Simulation-based method to evaluate a PV/wind hybrid renewable energy system in Terengganu

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Abstract

The potential for the Terengganu region to implement renewable energy is evaluated. This study evaluates the feasibility of a photovoltaic-wind hybrid renewable energy system in Terengganu using a simulation-based method to investigate the optimum design of the system that could be used as well as with the estimation of the system life-cycle cost. To simulate this operation, a software tool namely HOMER is used. The research is divided into 3 stages; data collection, simulation and data analysis stages. Data collection involves collecting and sorting the average data of solar radiation, wind speed and load profile in Terengganu as well as other necessary parameters through the off-grid PV/wind system located in Terengganu with reference to the NASA meteorology data. Simulation stage is then undertaken and optimised by resizing the parameters apart from determining the feasibility of the system using HOMER software. Optimization results showed the simulation of feasible systems configured with respect to total net present cost. It is concluded that a PV/wind hybrid system is able to be applied in Terengganu with the optimum design of PV/wind hybrid renewable energy system comprising 4 kW PV units, 1kW wind turbine and 22 battery strings units for a household application with an appropriate estimation of life-cycle cost of $28,046.
Keywords: PV/wind hybrid system, HOMER software, economic analysis, renewable energy.

1 Introduction

As an equatorial country, Malaysia has an approximate of 4000-5000Wh/m^2 of daily average solar radiation and thus the potential for solar power generation is very high. It has been estimated that the energy can be obtained from solar is at

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four times the world fossil fuel resources. However at present, this renewable energy source has not been fully utilized. So far, renewable energy contributes less than 1% to the total energy generated [1]. To increase the percentage of total energy generated by renewable sources, Malaysia has introduced a new fuel mixed strategy from Four to Five-Fuel Diversification Strategy in 2002, where the 5th fuel in the Malaysia's energy policies is generated from renewable energy sources [2]. Malaysia plans to achieve 5.5% share of renewable energy in the energy mix by 2015 and 11% of overall electricity generation by 2020 [1].

Producing energy from wind in Malaysia is still limited due to low average wind velocity in the whole country. The wind speed in Malaysia is light and varies from season to season in the range of 2–13 m/s. However, there are potential places which have been identified in [1] to generate electricity from wind energy such as Terengganu, Sabah and Johor (see Figure 1 for the location of states in Malaysia).

Figure 1: Map of Malaysian states.

A drawback of the abovementioned energy options is their unpredictable nature and dependence on weather and climatic conditions. Combining these renewable energy sources with back-up units such as batteries to form a hybrid system can provide a reliable supply of electricity in all load demand conditions compared to single-use of such system [3]. It also has been proven in [4] that hybrid renewable electrical systems in off-grid applications, especially in remote area such as an island, are economically viable.

Climate can make one type of hybrid system more profitable than another type. Since Malaysia can be considered as warm country which receives a yearly average of 1643 kWh/m^2 of the solar energy, and Terengganu has been identified as one of the most suitable places to generate electricity from wind energy [1], the most ideal hybrid system for this area is combination of PV and wind energy system. One of the most important issues in a hybrid system is to optimally size the hybrid system components as sufficient enough to meet all load requirements with possible minimum investment and operating cost [5].

Refer to Figure 1; Terengganu is located in north-eastern Peninsular Malaysia and is bordered by the South China Sea at the east. One of the attractive factors to Terengganu is the beautiful islands such as Pulau Bidong, Pulau Perhentian, Pulau Redang and Pulau Kapas. To supply electricity to these islands, Malaysia encourages researchers to study the feasibility of using renewable energy sources which have been identified in [1] to replace the generator which can cause pollution. Hence, in this study, a techno-economics analysis of an off-grid PV/wind hybrid system with and without diesel generator to provide electricity for a household in Terengganu is investigated using hybrid optimization model for electric renewable (HOMER) software.

2 Data collection

The selected area of this study is University Malaysia Terengganu (UMT) which is located in Kuala Terengganu, one of the districts in Terengganu as shown in Figure 2. The latitude and longitude of Kuala Terengganu are 5.31 and 103.12, respectively.

HOMER software requires some input parameters to calculate the optimization results for a specific configuration of system. The input parameters are daily solar radiation (kWh/m^2/d), wind speed (m/s) and load profile (kW).

