OFF-GRID OPTIMIZATION ANALYSIS OF HYBRID SOLAR-WIND POWER SYSTEM IN UTP USING HOMER SOFTWARE

By

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Dissertation submitted in partial fulfilment of the requirements for the Bachelor of Engineering (Hons) (Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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BACHELOR OF ENGINEERING (Hons)
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Approved by,

____

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January 2015

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.

Juan Mario Mokoko Ekifang Mangue

ABSTRACT

Through this Paper a project on studying the off-grid optimization of hybrid renewable energy system using Homer software in Universiti Teknologi PETRONAS will be introduced on an average of 20 modern homes located in Village 6. The government of Malaysia has expressed its interests and commitment towards developing the renewable energy sector as stated in the 9th 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. The paper also tend to calculate the cost analysis and to simulate the optimal model. For this particular case, a data of solar and wind energy system will be taken, and throughout the study of pattern of load consumption a designed model for optimization of the energy system using HOMER software will be made.

Homer as a program is a software free application technologically developed by the NREL (National Renewable Energy Laboratory) in the USA. The application is used for designing and evaluating technical and financial options of off-grid and on-grid power energy systems on remote, distributed and stand-alone generation applications. Homer allows the user to contemplate a great quantity of technology possibilities to justify energy sources accessibility and additional variables.

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.

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Finally, but by no means least, thanks go to my family and my friends for almost unbelievable support. They are the most important people in my world and I dedicate this FYP to them.

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ABBREVIATION AND NOMENCLATURES

UTP: Universiti Teknologi PETRONAS

FYP: Final Year Project

PV: Photovoltaic

PCB: Printed Circuit Board

DC: Direct Current

AC: Alternating Current

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia is a hot country located nearby the equator. It collects massive quantity of sun every year and this makes the country a perfect candidate for using solar power generation as the main basis of electrical energy. Additionally to solar, wind energy is as well a gifted source of energy in Malaysia. This is principally true near coastal areas and suburban townships where obstructions from tall buildings and pollution in the city are minimal. Wind and solar energy as sources have always been considered fresh, endless, limitless, and ecologically pleasant. These features have continuously fascinated for many years the energy part for using renewable energy headquarters on a bigger scale. Nonetheless, the sources of energy present some disadvantages. Both sources are reliant about changeable causes, for example the weather, the climatic situations, etc. So, due to both solar or wind sources matching environment, a particular of the complications could be resolved in a way that the softness of one can be overcome by the assets of the other.

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 such as costs and economic merits in Universiti Teknologi PETRONAS. This project study discusses on optimization for the renewable energy wind-solar system based through the sizing and the functioning approach of producing energy.

To carry the study, HOMER software is used to simulate the scheme based on the approximation of the mounting cost, the replacement cost, the operation and the preservation cost and the interest.

The software configuration is normally set as a device to perform the study. So, the key goal of the project is to evaluate the possibility and profitable feasibility to use the wind-solar created unrelated power source system to fulfil the necessities.

1.2 Problem Statement

UTP has been developing a multi input renewable energy system for off and on grid application.

Currently the design is mostly on analogue circuit and microcontroller design.

There is a need to develop and study the optimization model to suit for the project. The purpose is to evaluate the economic and technical merits.

Current project does not yet look into the economic and technical optimization factors. Therefore to ensure good optimization, the software will be utilized to determine the possible results.

1.3 Objectives

The objectives of this project are to carry out a feasibility study on implementing a solar-wind hybrid system in Universiti Teknologi PETRONAS. For that particular case, Homer software is going to be used to calculate the best optimized model for the project. HOMER software also helps determine the difference way of interaction among conventional, renewable, and hybrid systems with end-use demand.

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.

So, based on availability potential of the energy, the main objectives of this project are:

- ❖ To identify the models for renewable energy input sources.
- ❖ To simulate and optimize the model.
- ❖ To test and analyse the results based on economic and technical merits.

The project will also answer the question related to sustainability introduced by the modern technologies.

1.4 Project Feasibility

The project will be feasible within the 2-semester provided with a proper planning and implementation.

The semester 1 will basically involve the research part, literature reviews and the entire study of the project.

As for the semester 2 the execution part will begin by taking the appropriate coordinates, values and simulations.

Funds will be allocated in case of a need to purchase of any equipment listed. The coast estimated is within the budget as the project is financially feasible.

CHAPTER 2

LITERATURE REVIEW

Research on hybrid power systems combining renewable and fossil derived electricity started 25 years ago, but few have written papers about system implementation and experimental data collection. The first papers describing renewable energy hybrid systems appeared in the mid-eighties [1], but literature on hybrid systems did not blossom until the early 1990s. Initially, this expansion in hybrid literature was driven by the need to increase grid stability and reliability as large quantities of wind power were being added to small autonomous grids [2]. Researchers then used optimization techniques to model how hybrid systems can reduce electricity generation costs over conventional fossil fuel systems.

There are many papers that optimize hybrid system cost and a few noteworthy papers are mentioned here. Schmidt examined the economic feasibility of converting stationary diesel plants in rural Brazil into Diesel/Battery/Photovoltaic (PV) plants and found that conversions were economically favourable for smaller (<50 kW) diesel-based systems [3]. Park modelled the cost savings of converting a ferry's propulsion from diesel into PV/Battery/Diesel [4]. Chided created his own software that predicted the

Operational Cost of a hypothetical autonomous PV/Wind/Diesel system [5]. He concluded that the inclusion of renewable energy into a diesel power plant would significantly reduce the Operational Cost of the plant. Nehrir used a Mat lab model to examine the performance of a Wind/PV system and concluded that the use of an electric hot-water heater as a dump load made the renewable-only system more economically feasible [6]. Ashok used a Quasi-Newtonian method to find the system that provided the lowest cost electricity to a rural Indian village. He finds that a

PV/Wind/Diesel/Micro hydro system would provide 24 hour coverage at the cost of only

US$0.14/kWh [7]. Nfah examined Pico hydro/biogas/PV systems for use in rural Cameroon and reasoned that the inclusion of biogas would decrease the generation cost of hybrid systems [8].

2.1 Homer software

HOMER is defined [9] as a free software application and is used to project and estimate technical and financial options of the off-grid and on-grid power systems for stand-alone, remote and distribution power generation applications.
It also allows to reproduce a massive amount of technology possibilities to account for energy resource disposal and other variables.

2.2 Wind Power System

Wind is defined as a phenomenon associated with the movement of the air crowds made predominantly of the discrepancy heating from the solar system of the surface of the earth [9]. Periodical variants in the energy that are received from the sun as stated in the gsma distress the strong point and the track of the wind.
The wind’s turbine catches its kinetic energy through a rotor covering over two blades attached mechanically to the electrical generator. The turbine normally is always located over a high tower to rise the capture of the energy. 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 [9] and [10].

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 [11].
An even number of blades is often avoided when implementing a wind turbine due to stability issues as described by [12]. 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 [9], 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:

$$Kinetic\ Energy = \frac{1}{2} * m * v^2$$

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

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

$m = mass\ in\ kg$

$v = velocity\ in\ m/s$

$\rho = air\ density\ in\ kg/m^3$

$A = area\ swept\ by\ rotor\ in\ m^2$

$Cp = Coefficient\ of\ performance$

$Ng = generator\ efficiency$

$Nb = gearbox/bearings\ efficiency$

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 Solar Power System

The energy from the sun can be converted into electrical energy via semiconductor cells [13]. 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 [9].

The power generating capacity of a PV cell is directly dependent upon the orientation of the sun's rays and exposure [9] [13]. As described in [14] and [15] 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. The solar modules should be sloped at the best position for the specific place, facing the south and not being out of the sun at any time during day [9].

