Development of Portable Solar Electricity Generating System

By

AWANGKO ARSHADUDDIN BIN AWANG ZAINUDIN

13700

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Assoc Prof Dr Balbir Singh Mahinder Singh
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

May 2014

CERTIFICATION OF ORIGINALITY

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

AWANGKO ARSHADUDDIN BIN AWANG ZAINUDIN

ABSTRACT

The project aim is to develop a portable solar electricity generating system. Since Malaysia is located near to the equator, the country receive large and constant amount of solar energy during daytime. It would be a waste if this energy is not utilised for producing electrical energy. The development of solar energy generation system (SEGS) is needed to fully utilise the usage of solar energy received. However, SEGS in Malaysia is still seen as a new concept and research is still being done to produce an efficient and cost-effective SEGS. In this project, study On SEGS is conducted to get a clearer picture of the parameters and condition required to build the best SEGS. In order to have a good SEGS, design of a proper sun-tracking system and the system sizing are required. The measurement of insolation throughout the day is also been done to get a clearer picture for the insolation pattern. Other than that, the comparison for the type of PV modules has also been conducted. This is to ensure the SEGS utilises the best type of PV module. A proper storage system for SEGS is also a crucial part of this project. As Sunlight is only available during the day and the insolation changes throughout the day a proper storage system is required to optimise the usage of the SEGS. The portability of the SEGS has also been discussed in this project. To ensure the maximise usage of SEGS the SEGS has to be portable. Another factor we considered in this project is the price of production of the SEGS. Currently, SEGS is quite pricy. If the cost of production of SEGS can be reduced to a cheaper price, the market demand for the SEGS will increase. This report contains the theoretical background and project activities on completing the SEGS. Analyses of results are further discussed in this report after simulation studies and outdoor experiments are conducted to measure the value of solar insolation.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Malaysia is known for their production of petroleum and natural gas[1]. This causes them to depend on these resources as primary energy sources. These resources are limited and will be depleted in the future. To avoid dependency on these resources renewable energy research has been conducted. The renewable energy sources can come from hydroelectric, biomass, biogas, wind, thermal, geothermal and solar. Malaysia is located near the equator[2]. This causes Malaysia to experience hot and humid climatic regions. Malaysia has a tropical climate which gives an average of 27^{o}C yearly. It also experiences rain-fall all year round. This climate is suitable for the usage of solar energy as an alternative power source.

As of 2012, based from Malaysia Energy Information hub (MEIH)[3], Malaysia's primary energy supply is natural gas followed by crude oil, coal and coke, hydropower, biodiesel, biomass and biogas. This shows that Malaysia is dependent on non-renewable energy.

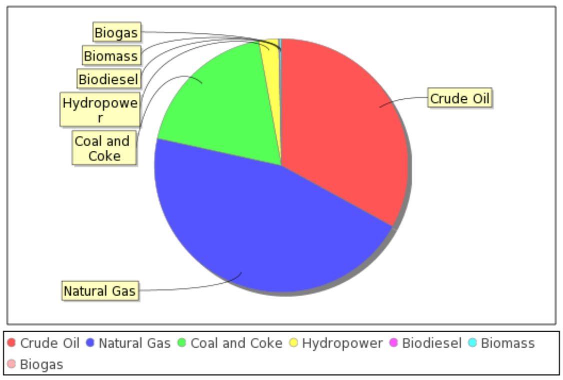

Figure 1: Malaysia Primary Energy Supply

Table 1 : Malaysia Primary Energy Supply. Retrieved from Malaysia Energy Information Hub

Type of Energy Supply	Energy (ktoe)
Crude Oil	28054
Natural Gas	38648
Coal and Coke	15882
Hydropower	2149
Biodiesel	115
Biomass	183
Biogas	4

Now, the utilization of solar energy is increasing and concerted efforts are aimed at developing solar electricity generation system (SEGS). To fully utilize solar power a proper design is needed to optimize the output. A good SEGS has to consider the alignment of the sun and time of the day to properly gather the solar energy. Common problems of the solar energy are Photovoltaic (PV) cell has very low conversion energy, ranging between 10% and 17% and costly. This shows that, an optimum SEGS is needed to supply sustainable output.

1.2 Problem statements

The main concern for SEGS is the cost for developing and implementation of the product is high. Other than that, a constant and optimize input for SEGS is also a main concern. SEGS depends on amount of solar radiation received from the PV to produce the required amount of electrical power. The input from SEGS is highly transient in nature as it needed solar radiation to produce electrical power[4]. Due to this, it can only be utilized during the day. Hence, there is a need to include storage system for the power generated. The solar radiation often fluctuates and this causes the output to fluctuate as well.[2] The power generation of SEGS is also affected by the apparent trajectory of the sun, as most SEGS is static. To overcome these problems, the orientation and the tilt angle of the SEGS must be adjusted to a correct position[5]. To further help this system, a sun tracking system can be used to ensure that the input and output is stable and sustainable.

1.3 Objectives

The objectives of the project are:

- To carry out simulation studies to determine the optimum parameters of PV based solar electricity generating system
- To design a reliable sun-tracking system for solar electricity generating system
- To incorporate the sun-tracking system in the design of a portable PV based solar electricity generating system

1.4 Scope of Study

For this project, an adequate knowledge for solar geometry and PV based electricity generating system is necessary. Study on solar radiation is also done for better understanding of the project. Study of software used for the project is also necessary.

1.5 Relevancy of project

This project is relevant for the research of alternative renewable energy in Malaysia. Study on renewable energy is highly relevant for the sustainability of energy. Solar energy is good alternative energy supply and is available throughout the year in Malaysia. This project aim is to fully utilise the solar energy as an alternative energy source for electrical generation system.

CHAPTER 2: LITERATURE REVIEW

2.1 Malaysia's Energy Mix

Solar energy is still considered a new energy supply in Malaysia. The usage of solar as energy supplier is quite late if compared to other energy supplier. It started from 2012 and the energy input in power stations is very low compared to other Energy supplier. MEIH has shown that solar only contribute 1 ktoe as of year 2012[6].

Table 2: Energy Input In Power Station. Retrieved from Malaysia Energy Information Hub

Year	Energy Input in Power Stations (ktoe)								
	Diesel	Fuel Oil	Natural Gas	Coal and Coke	Hydropower	Biomass	Biogas	Solar	Total
2007	314	199	12549	7486	1522				22070
2008	299	181	13651	8069	1964				24164
2009	384	205	13390	9010	1627				24164
2010	415	125	12628	12951	1577				27616
2011	981	1103	10977	13013	1850				27964
2012	811	550	11533	14138	2149	64	4	1	29250

Based from this data, we can see that Malaysia highly depends on coal and coke and natural gas. However, from year 2011 to 2012 we can see that the usage of fossil fuel and diesel has decreased. Fuel oil decreases rapidly from 1103 ktoe to 550 ktoe respectively. This is mainly due to because fuel oil price has started to become more expensive. In 2012, we see that Malaysia has started utilising renewable energy as energy input in power station. We can see the introduction of biomass, biogas and solar as energy input in power station.

In 2012, the introduction of renewable energy as alternative energy is due to Malaysia's view on the importance of alternative energy. Malaysia Feed-in Tariff (FIT) encourages the Distribution Licenses (DL) to buy from Feed-in Approval Holder (FIAHs) the power produces from renewable sources and sets the FIT rate.
The FIT rates for buying of the electricity produces from the renewable energy depend on multiple factors. The factors for FIT are type of renewable energy, installed capacity of renewable energy, renewable energy installation meet criteria entitling to additional bonus and date of renewable energy installation is completed. This effort shows that Malaysia is slowly and steadily warming up to the idea of

utilising renewable energy as an alternative energy. The introduction of the DL also encourages electricity provider to be involved in the renewable energy technology.

