SUSTAINABLE SOLAR-WIND HYBRID POWER PLANT IN MALAYSIA

By

YIEW DE AN

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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June 2009

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.

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Yiew De An

ABSTRACT

The aim of this project is to carry out studies on the development of a solar and wind hybrid power plant in Malaysia. Solar and wind energy are renewable sources of energy that can be used for electrical power generation. The government of Malaysia has expressed its interests and commitment towards developing the renewable energy sector as stated in the 9^{th} Malaysian Plan. Solar and wind energy sources are intermittent sources of energy. They are not available on demand and necessary implementation of backup systems is to be arranged to obtain a reliable supply. The reliability and overall performance of solar and wind power plants can be improved by implementing a hybrid system where both the solar and wind plants supplement each other to further enhance their energy harvesting capability. This project is to study the feasibility of a hybrid plant as compared standalone solar and wind power plants in areas pertaining to the reliability and sustainability of our energy sources. In addition to combining both power sources, the efficiency factors of solar powered systems were studied to further improve the overall performance of the hybrid system. Initially, at the theoretical development stage, the modeling equations were formulated for sizing simulations. Results were used for the construction of a prototype. The results obtained from this study includes data indicating factors, such as solar positioning, PV operating temperatures, PV efficiency, solar irradiance, and operating locations that affect solar power output of PV arrays and comprehensive sizing data for local implementation, while at the same time, addressing issues pertaining to reliability and sustainability of existing standalone solar power plants.

ACKNOWLEDGEMENTS

I would like to express my thanks to my supervisor of this project, Assoc. Prof. Dr. Balbir Singh Mahinder Singh for the inspirations and guidance in this project. He has constantly provided valuable guidance and advice which has motivated me to contribute my fullest to this project.

Additionally, gratitude is dedicated to my family, close friends and colleagues who has been there through thick and thin in providing moral and technical support during the course of this project. Their constant support has greatly motivated me to continuously put in effort towards the completion of this project, especially during challenging times. Special mention goes to the printed circuit board lab technician, En. Isnani Alias. He has spent a great deal of time assisting with the troubleshooting and printing of the charge controller of this project during the prototype construction phase.

Finally, I would like to thank Universiti Teknologi PETRONAS (UTP) for providing us with the excellent environment and access to facilities to complete this project on our own initiative. The progress of this project would have been slow should the PASCO data acquisition hardware and software were not made available for the experimentation.

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LIST OF ABBREVIATIONS

PV – Photovoltaic

PCB – Printed Circuit Board

DC – Direct Current

AC – Alternating Current

EDX – Engineering Design Exhibition

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The power generation capacity of Malaysia relies largely on fossil fuels. Coal and natural gasses are the main means of electricity generation, followed by petroleum and hydro dams. The former three sources of energy are non-renewable fossil fuels. Among the main concerns over the use of these fuels are sustainability and environmental damage caused by the release of byproducts such as greenhouse gasses into the atmosphere. Malaysia is a tropical country situated near the equator. It receives vast amount of sun light all year round and this makes it the perfect candidate for solar power generation as a main source of electrical energy. In addition to solar power, wind power is also a promising source of energy in Malaysia. This is particularly true near coastal areas and suburban townships where obstructions from tall buildings and pollution in the city are minimal. Solar and wind power has been great sources of renewable energy. The radiation received from the Sun can be effectively converted to electricity using solar cells.

This study looks into the aspect of combining these two individual sources of energy together to form a hybrid that aims to address issues encountered by standalone renewable energy plants (ie. solar power plants), such as poor reliability and over sizing due to source intermittence. This project studies how efficiency can be improved for solar power generation and studies how wind power can be integrated into the system to allow for better reliability and sustainability of the entire plant through optimized and efficient sizing.

1.2 Problem Statement

The main concern over renewable energy sources such as solar and wind power are the reliability, sustainability and economical feasibility in setting up and maintaining solar or wind power plants. Solar power is challenged by the fact that photovoltaic (PV) cells rely heavily on the available sunlight and irradiance on the surface of the panel. Electrical output can be predicted to increase in the morning, reaching the peak mid day and decrease as the day come to an end. No electricity output is expected during the night. With those limitations, PV power stations will require a form of storage or backup system should it be considered as the main source of electricity generation and supply. Commonly energy storage systems such as battery banks and flywheels are implemented with the PV system to allow it to continue supplying its loads during the times when there is insufficient sunlight. However this brings us to the concern of situations when there is an extended absence of useful sunlight for power generation. This directly impacts the economy of the plant should we consider either introducing more PV modules or increasing the capacity of the energy storage. Besides the initial costs involved, future maintenance should also be considered.

Another key concern with renewable energy power plants is proper sizing. Proper plant sizing allows for a reliable system and reduced overall cost and wastage. For a standalone solar power plant, large numbers PV arrays and battery systems are required to avoid system failure due to source intermittence, whenever the sun is not available. These numbers can be reduced by implementing a hybrid system that allows for an auxiliary source of energy (wind) to assist in power generation. However, sizing of a hybrid system should also be thoroughly examined to ensure overall system reliability and cost effectiveness.

Among some of the key areas studied under system sizing includes the optimal number of components: PV arrays, auxiliary wind turbines, battery systems, and energy converters. These parameters rely heavily on the operating condition of the load demand, operating conditions and operating location of the power plant.

1.3 Objectives and Scope of Study

The objectives of this project are to carry out a feasibility study on implementing a solar-wind hybrid system in Malaysia. This project aims to develop a theoretical model to understand the factors that would affect the efficiency of solar power generation and address them in the development of a hybrid power plant. Additionally, sizing studies are to be conducted in this project to determine the optimal sizing for that allows for reliable operation and is within economic sense.

1.3.1 Scope and Outcomes of Project

The objective of this project is to study the feasibility of a solar-wind hybrid power plant in Malaysia. A miniature working prototype is to be constructed to study how the combination of a solar and wind power generating source can complement one another in supplying a load. The scope of this study involves the understanding of the combined solar and wind power generation, regulation, control and storage before distribution to the connected load. Other efficiency and enhancement features will also come under the scope of this study.

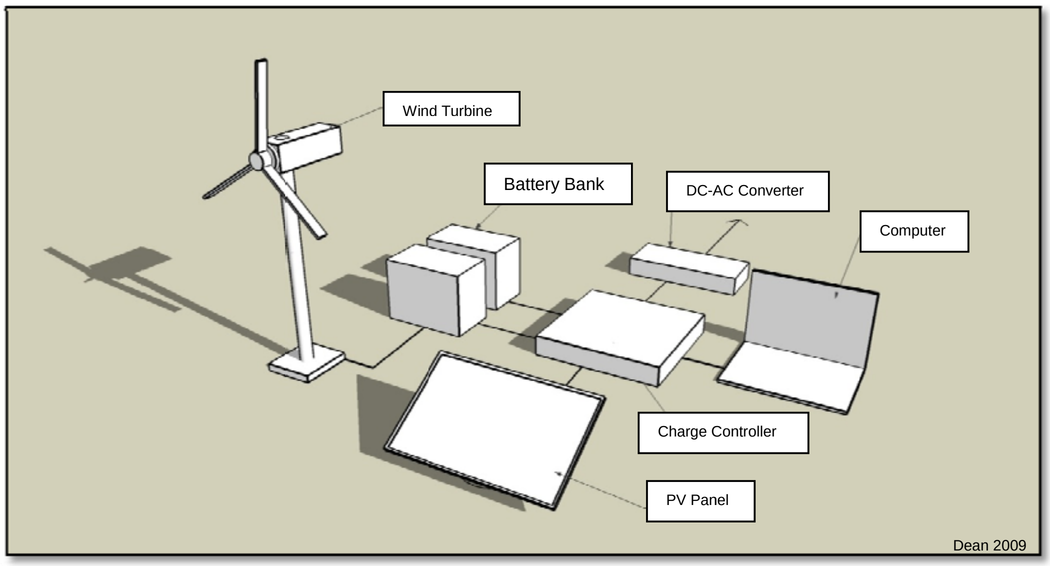


Figure 1 Initial Sketch of Prototype Setup

1.3.2 Relevance of Project with Regards to Problem Statement

A Solar-Wind Hybrid Power Plant will effectively solve the limitations of stand-alone solar and wind power plants by increasing the overall efficiency and reliability of the power station. The plant also answers the questions related to sustainability and pollution as introduced by the current technologies used.

1.3.3 Project Feasibility

Construction of a working prototype within the 2-semester period will be feasible provided proper planning and execution is done beforehand. Semester 1 will involve mostly research, literature reviews and study of the project as a whole.

Semester 2 will begin the construction of the working prototype of a hybrid power plant.

Funds will be allocated to the purchase of hardware and equipment listed under the updated Tools and Hardware Requirements Section. The cost estimated is within the allocated budget and this project is financially feasible.

CHAPTER 2
LITERATURE REVIEW

2.1 Solar Power

The energy from the sun can be converted into electrical energy via semiconductor cells. These cells generate electrical current as electrons are knocked free by photons hitting the cells' surface when exposed to sun light. PV cells deliver electricity in the form of direct current (DC) and for power transmission and distribution; a conversion to alternating current (AC) is required. Among some of the advantages of using PV cells over other methods for electricity generation include its modularity as additional PV cells can be connected or removed as and when needed. Additionally, PV cells have no moving parts and therefore offer enhanced durability and reduced weight [1].

The power generating capacity of a PV cell is directly dependent upon the orientation of the sun's rays and exposure [1] [2]. As described in [3]and [4] a constant orientation of the PV panel towards the direction of the Sun will greatly improve a PV cell's power generation output. The data required can be obtained from either a general formula calculating the Sun's path in the skies over the years or via continuous tracking of the Sun using sensors and equipment.

Upon generating electricity, a means of storage is required to compensate for the times when there is no generating capacity, for instance during the night or on cloudy days. The battery will function as a buffer supplying a steady flow of power to the load [1]. Necessary sizing and calculations needs to be studied to achieve the best combination of PV array size and battery capacity [5]. The following figure illustrates a typical setup of a standalone solar power plant:

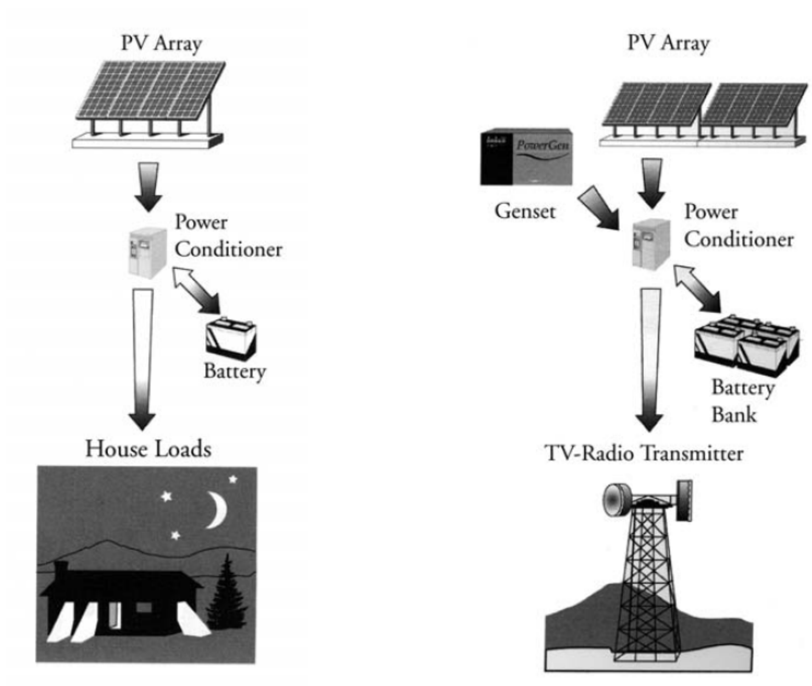


Figure 2 Typical Setup of standalone solar power plants

In general, a standalone solar power plant will consist of the following components [2]:

- **Batteries**, chemical energy storage devices that stores electricity to provide energy on demand when the plant is incapable of generating electricity due to the absence of the Sun.
- **Inverters**, power electronic devices required to convert the DC power produced by the Solar Cell into AC power before supplying it to consumers, or the load.
- **Controllers**, devices that manage the energy storage system, and regulate power to the load.
- **Support Structures**, supporting equipment required for the positioning and mounting of Solar Cells and other components.

Solar power generation is commonly used in isolated sites, where access to and from the electrical power grid is either unavailable or economically not viable. Often solar plants are implemented for applications requiring small amounts of power, usually 10kW or less [2]. A good example of such an implementation would be at Kampong Denai, Sabah, where villagers in remote residential areas rely on the clean energy of a solar power plant.

2.1.1 Types of PV cells

The four main solar cell technologies current on the market are of mono-crystalline silicon, multi-crystalline silicon, amorphous silicon (AS) and copper–indium–diselenide (CIS) types. These cells each portray different levels of efficiencies under different environmental settings and conditions [6], [7]. Environmental settings such as the ambient temperatures and the amount of beam and diffused solar radiation are greatly dependent upon geographical locations. Hence a careful selection of the type of solar cell technology to implement for the location of study (Malaysia) will greatly affect the overall results. The following table lists the comparison between the 4 common types of solar cells available on the market and their performance characteristics [6]:

Table 1 Performance Indices of a-Si, c-Si, mc-Si, CIS

	a-Si	c-Si	mc-Si	CIS
Rated value				
Maximum Power, P_{max} (W)	64.00	75.00	65.00	40.00
Maximum Current, I_{max} (A)	3.58	4.63	3.69	2.41
Maximum Voltage, V_{max} (V)	16.50	17.20	17.60	16.6
Short Circuit Current, I_{sc} (A)	4.80	4.87	3.99	2.68
Open Circuit Voltage, V_{oc} (V)	23.80	21.60	22.10	23.30
Measured value				
Average Ambient Temperature, $T_{a,ave}$ (°C)	30.3	30.3	30.3	30.3
Average Module Temperature, $T_{m,ave}$ (°C)	39.14	40.22	39.19	40.75
Average Module Voltage, V_{ave} (V)	14.277	13.7	14.34	13.88
Average Module Current, I_{ave} (A)	1.48	1.59	1.35	0.99
Average Module Power, P_{ave} (W)	21.6	22.58	19.72	14.13
Module Area (m^2)	0.938	0.432	0.483	0.384
Fill Factor, FF	0.56	0.712	0.73	0.64
Average Output Efficiency (%)	33.74	30.1	30.34	35.31
Average Module Efficiency, η (%)	2.23	6.87	5.14	3.99
Performance Ratio	1.046	0.933	0.941	1.094

2.1.2 *The effects of irradiance on the solar cell output*

Irradiance is the amount of energy per unit area contributed by the sun on a flat surface. The efficiency and usefulness of a solar panel depends heavily on the level of irradiance. Many studies were conducted on this field and the increase level of irradiance results in an increase in energy output of a solar cell. Irradiance is closely related to the extraterrestrial radiation and the clearness index [2], where the daily extraterrestrial radiation on a horizontal surface and clearness index can be estimated as follows:

$$H_0 = \frac{86400 G_{sc}}{\pi}\left(1 + 0.033\cos\left(2\pi\frac{n}{365}\right)\right)\left(\cos\psi\cos\delta\sin\omega_s + \omega_s\sin\psi\sin\delta\right) \quad (1)$$

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_0} \quad (2)$$

$\bar{H}$ = *Monthly average daily radiation on a horizontal surface*

$\bar{H}_0$ = *Monthly average extraterrestrial daily solar radiation on a horizontal surface*

$\bar{K}_T$ = *Monthly average clearness index (values between 0.3 - 0.8)*

The hourly irradiance of a solar cell can be further explored to obtain the calculations for estimating the effects of irradiance in the plane of a solar array.

