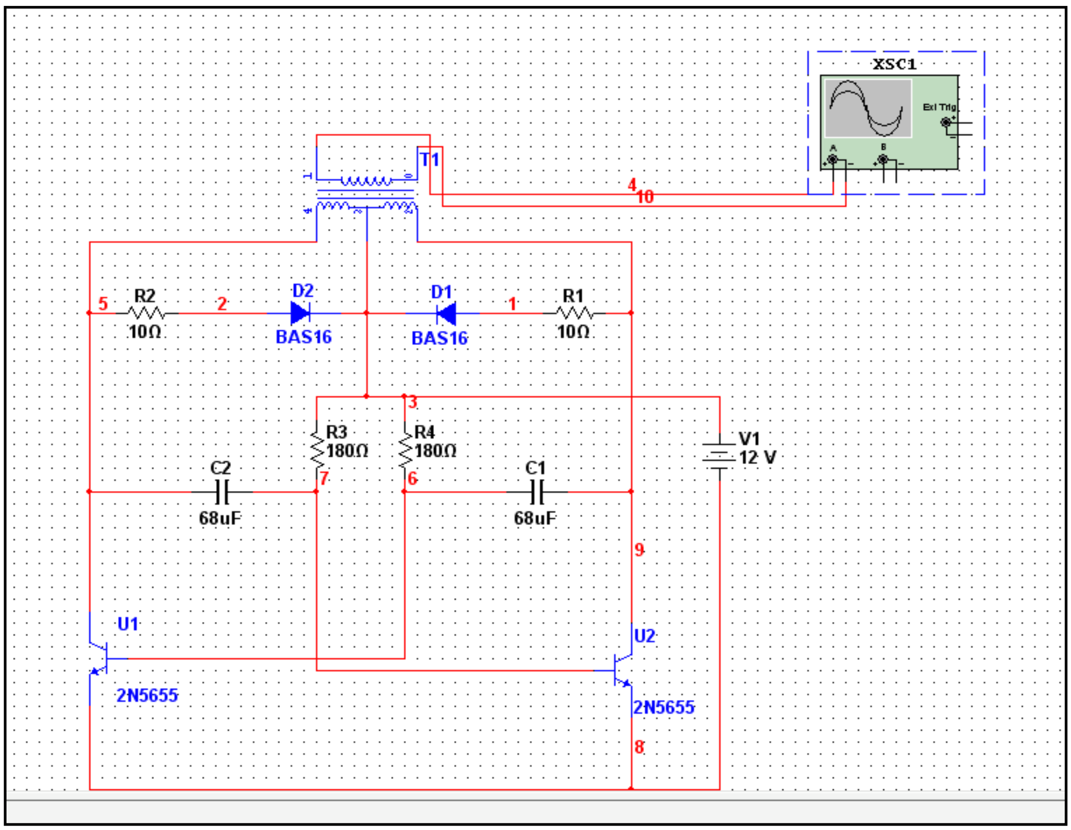
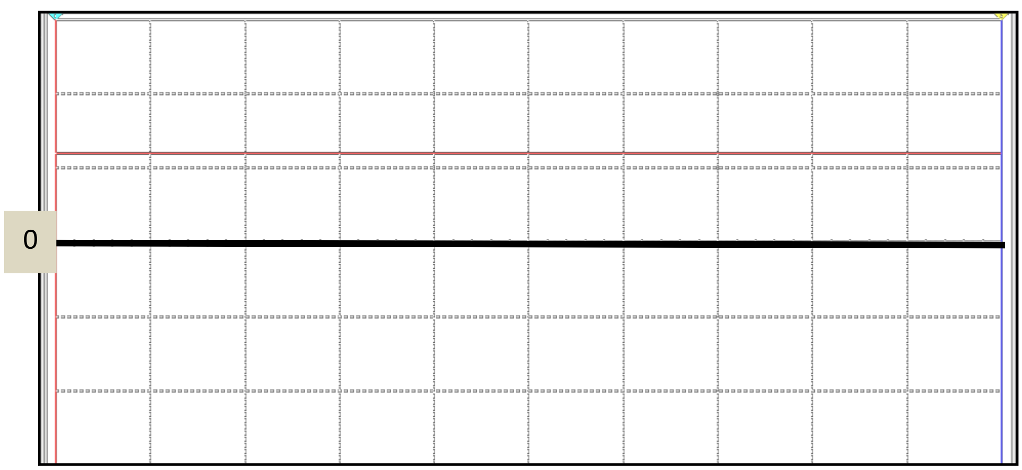