2.2 Solar Energy

The sun's light can be used as an alternative source of energy of electricity. The main concentration in this project is the generation of power from solar PV. The design of PV system depends on solar radiation. The sun is the source of solar energy. It acts as an emitter for solar radiation with average of $1000W/m^2$ at 25^oC at standard test condition. The earth's surface receives about 47% of the total solar energy that reaches the earth. Only this amount is usable for usage purposes.

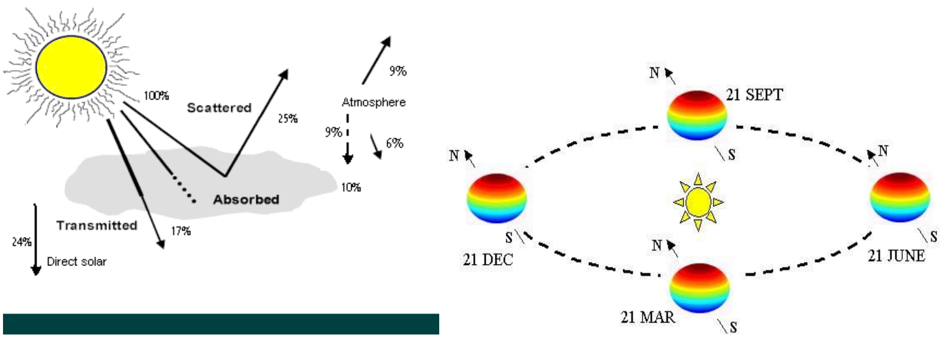

Figure 2: percentage of sun light received and earth orbit around sun

The earth revolves orbit the sun in an elliptical orbit. The earth's axis of rotation is tilted at 23.5^o with respect to its elliptical axis about the sun. Due to the earth's rotation and yearly revolution around the sun, the energy that reaches the surface varies on hourly and seasonal basis depending on the location.

Solar radiation also called as solar insolation is the product of the sun with any location of the earth. Solar energy production is highly dependent on the quality of solar insolation. Solar insolation can be received thru 2 different type of radiation. There are direct radiation and diffuse radiation. Direct radiation refers to the solar radiation which gives direct transmission to the earth. It is also known as beam radiation. While, for diffuse radiation solar radiation diffuses with the particle in the air (air, dust and water). Diffuses radiation can lower the quality of solar radiation.

Because of this, solar radiation has no constant radiation and can vary greatly. Other than that, the solar insolation also varies with the time of the day. Solar insolation hits peak radiation during the midday and there are no solar radiation in the night.

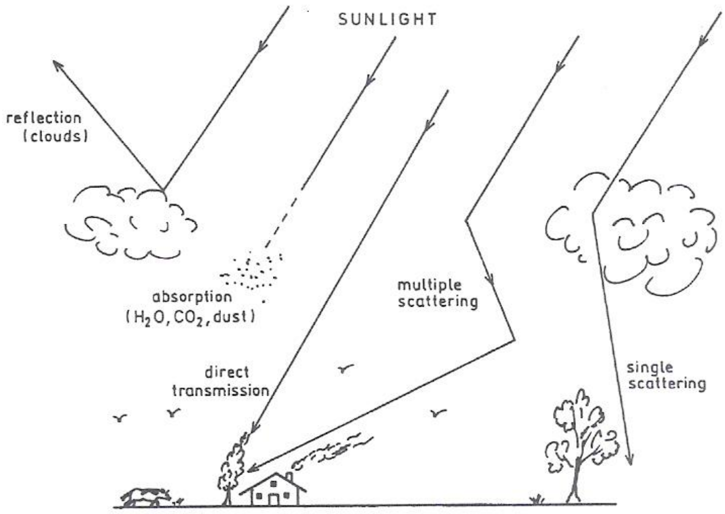

Figure 3: Sunlight's Radiation Trajectory

The average intensity of solar insolation reaching the earth's atmosphere is around 1353 W/m^{-2}. The solar insolation which passes through the atmosphere are called global solar insolation, $I_{GLOBAL.}$ I_{GLOBAL} is then divided into beam solar radiation, $I_{DIRECT,}$ reflected radiation $I_{REFLECT}$, and diffuse solar radiation, $I_{DIFFUSE}$. Their relationship can be express as the following equation.

$$I_G = I_B + I_D + I_R \quad (1)$$

Solar insolation can be affected thru shading effect. Shading effect is caused by clouds, dusts and pollutants. This effect cannot be avoided and all these combined with the transient nature of global irradiance can greatly affect the quality of solar insolation.

2.3 Angles made by solar radiation on receiving surface

In order to get a good sun tracking SEGS, there are calculations needed to be made. The main angle we need to focus on is the tilt angle, but in order to get tilt angle we need to find other angles associated with the tilt angle. These angles are needed to determine the right tilt and orientation of the PV. Sun's apparent position is calculated based on elevation and azimuth angles, A. the azimuth angle can be calculated using the equation 2.

$$A = \cos^{-1}\left[\frac{\sin\delta\cos\phi - \cos\delta\sin\phi\cos(HRA)}{\cos\alpha}\right] \quad (2)$$

$$Elevation, \alpha = \sin^{-1}\left[\sin\delta\sin\phi + \cos\delta\cos\phi\cos(HRA)\right] \quad (3)$$

The position's latitude, ϕ is obtained from Global Positioning System (GPS). Angle of declination,δ is the angular displacement of the sun to the center of the earth and is calculated using equation 4 and the Hour Angle (HRA) is calculated using equation 5.The d represents day in a year.

$$\delta = 23.45^{o}\sin\left[\frac{360(d+284)}{365}\right] \quad (4)$$

$$HRA = 15^{o}(LST - 12) \quad (5)$$

The local solar time (LST) can be calculated using equation 6. The Time Correction (TC) factor (in minues) is the variation of the LST within a given time zone due to the longitude variations and local time (LT). The TC is calculated using equation 7.

$$LST = LT + \frac{TC}{60} \quad (6)$$

$$TC = 4(Longitude - LSTM) + EoT \quad (7)$$

The Local Standard Meridian (LSTM) is a reference meridian used for a particular time zone and it is calculated using equation 8. The ΔT_{GMT} is the difference of the local time (LT) from Greenwich Mean Tim (GMT) in hours and the equation of time (EoT) is calculated by equation 9 with B (in degree) is calculated in equation 10.

$$LSTM = 15^{o}.\Delta T_{GMT} \quad (8)$$

$$EoT = \sin(2B) - 7.53\cos(B) - 1.5\sin(B) \quad (9)$$

$$B = \frac{360}{365}(d - 81) \quad (10)$$

Based from this equation 2 and 3, we can see that the information on the time of the day and also the location data as an input. This shows that different time or location produces different elevation and azimuth angles.

2.4 Solar Energy Generation System

Solar power system mainly uses PV modules to convert sunlight to electricity. The electricity produced can be stored in battery or used directly depending on their uses. Solar generation system consists of components. These components are selected according to the system type, location and applications. The components for solar generation systems are:

1) PV module
2) Solar Charger Controller
3) Power inverter
4) Battery
5) Load

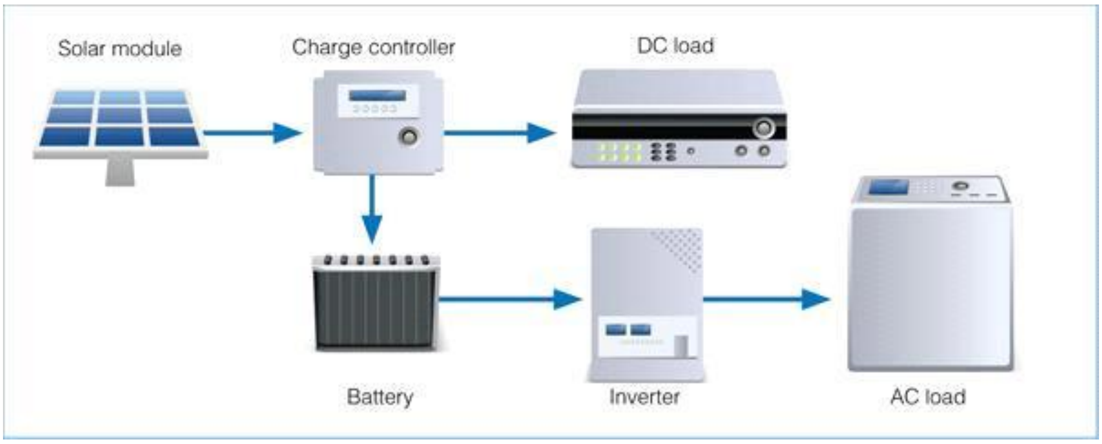

Figure 4: Solar energy generation system components

Solar generation system can also be divided according to their application. Which are stand-alone applications and grid-connected applications. Stand-alone solar generation systems are separated from the power grid. It only uses solar panels to power-up the applications. Stand-alone solar generation system can also be divided into smaller categories; direct-coupled system and stand-alone system with batteries. The main different between direct-coupled system and stand-alone system with batteries are the presence of battery. The direct-coupled system provides power directly to the application from solar panel while the stand-alone system with batteries provides power thru the batteries. The direct-coupled system can only be used during the day while the stand-alone system with batteries can be used at any time due to the energy stored in the battery. The functions of storage battery in stand-alone system with batteries are:

a) Energy storage capacity and autonomy – to store energy when there is an excess is available and provide it when needed.

b) Voltage and current stabilization – to provide stable current and voltage

c) Supply surge current – to provide surge currents to loads

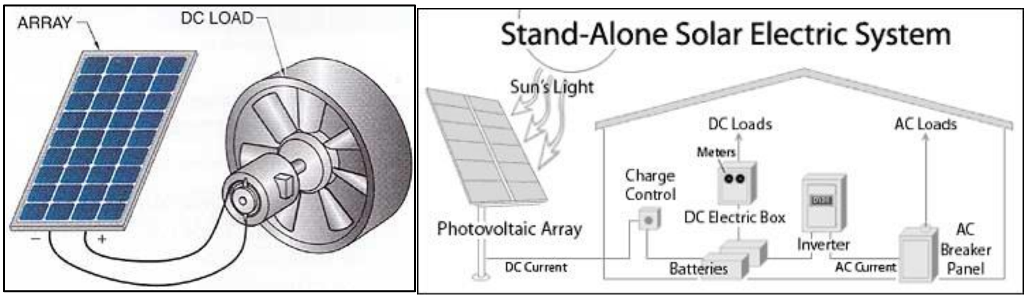

Figure 5: direct-coupled system and stand-alone system with batteries

The main concern for stand-alone systems is load related problems. Unlike grid-connected system the stand-alone needed to provide power with accordance to the load of the applications. The stand-alone system does not have the backing of grid system for excess load.

2.5 Current SEGS in Market

Figure 6: Examples of SEGS in Market[7-10]

Currently the SEGS offered in market are quiet pricy with price ranging from RM900+ to RM6000+[7-10]. They are sold based on their power rating. The smallest power rating for SEGS available in the market is 30W with price of rm900+. The advantages of the SEGS are they can act as backup power source in emergency and can be used as an alternative power source. The disadvantage of the SEGS in the market is as mentioned above they are pricy, not all are portable and do not have proper sun-tracking system. Currently with their price range customer views them as unnecessary. So in my project, I intent to produce a reasonable price SEGS with portability and sun-tracking features.

2.6 PV Module

Solar energy is produced from solar photovoltaic (PV) cell. PV produces electricity by taking advantage of the unique properties of the semiconductors used. This semiconductor is used to directly convert solar radiation into electricity. The semiconductor is arranged in a wafer like arrangement. This increases the sensitivity to sunlight. When exposed to light it produces a small direct current. This process is also known as photoelectric effect. There are 3 types of solar cells, which are monocrystalline cells, polycrystalline cells and amorphous cells (thin-film)[11, 12].

Table 3: Solar Cell Comparison

Solar cell	Monocrystalline cells	Polycrystalline cells	Amorphous cells
Advantages	-highest efficiency rate -space efficient -has long lifespan	-manufacturing cost is cheaper and simpler	-mass production is simple -look appealing -flexible heat -high heat tolerance
Disadvantages	-most expensive -more efficient in warm weather -highly sensitive (circuit can break down if solar cell is partially covered)	-efficiency is very low (13%-16%) -lower space -efficiency -not appealing	-low space -low efficiency -degrade faster

CHAPTER 3: METHODOLOGY

3.1 Procedure Identification

The methodology is divided into 5 main phase: planning, research, analysis, design and implementation phase. The planning phase is the most crucial phase. The planning phase determines the expectation milestone and timeline for completion of project. This will ensure all activities will be done on schedule and development of the project is on time. Flow chart below shows the methodology approach for this project:

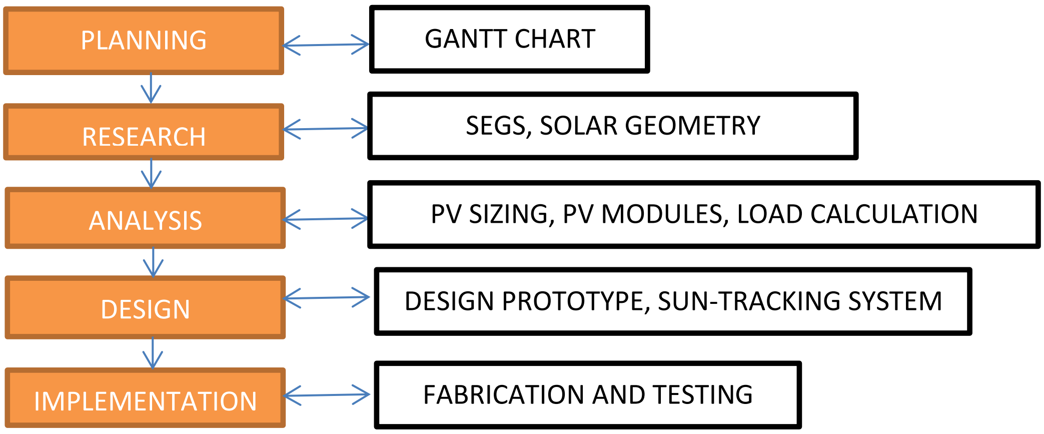

Figure 7: Methodology Approach

The research phase is where all the information and study of the literature review for this project is done. The research phase includes finding information on SEGS, solar geometry, PV modules and experimentation on solar radiation. Next, the analysis phase is where the computation and theoretical analysis is done. This process includes finding the PV sizing, suitable PV module and load calculation. The design phase determines the design of the prototype and its operational components. The selection of equipment for the prototype is also done during design phase.

Lastly, the final phase is the fabrication and testing of the prototype model. In this, the prototype is constructed and tested. The testing process is to ensure the prototype is functional and optimum output is produced. During the testing process, improvement of the prototype is also made to ensure there are no failures and improvement has been made.

3.2 Research Methodology

3.2.1 Solar Photovoltaic System

In order to find the optimum characteristic of SEGS, comparison on SEGS with sun-tracking and without sun-tracking is done. One solar panel will have fixed angle while the other have been applied with solar tacker. The basic components in solar photovoltaic system are solar panels, charger controller, battery, inverter and load applied which can be DC and AC load.

3.2.2 Single-Axis Solar Tracker

By using Light Dependent Resistor (LDR) to detect sunlight motion and using the output to control the rotation of motor, a basic single-axis solar tracker can be built. This single-axis solar tracker will be designed to track the sun in azimuth rotation or known as daily sun path from early morning to late evening. The LDR will determine the position of the sun and send the signal to the microcontroller to control the motor movement.[13] The detection of the light from light dependent Resistor (LDR) in figure below is simple and tolerable enough for a small scale solar tracking system. The DC motors direct the orientation of the frame axis weather to move to east or west.