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 [9]. Necessary sizing and calculations needs to be studied to achieve the best combination of PV array size and battery capacity [6]. The following figure illustrates a typical setup of a standalone solar power plant:

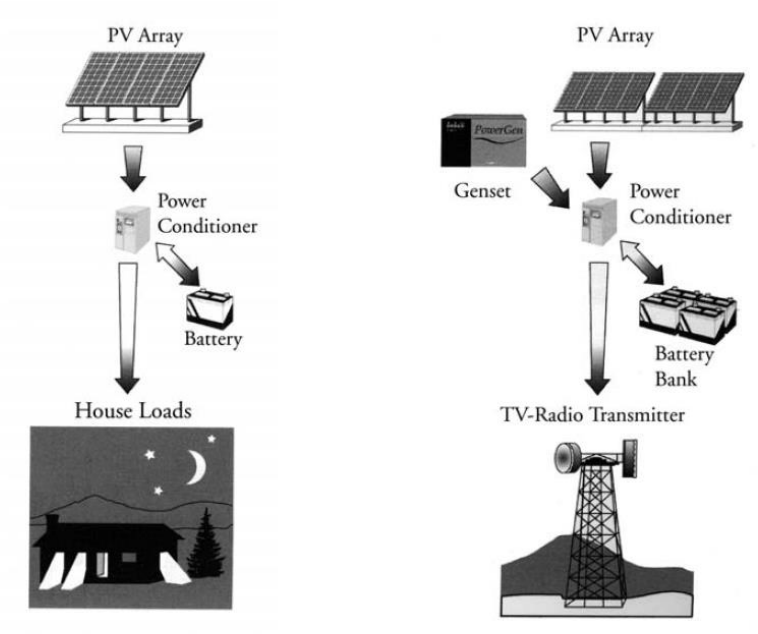

Figure 1: ***Typical Setup of standalone solar power plants***

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.

2.3.1 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-dieseline (CIS) types. These cells each portray different levels of efficiencies under different environment setting and conditions [17], [18].

Environment 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 study (UTP) will greatly affect the overall result. The following table lists the comparison between the 4 common types of solar cells available on the market and their performance characteristic [17]:

	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

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

2.3.2 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 extra-terrestrial radiation and the clearness index [13], where the daily extra-terrestrial radiation on a horizontal surface and clearness index can be estimated as follows:

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

$$\overline{K}_T = \frac{\overline{H}}{\overline{H}_0}$$

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

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

$\overline{K}_T$ = *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.

2.3.3 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:

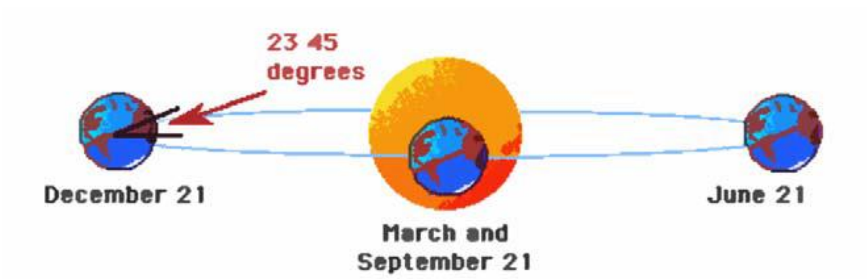

Figure 2: Solar position due to Earth's orientation around the Sun

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 midday 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 [19]. 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 [19]. 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:

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

$$cos\, w_s = -\, tan\, \psi\, tan\, \delta$$

$$n = day\ of\ the\ year;\ \Psi = latitude\ of\ the\ site$$

2.3.4 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 [20]. 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.

2.3.5 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 [20]. This information will assist in planning and analysing 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:

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

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

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

2.3.6 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 greenhouse 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 [21].

2.4 Solar-Wind System (Hybrid)

The hybrid system compose of solar and wind is the greatest grouping of the entire renewable power systems and usually is appropriate for the majorities of the requests, highly considering the climate periodic changes[14]. Both sources counterpart each other throughout lean stages, for instance, extra energy production through wind for the period of monsoon recompense the fewer productivity generated using solar system. In the same way, throughout winter once wind is overcast, the solar PV takes over. The figure 1 shows the solar-wind power system.

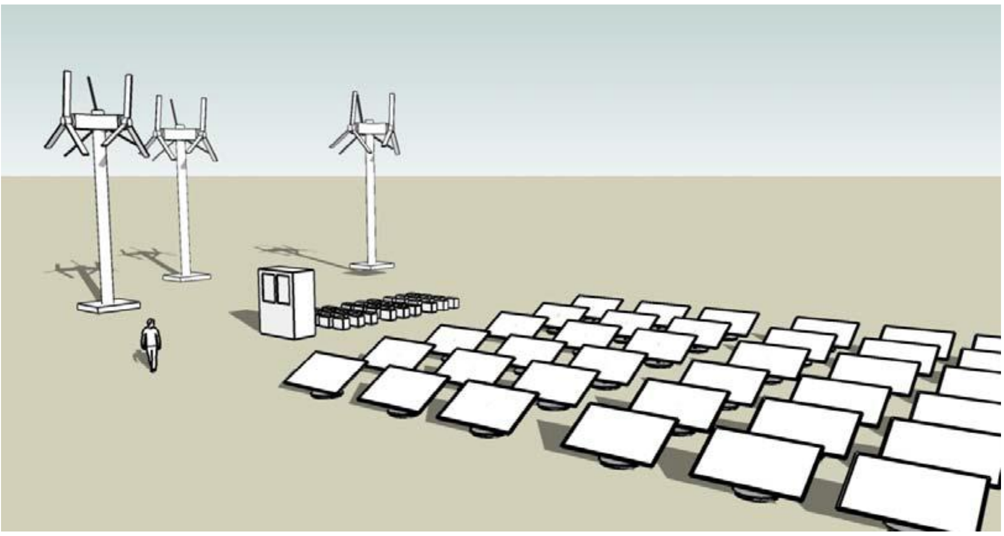

Figure 3: ***Theoretical solar-wind hybrid system plant design***

2.4.1 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.

2.5 System sizing

According to [4], system sizing plays a precarious role in successfully implementing a power plant. Appropriate system sizing diminishes the need for over-sizing, occasioning in wastage in cost of materials and components used. Using a proper system sizing, the greatest optimized setup can be 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.