Figure 2: Map of Terengganu districts.

2.1 Solar radiation

Using the latitude and longitude of the selected area, the solar radiation data was obtained from National Aeronautics and Space Administrative (NASA) [6]. It is a 22-year average monthly solar radiation data. Figure 3 shows the solar radiation data inputs as used in HOMER software. The clearness index of solar irradiation is automatically calculated by the HOMER when the daily radiation data is entered and is plotted based on the right axis of the same figure. The solar radiation ranges from 3.71kWh/m^2/day to 5.99kWh/m^2/day. The average of solar is 5.06kWh/m^2/day. It is noticed that solar irradiance is high from February to October, while it is low from November to January. The low solar radiation is because of the Northeast Monsoon season during this period.

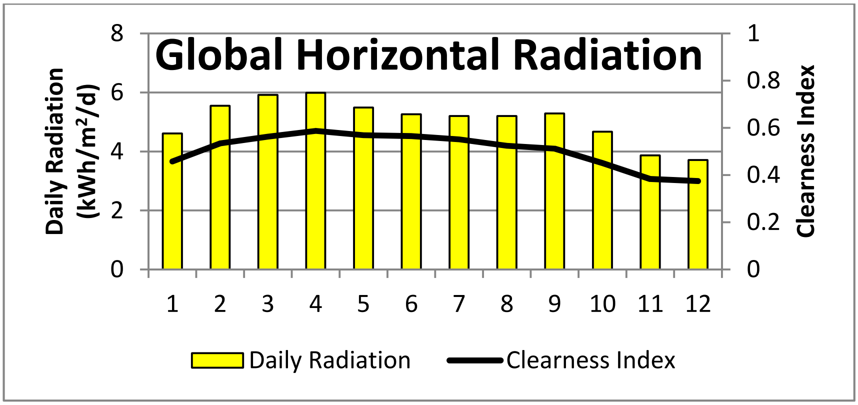


Figure 3: The annual solar radiation and the clearness index for the location of Kuala Terengganu, Malaysia.

2.2 Wind speed

The wind speed data is also obtained from NASA database for the location of Kuala Terengganu, Malaysia [6]. It is a 10-year average monthly wind speed data at 10 m above the surface of sea level as shown in Figure 4. The figure shows that the wind speed ranges from 2.02m/s to 4.68m/s with the annual average is 3.2m/s. In contrast to the solar radiation, the wind speed is high during the Northeast Monsoon season.

2.3 Load profile

Load profile shows the trend of electricity used in daily life of the selected consumer. For the purpose of comparison, the similar load profile as in [7] was used in this study as illustrated in Figure 5. The figure shows a typical sample of the daily load profile obtained from a household that consist of common electronic appliances such as lamps, TV, refrigerator, fan, washing machine and air conditioner.

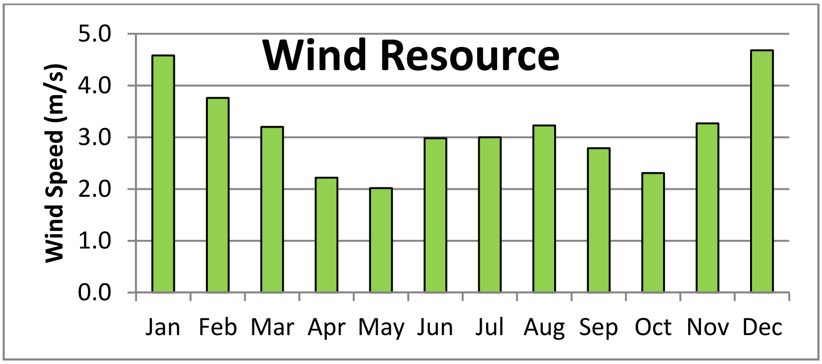


Figure 4: The monthly wind speed data in Kuala Terengganu, Malaysia.

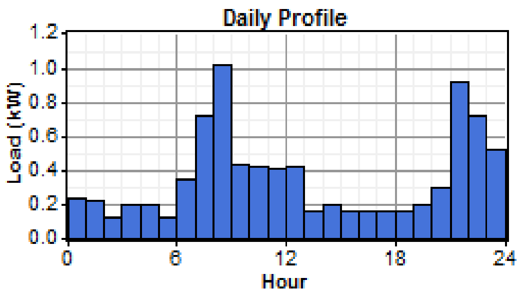


Figure 5: A sample of the daily load profile for a house.