Figure 4.12: Square Wave Inverter Schematics using NI Multisim

Table 8: Items on the circuit schematics and description

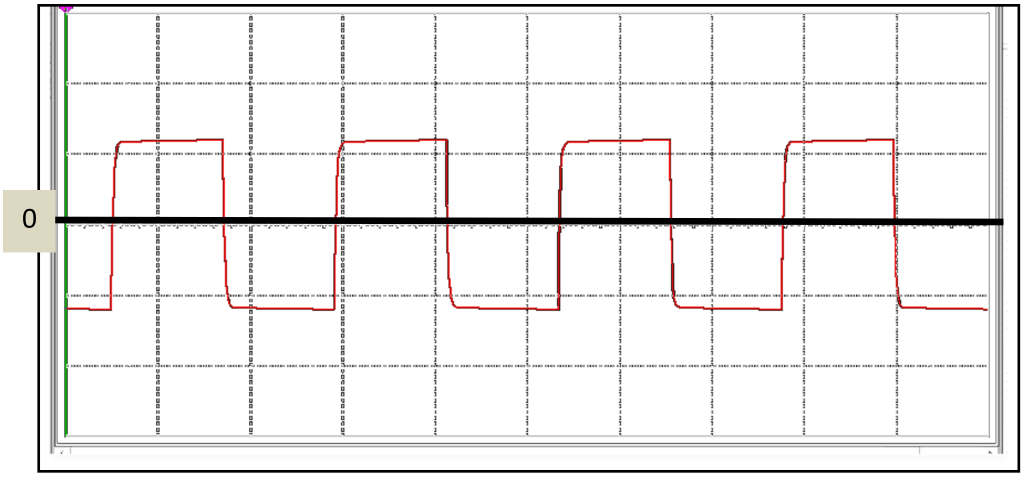
Items	Quantity	Description
C1, C2	2	68 uf, 25 V Tantalum Capacitor
R1, R2	2	10 Ohm, 5 Watt Resistor
R3, R4	2	180 Ohm, 1 Watt Resistor
D1, D2	2	BAS 16 Silicon Diode
Q1, Q2	2	2N5655 NPN Transistor
T1	1	24V, Center Tapped Transformer
MISC	1	Wire, Case, Receptical

Q1, Q2 and also T1 determine how much power the inverter can supply. The inverter above can supply up to 300 watts. Larger transformer and more powerful transistors can replace T1, Q1 and Q2 for more power. C1 and C2 must use tantalum capacitor as regular electrolytic capacitor will overheat and explode. This inverter must include fuse and build in a case.



X - scale	10ms/div
Y - scale	10volt/div

Figure 4.13: Input Voltage (12Vdc) Plot



X - scale	10ms/div
Y - scale	200volt/div

Figure 4.14: Output voltage (240Vac) Plot

4.3.4 PV Systems Design

Figure 4.15 below shows a complete system for a 1 kW PV systems which are designed to meet the requirement of a single rural house in the modeling above. PV array are rated as 1 kWp, and for 12V battery, the capacity needed is 2100 amp hour. The power inverter is required to convert DC current to AC current for the usage of AC appliances.