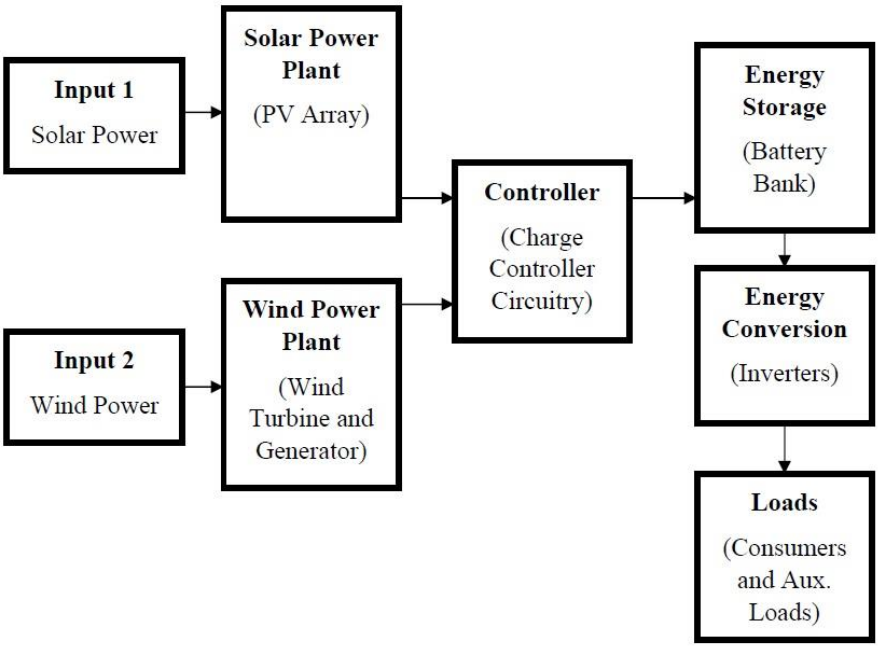

Figure 4: ***Energy flow diagram***

CHAPTER 3

METHODOLOGY

HOMER software's simulations are made by analysing energy stability scheming and display the all potential structures. These possible structures settled by net existing cost which is able to be suitable for evaluation of system plan. HOMER's analysis make the job easier and finds all total probable system configurations associated to it. The software similarly delivers the worth gain study for wind-solar power system. When planning whichever power system, choices on the outline of the structure must be evaluated. This include components and description of the system plan, the size of every component, the accessibility of the resources of the energy system and the industrial choices, and rate of every existing technology [9].

In gathering data and information for the study of ability of solar PV to continue develop in Malaysia; extensive desk research was carried out. A comprehensive literature review was conducted to identify information and ideas, also to increase the knowledge that is relevant to this research.

3.1 Wind Resources

According to [22] mostly wind resources are established using NASA Solar Energy and Surface Meteorology database through the following link http://eosweb.larc.nasa.gov" by considering the direction of the wind at 50 metres above the earth's surface. The catalogue offers a periodic monthly wind speed average for the specific month over a 10-year dated.

Every monthly averaged percentage is calculated as the mathematical average of three hourly values for the specified month. The locations are not always appropriate for the setting up of effective wind turbines. So, the yearly wind speed average might be a good pointer of the appropriateness of the installation of a wind turbine in a certain location and usually values above 5.0 m/s with limited months below 4.0 m/s are normally considered acceptable for adequate results [9].

3.2 Solar Resource

The resources of the solar system are introduced straight by the homer software from the NASA Solar Energy and Surface meteorology database by entering the coordinates from the GPS [22].

The process to hybridize the system is carefully planned and the approach to be used is as illustrated in figure 5.

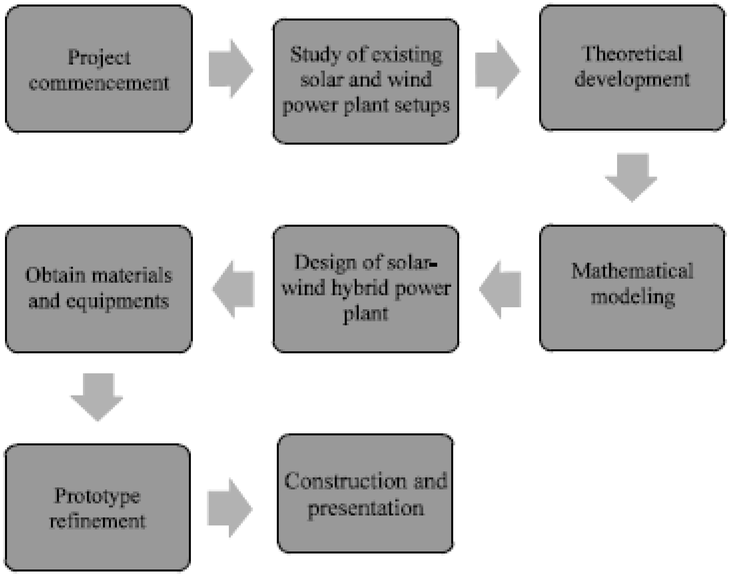

Figure 5: ***Flow chart indicating the approach proposed***

3.3 Project Planning

For the project planning it has been divided into several stages in addition to the 2 semesters as it involves multiple sections to be completed before the final optimize model 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 analysing a hybrid plant.

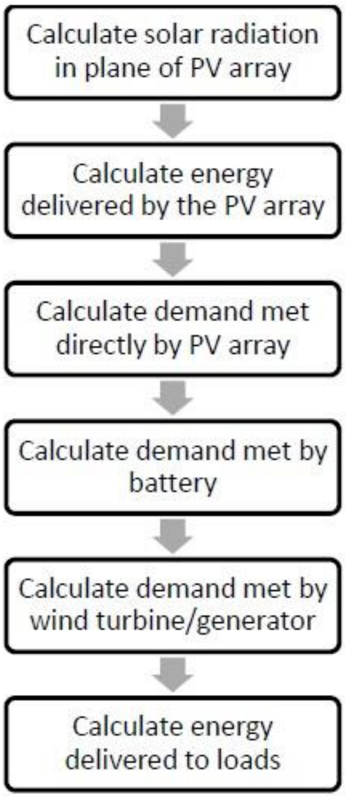

Figure 6: ***Theoretical development flow chart for hybrid power plant***

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 extra-terrestrial radiation and clearness index calculations to identify 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 [13] 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. 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

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 non-existent 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 that can be found in Appendix C 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.

3.6 Sizing simulation using HOMER

Proper sizing was conducted to study the economic feasibility of implementing a hybrid power plant in Universiti Teknologi PETRONAS. 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 UTP, particularly in Village 6. 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.

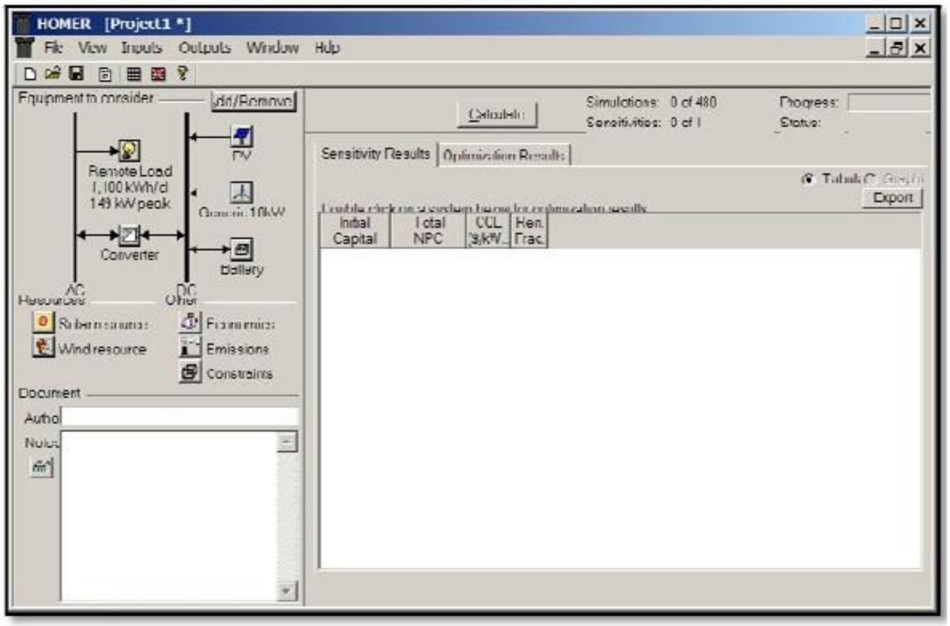

Figure 7: Screenshot HOMER simulation software

3.6.1 Primary Load

A daily-averaged electrical usage for an average home was calculated using electrical usage estimation sheet [23]. 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 24-hour period was used to simulate the energy requirements for each home. The following screenshot illustrates the configuration. The figure bellow illustrated the primary load setup screen and load profile.