3 System description and specification

In this study, three types of system configurations are evaluated namely PV/wind hybrid system, PV/wind/generator hybrid system and PV/generator hybrid system. Basically there are five main components which are a generator (for a hybrid system with generator only), PV modules, wind turbines, batteries, and converters as shown in Figure 6.

In the proposed system, the PV modules and wind turbine produced DC power which needs to be converted to AC source using an inverter. When there is excess energy after meeting the load demand, the PV and wind turbine will charge the battery. In case if both PV and wind energy are not enough to meet the demand, the battery will discharge to cater the demand. For a hybrid system with generator, the generator will only operate if all the energy sources fail to meet the load demand which typically happens during night time.

The design specification, initial and replacement costs, and operating and maintenance cost for each component used in the system are provided in the following subsections. The HOMER software simulates the system costs based on US dollar. The size of each component also is varied for a certain range to find the optimum system.

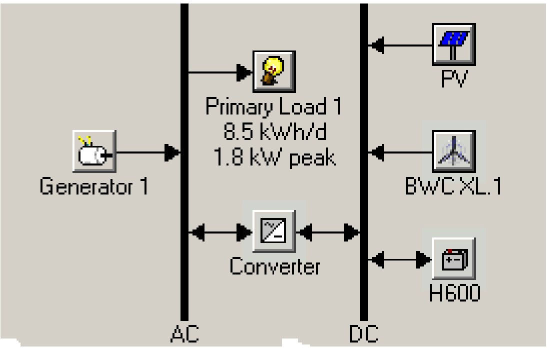


Figure 6: System configuration.

3.1 Solar PV panels

Solar PV panels are used to convert the solar radiation to electricity. The capital cost and a replacement cost of a 200W solar panel are set to be equal to $504 [8]. In order to fulfil the basic load demand with average 8.5kWh/d and the peak demand of approximately 1.8kW, the sizing range of PV array is considered from 1–10 kW.

3.2 Wind turbine

In this simulation, the model BWCXL.1 1kW DC type wind turbine was chosen [9]. The capital cost for this wind turbine is $4595 and the replacement cost is assumed to be the same. The sizing range of wind turbine is considered from 0 to 2 units.

3.3 Diesel generator

The same diesel generator as in [7] is used in this study with the diesel price is at $2.17 per litre. The sizing range is limited to 0–1kW (0kW for a system without generator and 1 kW for a system with one unit generator) to reduce air pollutant.

3.4 Converter

A converter is used to convert from DC to AC and vice versa. In this study, the initial cost of a 45kW converter is obtained from [7] which is $14,264 with the same amount of a replacement cost. The expected lifetime of the converter is 25 years. However, the sizing range of converter is considered from 1–10kW.

3.5 Battery

The battery is used in the system to store any extra energy produced by the system. The specification of the battery is as in [7] and the sizing range is from 1–30 units batteries.

4 Operating strategies

In order to reduce air pollution, the proposed system is set to operate according to load following dispatch strategy. Using this strategy, PV modules and wind turbines will charge the battery storage. Whenever the generator is needed, it will only produce enough power to meet the load demand. This strategy tends to be optimal in systems with more than one renewable energy sources. Using this strategy, it may help to reduce the net present cost (NPC) and excess electricity produced [10].

In HOMER simulation, the operating reserve is the surplus operating capacity that ensures reliable electricity supply even if the load suddenly increases or renewable power output suddenly decreases [11]. In its simulation, HOMER operates the power system so as to keep the operating reserve equal to or greater than the required operating reserve. Any shortfall is recorded as a capacity shortage.

In this simulation, the operating reserve as a percent of hourly load is set to be 10%. A value of 10% means that the system must keep enough spare capacity operating to serve a sudden 10% increase in the load. While the operating reserve as a percent of solar power output and wind power outputs are set to be 25% and 50%, respectively. It means the system must keep enough spare capacity operating to serve the load even if the PV array output suddenly decreases 25% and wind turbine output suddenly decreases 50% [12]. In most cases, the output of the PV array should be less variable than the output of a wind turbine, so this input will usually be set at a lower value than the previous one [11].