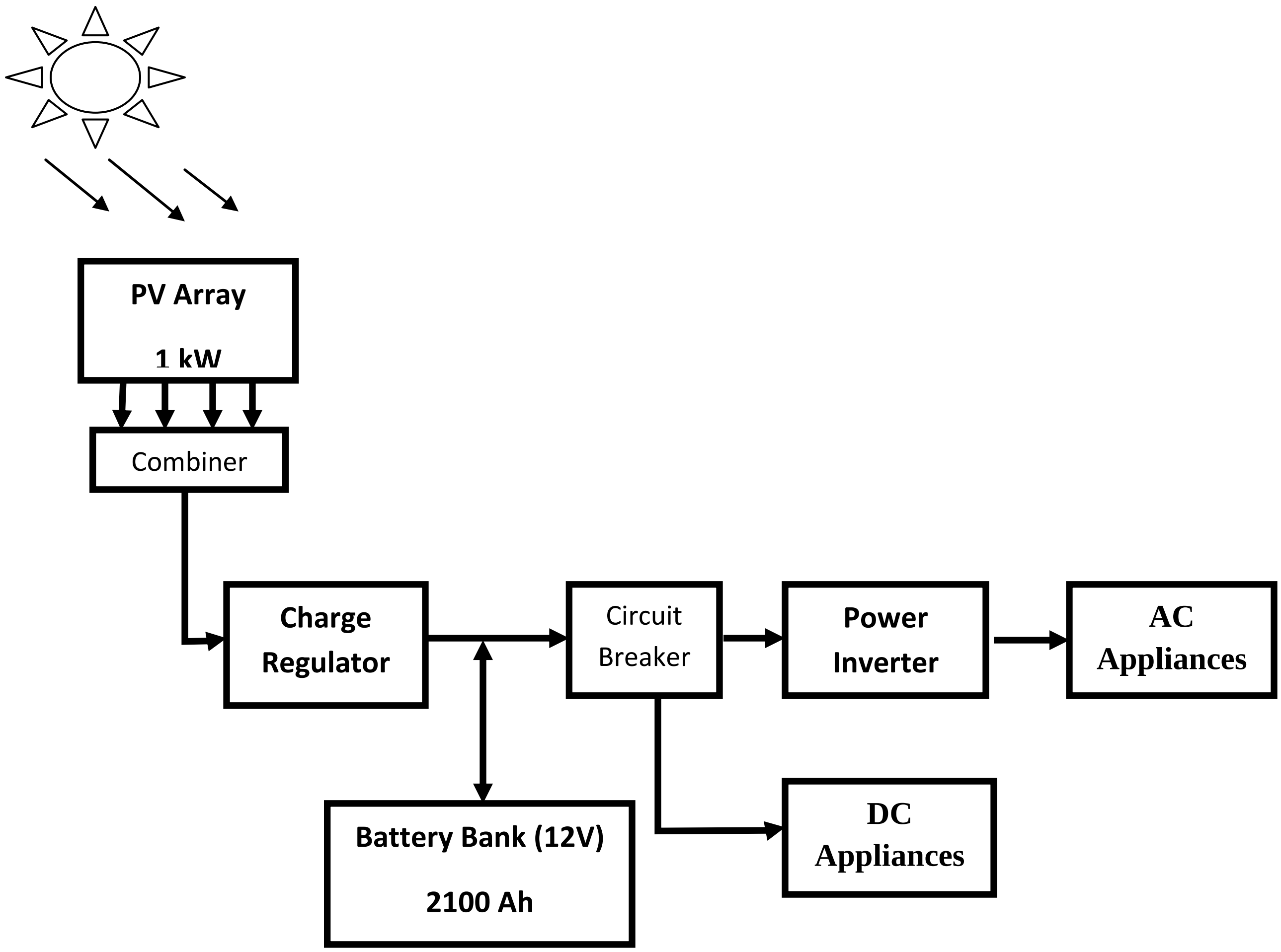


Figure 4.15: PV Systems Design for 1 kW System

4.3.5 Safety Aspect and System Maintenance

Safety is the most important consideration in the installation of the system. The batteries are the most critical components of the PV system in terms of safety. Hazards related to batteries are acid spillage and the risk of explosion. Spilled battery acid permanently destroys any fabric and causes blindness if in contact with the eyes. In addition, an explosive mixture of hydrogen and oxygen is generated in each cell of a lead acid battery and, if no proper ventilation is ensured, any spark or short-circuit can make the battery explode. Therefore, proper precautions must be taken by any person who is in contact with batteries. Sufficient manuals for installer, maintainers, and users must be provided and followed [15]. Disposal of written-off batteries also involves health risks and must be handled professionally.

PV systems in rural areas must required minimal and expected maintenance. For PV systems in rural areas, a maintenance schedule with monthly and semiannual maintenance procedures is practical. In all cases, proper planning is required.

Maintenance of the array in Malaysian climate is relatively zero but proper cleaning can become crucial for the systems to function excellently. Batteries are the components that require most maintenance. For open lead-acid batteries, some means of keeping enough electrolytes in the cell is necessary for their optimal operation [15].