2.1.3 *Relationship between direction of sun light and solar power output*

As the Earth orbit the Sun at a tilted angle of 23.45 degrees, it can be observed that the position of the sun in the sky is constantly changing throughout the year. The figure below illustrates the phenomena:

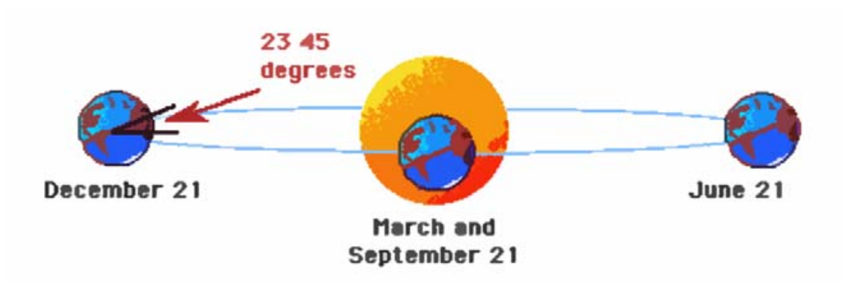


Figure 3 Solar position due to Earth's orientation around the Sun

As illustrated in the figure above, the sun's position in the skies is constantly changing in addition to the everyday effect (morning till evening – east to west), but in a seasonal manner, the sun's position during mid day is different. Hence this greatly affects the output of PV arrays should their position remain unchanged throughout the year when in operation. An obvious solution is to direct PV arrays to face the sun by calculation, which can be implemented via automatic tracking systems and GPS devices.

The Sun's position can be effectively calculated and predicted by a set of mathematical formulas, which will allow us to identify its polar coordinates and enhance the energy harvesting capabilities of PV panels. Tilting a PV panel to face the sun can further enhance the power output. This is illustrated in detail by a study done by [8]. Even so, it is not necessary to constantly adjust the direction of the solar panels by the day. Almost the same level of power output can still be obtained should the solar panels are adjusted on a seasonal basis of once every three months [8]. This answers some of the questions raised on whether it would be practical to install an active tracking system to continuously track the solar path or to manually adjust the system every other day. The former uses additional energy in maintaining the system and increases its complexity and the latter is simply impractical. The declination or the angular position of the sun at solar noon with respect to the plane of the equator and the solar hour angle can be obtained by this formula:

$$\text{Declination, } \delta = 23.45 sin\ (2\pi \frac{284+n}{365}) \quad (3)$$

$$cos\, w_s = -tan\,\psi\, tan\,\delta \quad (4)$$

n = day of the year; Ψ = latitude of the site

2.1.4 Effects of dust on solar power output

In addition to the amount of radiation a PV cell is exposed to, dust particles and sediments collecting on the surface of a PV panel will cause a significant drop in the solar power output as proven in a study by [9]. From said study, it was concluded that a drop from 50% to 12% in terms of efficiency for a proprietary system was observed when the setup was exposed to dust particles.

2.1.5 Effects of operating temperature on solar power output

Operating temperature of a PV panel greatly affects its efficiency and the overall performance of the generated power [9]. This information will assist in planning and analyzing the project design on the implementation of the hybrid power plant. Given the increased average temperature, decentralized systems and placement in urban areas are not suitable for the project. The relationship between the efficiency and ambient temperature of a solar cell can be observed in the following equations:

$$\eta_p = \eta_r \left[1 - \beta_p \left(T_c - T_r\right)\right] \tag{5}$$

$$T_c - T_a = \left(219 + 832\bar{K}_t\right)\frac{NOCT - 20}{800} \tag{6}$$

n_p = *Average efficiency*

n_r = *Solar Cell efficiency*

β_p = *temperature coefficient for module efficiency*

NOCT = Nominal Operating Cell Temperature

$\bar{K}_T$ = *Montly clearness index*

Tc = average module temperature

Tr = reference temperature 25 degrees Celsius

Ta= Mean monthly ambient temperature

2.1.6 Building integrated photovoltaic (BIPV) implementation

In many parts of the word, solar power is implemented in the form of a panel of glass or wall section of a building. These are known as Building Integrated Photovoltaic (BIPV). There are many benefits of BIPV implementation, for one, large areas for plant setup will not be required as the panels can be neatly installed on the buildings they supply power to. This is highly desirable when the loads are large cities. The disadvantages pertaining to BIPV implementation includes the operating temperature increase as large buildings are often located in densely packed cities with higher exposure to green house gasses and heavily polluted air. The increase in ambient temperature will significantly affect the operating efficiency and ultimately the output power of a solar system. Additionally, the cost of maintaining and expanding a decentralized BIPV solar power plant will prove to be significantly more costly and impractical as compared to a centralized system [10].

2.2 Wind Power

Wind energy is converted into electrical energy by an electromechanical device called the wind turbine. Wind turbines come in various forms and the most commonly used in modern wind farms are the 2-3 blade configurations [1]. A wind turbine is setup on top of a tower, connected to a rotating nacelle. The nacelle houses the gear box, generator and the power electronics needed for energy conversion and processing. Similar to solar power, wind is not a constantly available source of energy and therefore requires a form of energy storage as well. To improve the efficiency of wind power, wind patterns, speed, and power relations are often studied before determining the type of wind turbine and size to implement [1] and [11].

2.2.1 Types of wind turbine

The size of the wind turbines rotor coverage is proportional to the amount of wind the system can capture and convert to electrical energy. Additionally, different types of wind turbines yields different amount of energy output when exposed to the same amount of wind [12].

An even number of blades is often avoided when implementing a wind turbine due to stability issues as described by [13]. It is explained that an odd number of blades can be considered to be similar to a disc when the dynamic properties of the machine is evaluated. The most common turbine design currently available is the Danish Three Blade Concept.

2.2.2 Wind turbine sizing

The wind turbine can be effectively sized by tracing the amount of energy required to charge the battery bank. Estimations can be made according to the demand required during peak hours and when the PV panels alone are insufficient to supplying the demand. As wind turbines are complicated and expensive machines [1], cost in implementing multiple wind generating units shall be kept to a minimum by designing a more efficient and cost effective unit.

The wind turbine sizing is can be obtained using the following equations to effectively size and approximate the power rating and capacity of a wind turbine:

$$Kinetic\ Energy = \frac{1}{2} * m * v^2 \quad (7)$$

$$Power\ Swept\ by\ Rotor = \frac{1}{2} * \rho * A * v^3 \quad (8)$$

$$Wind\ Turbine\ Power = \frac{1}{2} * \rho * C_p * v^3 * N_g * N_b \quad (9)$$

m = mass in kg

v = velocity in m/s

ρ = air density in kg/m^3

A = area swept by rotor in m^2

Cp = Coefficient of performance

Ng = generator efficiency

Nb = gearbox/bearings efficiency

2.2.3 Local Implementation of solar and wind power generation

Malaysia is located on the Equator where it receives large quantities of sun light and eventually air movement which leads to wind. This makes it an excellent candidate for the use of renewable energy, such as solar and wind power. According to records obtained from the Malaysian Metrological Department, Malaysia is exposed to large quantities of sunlight and winds speeds of up to 3m/s. However, solar power is generated in small quantities and is implemented in small scaled projects. Some common applications of solar power use are in street lighting and communication terminal operations and parking ticket machinery use. Solar power use of electrification in a remote location is implemented in Sabah, near Kampong Denai where the power plant services the residential area consisting of only 20 homes.

Similarly, wind power is implemented in a very small scale. One such example would be the 150kW wind power plant used to support local commercial activities at Pulau Layang-Layang (formerly known as Swallows Islands), Sabah.

2.3 Hybrid solar and wind power

The Solar-Wind Power Hybrid Power Plant will combine the stand-alone solar and wind power plant to provided a more reliable and form of output. Studies done in [7] showed the complementary relationship between solar and wind power which further strengthens the feasibility study of implementing the technology here in Malaysia where both solar and wind sources are of abundance. The following figure illustrates a large scale solar-wind hybrid power plant.

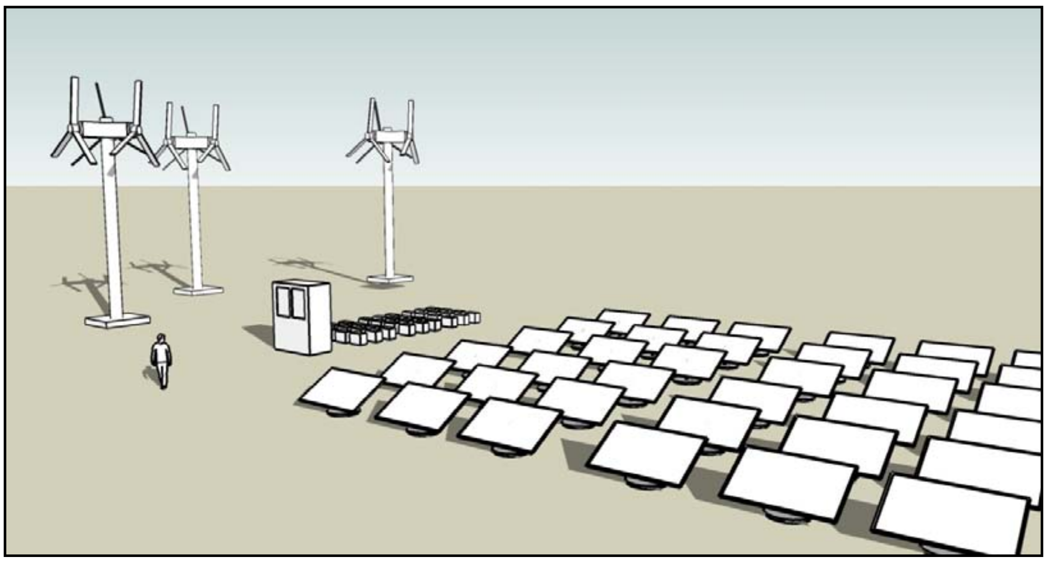


Figure 4 Conceptual solar-wind hybrid power plant design

2.3.1 Level of hybridization

The hybridization for the solar-wind hybrid power plant is at the level of battery charging. This is where the wind turbine replaces an existing diesel generator in supporting the solar power generation system alone.

2.3.2 Cost of hybridization

The cost of implementing a hybrid system will be greatly reduced as indicated in a study [2]. Expensive components of a solar or wind power plant alone such as PV modules and wind generators can be reduced in numbers and designed to operate more efficiently as they complement each other's existence. By using software like HOMER, an optimal balance between each source of renewable energy can be determine to provide the power plant a reliable output and at the same time, avoid over-sizing of the power plant, hence reducing cost.

2.4 System sizing

According to [5], system sizing plays a critical role in effectively implementing a power plant. Proper system sizing reduces the need for over-sizing, resulting in wastage in cost of materials and components used. With proper system sizing, the most optimized setup can determined, which represents a balanced number of components, for instance, PV modules, wind turbines, batteries and power converters to reliably service the load requirements and still stay within economic constraints. The figure below illustrates the breakdown of energy flow and components that system sizing will be capable of addressing.

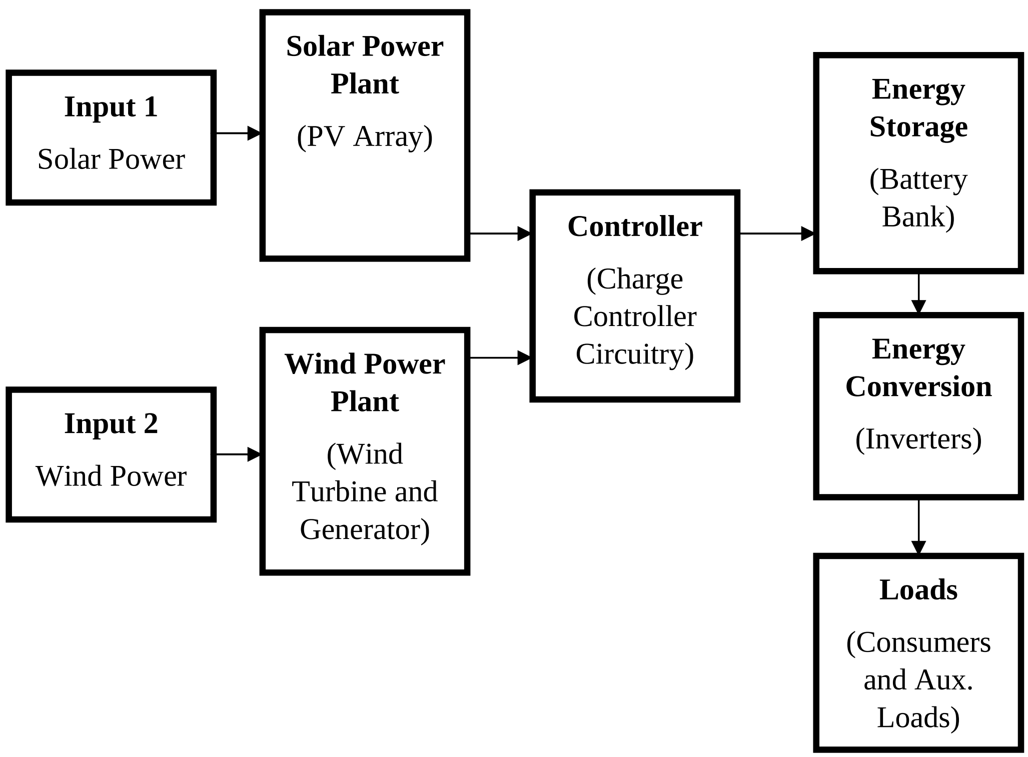


Figure 5 Energy flow diagram

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

Preliminary steps and planning were carried before the construction of a working prototype. The steps are illustrated in the flow chart in the following figure.

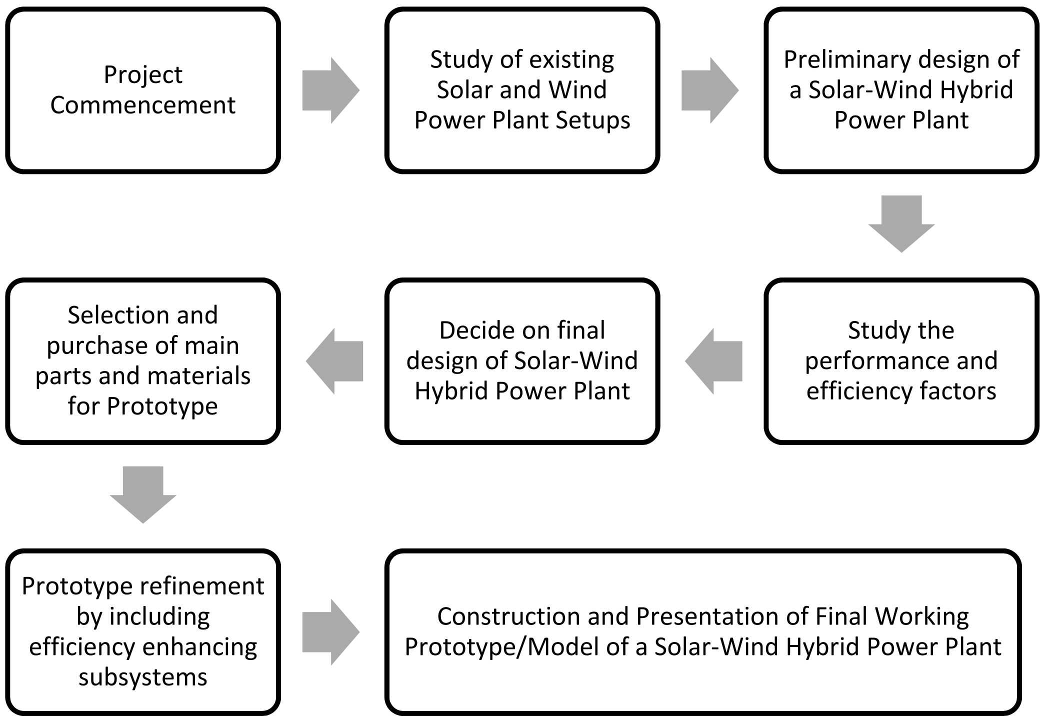


Figure 6 Flow diagram of project progress

The flow chart above illustrates the general progression of the project. During the time of writing, the current progress has reached the final stage. Current works includes the construction and presentation of final prototype of the solar-wind hybrid power plant.