During simulation, HOMER software performs iterations by running multiple optimizations under a range of input assumptions [7]. The size of the search space is calculated using the following equation:

$$\eta_{PV} \times \eta_{WT} \times \eta_G \times \eta_B \times \eta_C \tag{1}$$

where η is the number of size of PV, wind turbine (WT), generator (G), battery (B) and converter (C), respectively. In the optimization process, every system configuration in the search space is simulated.

After simulation was performed, HOMER ranks all systems according to total net present cost (NPC). The NPC represents the life-cycle cost of a system including the cost of initial construction, component replacement, maintenance and fuel. Besides that, the levelized cost of energy (COE) might be taken into account to obtain the optimal results of different system configurations because it is another convenient metric for comparison. This value shows the average cost per kilowatt hour ($/kWh) of useful electrical energy produced by the system [11].

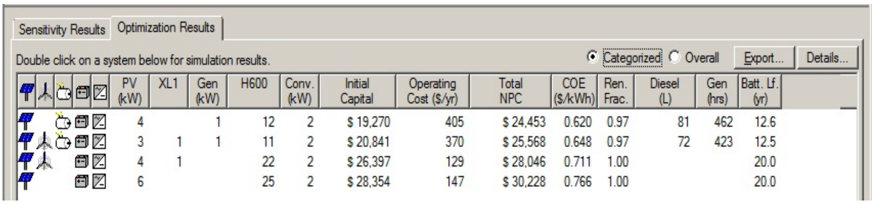
5 Results and discussion

The optimal configuration is evaluated based on the collected data and loads. Using the equation in (1), the total search space for this simulation is 18000. The optimal configurations obtained from the simulation are then compared with results in [7] which have investigated the wind/PV/generator hybrid system at four different states namely Selangor, Johor, Sarawak and Penang (refer to Figure 1 to see the location of the states). Then, for the next discussion, the three different optimal configurations which are PV/wind hybrid system, PV/wind/generator hybrid system and PV/generator hybrid system in Terengganu will be discussed and compared.

5.1 Comparison between the proposed systems and results in [7]

Since the proposed system used the same load profile as in [7], the results from this simulation can be compared with the results in [7] to see the most potential area that can generate renewable energy sources in Malaysia. The type of configuration used in [7] is a wind/PV/generator hybrid system.

From Figure 7, it can be seen clearly that the total NPC and COE for a PV/wind /generator hybrid system in Terengganu are $25,568 and $0.648 per kWh, respectively. For the same value of load demand which is 8.5kWh/d, these values are very low compared to other states which can be referred to in Table 1 of [7].



Sensitivity Results | Optimization Results

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PV (kW)	XL1	Gen (kW)	H600	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)	Batt. Lf. (yr)
4		1	12	2	$ 19,270	405	$ 24,453	0.620	0.97	81	462	12.6
3	1	1	11	2	$ 20,841	370	$ 25,568	0.648	0.97	72	423	12.5
4	1		22	2	$ 26,397	129	$ 28,046	0.711	1.00			20.0
6			25	2	$ 28,354	147	$ 30,228	0.766	1.00			20.0

Figure 7: The optimal configurations.

5.2 Comparison between three different configurations

To find the most suitable system configuration in Terengganu, the optimum results for three different configurations of hybrid system are compared as shown in Figure 7. From the figure, the lowest cost of total NPC is a PV/generator hybrid system configuration that consists of 4 kW PV panels, 1 kW diesel generator, 12 unit batteries and 2 kW converters. This is true as the cost of wind turbine is very high.

The second lowest cost of total NPC is a PV/wind/generator hybrid system configuration that consist of 3 kW PV, 1 kW unit of wind turbine, 1 kW diesel generator, 11 unit batteries and 2 kW converters. Since there is one unit wind turbine is used, the total NPC is little bit higher that the first configuration (without wind turbine).

If a totally clean energy system is needed without considering the cost, the third configuration which is a PV/wind hybrid system can be considered. The NPC cost for this configuration is $28,046, still considered lower compared to the results in [7] which is not totally clean. The total NPC is high for this type of configuration compared to the first two configurations because without a generator, the system needs 4 kW PV panels, 1 kW wind turbines, 22 unit batteries and 2 kW converters to supply the load demand.