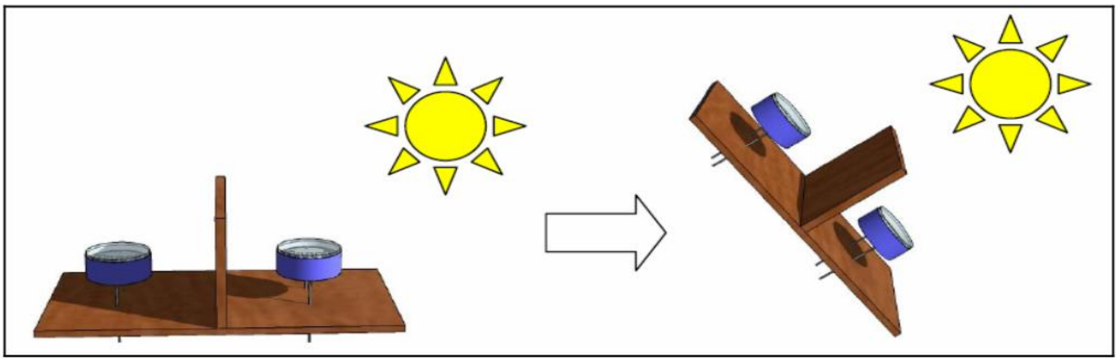

Figure 8: Sensor Response

The Design concept for the prototype is similar as shown as in figure 9. The Design is a flat positioned solar panel which rotates from east to west. The process flow of how it works is shown in figure 10.

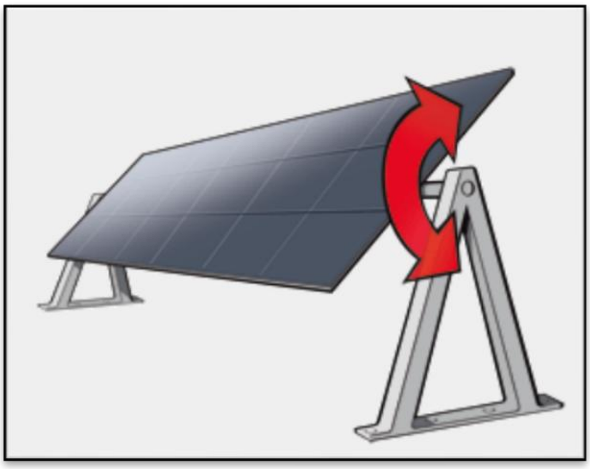

Figure 9: Single-axis Solar Tracker Concept Design

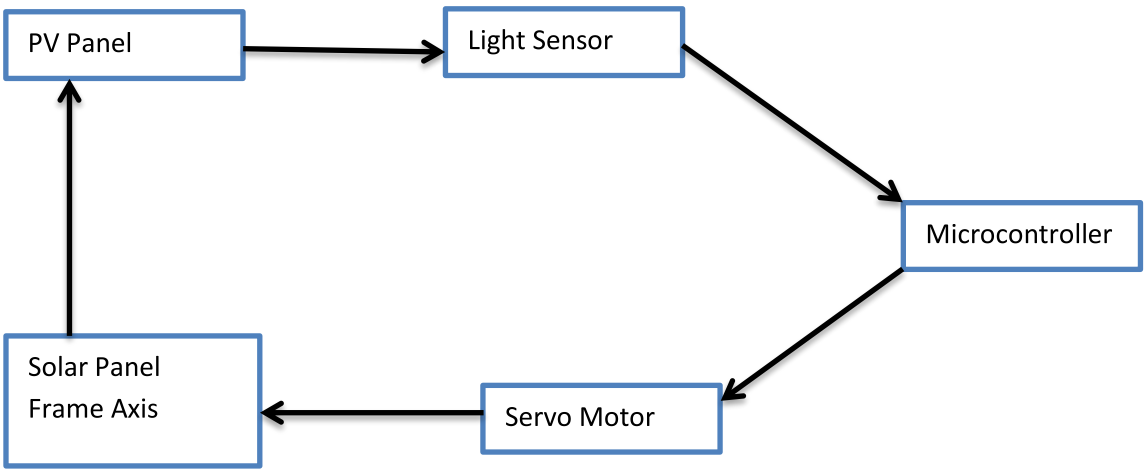

Figure 10: Process flow of single-axis solar

3.3 Project Analysis

3.3.1 Solar PV System Sizing

1) Determine power consumption demands

The first step in designing a solar PV system, we need to find the total power and energy consumption of all loads that need to be supplied by solar PV system. The calculations needed are:

a) Total watt-hours per day for load
b) Calculate total watt-hours per day needed from the PV modules

2) Size of PV modules

Different size of PV modules has different rating. For us to obtain the sizing of the PV module, we need to find the value of total peak watt (Wp).The Wp value are affected by the PV module and climate of site. Different climate of site gives different "panel generation factor", in which case for Malaysia, the panel generation factor is 3.43. The calculations needed are:

a) Total Watt-peak rating needed for PV modules
b) Total number of PV panels for the system

3) Inverter Sizing

An Inverter is used to convert Direct Current (DC) from PV panel or Battery to Alternating Current (AC) for appliances that use AC as power source. The project is a stand-alone system, so the inverter used must be large enough to handle the amount of power used at one time. The calculation for Inverter sizing is as follows:

$$\text{Inverter Power} = \text{Maximum Load} \times 3 \qquad (11)$$

4) Battery Sizing

The battery functions as storing medium for electrical energy for the system. The battery selection criteria depend on its total power demand. Calculation for battery capacity in Ah and Wh are shown in equation 12 and 13.

Table 4: Battery Selection Criteria

Battery Selection Criteria	
Total Power Demand (kWh)	Battery Voltage (V)
<1000	12
1000 to 2000	24
2000 to 3000	36
3000 to 4000	48
4000 to 5000	60

$$Battery\ Capacity\ (Ah) = \frac{Battery\ Capacity(Wh)}{Battery\ Voltage} \tag{12}$$

$$Battery\ Capacity(Wh) = Total\ Power\ Demand \times Storage\ Days\ x \frac{100}{Battery\ DOD} \tag{13}$$

5) Solar Charger controller sizing

The solar charge controller must have enough capacity to handle the current from PV. The equation for solar charger is shown in equation 16.

$$Solar\ Charger(Amps) = \frac{Panel\ Wattage}{Battery\ Voltage} \tag{14}$$

3.4 Tools/ Equipment used

The tools and equipment are categorised into two categories: software and prototype. For software, the design of the prototype is done by using Google Sketch up software and the solar insolation recorder is recorded by using data taker software.

For the prototype, it is divided into two parts which are sun-tracking system and solar generation system. The sun-tracking system is mainly consisted of light resistor, microcontroller and motor. The solar generation system is mainly consisted of PV panels, casing, solar charge controller, battery and power inverter,

3.5 Design Justification

The proposed SEGS design is constructed using the software Sketch-up. With portability in mind for the design of the SEGS, the SEGS needed to be easily carried and assemble when it is needed to be use. I have decided to incorporate the SEGS design with a luggage bag to provide the ease of access and movement of the SEGS. The upper compartment of the bag is attached with the Solar PV and the lower part is the circuit of the SEGS system. The system are discussed and explained according to each parts involved.