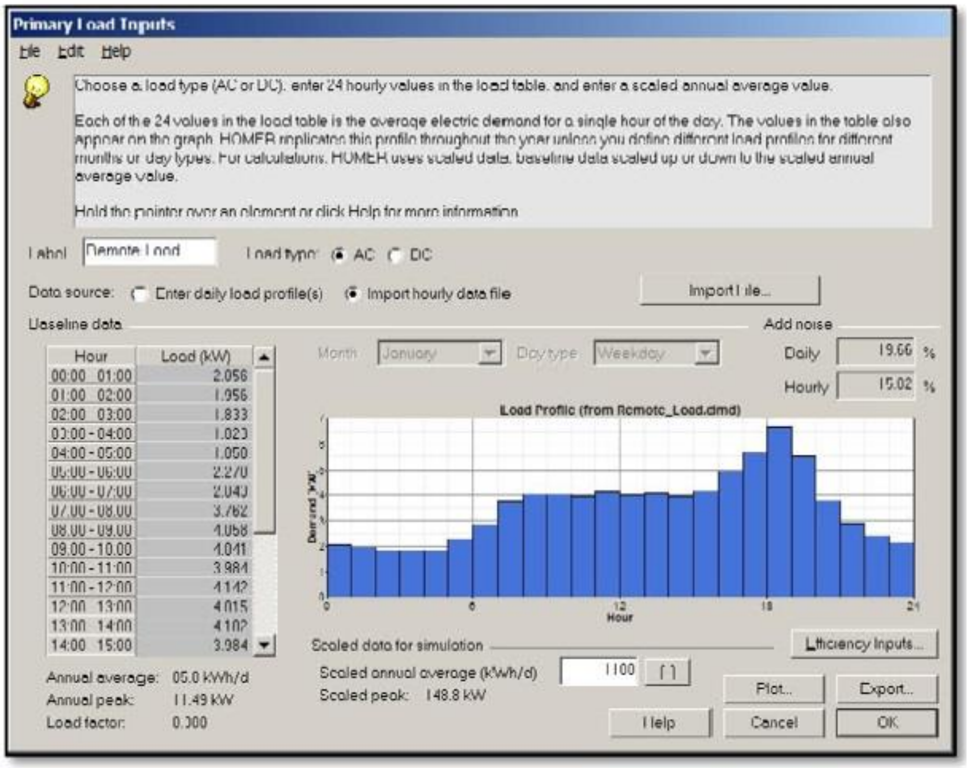

Figure 8: Primary load profile and setup screen

3.6.2 Solar Panels

Based on an article presented by PopularMechanis [24], the average cost per kW of energy generated by commercial solar panels is at USD 4,500. 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.

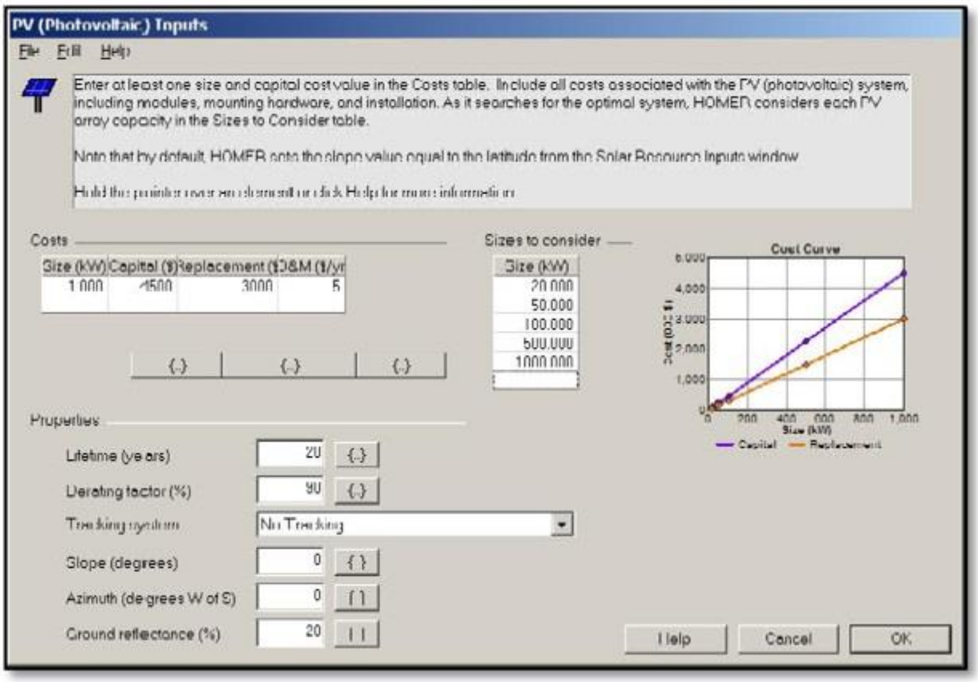

Figure 9: PV panel setup screen

3.6.3 Wind Turbines

According to [25], the average cost of 10 kW wind turbines cost USD 30,000 to USD 50,000 per unit. Hence this information is used for cost calculation. Weather data were collected from NASA website [22]. Monthly averaged wind speeds were collected to generate a wind profile for Malaysia. The following figure illustrate how these data were entered into HOMER before the actual simulation was conducted.

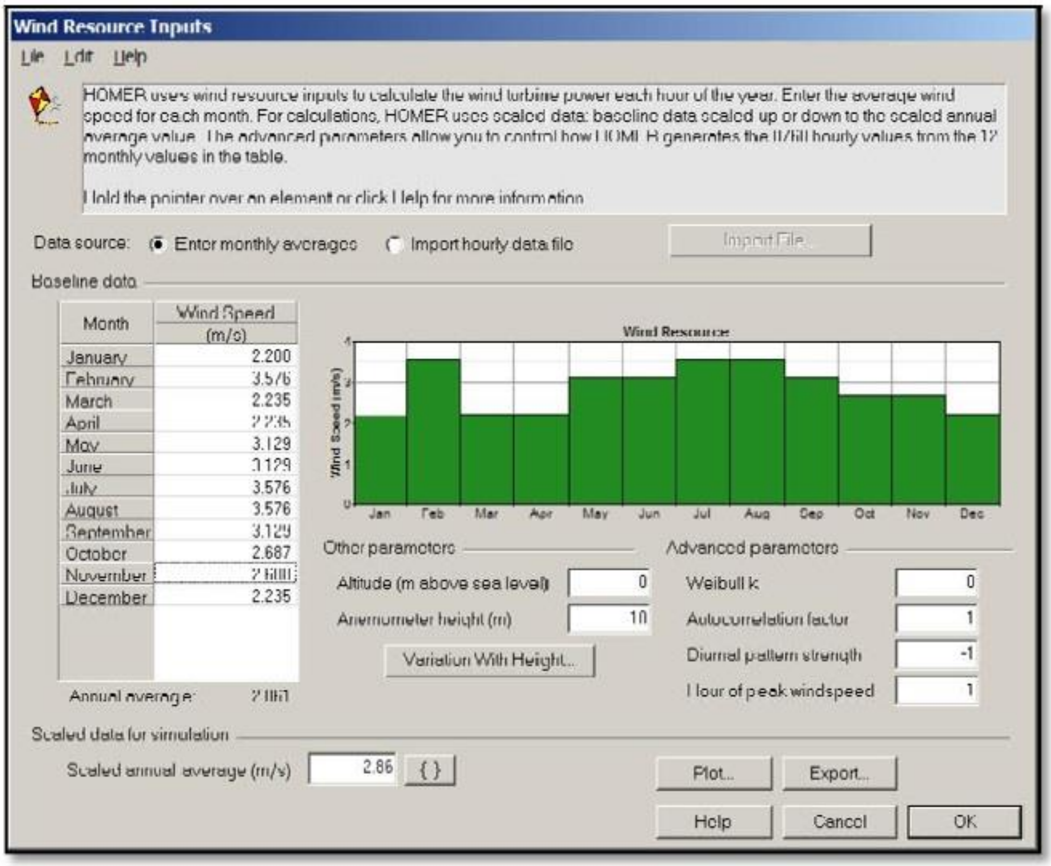

Figure 10: Wind profile for Malaysia

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 illustrated the setup for battery sizing.