The last configuration is not a hybrid system. It is a stand-alone PV system. Although the system can supply the load demand, the cost is very high as it needs 6 kW PV panels and a large amount of batteries. The summarized of total NPC and COE for hybrid configurations are shown in Table 1.

Table 1: Summarized total NPC and COE.

Hybrid configurations	Total NPC($)	COE ($/kWh)
PV/generator hybrid system	24,453	0.620
PV/wind/generator hybrid system	25,568	0.648
PV/wind hybrid system	28,046	0.711

Since there are two types of configurations using a generator, thus pollutants originate from the consumption of fuel and biomass in the generator has to be taken into account. Table 2 shows the total amount of each pollutant produced annually by the diesel generator.

Table 2: Amount of pollutants produced by diesel generator.

Pollutant emission	PV/generator hybrid system	PV/wind/generator hybrid system	PV/wind hybrid system
CO_2	212	191	0
CO	0.524	0.471	0
UHC	0.0581	0.0521	0
PM	0.0395	0.0355	0
SO_2	0.426	0.383	0
NO_X	4.68	4.2	0

The maximum power output (P_{max}), the total power production in kWh per year and levelized cost of energy (LCE) for PV output are given in Table 3. For the same parameters for wind turbine output and diesel generator output are given in Table 4 and Table 5, respectively.

From the tables, PV is the cheapest yet produced the largest amount of energy compared to wind turbine and diesel generator. To compare in terms of electric production among these three configurations, Figure 8 to Figure 10 can be used.

Table 3: PV output.

Configuration	P_{max} (kW)	Total power (kW/year)	LCE ($/kWh)
PV/generator hybrid system	3.29	5,173	0.152
PV/wind/generator hybrid system	2.47	3,879	0.152
PV/wind hybrid system	3.29	5,173	0.152

Table 4: Wind turbine output.

Configuration	P_{max} (kW)	Total power (kW/year)	LCE ($/kWh)
PV/generator hybrid system	0	0	0
PV/wind/generator hybrid system	1.23	734	0.490
PV/wind hybrid system	1.23	734	0.490

Table 5: Diesel generator output.

Configuration	P_{max} (kW)	Total power (kW/year)	LCE ($/kWh)
PV/generator hybrid system	1.00	175	0.543
PV/wind/generator hybrid system	1.00	154	0.543
PV/wind hybrid system	0.00	0	0

Refer to Figure 8, the total electric production for PV/diesel hybrid system is 5,347kW/year. 97% of this production is generated by PV and only 3% by generator. The total electric consumption is 3,087kW/year with excess electricity is 27.2%.

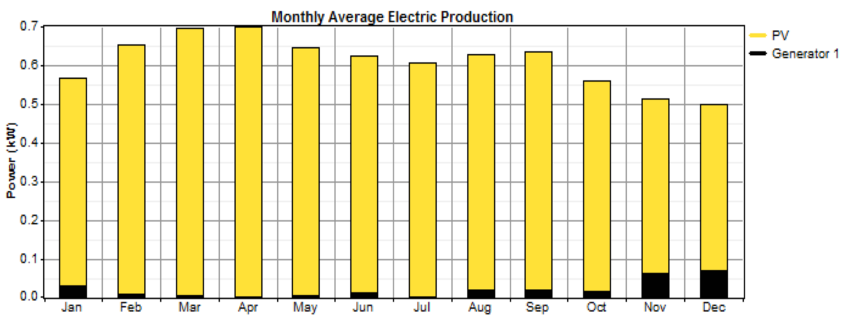

Figure 8: Monthly average electric production for PV/generator hybrid system.

Refer to Figure 9, the total electric production for PV/wind/diesel hybrid system is 4,768kW/year. 96% of this production is generated by renewable energy sources which are 81% by PV array and 15% by wind turbine. It is only 4% of electricity produced by generator. The total electric consumption is 3,088kW/year with excess electricity is 18.6%. Note that, electricity produced by wind energy is higher during the Northeast Monsoon because Terengganu is windy during this season.