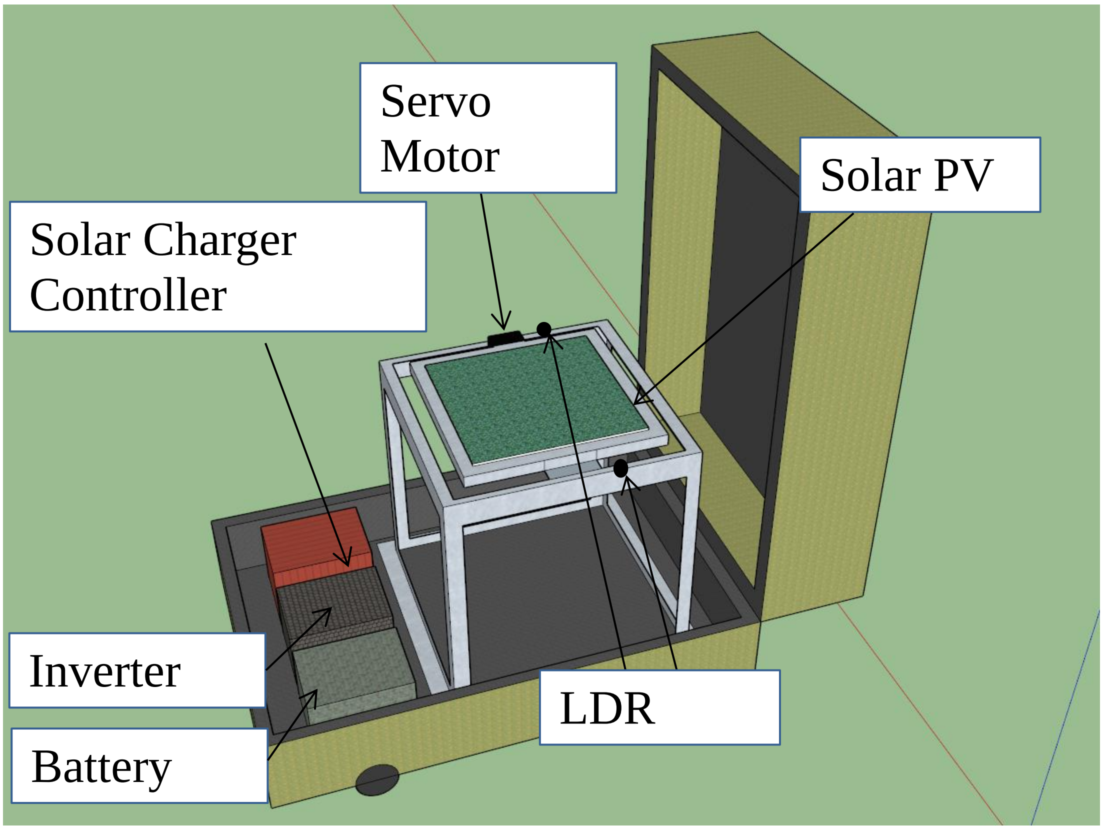

Figure 11: SEGS Design

3.5.1 Specifications

Solar Panel

PV panels are required to produce direct current (DC) electricity from the solar insolation. The electricity produced depend on efficiency of the cell used, array area and array orientation.

Table 5: Solar Panel Specification

Poly Solar Specification	
Type	Solar Module
Maximum Power (Wp)	10W
Maximum Power Voltage (V)	18V
Maximum Power Current (I)	0.56A
Open Circuit Voltage (V)	21.67V
Short circuit current	0.61A
Size of module	360”300”17
Weight (Kg)	1.2Kg

Battery Storage

Battery is used as an auxiliary system when solar panel is unable to provide the sufficient energy such as at night or cloudy day. The batteries are available in many type and sizes. The specifications of battery used are

Type: Sealed Lead Acid

Rated Voltage: 12V

Rated Ampere: 7Ah

Charge Controller

Charge controller is required to protect the battery bank from overcharging. It does this by monitoring the battery bank. When the bank is fully charged, the controller interrupts the flow of electricity from the PV panels. Basically it is used to regulates the voltage and current coming from PV panels to battery.

Power Inverter

Power Inverter is used to converts DC output of PV panels or wind turbine into a clean AC current for AC appliances or fed back into grid line.

Servo Motor

Servo motor is used to turn the solar panel for the sun-tracking system. The servo motor is chosen because it is easier to program and cheaper compared to other motor. The Servo motor has two input source mode, 4.8V and 6.0V. In this project the setting for 6.0V input power source is used to provide higher torque to turn the solar panel.

Table 6: Servo Motor Specification

Model		C40R
Size (mm)		40.8x20.18x36.5
Weight(g)		36
4.8V	**Speed/60°**	0.19
	Torque (kg-cm)	6.00
6.0V	**Speed/60°**	0.16
	Torques (kg-cm)	7.00

Arduino Mega 2560 (Microcontroller)

Arduino is an open-source electronics prototyping platform. It is an easy to use hardware and software. It has many types of microcontroller depending on the usage. The Arduino component that is used in this project is Arduino Mega. The Arduino Mega has a higher number of pin compared to other Arduino.

3.6 Project Activity

The project is divided into 3 phase: input, process and output. The input for this project is the entire component required which include solar panel, charge controller and battery. Other input is the data needed which include the radiation and load data. Next, in the process phase the input being used to provide solar electricity to the system and used for tracking purposes. The prototype of solar electrical generation system is then designed and fabricated. The output is then provided with either AC source or DC source depending on the equipment used. The project flow is drafted in figure 13.