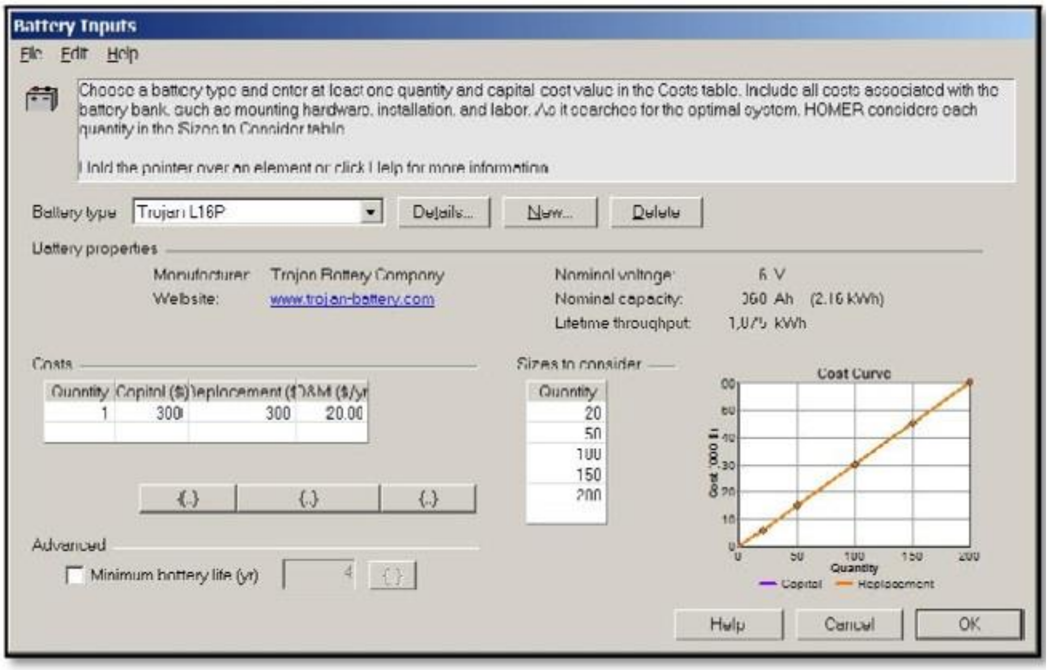

Figure 11: Battery sizing estimations

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Mathematical modelling for solar power output

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

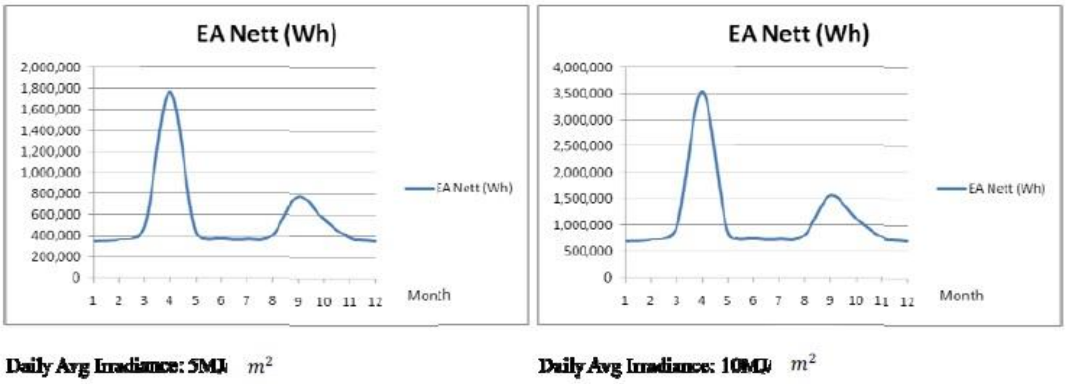

Figure 12: Comparison between EA for different levels of irradiance

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

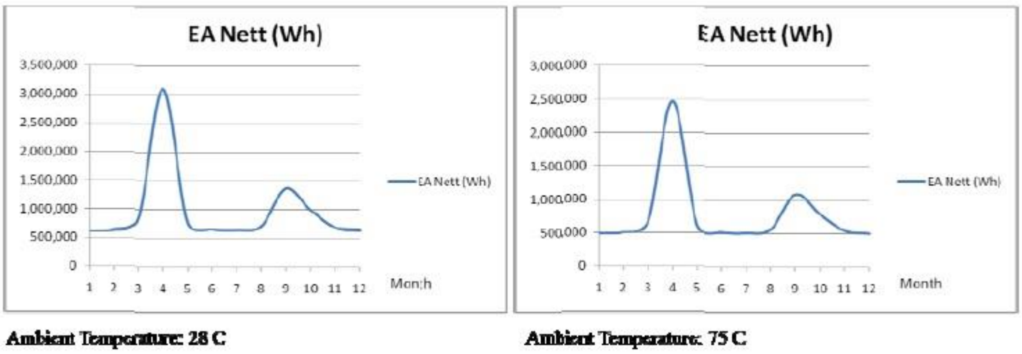

Figure 13: Comparison between EA for different levels of temperature

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

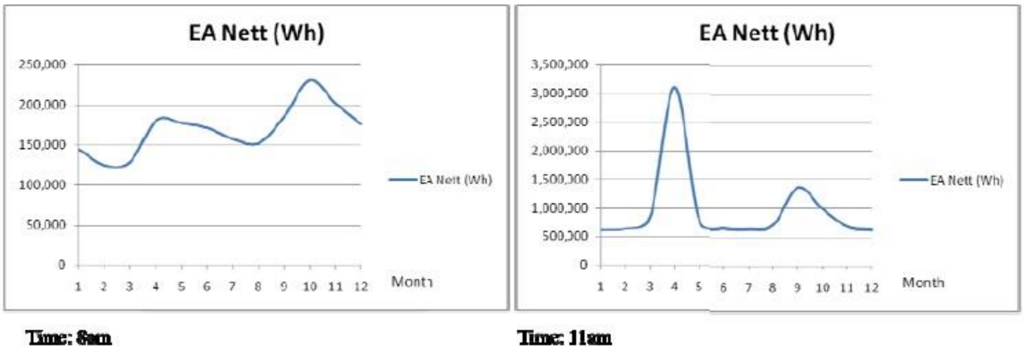

Figure 14: Comparison between EA for different solar positions

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

4.2 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 220 simulations were conducted and 9 out of which were shortlisted for consideration. Figure 15 and 16 below illustrates the outcome. A detailed graph was generated to indicate the cut off 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 analyse the systems based entirely on the typical components of a standalone solar power plant. The following figure illustrates the simulation output from HOMER.