The scope of the project has recently become more focused on the various efficiency issues affecting a solar power plant and how the implementation of a wind generator will assist in a hybridized environment. A Gantt Chart dictating the schedule and milestones for the project is attached in Appendix A.

3.2 Tools and software requirements

The table below lists the revised hardware and software requirements for this project.

Table 2 List of tools and equipment required

NO.	ITEM	Quantity	EST. UNIT PRICE (MYR)	TOTAL EST. PRICE (MYR)
1.	Photovoltaic (PV) Array Panel	1 Unit	n/a	n/a
2.	12V Lead Acid Battery	1 Unit	75.00	75.00
3.	6 Blade Rotor Set	1 Lot	10.00	10.00
4.	Induction Motor/Generator Set	1 Lot	50.00	100.00
5.	Voltage Regulator and Charge Controller	1 Unit	150.00	150.00
6.	120VAC Inverter Module	1 Unit	50.00	50.00
7.	AC – DC Voltage Converter	1 Unit	n/a	n/a
8.	Support Structure for PV panel	1 Unit	n/a	n/a
9.	PASCO Data Acquisition System	1 Unit	n/a	n/a
10.	Portable AC DC Power Source	1 Unit	n/a	n/a
11.	Power Electronics Components	1 Lot	n/a	n/a
12.	Microsoft Office Excel	1 Lot	n/a	n/a
13.	HOMER Software	1 Lot	n/a	n/a
Grand Total				**385.00**

The cost planning for this project is RM 385.00, which is within the stipulated cost allowance allocated by the university.

3.3 Project Planning

The planning of this project can be divided into multiple phases in addition to the 2 semesters as it involves multiple sections to be completed before the final prototype is implemented together as a whole. The Gantt chart in Appendix A further describes the overall planning of major milestones to be achieved for the overall project.

3.4 Theoretical Development

A detailed theoretical development to implementation a functional solar power plant was established. Further modifications were made to hybridize the default system and to implement a wind generator to form the proposed solar-wind hybrid power plant [2]. The figure below illustrates the approach towards analyzing a hybrid plant.

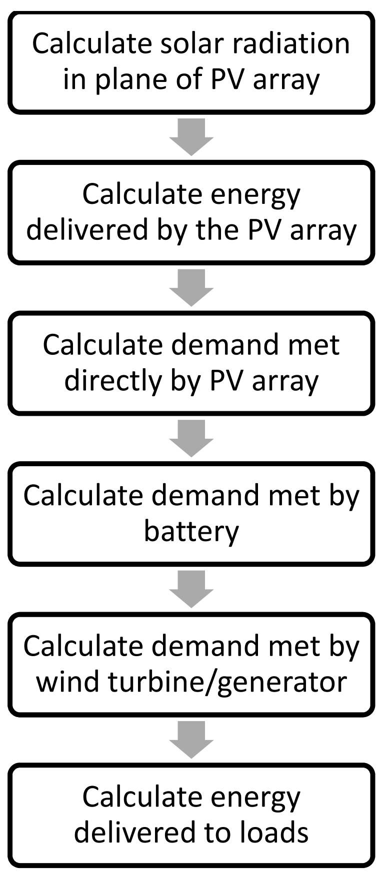


Figure 7 Theoretical development flow chart for hybrid power plant

In approaching the theoretical development, the metrological element was first studied to understand the relationship between declination angles of the sun, the solar hour angles, and altitude angle. This was followed by the extraterrestrial radiation and clearness index calculations to indentify the relationship between the amount of radiation and overall PV system output.

Additionally, the tilted irradiance calculations were made using the set of formulas introduced in [2] to help estimate the effects of tilting a PV panel to face the direction of the sun. The information obtained from the solar study was then applied to the PV Array model where the efficiencies and parameters were linked to obtained output information for PV array sizing purposes based on the environmental situations.

An off-grid model was chosen for the study of this project. A general number of 20 homes using 60kWh per day were used as an estimate for the load calculations. The estimation was done using the break down below:

Table 3 Breakdown of load estimates in an average home

Electrically powered items	Quantity	Average monthly KWh	KWh/month
Refrigerator	1	182	182
Freezer	1	190	190
Range/Oven	1	104	104
Microwave Oven	1	16	16
Coffee Maker	1	19	19
Well Pump ½ HP	1	90	90
Stereo system	1	5	5
TV (19 inches)	1	18	18
Washing Machine	2 (loads a week)	0.33	1
Lighting (# of rooms)	3	10	30

Outdoor Lamp	1	60	60
Outdoor Lamp	1	87	87

From the estimated values used in the table above, the calculated household energy usage per month is 1776kWh. By dividing this value by 30 days, we can approximate the amount of energy needed in a day, which is close to 60kWh. Using this value, the load value can be approximated for further sizing simulations of components on the hybrid power plant.

The energy demand was further separated into matched demand, continuous demand and battery demand for detailed analysis of the energy distribution. The energy breakdown analysis allowed the estimation and sizing of the battery system in terms of capacity. An estimated amount of standby time by the battery bank was estimated to last 3 days when there is poor or nonexistent sunlight for electricity production.

A modification to the model was made in this section to implement a wind generator in place of a conventional diesel generator. The generator rating was obtained based on the scope of said generator will only be used to charge the battery bank when needed. This information allowed further estimations on the environmental factors that affect wind power generators.

Mathematical models were compiled using Microsoft Excel to allow quick and comprehensive computation of these relationships. From these models, meteorological and geographical data, such as average daily irradiance, average wind speeds, and coordinates for Malaysia were obtained and used as inputs to facilitate the closest estimation to the local context. A complete list of equations used in the mathematical model is listed in Appendix B.

3.5 Design of an efficient wind turbine

During the course of this project, different wind turbine configurations were tested to determine the most efficient design to optimize electricity generation. A proprietary wind turbine was to be designed to harness as much wind as possible given the same rotor area as the standard turbine. An experiment was conducted using DC induction motor/fans by reversing their rotation.

The five configurations tested for this were the single turbine, single turbine in wind tunnel, two turbines back to back, single turbine in funnel, and single turbine with reduced blades. A control fan was attached to the generating fans to provide the upstream breeze. The generating fans were connected to the PASCO data acquisition system to obtain the output voltage.

3.6 Sizing simulation using HOMER

Proper sizing was conducted to study the economic feasibility of implementing a hybrid power plant in Malaysia. The simulation was conducted using the underlying factors that affect the electricity generation of renewable energy systems such as solar power and wind power. The HOMER software allowed the detailed analysis of the commercial factors and also overall operation factors involved in determining the feasibility of the project. A simulation or 'test' scenario was designed to see how a small-scale standalone hybrid plant would fit into context. The setup consists of supplying uninterrupted electricity to 20 modern homes in the Malaysian climate, particularly in suburban Kuala Lumpur, Malaysia. The hybrid configuration was first setup where the main network involved the primary load, solar panels, wind turbines, converters and battery banks. The sections below further elaborate the methodology used to obtain the best setup for the most practical and cost effective implementation of the system. The figure below illustrates the user interface of the HOMER software.

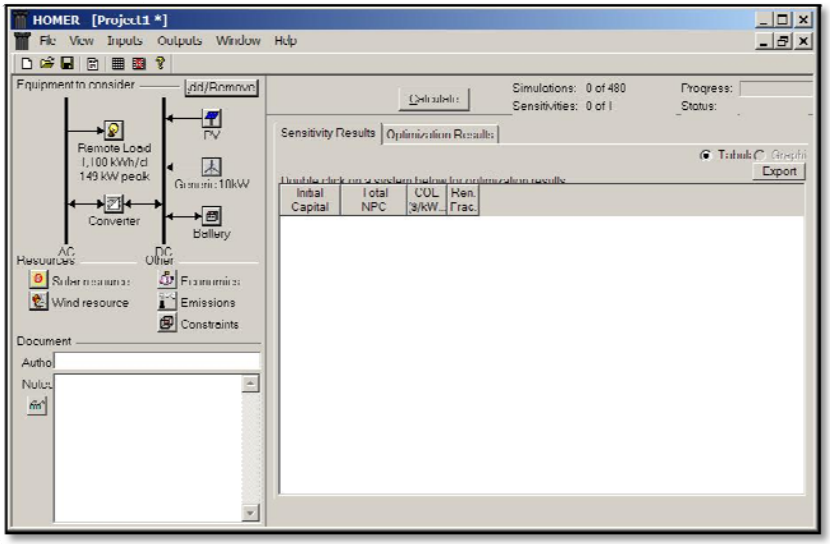


Figure 8 HOMER software schematic setup screen

3.6.1 Primary Load

A daily-averaged electrical usage for an average home was calculated using an electrical usage estimation sheet [14]. The average home uses an estimated 60kWh/d. The modifier was introduced based on the typical energy usage pattern preloaded with HOMER. The estimated value was then multiplied by 20 homes to simulate the demand for this project. A predefined load profile for a 24-hour period was used to simulate the energy requirements for each home. The following screenshot illustrates the configuration. The figure bellow illustrates the primary load setup screen and load profile.

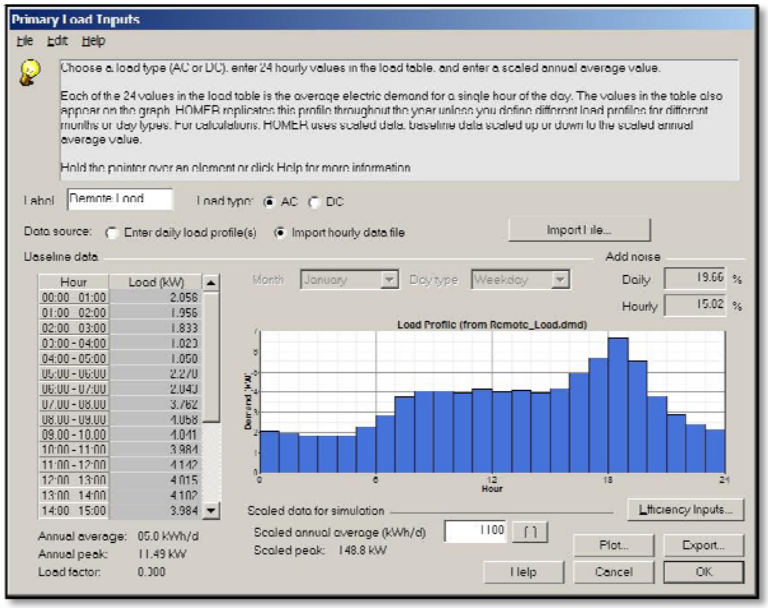


Figure 9   Primary load profile and setup screen

3.6.2   Solar Panels

Based on an article presented by PopularMechanics [15], the average cost per kW of energy generated by commercial solar panels is at USD4,500. Hence this information was used to enable cost estimation in the simulation. Values for estimating the amount of energy harvested were obtained from the theoretical development conducted previously. The following figure illustrates the solar panel setup screen.

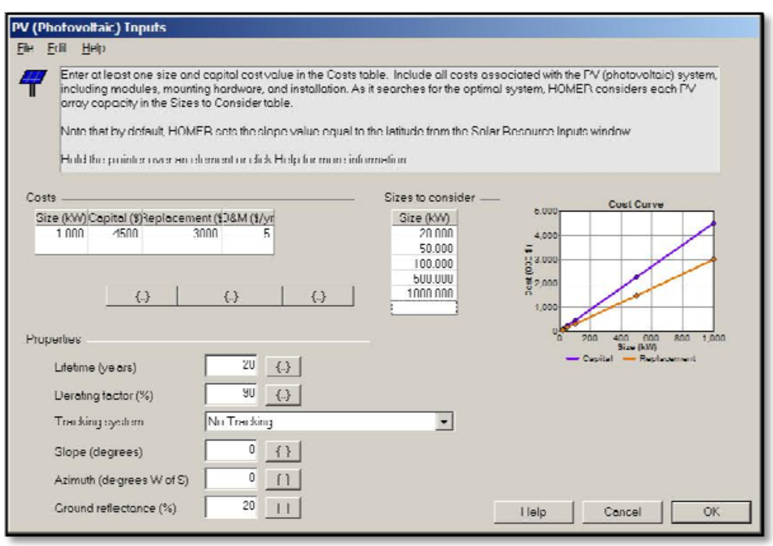


Figure 10   PV panel setup screen

3.6.3 Wind turbines

According to [16], the average cost of 10kW wind turbines cost USD30,000 to USD 50,000 per unit. Hence this information is used for cost calculation. Weather data were collected from historical archives of the Malaysian forecasting website [17]. Monthly averaged wind speeds were collected to generate a wind profile for Kuala Lumpur. The following figure illustrates how these data were entered into HOMER before the actual simulation was conducted.

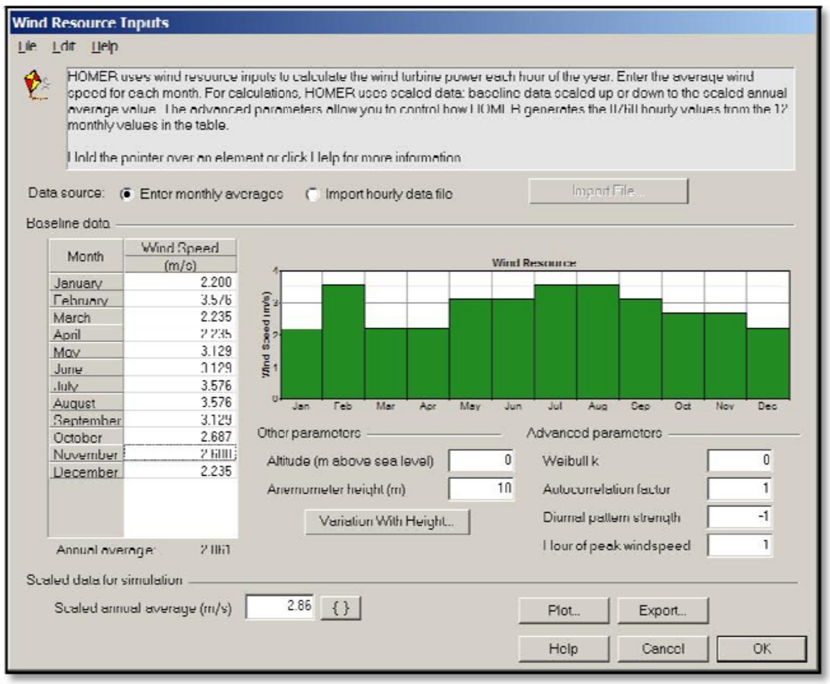


Figure 11 Wind profile for Kuala Lumpur

3.6.4 Converters and Battery Banks

These components are included as energy distribution and storage devices respectively and are also included into the simulation setup to accurately simulate the entire project. The following figure illustrates the setup for battery sizing.