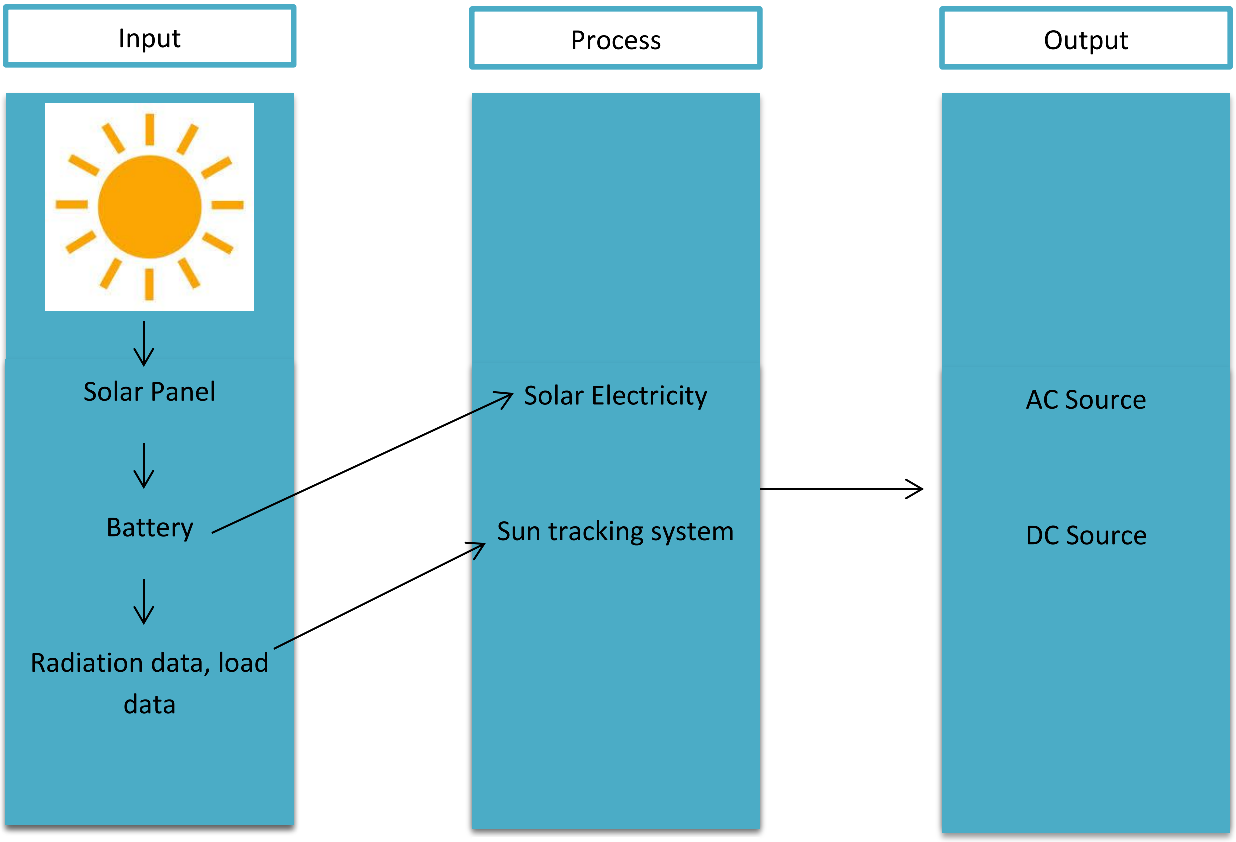

Figure 12: Project Work

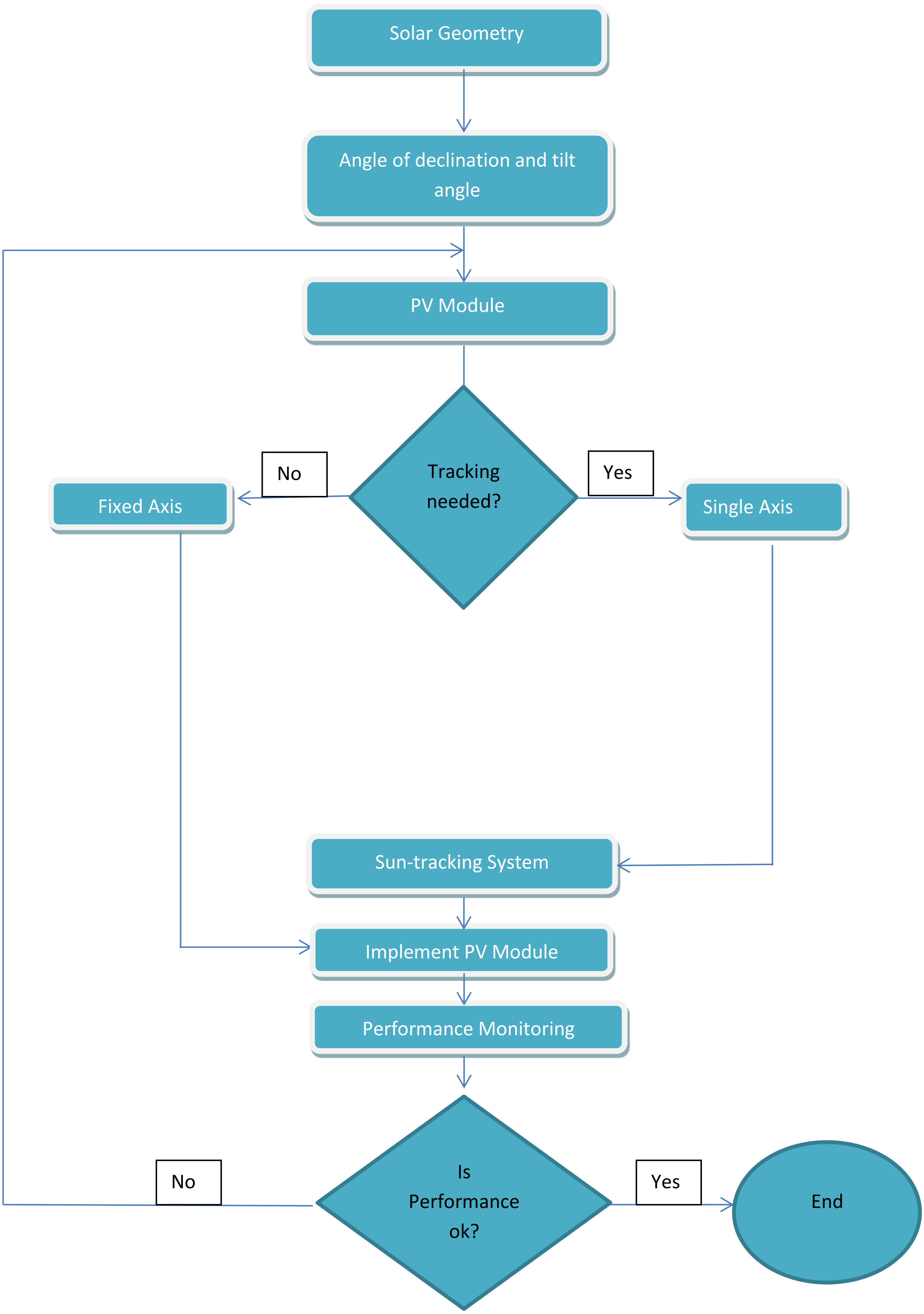

Figure 13: Project Process Flow

3.7 Solar Insolation monitoring experiment

In order to get a clearer understanding on solar radiation, solar insolation monitoring experiment has been done. The experiment is conducted from 9am to 5pm. The experiment is conducted at UTP solar farm.

Tools used:

1) DataTaker – to record solar insolation and voltage
2) Pyranometer – to measure solar insolation
3) 6V PV panel – to measure voltage
4) Internet browser – to access recorded data

Figure 14: Pyranometer, PV panel and DataTaker

Procedure:

1) AT 8.50 AM, The PV panel and pyranometer were put in a fixed axis and facing upward.
2) The dataTaker was connected with a laptop by using a LAN wire.
3) The data recorded in dataTaker was display by using internet browser by entering the IP address of the dataTaker into the browser address.
4) After 5pm, the experiment was stopped and the data recorded is saved in excel format.
5) The experiment is the repeated with a single-axis sun-tracking system