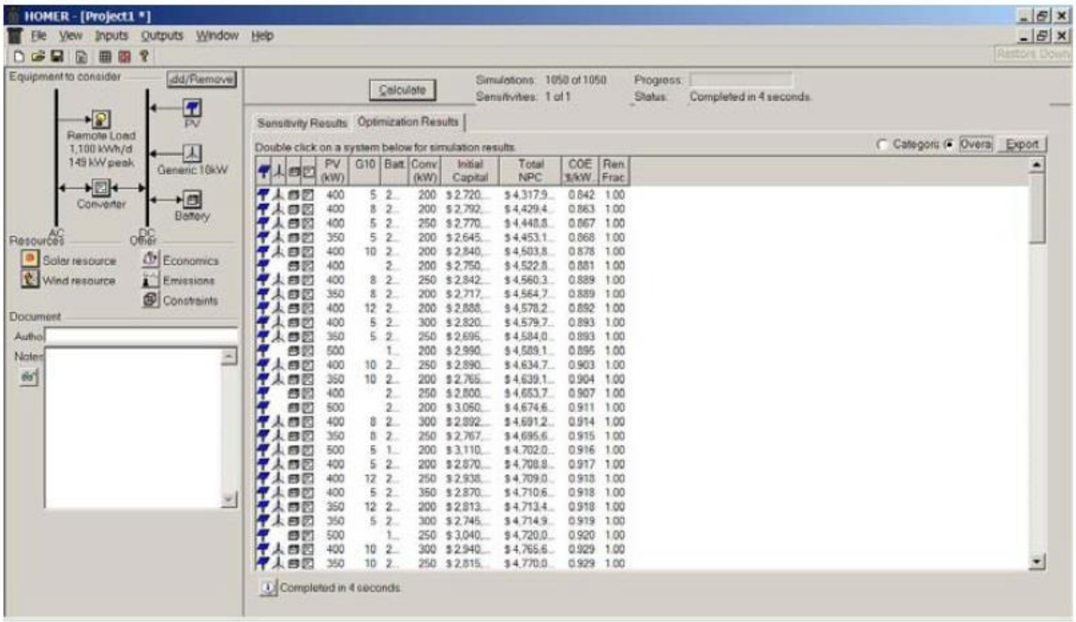

Figure 15: HOMER sizing simulation results

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.

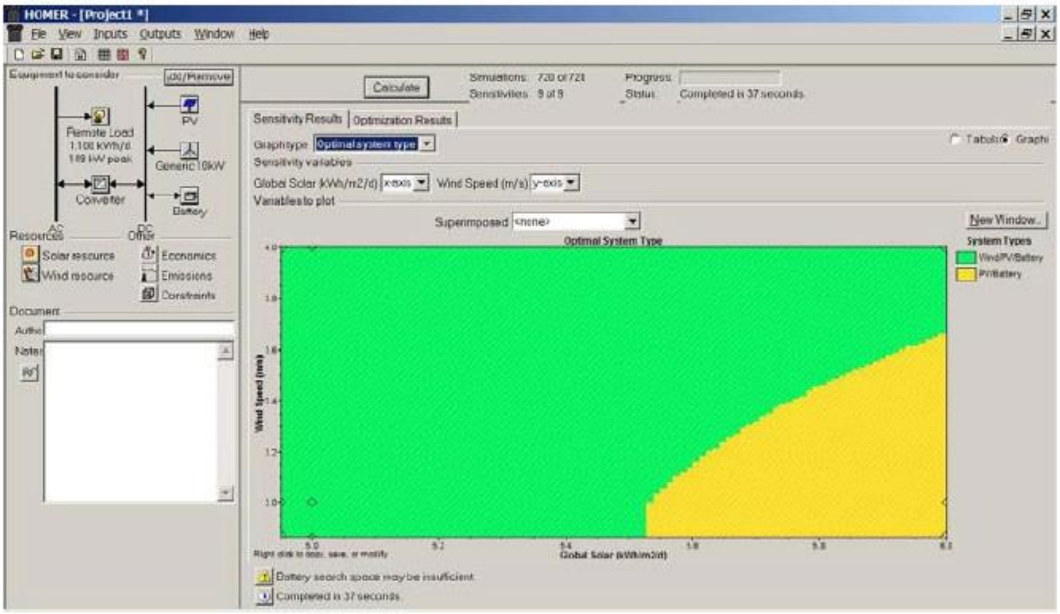

Figure 16: Graphical display of optimized simulation results

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.

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.

CHAPTER 5

CONCLUSION

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 economic feasibility of implementing a solar-wind hybrid power plant in UNIVERSITI TEKNOLOGI PETRONAS based in Village 6. 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 UTP. 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 in Village 6. From the analysis, a solar-wind hybrid power plant is highly feasible and will improve the reliability and sustainability of a 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 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.

5.1.3 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.

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APPENDICES

APPENDIX A

GANTT CHART OF THE PROJECT

Activities | Week	Semester 1														Semester Break					Semester 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research Work, Literature Review	■	■	■	■																													
Submission of Preliminary Report				■																													
Scaled Experiments/ Test Models and Design Work					■	■	■	■	■																								
Study of Software Implementation						■	■	■	■	■																							
Submission of Progress Report 1								■																									
Sourcing of Equipment and Hardware								■	■	■	■	■	■	■	■	■	■	■															
Seminar									■																								
Construction of Prototype									■	■	■	■	■	■	■	■	■	■	■														
Submission of Interim Report													■																				
Oral Presentation														■																			
Testing, Optimization of Prototype																	■	■	■	■	■	■	■										
Submission of Progress Report 2																							■										
Fine-tuning and performance enhancements																							■	■	■	■	■						
Submission of Progress Report 3																											■						
Seminar																												■					
Poster Exhibition																													■				
Submission of Disssertation (softbound)																															■		
Submission of Project Dissertation (hardbound)																																	■