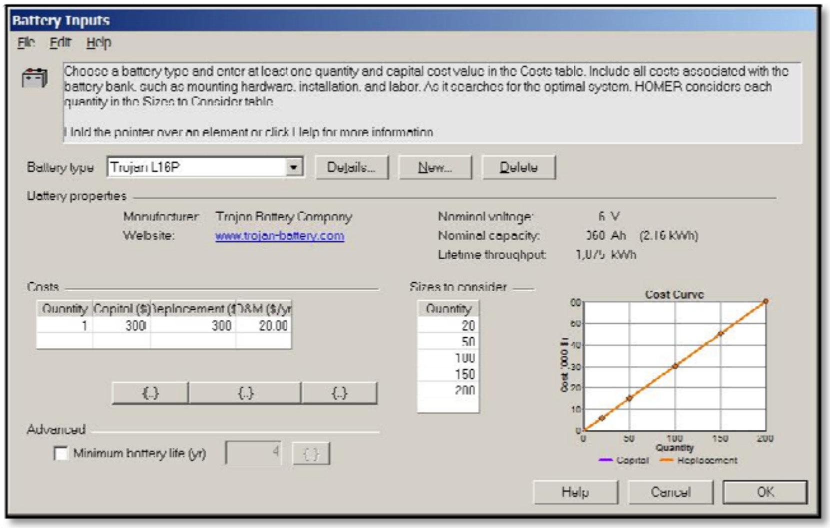


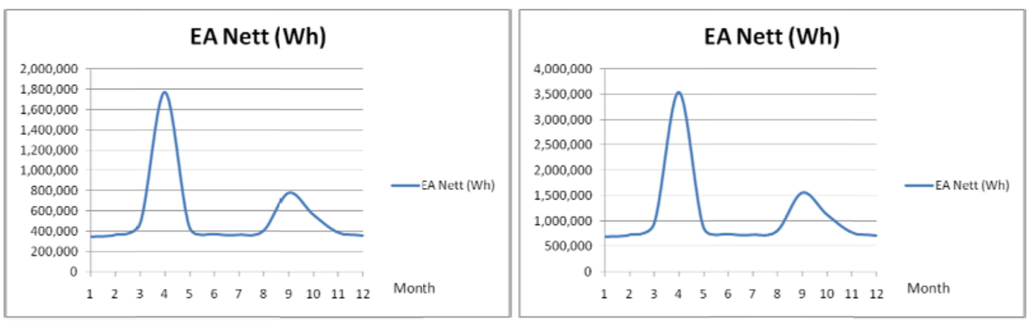
Figure 12 Battery sizing estimations

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Mathematical modeling for solar power output

The following shows the results of the mathematical modeling that indicates the average energy output are greatly affected by the level of daily irradiance. The following figure shows a comparison between the average energy outputs, EA given daily average irradiance of 5MJ/m^2 and 10MJ/m^2.



Daily Avg Irradiance: 5MJ/ m^2 Daily Avg Irradiance: 10MJ/ m^2

Figure 13 Comparison between EA for different levels of irradiance

Secondly, the average output energy, EA from the PVs decreases with increasing levels of operating or ambience temperature. The following figure shows how EA varies for given temperatures of 28˚C and 75˚C (when operating under direct sun light).

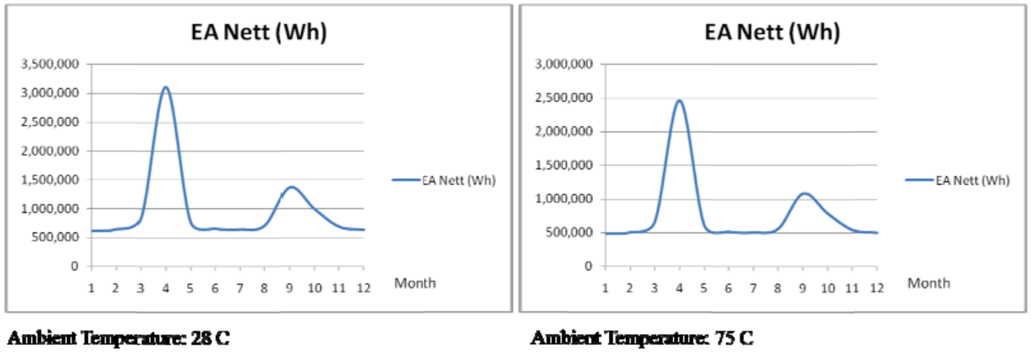


Figure 14 Comparison between EA for different levels of temperatures

Additionally, PV output varies with the position of the Sun in the sky. The figure below illustrates the difference in average output energy, EA at different times of the day, at 8am and 11am.

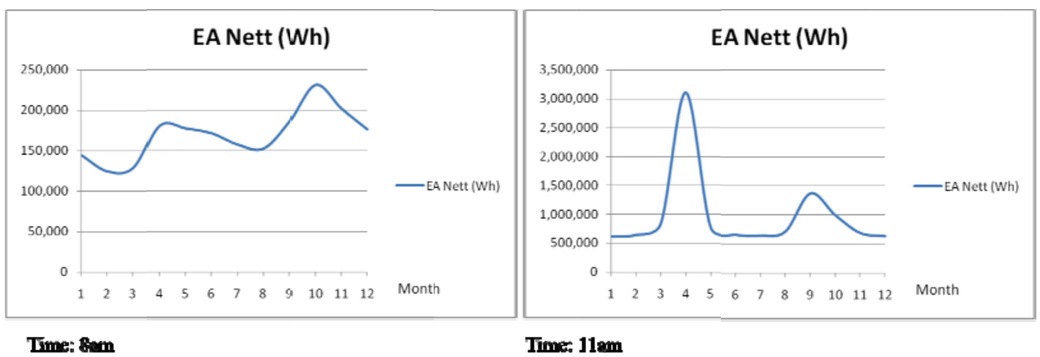


Figure 15 Comparison between EA for different solar positions

A complete listing of screenshots for this mathematical model is compiled in Appendix C.

4.2 Solar positioning experiment using PASCAL

An experiment to analyze the electrical output of a PV panel with regards to the changing position of the Sun was conducted using a standard a-Si PV module. The module was placed horizontally across the work bench, connected to the PASCAL data logging system to obtain the readings as a light source is passed over the PV module in 180˚. This aims to simulate and observe the results of having the Sun's irradiance applied to the PV module at an angle of incident. The figure below illustrates the output observed from PASCAL's data acquisition interface.

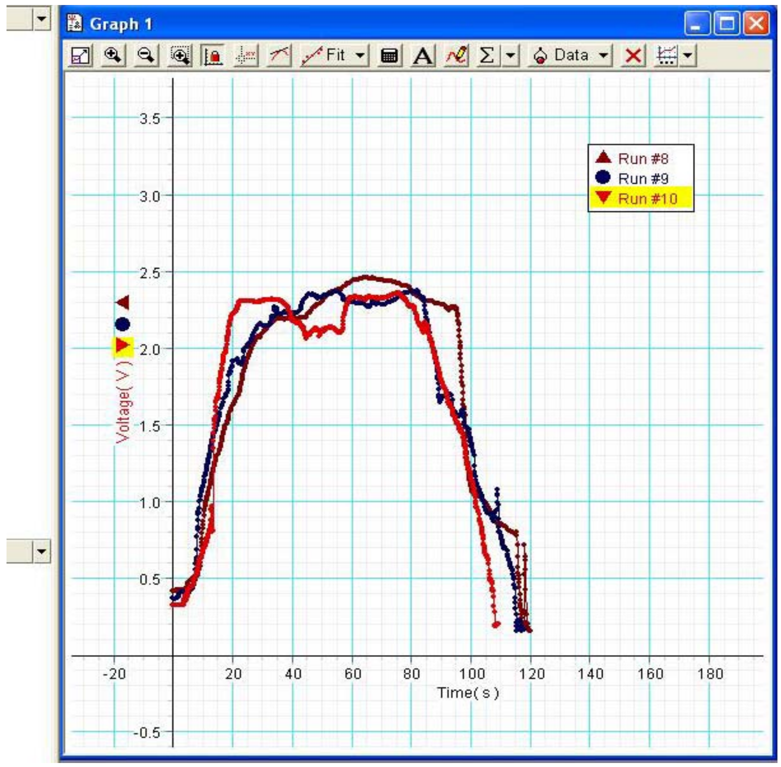


Figure 16 Voltage output curves from PV module

The output from the PASCO data acquisition software indicated a fairly consistent reading when a light source passes over the solar cell. This applies to situations where the Sun rises and sets across a predictable path every day. This indicates the existence of an immediate real time relationship between the level of irradiance and the output voltage. By pointing the solar cell towards the direction of the Sun will definitely provide a constant output voltage regardless of the position of the Sun in the sky.

From an application perspective, special mounts may be used to allow the tilting and manual or automatic adjustments of panel tilt position to further enhance the efficiency and output. However, operations costs are to be examined to understand whether costs incurred from the equipment, manual labor and maintenance in the long run should outweigh the concept alone.

4.3 Wind turbine configuration

To test the wind turbine design, 5 configurations were examined using DC fans operated in reverse. The fans were exposed to a constant wind speed and the electrical outputs were recorded using PASCAL. The following shows the DC output generated from the different fan configurations.