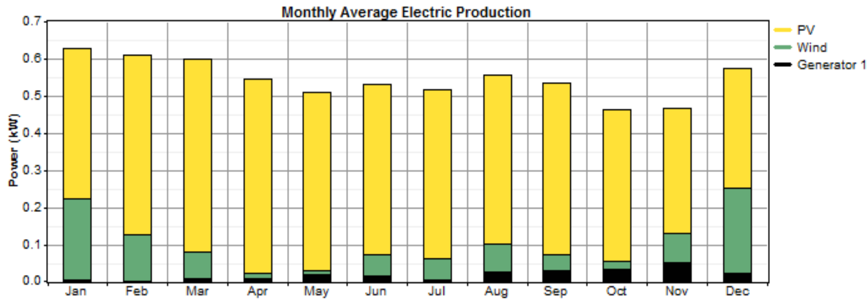

Figure 9: Monthly average electric production for PV/wind/generator hybrid system.

The monthly average of electric production for PV/wind hybrid system is shown in Figure 10. The total amount of electric production for this type of configuration is 5,906kW/year where 88% of electric production is generated by PV array and 12% is generated by wind turbine. The total electric consumption is 3,087kW/year with excess electricity is 33.8%.

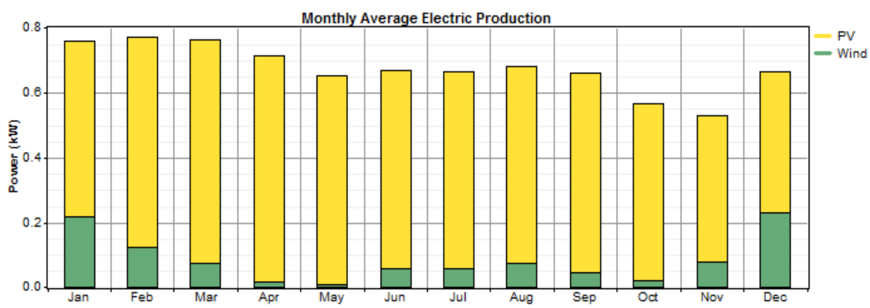

Figure 10: Monthly average electric production for PV/wind hybrid system.

6 Conclusion

From the results, Terengganu is a very suitable place to generate electricity from renewable energy sources. Based on this study, the lowest cost of total NPC belongs to PV/diesel hybrid system as the cost of wind turbine is expensive. However, to produce electricity in a clean environment, the PV/wind hybrid system is not a bad choice. The total NPC for this configuration is lower compared to other states which can offer not totally clean system. In addition, the total electric production per year for this configuration is high compared to the other two configurations. In the next 10 years, when the wind turbine becomes cheaper, the NPC for this kind of system will be lower and becomes one of the promising systems in producing energy.

References

[1] Rosnazri Ali, Ismail Daut, and Soib Taib, A review on existing and future energy sources for electrical power generation in Malaysia, *Renewable and Sustainable Energy Reviews*, **16(6)**, pp. 4047-4055, 2012.

[2] Pusat Tenaga Malaysia, Energy sector embracing climate change, National conference on climate change preparedness towards policy changes, 2007.

[3] Bagen, Billinton R, Evaluation of different operating strategies in small stand-alone power systems, *IEEE Trans Energy Conversion*, **20(3)**, pp. 654-660, 2005.

[4] Shaahid SM, Elhadidy MA. Opportunities of utilization of stand-alone hybrid (photovoltaic+diesel+battery) power systems in hot climates, *Renew Energy*, **28(11)**, pp. 1741-1753, 2003.

[5] Erdinc O, and Uzunoglu M, Optimum design of hybrid renewable energy systems: Overview of different approaches, *Renewable and Sustainable Energy Reviews*, **16(3)**, pp. 1412-1425, 2012.

[6] NASA, https://eosweb.larc.nasa.gov/

[7] Ahmed M.A., Priscilla N. John and Mohd Shawal, Optimal configuration assessment of renewable energy in Malaysia, *Renewable Energy*, **36(2)**, pp. 881-888, 2011.

[8] RADTEC, www.radtec.com.my

[9] Bergey BWCXL.1 spec. http://www.windturbinewarehouse.com

[10] Bernal-Agustin JL, Dufo-Lopez R, Rivas-Ascaso DM. Design of isolated hybrid systems minimizing costs and pollutant emissions. *Renewable Energy,* **31(14)**, pp. 2227-2244, 2006.

[11] HOMER, http://www.homerenergy.com/

[12] Mei Shan Ngan and Chee Wei Tan, Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia. *Renewable and Sustainable Energy Reviews,* **16(1)**, pp. 634-647, 2012.