Table 2: Project Gantt chart for FYP1 & FYP2

APPENDIX B

LIST OF EQUATIONS FROM MATHEMATICAL MODELLING

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

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

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

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

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

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

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

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

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

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

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

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

$$H_b = H - H_d \tag{23}$$

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

$$R_b = \frac{\cos\theta}{\cos\theta_z} \tag{25}$$

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

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

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

$$E_P = S \eta_p \bar{H}_t \tag{29}$$

$$E_A = E_P \left(1 - \lambda_p \right) \left(1 - \lambda_c \right) \tag{30}$$

$$\eta_A = \frac{E_A}{S \ \bar{H}_t} \tag{31}$$

$$E_{grid} = E_A \ \ \eta_{inv} \tag{32}$$

$$E_{dlvd} = E_{grid} \ \ \eta_{abs} \tag{34}$$

$$D_{DC,equ} = D_{DC} + \frac{D_{AC}}{\eta_{inv}} \tag{35}$$

$$D_{DC,equ} = D_{matched} + D_{continuous} + D_{battery} \tag{36}$$

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

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

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

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

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

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

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

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

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

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

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

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

$$ALR = E_A' / L' \tag{49}$$

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

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

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

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

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

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

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

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

$$\frac{1}{8} \frac{Q_B}{\eta_R} \tag{58}$$

(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

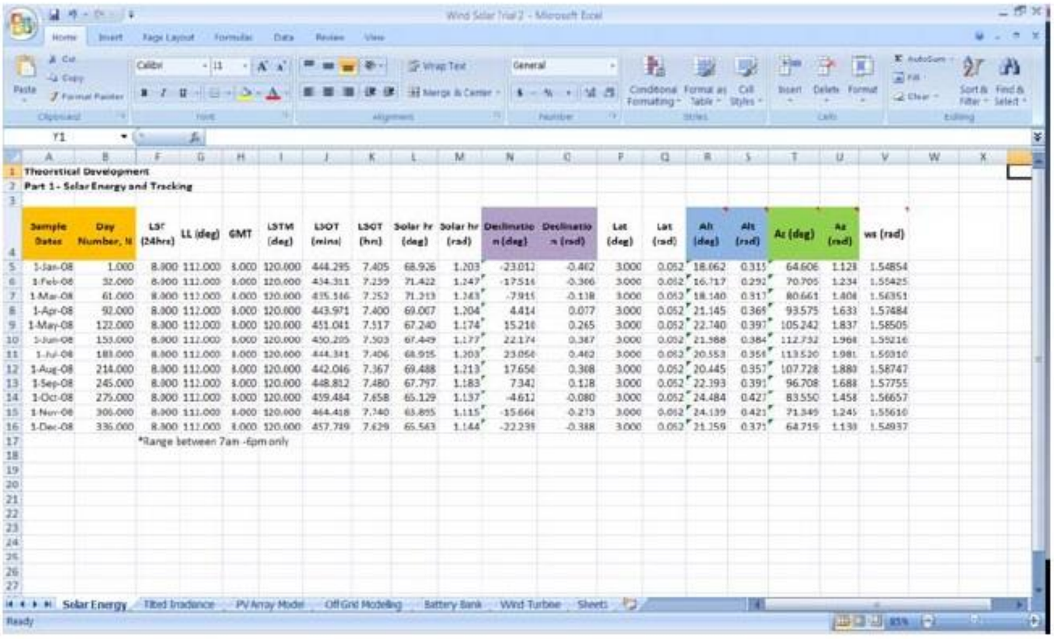
(56) Usable battery capacity

(57) Usable fraction of capacity available

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

APPENDIX C

EXCEL MODELLING PROGRAM



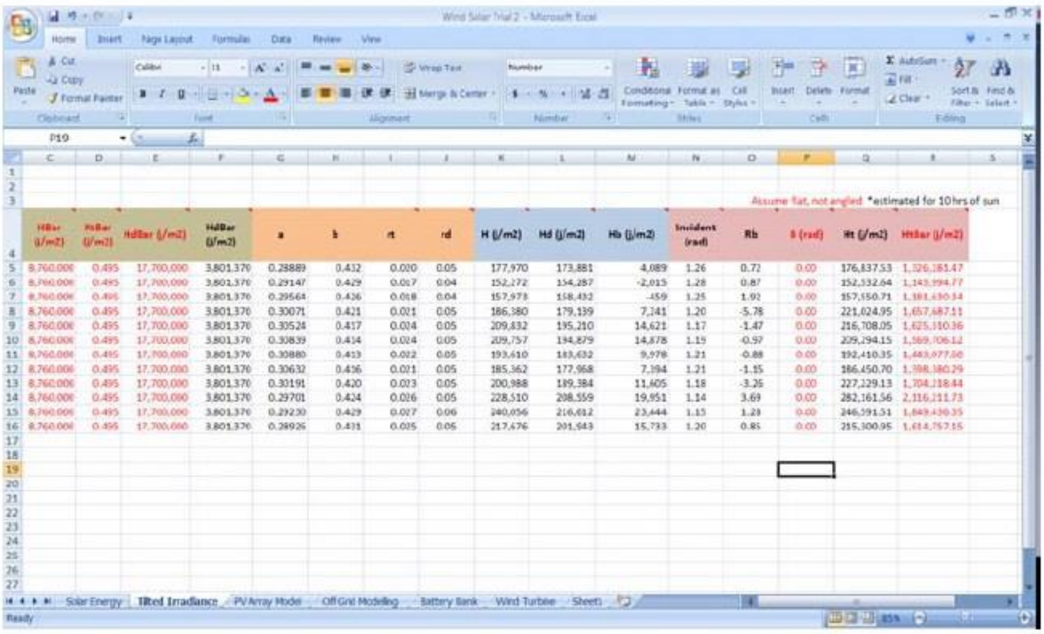
Theoretical Development

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	15.216	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	23.056	0.402	3.000	0.052	20.553	0.358	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	17.656	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	-15.664	-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	457.719	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 17: Excel modelling for solar positioning studies



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

HBar (J/m2)	HoBar (J/m2)	HdBar (J/m2)	HdBar (J/m2)	a	b	rt	rd	H (J/m2)	Hd (J/m2)	Hb (J/m2)	Incident (rad)	Rb	β (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	1,326,181.47
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	1.23	0.00	246,591.51	1,849,430.35
8,760.000	0.495	17,700,000	3,801,370	0.28926	0.431	0.025	0.06	217,476	201,943	15,733	1.20	0.85	0.00	215,300.95	1,614,757.15