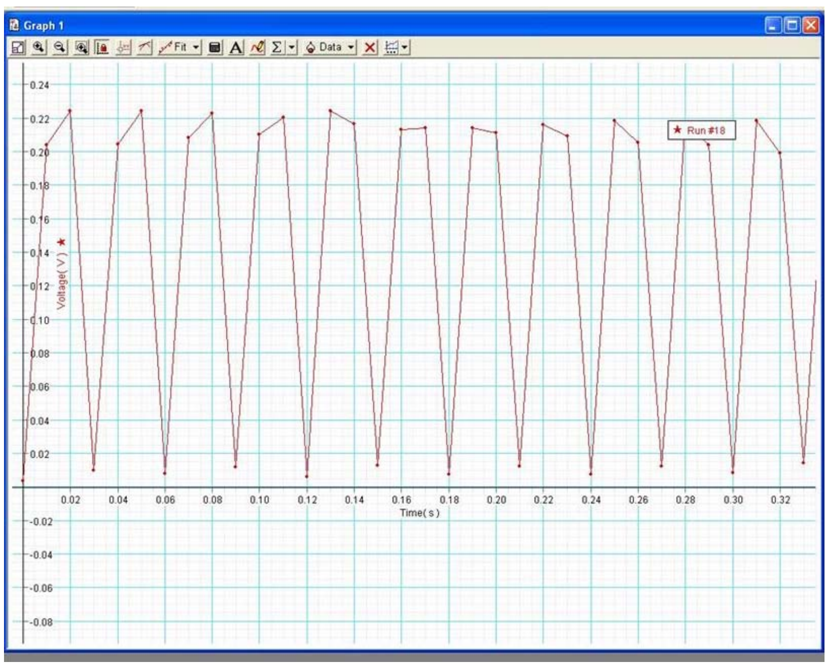


Figure 17 Single turbine configuration

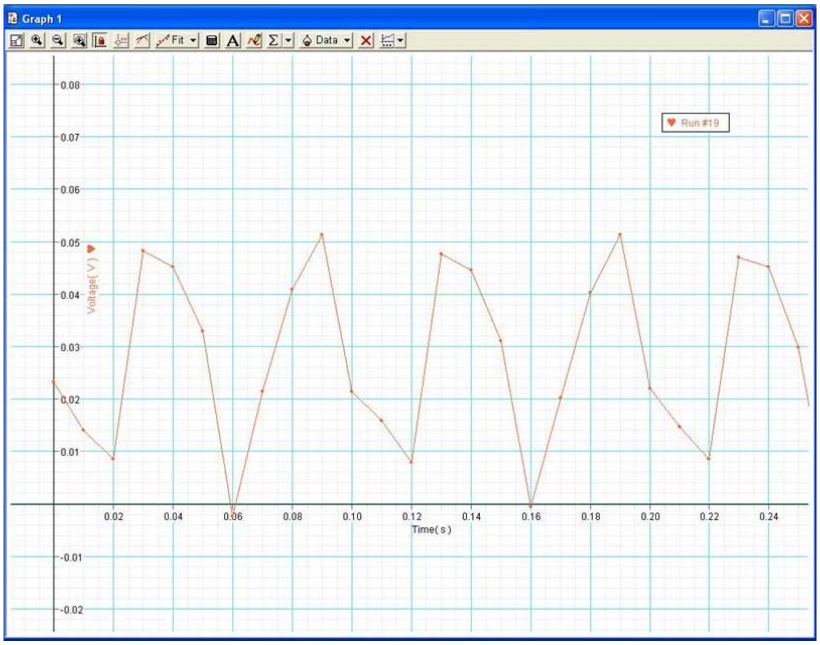


Figure 18 Single turbine with attached wind tunnel configuration

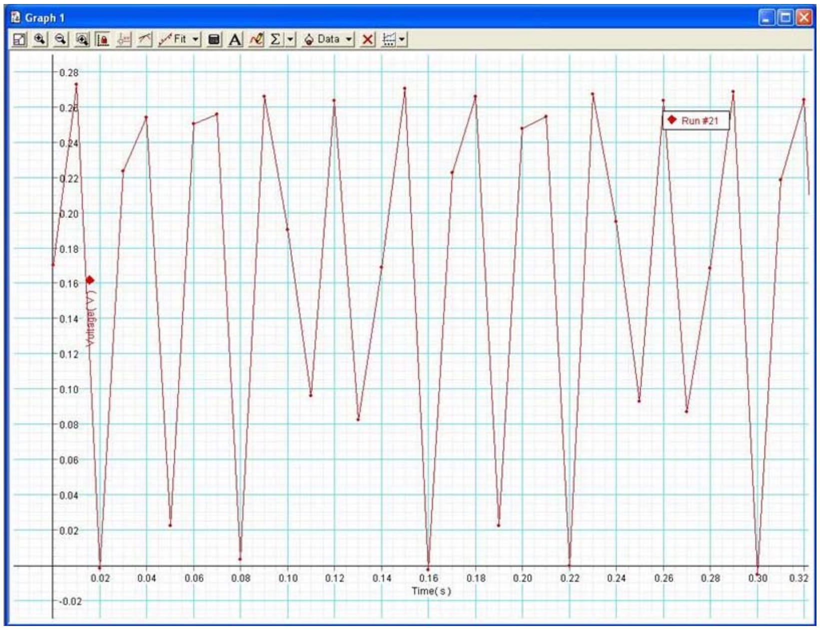


Figure 19 Double turbine attached back to back configuration

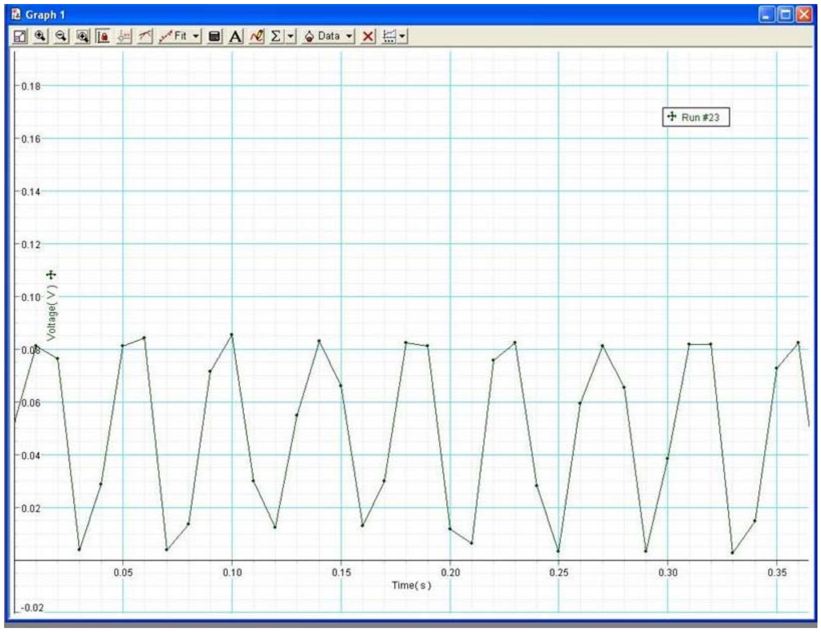


Figure 20   Single turbine with attached funnel configuration

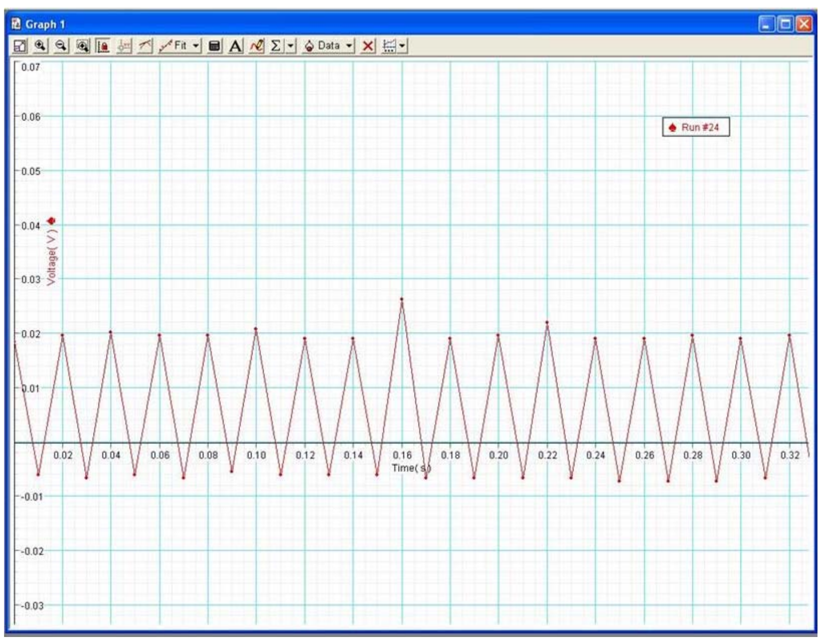


Figure 21   Single turbine with reduced blades configuration

The output voltage generated by the DC fan configurations were observed from the PASCO data acquisition system interface. It can be seen that the highest amount of voltage induced is by wind turbine configuration 1. Wind turbine configuration 3 was comparable in terms of performance; however should the secondary fan stop due to the drop of wind energy, the total output voltage also significantly dropped.

The results obtained were far from conclusive, mainly because commercial wind turbines are available with high levels or accuracy and efficiency that can be used in place of a wind turbine redesigned from the ground up.

4.4 HOMER sizing simulation results

Upon setting up the hybrid system components, a number of simulations were conducted using multiple sensitivity values to estimate the most efficient and cost effective configuration. A few sets of results were obtained from the simulation with a combination of solar radiation value of 4.95, 5.00, and 6.00 kWh/m^2/d against wind speeds velocities of 2.86, 3 and 4m/s. A total of 720 simulations were conducted and 9 out of which were shortlisted for consideration. Figure20 and 21 below illustrates the outcome. A detailed graph was generated to indicate the cutoff regions where a hybrid is most feasible as compared to a standalone power plant. It can be concluded that should the global solar radiation exceeds a consistently high wind speed; it is more practical to just maintain a standalone power plant. However should wind speeds exceed 3.6m/s with global solar radiation below 5.1kWh/m^2/d, it is more feasible to implement a hybrid system.

However, another important factor to acknowledge in this simulation that fuel used in a diesel generator for a standalone solar power plant will fluctuate in the long run and may influence our cost analysis from HOMER and ultimately our decision on the system comparison. Hence an assumption is made where we omit the cost of fuel in our analysis and analyze the systems based entirely on the typical components of a standalone solar power plant. The following figure illustrates the simulation output from HOMER.

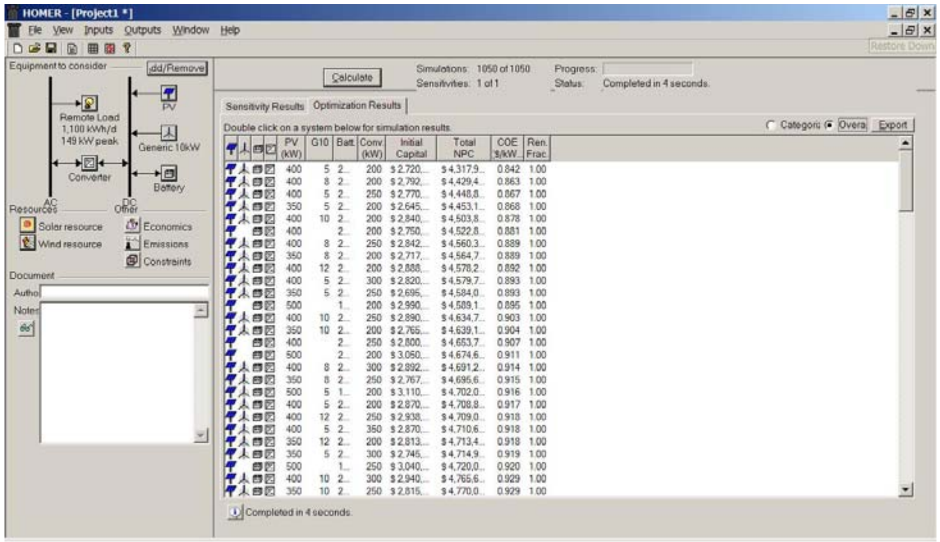


Figure 22 HOMER sizing simulation results

From the sizing output, a graphical representation for optimization was also obtained to identify the most cost effective balance between configuration and available sources of renewable energy. The following figure illustrates the breakeven points between available solar radiation and wind.

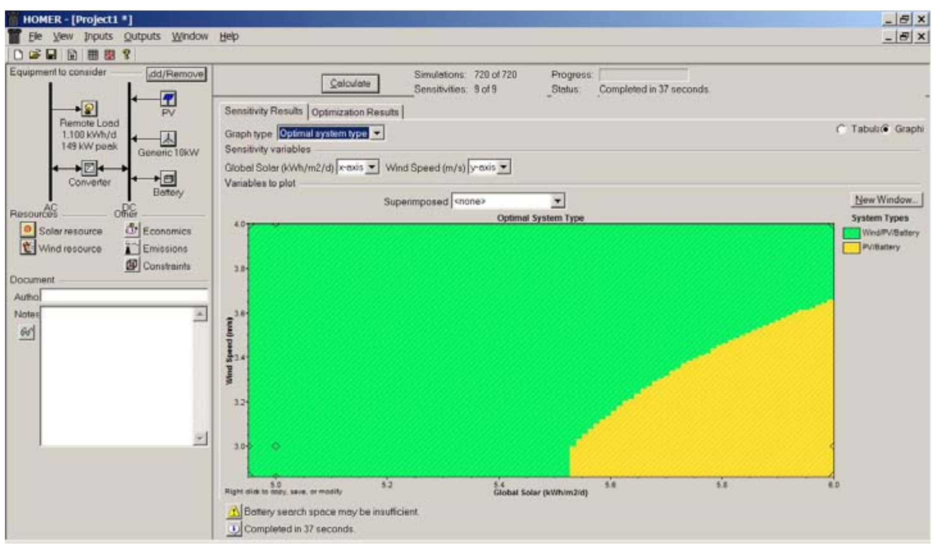


Figure 23 Graphical display of optimized simulation results

From the sizing study, the most efficient and cost effective system configuration was obtained. The conditions provided best fit Malaysia's weather conditions, based on the average solar irradiance of 4.95kWh/m^2 and average wind speeds of 3m/s. The following table summarizes the sizing simulation output and compares the hybrid system and a standalone solar power system should it be implemented on the same given operating conditions.

Table 4 HOMER hybrid plant sizing output

Requirements	Standalone	Hybrid
Solar Panels	450 kW	400 kW
Wind Generators	-	50 kW
Batteries	2000 units	2000 units
Converters	200 kW	200 kW
Initial Capital	$2.83 million	$2.72 million
Total NPC	$4.44 million	$4.32 million

**Default simulation condition:*

Irradiance – 4.95kWh/m^2

Wind speed – 3m/s

From the table, we observed that a hybrid system is more cost effective as compared to a standalone solar power plant that is of similar capacity. For one, PV modules are costly to manufacture and implement, not to mention their low energy output rating. However, wind turbines on the other hand are rather mature technology and they are capable of generating larger amounts of electricity per session. Hence by using the right sizing configuration, the number of PV modules required is reduced, reducing the overall cost while maintaining the overall system capacity.

4.5 Construction of prototype/working model

The literature review done in the early stages of this course allowed us to identify some of the major components required to implement a hybrid system. The three major components designed in the prototype are the solar panel to convert solar energy to electricity, a wind turbine connected to a generator to convert kinetic energy to electricity, a battery system to store electricity for future use and charge controller to regulate the charging and discharging of the system to protect the battery bank. The individual sections below further describe the progress and work done in construction of the prototype.

4.5.1 PV panel

A 4W, 15V solar panel was purchased off the shelf as a major part of the prototype. The component was tested under sun light and a useful 15V of potential difference was obtained at the output of the module. The device generated between 100-200mA of constant current output when placed under strong direct sun light. A specially constructed mounting device was built to support the PV panel that allows the panel to be position in various directions to track the sun. A motorized version may be implemented in the future for better automation.

4.5.2 Wind turbine and DC generator

The wind turbine was constructed from the ground up due to the cost and expenses involved in obtaining an actual turbine and generator off the shelf. A six-bladed wind mill was purchased and retrofitted to drive a $12V_{DC}$ motor in reverse. When placed directly in front of a table fan, the setup is capable of constantly outputting $3V_{DC}$.

Due to the size of the prototype, a 6-bladed wind mill was used instead of the recommended 3-blade system. The 6-bladed wind mill proved more efficient and practical with a larger coverage area relative to the size of the prototype. However, the prototype is designed in a way that future modifications to install more efficient equipment are possible. To further enhance the running speed of the generator, a gear system was implemented. The section below further describes the gear ratio calculation used.

4.5.3 Wind turbine gear ratio

Two spur gears were used to transfer and convert the rotational speed between the wind turbine and DC generator. A large gear is attached to the slower-spinning wind turbine and a smaller gear is installed on the DC generator. The gear ratio implemented is described as follows:

$$\textit{Gear Ratio} = \textit{15 teeth : 30 teeth} \quad (10)$$
$$= 1:2$$

Generally for every complete turn by the wind turbine, the generator shaft is turned twice. With this setup, we are able to obtain a generally more constant and stable electrical output from the wind turbine. The generator will still be able to output electricity should the wind turbine rotates slowly in lower wind speeds.

4.5.4 Battery pack

A 12V, 4.7Ah sealed lead acid battery was chosen to be implemented for the scaled prototype. The chosen battery is capable of multiple recharges and has the storage capacity for extended periods of time when renewable energy sources are not available. The battery technology was chosen due to its cost of implementation, and reliability as compared to other types of battery such as nickel cadmium, nickel metal hydride and lithium ion or polymer types.

4.5.5 Charge controller

A charge controller circuit was built based on the following circuit diagram [18]. The function of the charge controller is to regulate charging and discharging from the solar panel and wind turbine to the battery pack. Over-charging or over-draining the battery pack will lead to permanent damage, resulting in a shorter service life. The charge controller constantly monitors the voltage level across the battery pack. It compares it to 2 values preset by the user via the two potentiometers. The user presets the float voltage and drain voltages according to the values recommended by the battery manufacturer. The circuit then automatically regulates between charging mode and dumping mode, where the latter routes the current to a dummy load. The settings made for this particular prototype is $14.2V_{DC}$ and $11.8V_{DC}$.

When the battery voltage lies within the intermediate state, a range of voltages between the charge and discharge modes, the user may manually override the system to either charge or dump the generated current. Appendix A3 lists the photographs of the charge controller circuit.

Two charge controller circuits were fabricated based on a generic solar charger design [18], one using a vera-board approach and the other a printed circuit board (PCB). The schematic diagram of this circuit is shown in Appendix A4. The printed circuit board was designed on PCB layout software called RIMU PCB. A screenshot of the charge controller circuit design is illustrated in the following figure:

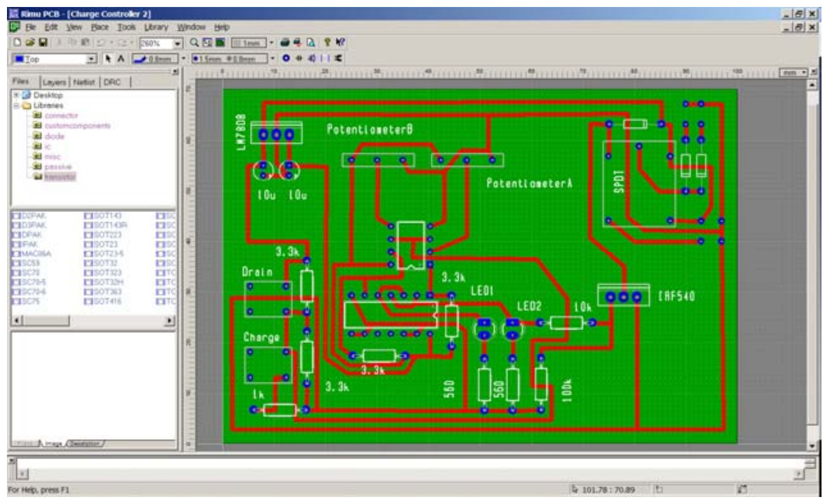


Figure 24 PCB layout design on RIMU PCB

The printed circuit board took 3 days to complete as we explored the various stages in fabrication. The layout design was first simulated and tested on a computer to ensure no errors were present and the layout was printed onto a film for UV exposure. The UV exposure was done onto the copper board which then allows etching to be done. An additional layout of the pads was prepared for drilling of holes using a separate machine. The use of a PCB provides the advantage of better reliability and aesthetics over the use of a vera board. Additionally it minimizes the level of errors when soldering the components onto the board. Photographs of the completed prototype are illustrated in Appendix E.

4.6 Publicity and presentations

The solar and wind hybrid power plant, among other research projects were featured in the preview of Universiti Teknologi PETRONAS' renewable energy research lab in August 2009. It was part of a showcase during the visit of the

Chancellor, Rector, and board of directors as well as stakeholders as an introduction to the research team based at the university. Additionally, this project was featured in the 24th Engineering Design Exhibition in October 2009, and was awarded the silver medal for innovation and design.