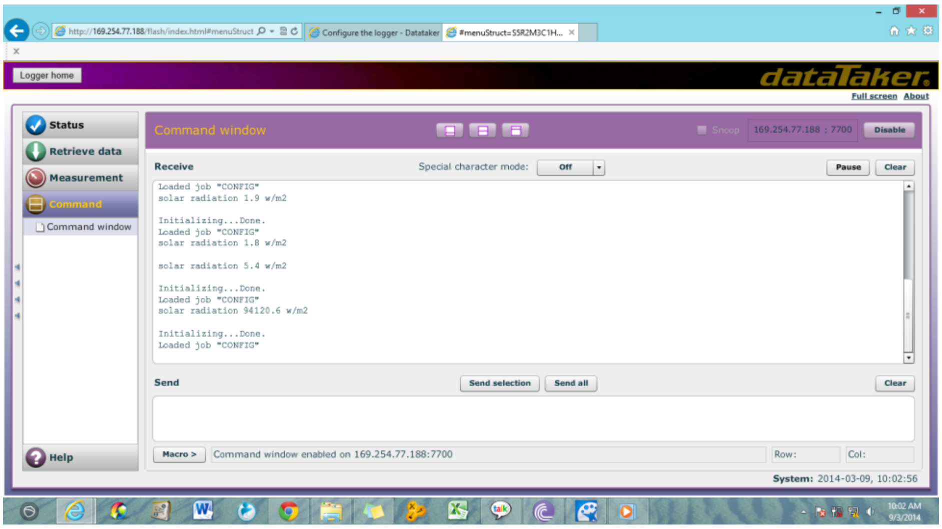

Figure 15: Data Taker Browser Display

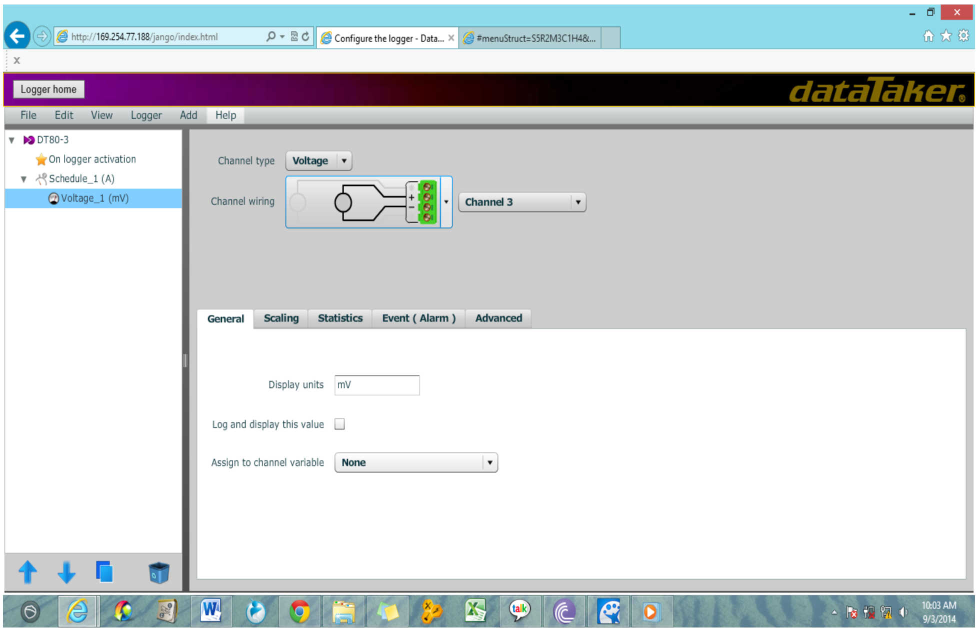

Figure 16: Data Taker Browser Display

3.8 GANTT CHART

No.	Actvities	Weeks													
	FYP 1 Progress and Milestone (Jan 2014)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Title Selection														
2	Preliminary Research & Literature Review														
3	Components Identification & Evaluation														
4	Learning basic for data-tacker														
5	Experiment for angle of decline, tilt angle and sun-tracking														
6	Extended Proposal														
7	Proposal Defend														
8	Preparing Interim Draft Report														
9	Preparing Interim Final Report														
	FYP 2 Progress and Milestone (May 2014)														
1	Install Circuit in Vehicles														
2	Test Drive														
3	Thesis/Report														

CHAPTER 4: RESULT AND DISCUSSION

4.1 Result for Solar monitoring experiment:

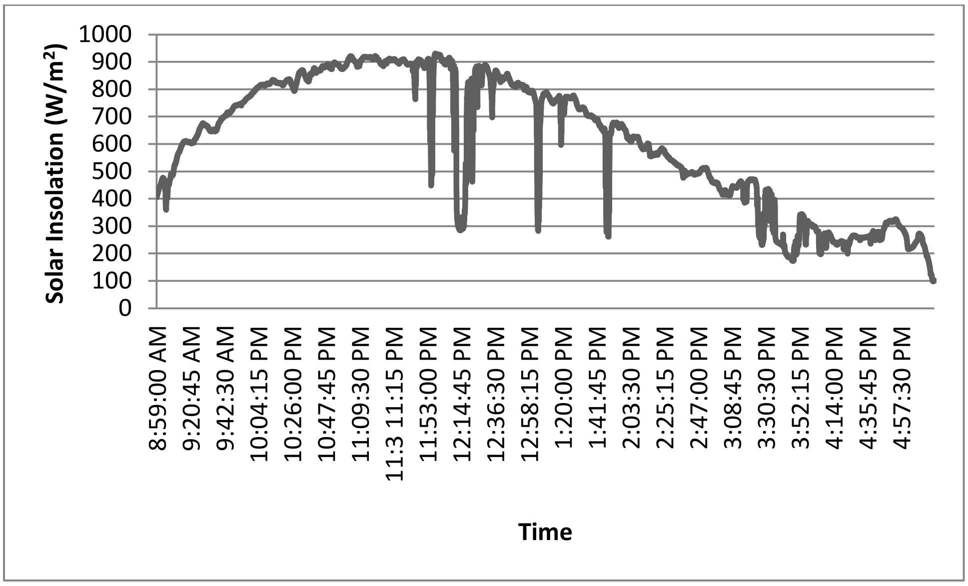

Figure 17: Solar Radiation vs. time

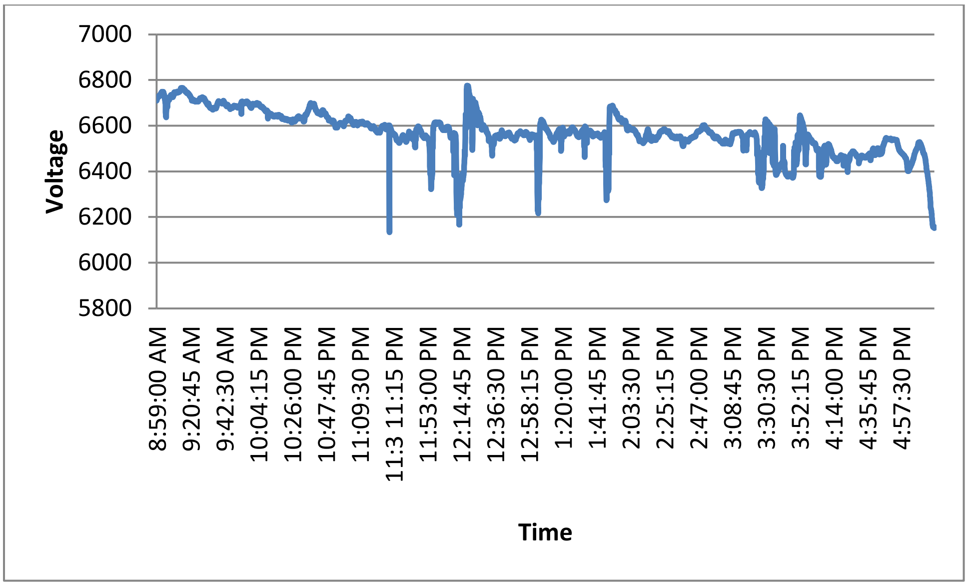

Figure 18: Voltage vs. time

Based from the result obtain, we can see that the solar radiation increases from 9am to 12pm. The solar radiation reaches peak value at around 12 pm with around 925 W/m^2. Then the solar radiation started to decrease until the end of the experiment. We can also see that the solar insolation fluctuates throughout the experiment. This is due to the shading effect caused by clouds, dusts and pollutants. We can also see there are fluctuations of voltage value and the value of voltage in the morning is slightly higher than in the afternoon. This is because there is energy loss due to the hot temperature in the afternoon. For the PV panel to produce the rated voltage, the PV panel needed to have insolation value of $1000W/m^2$ and temperature of 25^o Celsius. This experiment shows that there is a need for a good sun-tracking system to obtain an optimum value of insolation. This in turn gives benefit for the SEGS as the rated voltage and power produce depends on the insolation value.

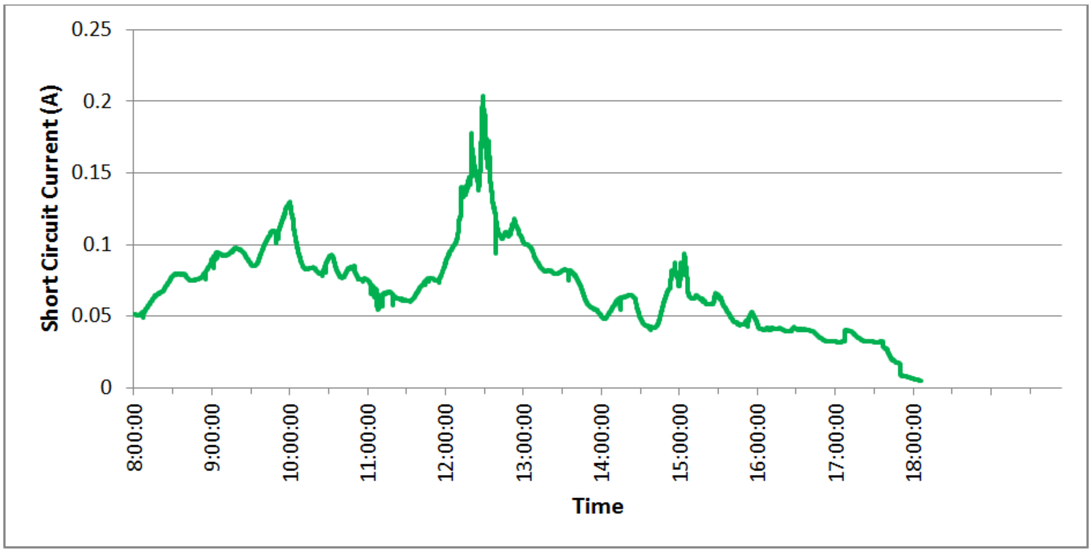

Figure 19: Short circuit current of the fixed solar panel (experiment control)