Figure 18: Excel modelling for irradiance studies

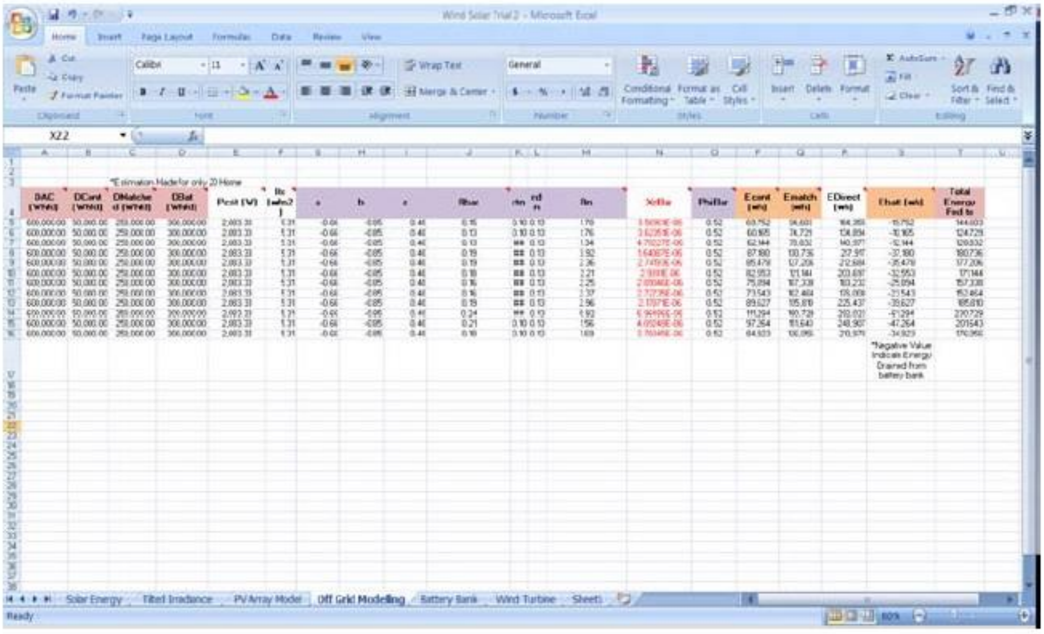


Figure 19: Excel modelling for PV array model

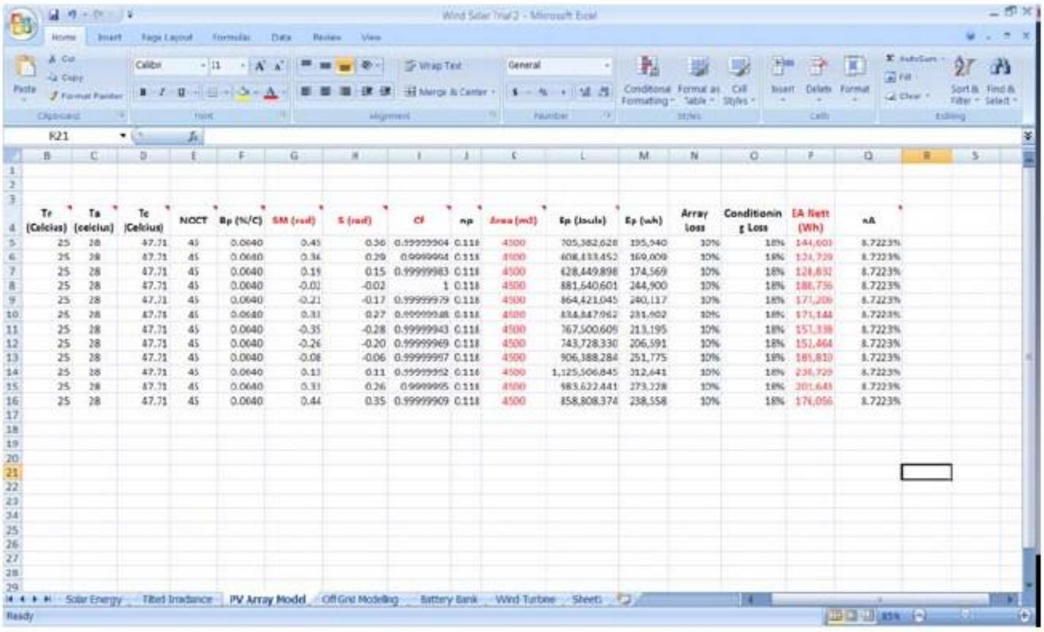


Figure 20: Excel modelling for off grid modelling

APPENDIX D

ELECTREX POSTER FOR SOLAR-WIND HYBRID POWER SYSTEM

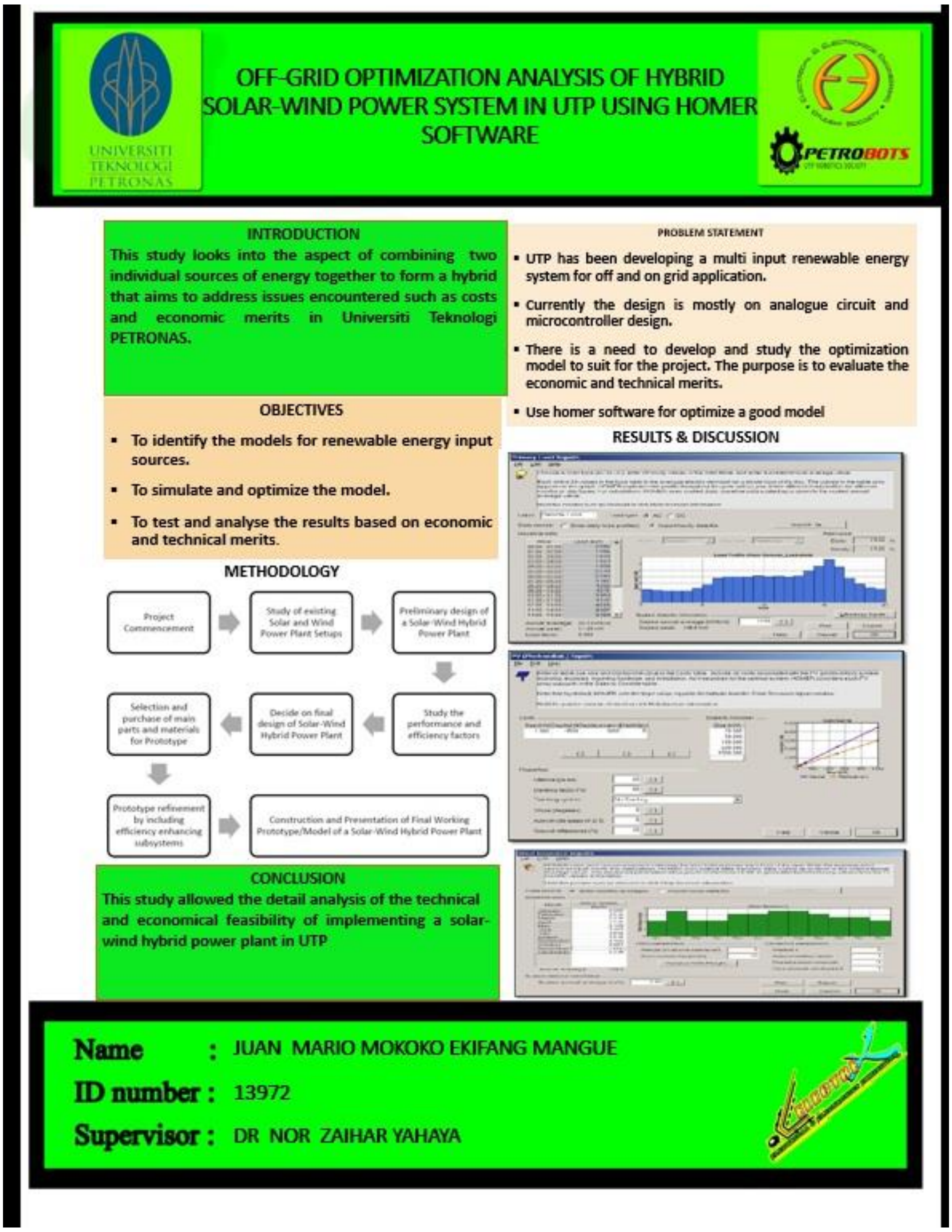


Figure 21: Technical ELECTREX Poster for Solar and Wind power system

APPENDIX E

HOME SOFTWARE SCREEN SHOT

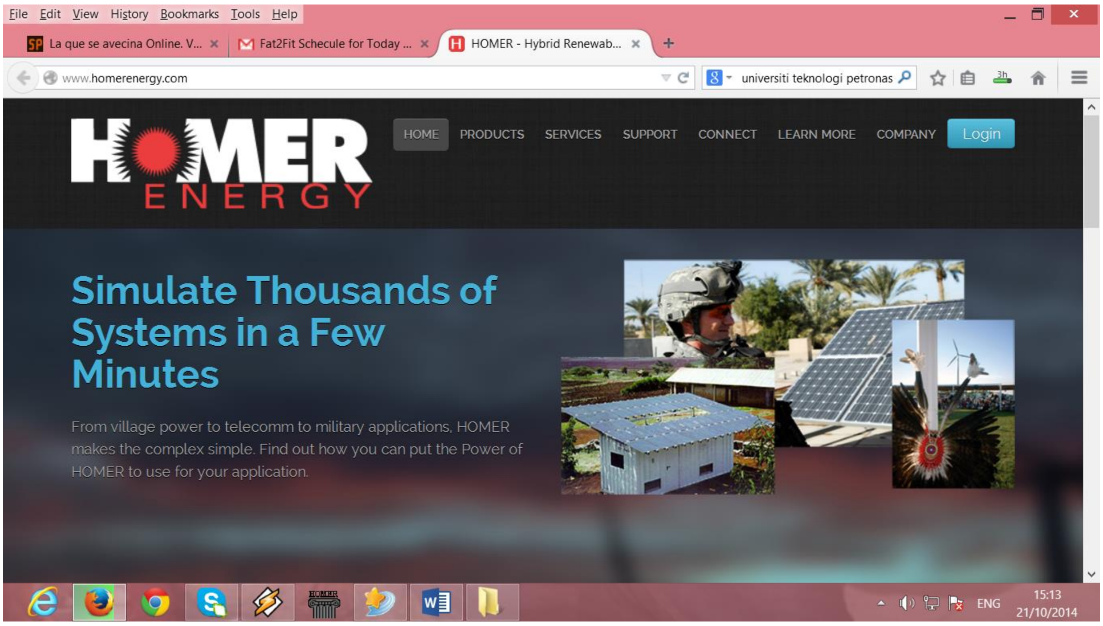


Figure 22: Homer website screenshot