Two A1-sized technical posters were prepared describing the key concepts this project hopes to achieve. Appendix F contains the sample of the technical poster.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

In conclusion, this project was successfully conducted as it met all the objectives that were set forth. This study allowed the detail analysis of the technical and economical feasibility of implementing a solar-wind hybrid power plant in Malaysia. A theoretical development was successfully formed to obtain the mathematical models required to define the various factors and relationships that represent the system. These factors were taken into account in determining the best possible location, operating conditions for optimal electricity generation for the solar and wind hybrid power plant. Among some of the key factors that significantly affected solar power output were solar positioning, average daily irradiance, PV efficiency, PV operating or ambience temperature, and available airborne particles. Sizing simulations were conducted to determine the economic feasibility of the hybrid power plant in Malaysia. A comparison was made between the hybrid system and a conventional standalone system to obverse the direct cost difference. The results were positive as a hybrid system was far more economical even, for a small system consisting of only 20 conventional homes. From the analysis, a solar-wind hybrid power plant is highly feasible and will improve the reliability and sustainability of existing standalone solar power plants.

5.1 Recommendations

Further studies can be conducted to further improve and build upon the current hybrid system studied in this project. The sections below further describe each individual approach:

5.1.1 Automated solar tracker/positioning system

An automated solar tracker/positioning system can be implemented into the current system to allow the PV panel to automatically position itself towards the direction of the Sun’s radiation. This will increase the overall solar power output and improve the overall efficiency of the system. There are various ways to implement this approach, one method may be attaching a pilot tracker to provide positioning information to the positioning servo motors on the individual PV arrays. Alternatively, a manual or seasonal adjustment can be made to the PV arrays by means of using data readily available from weather forecasting authorities.

5.1.2 Installation of components with higher efficiency

Simple components were implanted on the final prototype of the solar-wind hybrid power plant. From our mathematical modeling and analysis, equipment such as CIS type of PV panels and commercially available wind turbines are capable of achieving higher rates of efficiencies.

5.1.3 Supervisory or monitoring system

A computer data acquisition system can be implemented into the solar-wind hybrid power plant to allow monitoring and recording of performance by both the PV modules and wind turbine. From the data obtained, further analysis can be done through computer programs and algorithms to suggest further actions or improvements to the system. These improvements may include increase of system efficiency, supply/demand balancing which will be very useful for planning system expansions. Efficiency of the entire system can be carefully monitored to address losses in the system during conversion, charging, and distribution. Additionally battery monitoring systems may be coupled with battery cooling systems to keep battery operating temperatures within desirable limits to lengthen their service life and improve their efficiency.

5.1.4 Use of super capacitors

Batteries are used in the hybrid power plant as a means of energy storage for use when there is insufficient renewable energy for power generation. Batteries require maintenance and proper charging methods to protect them from damage. Over time, batteries lose their ability to sustain a charge and must be replaced.

An alternative to battery use is the super capacitor. Super capacitors are similar to conventional capacitors by holding charge in the form of static electricity. Super capacitors are have virtually unlimited cycle life, along them to be charged and discharged infinitely. Additionally, they contain very low impedance, which enhances load impedance when placed in parallel with a battery. Super capacitors are also capable of rapid charging; reducing the amount of time it takes to store electricity without the need for sophisticated charge controller circuitry. However, further studies must be conducted to address issues pertaining to the practicality of super capacitors because super capacitors have low capacities, and they can only hold small quantities of charge. Furthermore, they have high self discharge rates that requires consistent charging and topping up.

5.1.5 A distributed system approach

Distributed power generation can be further studied and be implemented using the solar-wind hybrid power plant concept. Through distributed power generation, flexibility in the entire implementation can be obtained as small plants are setup to service specific locations or loads only. These individual plants can later be linked to establish a wider grid, connecting smaller towns and locations, supporting the idea of megacities. This approach may provide a more reliable power grid as far as renewable energy is concerned since renewable sources of energy are not available on demand as compared to fossil fuels. Additionally, a distributed system may also be able to support the concept of a deregulated power supply, where private companies and even consumers may invest and maintain specific power plants, ultimately removing the monopoly of the utility. This will generally improve quality and services, and provide competitive pricing to consumers.

5.1.6 Implementation of inverter into prototype

For the scope of this prototype, the attached loads are of direct current (DC) form, hence they do not sustain further loss due to alternating current (AC) conversions. For real world implementation, AC output is required to power appliances and supply homes. Hence, to convert the system into AC output, inverters are required. Further work can be done in this area, equipping the prototype with an inverter to supply AC loads.

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APPENDICES

APPENDIX A

OVERALL PROJECT SCEHDULE

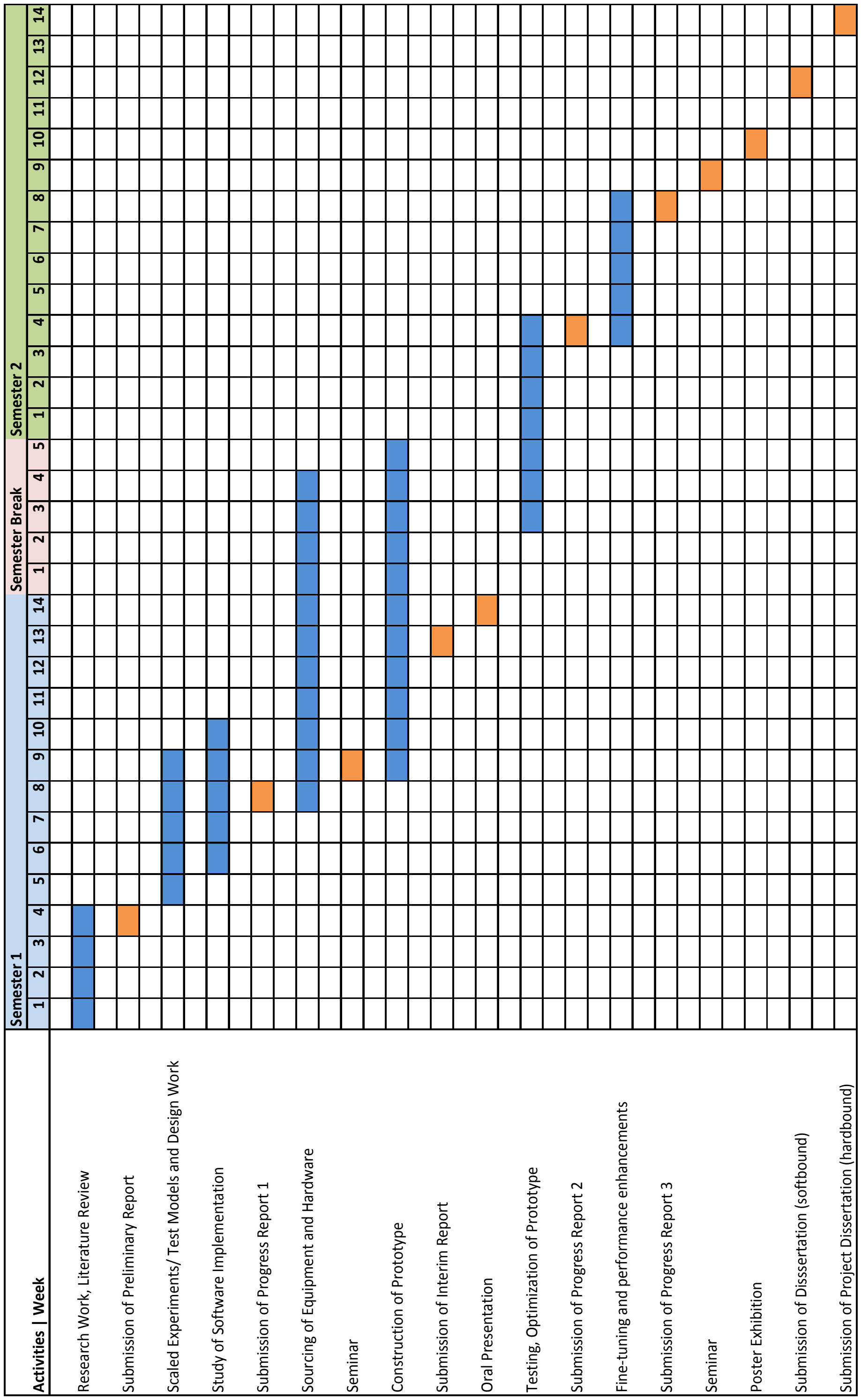


Figure 25 Gantt chart indicating overall project progress

APPENDIX B

LIST OF EQUATIONS FROM MATHEMATICAL MODELLING

$$\delta = 23.45 \sin\left(2\pi \frac{284+n}{365}\right) \tag{11}$$

$$\cos\omega_s = -\tan\psi \tan\delta \tag{12}$$

$$H_0 = \frac{86400 G_{sc}}{\pi}\left(1 + 0.033\cos\left(2\pi \frac{n}{365}\right)\right)\left(\cos\psi \cos\delta \sin\omega_s + \omega_s \sin\psi \sin\delta\right) \tag{13}$$

$$\bar{K}_T = \frac{\bar{H}}{\bar{H}_0} \tag{14}$$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \tag{15}$$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \tag{16}$$

$$r_t = \frac{\pi}{24}\left(a + b \;\cos\omega\right)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s \cos\omega_s} \tag{17}$$

$$a = 0.409 + 0.5016 \sin\left(\omega_s - \frac{\pi}{3}\right) \tag{18}$$

$$b = 0.6609 - 0.4767 \sin\left(\omega_s - \frac{\pi}{3}\right) \tag{19}$$

$$r_d = \frac{\pi}{24}\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s \cos\omega_s} \tag{20}$$

$$H = r_t \bar{H} \tag{21}$$

$$H_d = r_d \bar{H}_d \tag{22}$$

$$H_b = H - H_d \quad (23)$$

$$H_t = H_b R_b + H_d \left(\frac{1 + \cos\beta}{2} \right) + H\rho \left(\frac{1 - \cos\beta}{2} \right) \quad (24)$$

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (25)$$

$$\eta_p = \eta_r \left[1 - \beta_p \left(T_c - T_r \right) \right] \quad (26)$$

$$T_c - T_a = \left(219 + 832\bar{K}_t \right) \frac{NOCT - 20}{800} \quad (27)$$

$$C_f = 1 - 1.17 \times 10^{-4} \left(s_M - s \right)^2 \quad (28)$$

$$E_P = S\eta_p \bar{H}_t \quad (29)$$

$$E_A = E_P \left(1 - \lambda_p \right) \left(1 - \lambda_c \right) \quad (30)$$

$$\eta_A = \frac{E_A}{S \quad \bar{H}_t} \quad (31)$$

$$E_{grid} = E_A \quad \eta_{inv} \quad (32)$$

$$E_{dlvd} = E_{grid} \quad \eta_{abs} \quad (34)$$

$$D_{DC,equ} = D_{DC} + \frac{D_{AC}}{\eta_{inv}} \quad (35)$$

$$D_{DC,equ} = D_{matched} + D_{continuous} + D_{battery} \quad (36)$$

$$P_{crit} = \frac{D_{continuous}}{24} \tag{37}$$

$$I_{Tc} = \frac{P_{crit}}{\eta_A S} \tag{38}$$

$$\bar{X}_c = \frac{I_{Tc}}{r_{t,n} R_n \bar{H}} \tag{39}$$

$$\bar{\phi} = \exp\left\{ \left[a + b \frac{R_n}{\bar{R}} \right] \left[\bar{X}_c + c\bar{X}_c^2 \right] \right\} \tag{40}$$

$$a = 2.943 - 9.271\bar{K}_T + 4.031\bar{K}_T^2 \tag{41}$$

$$b = -4.345 + 8.853\bar{K}_T - 3.602\bar{K}_T^2 \tag{42}$$

$$c = -0.170 - 0.306\bar{K}_T + 2.936\bar{K}_T^2 \tag{43}$$

$$R_n = \left(1 - \frac{r_{d,n} H_d}{r_{t,n} H}\right) R_{b,n} + \left(\frac{r_{d,n} H_d}{r_{t,n} H}\right)\left(\frac{1+\cos\beta}{2}\right) + \rho_g \left(\frac{1-\cos\beta}{2}\right) \tag{44}$$