4.4 Economic Aspects

4.4.1 Overview of Economic Aspects

This section will provide reviews on economic aspects in relation to different energy options in relation to their scale. The concept of life-cycle costing is introduced and its importance and limitation to solar photovoltaic systems are discussed.

The typical costs of different types of standalone energy equipment such as Stand-Alone Photovoltaic (SAPV), diesel generators and other stand alone renewable energy equipment can be vastly variable, depending on the country and location, the source and quality of equipments and whether there are taxes or subsidies involved.

In general, each energy technology has a certain range of average energy demands which it is most cost-effective in supplying [12]. It indicates the appropriate size ranges are common options usually considered.

4.4.2 Photovoltaic Systems Costs

The costs of PV systems include estimation of PV array system, battery bank, inverter, controllers, switches, wiring, and etc. Many PV modules can be purchased at retail for about RM25 to RM30 per watt for most small systems. There are opportunities to purchase modules at a lower price, especially when the system is larger and can be purchased in bulk.

To select battery, there are some characteristics which should be considered. The battery should be able to meet the load demand with no contribution from the PV system. The principal goal of the battery bank is to ensure that the annual minimum PV systems output equals the annual maximum load energy input. Other than that, the battery depth of discharge, rated battery capacity and battery life should also be considered. There are many types of batteries available in the market for PV systems but the most commonly used is lead-acid battery.

4.4.3 Life Cycle Cost

The life cycle cost of an item consists of the total cost of owning and operating an item over its lifetime. Some costs involved in the owning and operating of an item are incurred at the time of the acquisition, and other costs are incurred at later times [13]. Some types of economic assessment is required to determine which system from a number of choices will give the best value for money in the longer run.

To do the economic assessment, life cycle cost method, LCC has been used to find the cost of kilowatt hour generated by each of three alternatives during the lifetime of PV systems which is assumed to be 20 years. The below formulas used for doing the economic analysis:

$$\boldsymbol{PW = C_o\left(\frac{1+i}{d-i}\right)\left[1-\left(\frac{1+i}{1+d}\right)^{n}\right]}$$

Where:

PW	:	Present Worth
C_o	:	Equal Cash Amount
i	:	Constant Inflation Rate
d	:	Constant Discount Rate
n	:	Period of Lifetime

Two things affect the value of money over time. The inflation rate, *i*, is a measure of the decline in value of money [13]. For example, if the inflation rate is 2% per year, then an item will cost 2% more next year. The discount rate, *d*, relates to the amount of interest that can be earned on principal that is saved. In this equation, we assumed that inflation rate is 0%. The following is the LCC formula:

$$\boldsymbol{LCC} = \boldsymbol{P} + \boldsymbol{E} + (\boldsymbol{O}\&M)$$

Where:

LCC	:	Life Cycle Cost
P	:	Investment Costs
E	:	Energy Cost
O&M	:	Operation and Maintenance Costs

The cost of kilowatt hour is calculated using below formula

$$\boldsymbol{C} = \frac{\boldsymbol{LCC}}{\boldsymbol{E}}$$

Where :

C	:	Cost of Kilowatt Hour
E	:	Total Energy Produced

4.4.4 Photovoltaic Systems Price in Malaysia

To determine the average price of photovoltaic price in Malaysia, several value of photovoltaic projects in Malaysia are taken into consideration to estimate the value of photovoltaic systems in Malaysia. The values of systems are taken over the stretched of 5 years starting from December 2005. The average price of the system will then be used to calculate the life cycle cost of photovoltaic systems. Refer Appendix 3 for the system price of photovoltaic systems in Malaysia.