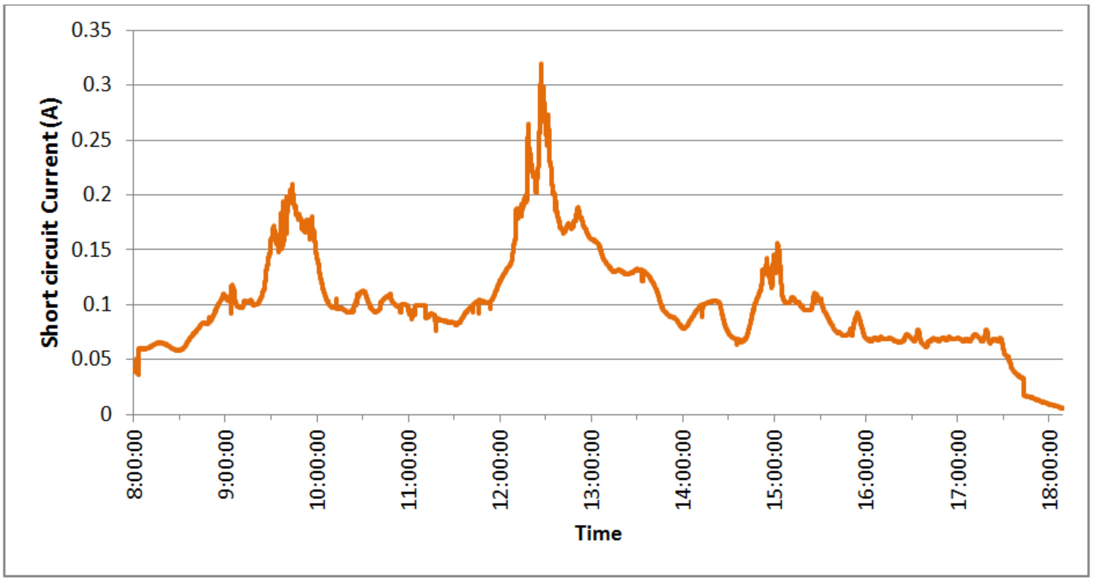

Figure 20: Short circuit current of the single-axis solar tracker

Figure 19 and 20 shows the graph of short-circuit current generated from the fixed solar panel and the single-axis solar panel. The current value measured shows increasing and decreasing pattern according to the intensity light at certain time. As light intensity increases the short circuit current increases. However, the values are different with the single-axis gaining considerably higher compared to fixed axis. As we can see, the difference in value from all panels is big during the early morning and late evening. However the value of current value is smaller during the late evening. This happen because the solar trackers' angle of incidence are about the same to the fixed angle solar panel. The fixed does not face the sun directly during morning and late evening. In overall the single-axis solar tracker generated the highest short circuit compared to the fixed angle solar panel.

4.2 Calculation on Load analysis

Load analysis is calculation for the load used for the evaporative solar cooler system which includes the fan and water pump. In this calculation, it is assumed that the average usage of the SEGS is 35 hour per week and the load has DC system voltage of 12V and 2A. The power requirement for the load is calculated by using equation:

Power = Voltage (V) x Current (I) (15)

Table 7: Load Parameter

Items	Voltage (V)	Current (I)	Power (P)	Quantities	Total Watt	Hours/Week	Watt-Hour/Week
Load	12	2	24	1	24	35	840
Total							840

The total amp-hours per week used by DC loads:

$$= \frac{840Watt - hour/week}{12V}$$

= 70 A-h/week

The total average ampere hour per day

$$= \frac{70A - hour/week}{7days}$$

= 10 A-h/day

4.3 Calculation on PV Array Sizing

Harnessing device such as PV panel is rather expensive. Thus, proper sizing of the solar panel should be done. From the load analysis calculation, total average ampere-hour per day = 10 A-h. It is assumed that the average sun hour per day in Malaysia is 5 hours. From the solar panel specification, peak amp of solar module or current at maximum power = 1.5 A

Total ampere-hour per day with compensation for loss of battery charge/discharge

= 0.7 x Ampere-hour per day

=0.7 x 10 A-h/day

=7 A-h/day

Total Solar array amp required for the system

$$= \frac{7A - h/day(Ampere - hour\ per\ day)}{5hour/day\ (\ sun\ hour\ per\ day)}$$

= 1.4A

Total modules of solar modules in parallel required

$$= \frac{1.4\ (total\ solar\ array\ amp\ required)}{1.5(current\ at\ maximum\ Power)}$$

= 1 module

4.4 Battery Sizing

From the load analysis calculation, daily amp-hour requirement = 8.5 Ah-hr. Maximum number of consecutive cloudy weather days expected in Malaysia or numbers of days of autonomy the system can support is taken to be 2 days.

Amount of amp-hour need to store in the battery

= Daily amp-hour requirement x days off autonomy

= 7 A-h/day x 2 days

= 14 Ah

Given that the depth of discharge of battery or safety factor to avoid overdraining of battery = 0.5 (50%)

$$= \frac{14Ah(Amount\ of\ amp - hour\ need\ to\ store\ in\ battery)}{0.5\ (depth\ of\ discharge\ of\ battery)}$$

= 40.8Ah

From the specification of the battery, total amp-hour rating of battery = 7.2Ah. So, number of batteries wired in parallel required

$$= \frac{40.8Ah(Total\ Battery\ capacity)}{7.2\ (Total\ Amp - hour\ rating\ of\ battery)}$$

= 6

$$Number\ of\ batteries\ wired\ in\ series\ required =$$
$$= \frac{12V(nominal\ system\ voltage)}{12\ (Battery\ voltage\ )}$$

= 1

$$Number\ of\ batteries\ required\ in\ system =$$
$$= 6(number\ of\ batteries\ wired\ in\ series)\ x\ 1(number\ of\ batteries\ wired\ in\ parallel)$$

= 6 batteries

4.5 Cost of production

The Cost of production is calculated and shown in the table below. The total price is Rm 678. The price is lower if compared to the current market price for SEGS.

Table 8: Cost of Production

no	item	units	price
1	Solar Panel 17V 290mA (5W)	X1	Rm145
2	12V/7.0Ah Lead Acid	X1	Rm55
3	Arduino Mega 2560 R3-Main Board	X1	Rm168
4	RC Micro Servo Motor	X1	Rm40
5	Power Inverter	X1	Rm140
6	Luggage bag	X1	Rm40
7	Charger Controller	X1	Rm75
8	Wires, screws and breadboard		Rm15
	Total Price		Rm678

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

All of the work planned is successfully completed within the expected time. The feasibility study on the production of SEGS has been completed. The analysis on PV sizing has been done. The prototype has been designed, fabricated and tested. Thus, the objectives of this project have been met.

This SEGS is suitable as an alternative power source because it is portable and utilises solar energy to produce clean energy. The cost is also considerably lower than the SEGS available in the current market. The sun-tracking system used provides optimum energy gained for the SEGS.

5.2 Recommendation

It is recommended that this SEGS is being applied in real life domestic sector. This is because it can act as an alternative power source for AC and DC load. Integrating this system in the domestic sector will be energy-saving and cost-effective.

Further improvement in the future for the project is to put multiple solar panel and dual-tracking system. Multiple solar panels and dual-tracking system can increase the efficiency of the SEGS to another level.

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