$$E_{continuous} = (1-\phi)\ E_A \tag{45}$$

$$E_{matched} = \min\left(D_{matched}, E_A - E_{continuous}\right) \tag{46}$$

$$E_D = E_{continuous} + E_{matched} \tag{47}$$

$$E_A - E_D \tag{48}$$

$$ALR = E'_A / L' \tag{49}$$

$$SLR = Q_U / L' \tag{50}$$

$$L' = L - E_D \tag{51}$$

$$E'_A = \left(E_A - E_D \right) \quad \eta_c \eta_b \tag{52}$$

$$Q_U = Q_B f_B \tag{53}$$

$$E_G = L - E_D - E_B \tag{54}$$

$$Q_G = \frac{E_G}{\eta_R \eta_G \eta_b} \tag{55}$$

$$Q_{\ } = \frac{Ln}{\ } \tag{56}$$

$$Q_B = \frac{Q_U}{f_B} \tag{57}$$

$$\frac{1}{8} \frac{Q_B}{\eta_R} \tag{57}$$

(11) Coopers equation

(12) Solar angle hour

(13) Extraterrestrial radiation

(14) Clearness Index

(15) Global radiation

(16) Global radiation given sunset hour angle less than 81.4 degrees

(17) Collares-Pereira and Rabl Global irradiance

(18) Constant a

(19) Constant b

(20) Liu and Jordan diffuse irradiance

(21) Global horizontal irradiance

(22) Diffuse component

(23) Beam component

(24) Isotropic model

(25) Ratio of beam irradiance on PV array to that on the horizontal

(26) Average efficiency

(27) Temperature coefficient for module efficiency

(28) Correction factor

(29) Energy delivered to PV array

(30) Energy after miscellaneous PV array losses

(31) Array energy available to load and battery

(32) Overall array efficiency

(33) Energy delivered through grid

(34) Energy after grid absorption

(35) DC equivalent demand

(36) DC equivalent electrical demand

(37) Critical PV absorption level

(38) Critical radiation level

(39) Monthly average critical radiation level

(40) Monthly average daily utilizability

(41) Constant a for utilizability

(42) Constant b for utilizability

(43) Constant c for utilizability

(44) Ratio for hours centered at noon to tilted surface for average day of month

(45) Energy delivered directly to the continuous load

(46) Energy delivered to the matched load

(47) Energy delivered directly to load

(48) Energy delivered to the battery

(49) Array load ratio

(50) Storage load ratio

(51) Load not met by PV system

(52) Available array output reduced

(53) Usable battery capacity

(54) Energy delivered by Genset/Wind turbine

(55) Energy used by Genset

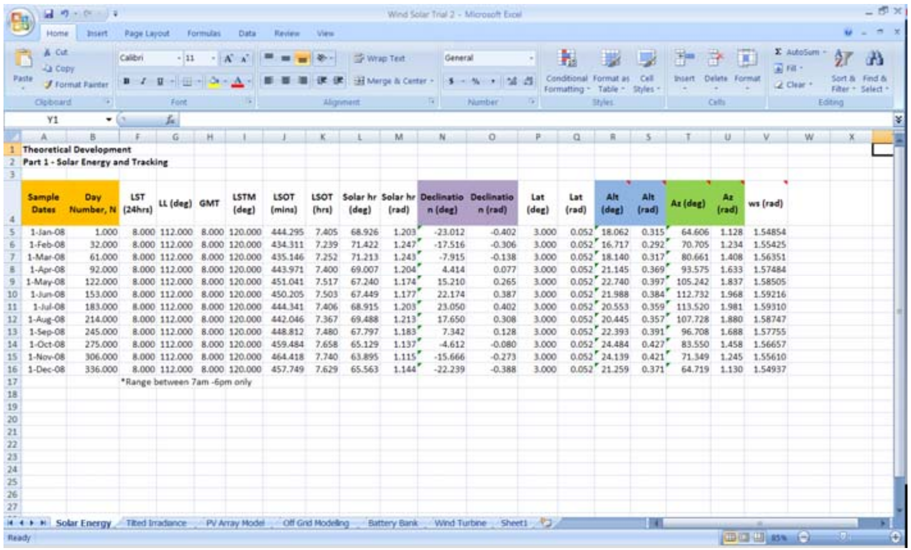
(56) Usable battery capacity

(57) Usable fraction of capacity available

(58) Suggested genset capacity taken as maximum of AC demand

APPENDIX C

EXCEL MODELLING PROGRAM

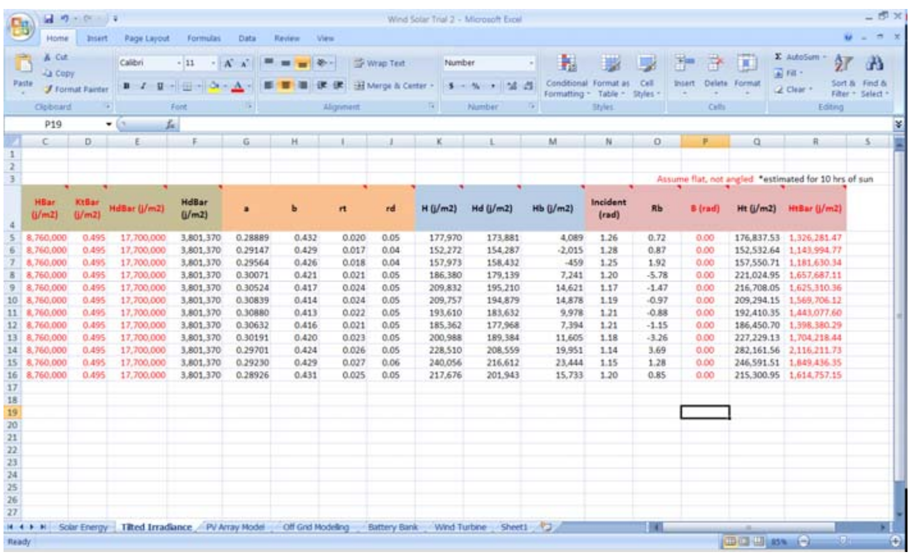


Theoretical Development
Part 1 - Solar Energy and Tracking

Sample Dates	Day Number, N	LST (24hrs)	LL (deg)	GMT	LSTM (deg)	LSOT (mins)	LSOT (hrs)	Solar hr (deg)	Solar hr (rad)	Declination (deg)	Declination (rad)	Lat (deg)	Lat (rad)	Alt (deg)	Alt (rad)	Az (deg)	Az (rad)	ws (rad)
1-Jan-08	1.000	8.000	112.000	8.000	120.000	444.295	7.405	68.926	1.203	-23.012	-0.402	3.000	0.052	18.062	0.315	64.606	1.128	1.54854
1-Feb-08	32.000	8.000	112.000	8.000	120.000	434.311	7.239	71.422	1.247	-17.516	-0.306	3.000	0.052	16.717	0.292	70.705	1.234	1.55425
1-Mar-08	61.000	8.000	112.000	8.000	120.000	435.146	7.252	71.213	1.243	-7.915	-0.138	3.000	0.052	18.140	0.317	80.661	1.408	1.56351
1-Apr-08	92.000	8.000	112.000	8.000	120.000	443.971	7.400	69.007	1.204	4.414	0.077	3.000	0.052	21.145	0.369	93.575	1.633	1.57484
1-May-08	122.000	8.000	112.000	8.000	120.000	451.041	7.517	67.240	1.174	15.210	0.265	3.000	0.052	22.740	0.397	105.242	1.837	1.58505
1-Jun-08	153.000	8.000	112.000	8.000	120.000	450.205	7.503	67.449	1.177	22.174	0.387	3.000	0.052	21.988	0.384	112.732	1.968	1.59216
1-Jul-08	183.000	8.000	112.000	8.000	120.000	444.341	7.406	68.915	1.203	23.050	0.402	3.000	0.052	20.553	0.359	113.520	1.981	1.59310
1-Aug-08	214.000	8.000	112.000	8.000	120.000	442.046	7.367	69.488	1.213	17.650	0.308	3.000	0.052	20.445	0.357	107.728	1.880	1.58747
1-Sep-08	245.000	8.000	112.000	8.000	120.000	448.812	7.480	67.797	1.183	7.342	0.128	3.000	0.052	22.393	0.391	96.708	1.688	1.57755
1-Oct-08	275.000	8.000	112.000	8.000	120.000	459.484	7.658	65.129	1.137	-4.612	-0.080	3.000	0.052	24.484	0.427	83.550	1.458	1.56657
1-Nov-08	306.000	8.000	112.000	8.000	120.000	464.418	7.740	63.895	1.115	-15.666	-0.273	3.000	0.052	24.139	0.421	71.349	1.245	1.55610
1-Dec-08	336.000	8.000	112.000	8.000	120.000	457.749	7.629	65.563	1.144	-22.239	-0.388	3.000	0.052	21.259	0.371	64.719	1.130	1.54937

*Range between 7am -6pm only

Figure 26 Excel modeling for solar positioning studies



Assume flat, not angled *estimated for 10 hrs of sun

HBar (j/m2)	KtBar (j/m2)	HdBar (j/m2)	HdBar (j/m2)	a	b	rt	rd	H (j/m2)	Hd (j/m2)	Hb (j/m2)	Incident (rad)	Rb	B (rad)	Ht (j/m2)	HtBar (j/m2)
8,760,000	0.495	17,700,000	3,801,370	0.28889	0.432	0.020	0.05	177,970	173,881	4,089	1.26	0.72	0.00	176,837.53	1,326,281.47
8,760,000	0.495	17,700,000	3,801,370	0.29147	0.429	0.017	0.04	152,272	154,287	-2,015	1.28	0.87	0.00	152,532.64	1,143,994.77
8,760,000	0.495	17,700,000	3,801,370	0.29564	0.426	0.018	0.04	157,973	158,432	-459	1.25	1.92	0.00	157,550.71	1,181,630.34
8,760,000	0.495	17,700,000	3,801,370	0.30071	0.421	0.021	0.05	186,380	179,139	7,241	1.20	-5.78	0.00	221,024.95	1,657,687.11
8,760,000	0.495	17,700,000	3,801,370	0.30524	0.417	0.024	0.05	209,832	195,210	14,621	1.17	-1.47	0.00	216,708.05	1,625,310.36
8,760,000	0.495	17,700,000	3,801,370	0.30839	0.414	0.024	0.05	209,757	194,879	14,878	1.19	-0.97	0.00	209,294.15	1,569,706.12
8,760,000	0.495	17,700,000	3,801,370	0.30880	0.413	0.022	0.05	193,610	183,632	9,978	1.21	-0.88	0.00	192,410.35	1,443,077.60
8,760,000	0.495	17,700,000	3,801,370	0.30632	0.416	0.021	0.05	185,362	177,968	7,394	1.21	-1.15	0.00	186,450.70	1,398,380.29
8,760,000	0.495	17,700,000	3,801,370	0.30191	0.420	0.023	0.05	200,988	189,384	11,605	1.18	-3.26	0.00	227,229.13	1,704,218.44
8,760,000	0.495	17,700,000	3,801,370	0.29701	0.424	0.026	0.05	228,510	208,559	19,951	1.14	3.69	0.00	282,161.56	2,116,211.73
8,760,000	0.495	17,700,000	3,801,370	0.29230	0.429	0.027	0.06	240,056	216,612	23,444	1.15	1.28	0.00	246,591.51	1,849,436.35
8,760,000	0.495	17,700,000	3,801,370	0.28926	0.431	0.025	0.05	217,676	201,943	15,733	1.20	0.85	0.00	215,300.95	1,614,757.15