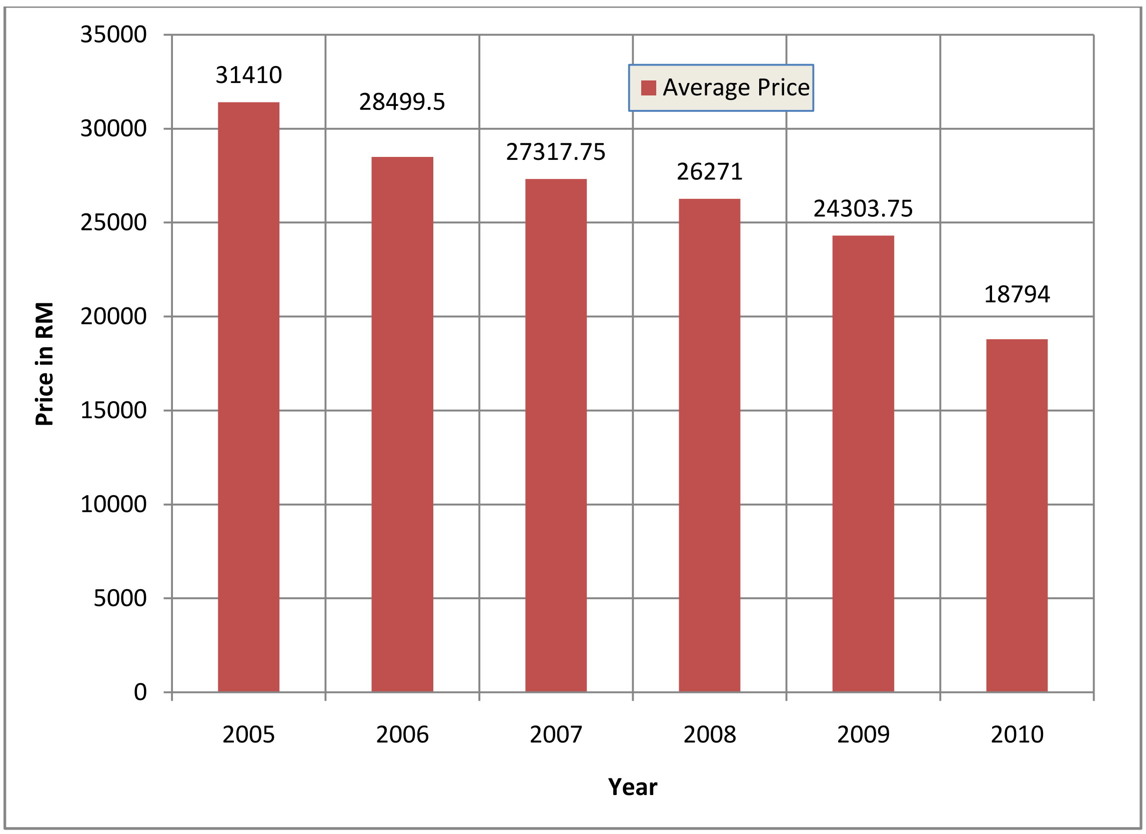


Figure 4.16: Average Photovoltaic System Price in Malaysia

The Bar Graph above shows the price of photovoltaic systems in Malaysia over 5 years. The average price of PV systems over 5 years is about RM 26,500. Photovoltaic price in Malaysia shows a decreasing pattern which demonstrates the cost reduction of PV system installation in recent years.

4.4.5 Economic Comparisons

Different energy technologies prove to be more cost effective in different situations. In general, it is the average amount of energy required that decides the choice of the systems. In this case, solar PV systems are compared to diesel generators and also to the grid extension. Refer Appendix 4 for detail table and calculations.