Figure 27 Excel modeling for irradiance studies

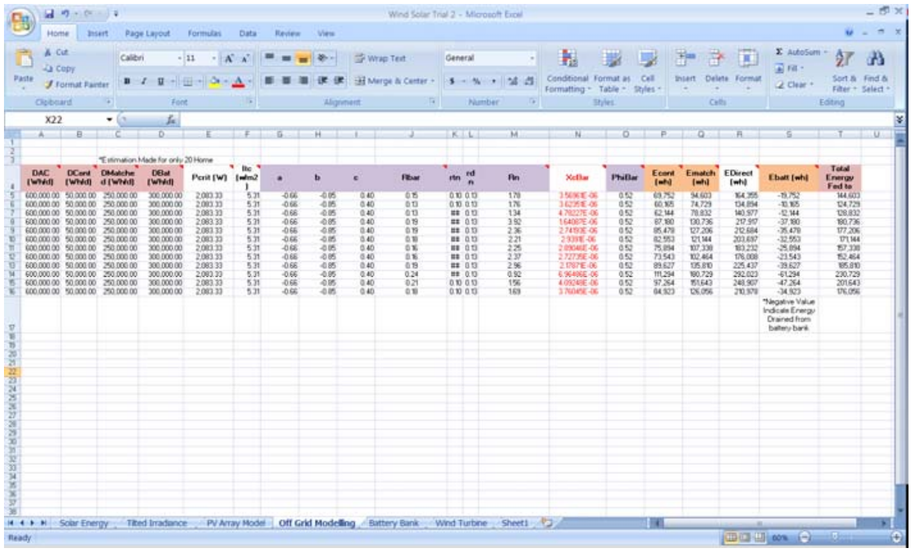


Figure 28 Excel modeling for PV array model

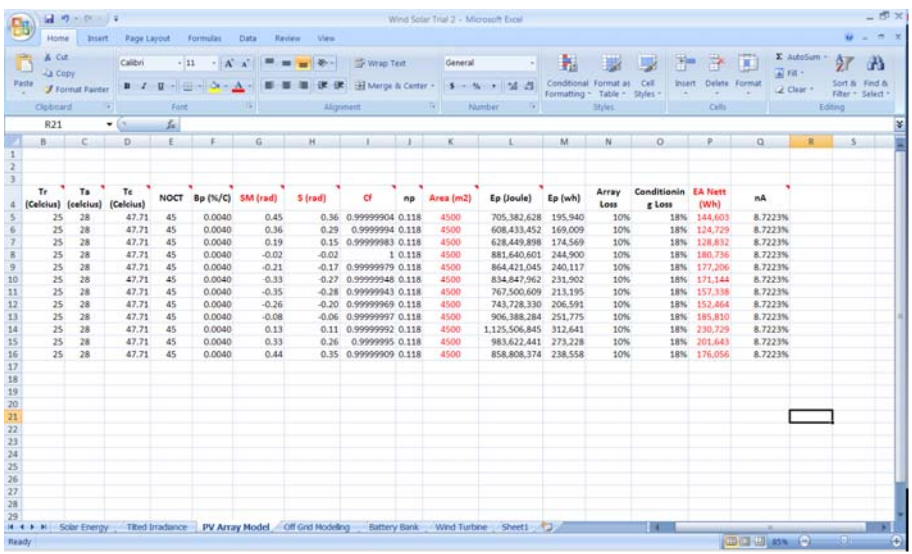


Figure 29 Excel modeling for off grid modelling

APPENDIX D

PHOTOGRAPHS OF CHARGE CONTROLLER CIRCUIT

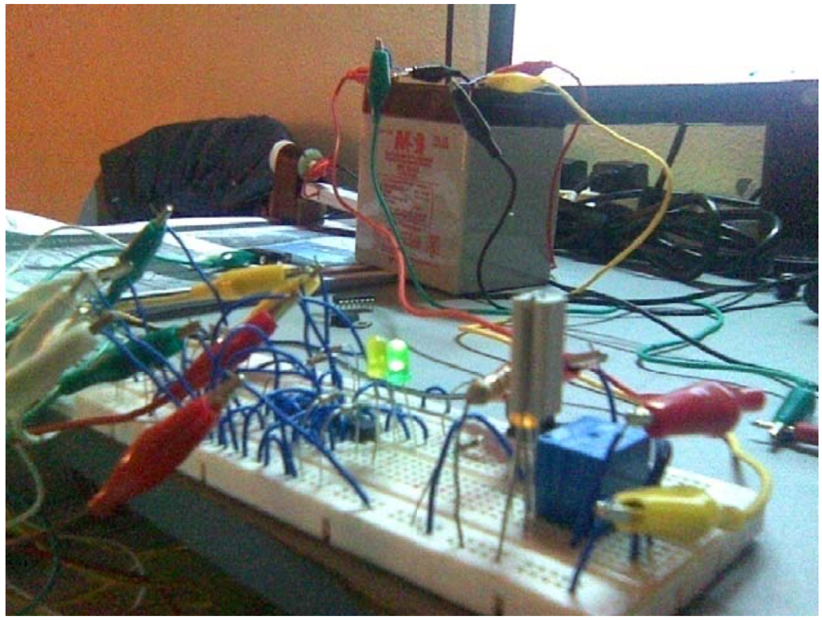


Figure 30 Charge controller circuit implemented on bread board

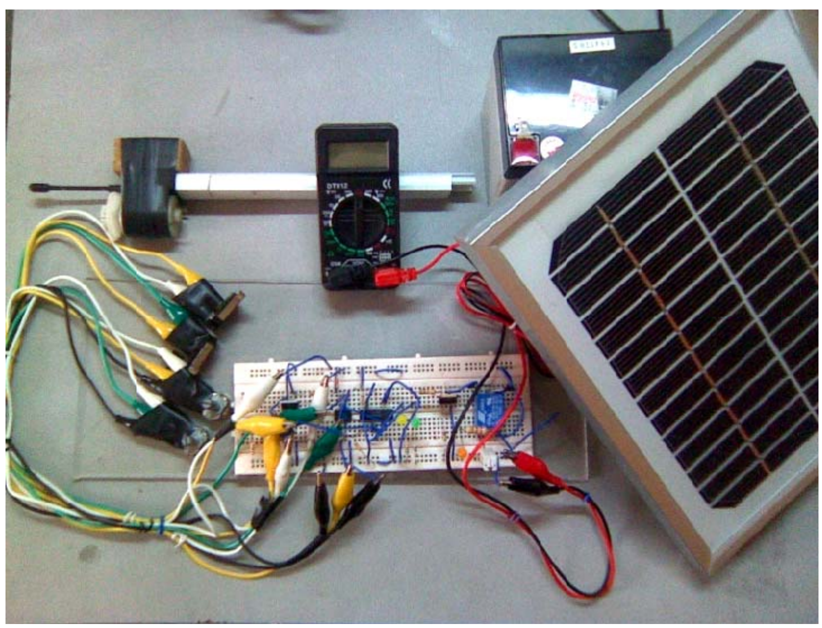


Figure 31 Charge controller circuit connected to peripherals and components

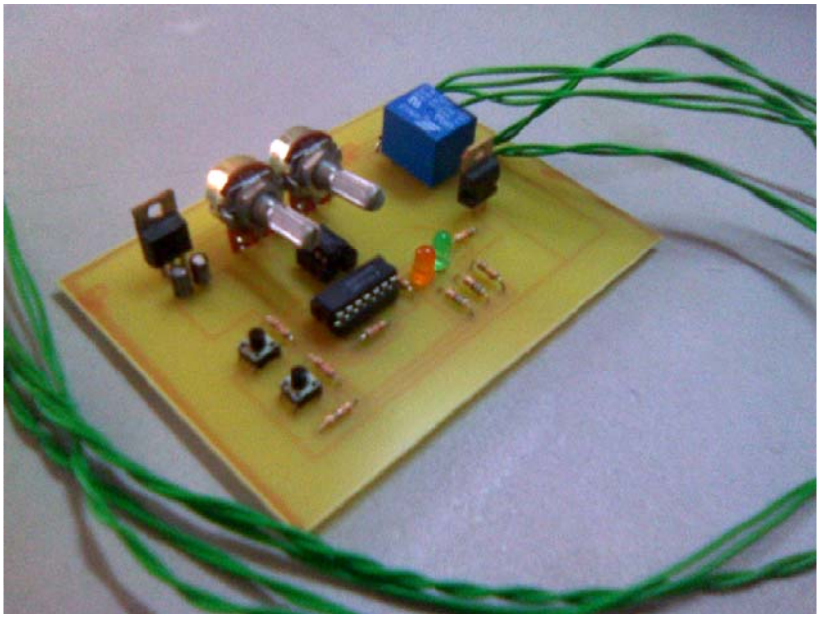


Figure 32 Charge controller circuit on printed circuit board

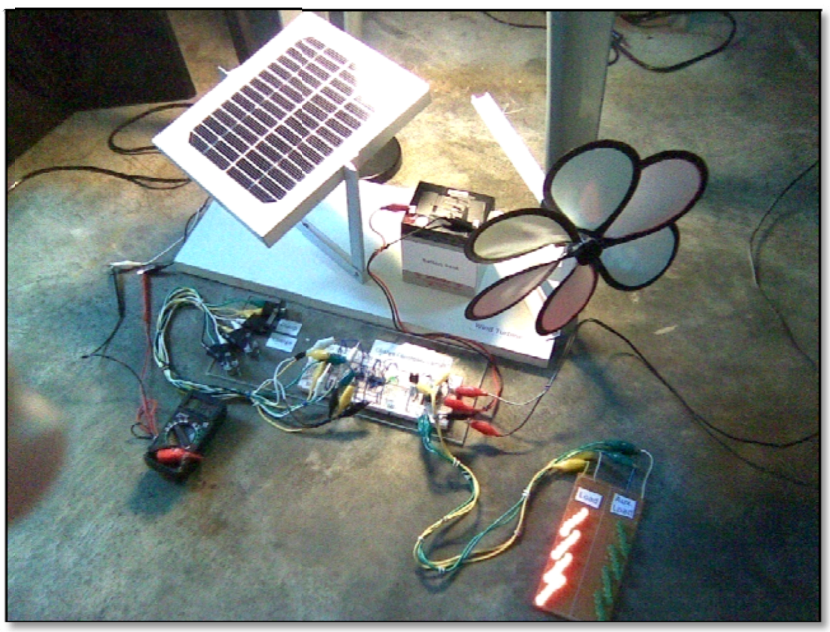


Figure 33 Final working prototype of solar-wind hybrid power plant

APPENDIX E

SCHEMATIC DIAGRAM OF CHARGE CONTROLLER CIRCUIT

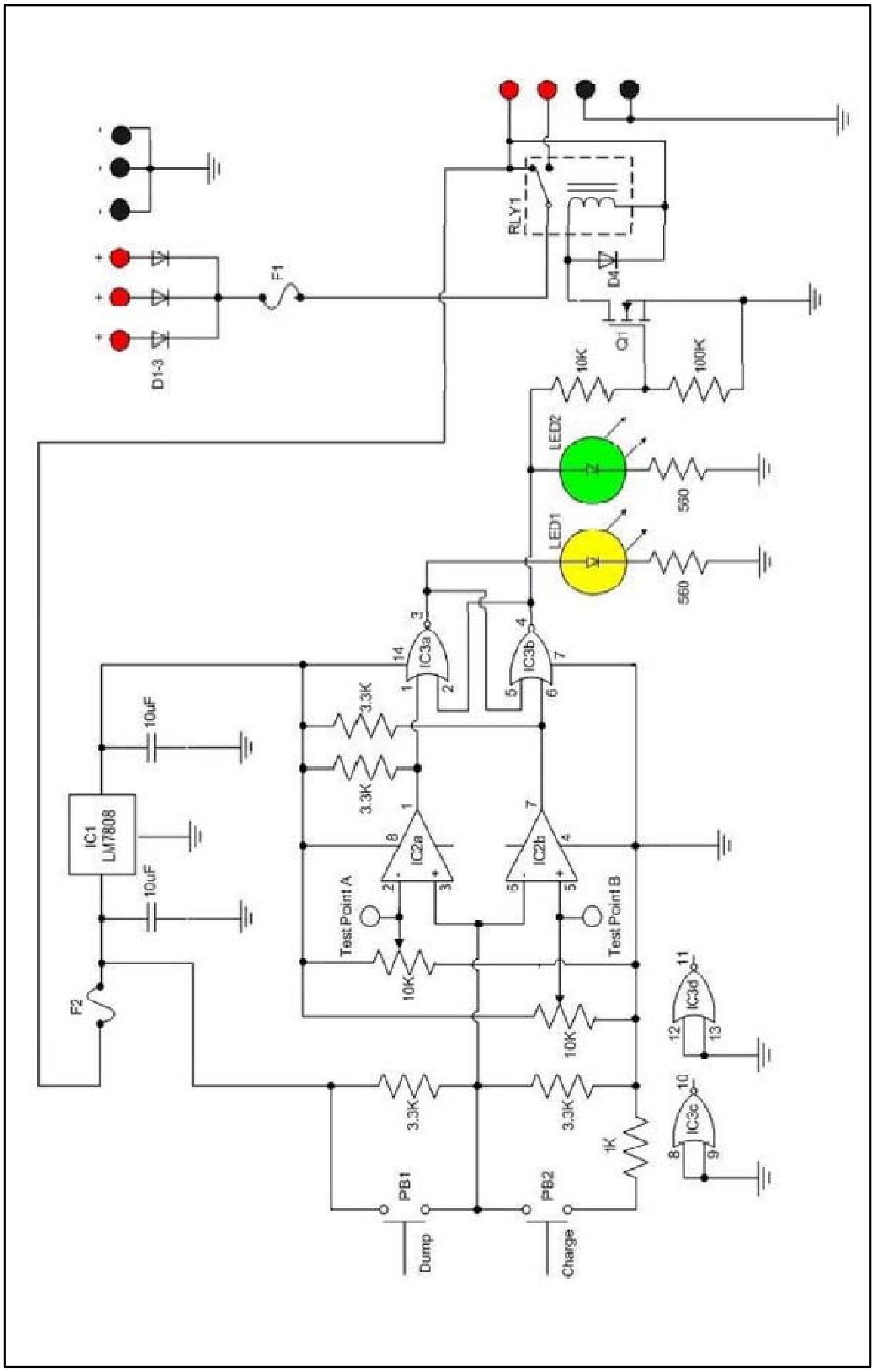


Figure 34 Schematic diagram of charge controller circuit

APPENDIX F

TECHNICAL POSTER FOR SOLAR-WIND HYBRID POWER PLANT

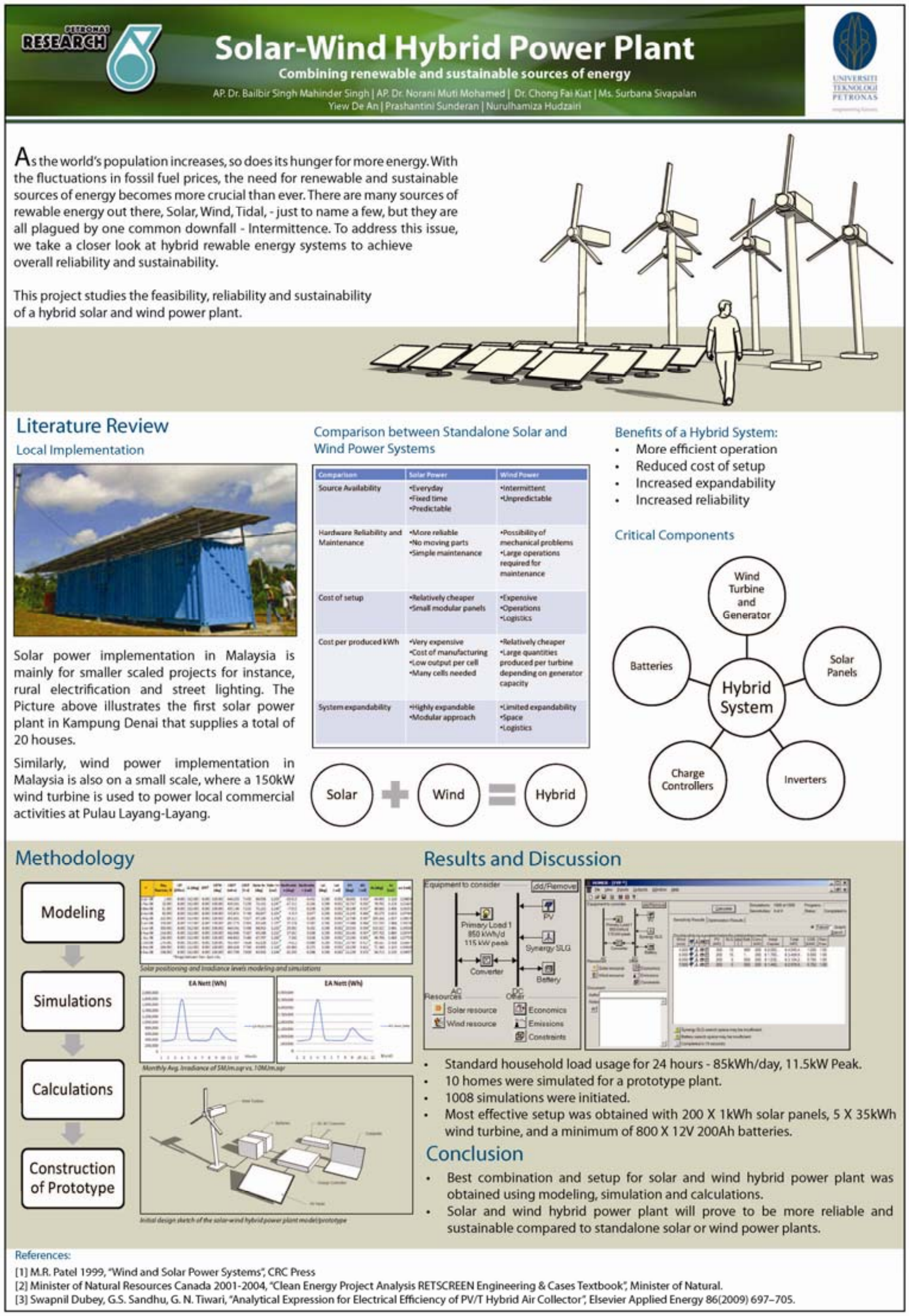


Figure 35 Technical poster for solar lab preview 16th August 2009

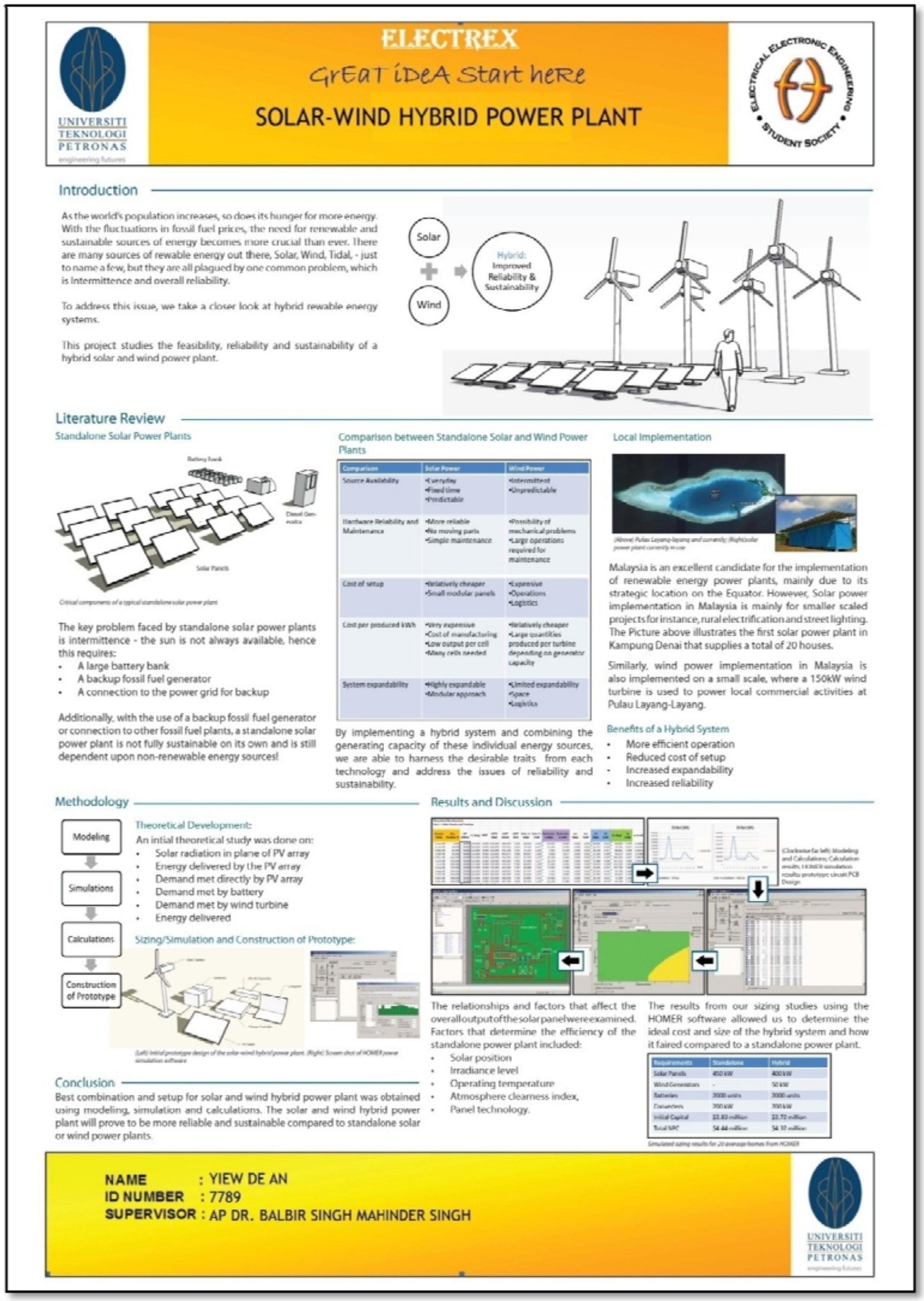


Figure 36 Technical poster for Pre-EDX and EDX on campus