1. PV systems versus diesel generators

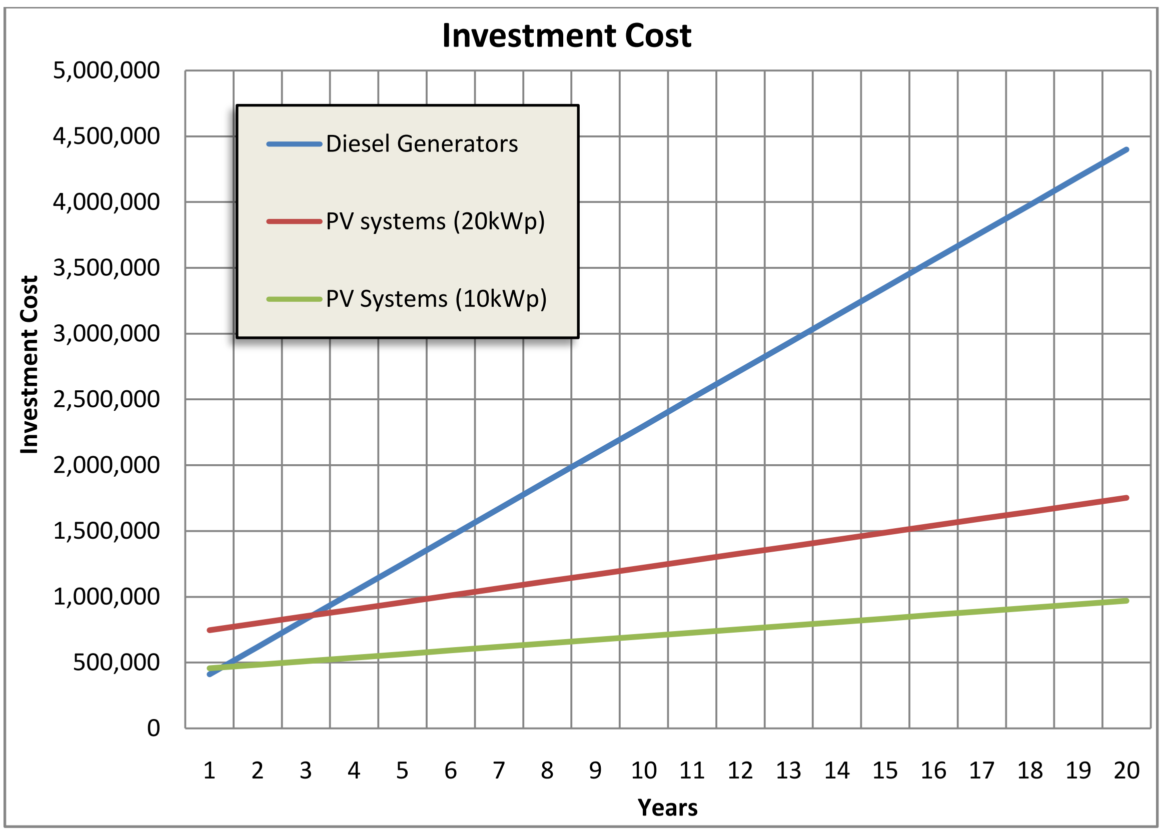


Figure 4.17: Investment cost comparison between PV systems and diesel generators

A diesel engine runs nearly 24 hours per day, it must be replaced once a year or need a general overhaul. The running cost or the variable or the variable costs of the diesel option is added on the yearly costs of the investment which are monthly maintenance, spare parts, fuel, refilling of fuel, transport of fuel, oil and also cleaning.

In the graph above, the initial cost of diesel generators is cheaper than 20kWp PV systems and also 10kWp systems but because of high running annual cost of diesel generators, the 20kWp PV systems crossover diesel generators cost in 3 years. In an investment period of 20 years, PV systems turns out half as expensive as the diesel generators because it has no fuel costs, low maintenance, and technically very reliable compared to diesel generators.

2. *PV systems versus grid extension*

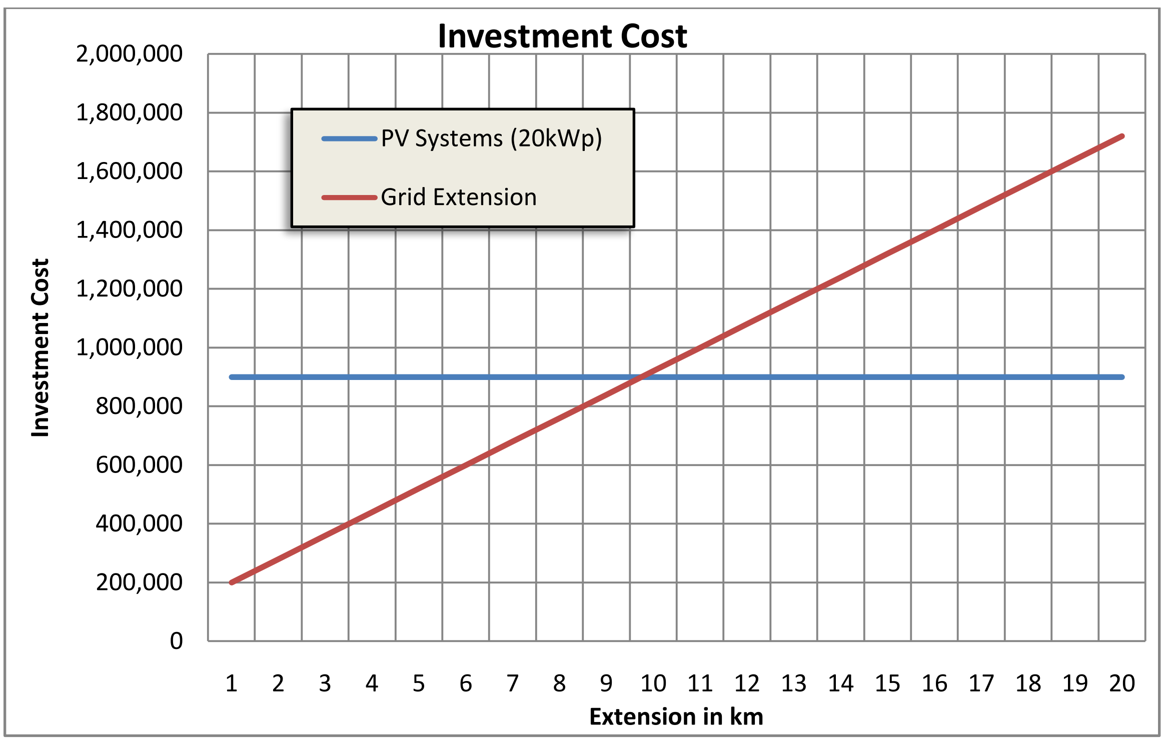


Figure 4.18: Investment cost comparison between PV systems and grid extension

Figure above compare the investment cost between independent 20kWp PV systems with the investment cost of grid extension. If we suppose the investment for a transformer station and certain amount per km of grid extension, the initial investment cost of PV system is cheaper if it situated farer than 10 km from the nearest 11kV gridlines. For distance less than 10 km, the grid extension is a much better solution than PV system. Refer Appendix 5 for the detail table.

4.4.6: Operation and Maintenance Cost

The design and dependability of Solar PV system allow a single technician to service a large number of systems. However, the need for local technical support remains important. The rural users can carry out simple maintenance functions and be trained to assure the good performance of the system.

The number of technicians required to service the systems depend on the number of systems of use, their quality and their accessibility (remoteness, road condition and available transportation to the site). A rule of thumb is that no system should be further than 50 km from the service centre, and that a well equipped technician can service no more than 200 systems. The cost of operation and maintenance must be included in the price of the system [15].

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main goal of this project is to design Rural Electrification by using Solar Photovoltaic Generation System. Solar Photovoltaic Generation System is chosen in this project because solar energy sources are among the least cost and most practical solutions, since they are coming from unlimited and available sources, they are sustainable (minimum maintenance needs) and will cause no impact towards fragile ecosystems. Rural areas are suitable for solar energy applications due to their geographical location and are often too lightly populated or have a low potential electricity demand to justify the extension of the grid. Solar PV systems also avoid greenhouse emissions, have low operation and maintenance costs, and allow production for the development of rural communities.

The initial cost of diesel generators is generally cheaper than PV systems but because of high running annual cost of diesel generators, the PV systems crossover diesel generators cost in 3 years. In an investment period of 20 years, PV systems turns out half as expensive as the diesel generators because it has no fuel costs, low maintenance, and technically very reliable compared to diesel generators. On the other hand, the initial investment cost of PV system is cheaper than grid extension if it situated farer than 10 km from the nearest 11kV gridlines. However, if the distance is less than 10 km, the grid extension is a much better solution than PV system.

Rural Electrification by Solar Photovoltaic Generation System seems to be the ideal choice because of several main factors such as the climate condition in Malaysia which is equatorial tropical, average solar radiation intensity between 4000 to 5500 w/m^2 and also policy of government in ninth Malaysian Plan to promote greater use of renewable energy for power generation.

5.2 Recommendations

1. For higher loads or high electrical energy consumption, the PV-diesel hybrid is the best option to provide reliable energy at rural or remote villages because it generally cheaper than sole PV generators and can compete with diesel generators depending on the price of fuel. The hybrid systems are recommended because of the vulnerability and troublesome of battery bank system in sole PV generators.

2. In rural areas with small population, the rural electrification using solar PV systems are the feasible option for supplying the electricity. This is because gird extension is not a feasible option for the predominantly small loads.

3. The Government should sustain or increase efforts to reduce the cost price of PV components and cost calculations methods using life-cycle costing should be applied when analyzing the feasibility of PV system.

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APPENDICES