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A hybrid renewable energy system for a longhouse

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Abstract: Renewable energy sources (RES) have already become important alternative electric power generation technologies, due to the adverse impacts of global warming brought about by the use of fossil-fuelled generation. To combat such impacts, a hybrid energy system which consists of more than one source of renewable energy would replace conventional electricity generation for Malaysia's longhouses existing in rural areas. Due to the limitation of electricity access in such areas, a hybrid system that consists of solar PV and wind energy as well as energy storage is proposed in this paper as a standalone RE system for electricity supply. Modelling of the hybrid system is then carried out based on selecting the most suitable system components, such as PV arrays, wind turbines, batteries and the inverter that satisfy both the technical and financial feasibility criteria. The model is then simulated using HOMER software to calculate the net present cost and the levelised cost of energy (LCOE). Results of the hybrid system simulation are compared with a diesel power generation, representing conventional energy supply, as the existing energy source. The comparison highlights the economic viability of the proposed hybrid system as a sustainable energy alternative to supply electricity to the longhouse.

Keywords: Hybrid power system, renewable energy resources, optimization.

1. INTRODUCTION

The world mainly consists of three major energy sources: fossil fuels, nuclear and renewable energy sources [1]. Fossil fuel will continually remain as the major source of power generation in the world, as well as in Malaysia [2]. However, there are a number of negatives environmental impacts associated with using fossil-fuelled generation, such as acid rain, ozone layer depletion and global climate change [2, 3]. A renewable energy resource is defined as a sustainable resource available at a reasonable cost that can be regenerated or replenished for fulfilling the load demand without causing negative impacts to the environment. A renewable resource is also expressed as a clean energy source. The optimal use of these resources in power system could minimise the environmental impacts with the reduction in greenhouse gases emission, which is a major factor of global warming [4]. An integrated hybrid power system is a power generation system which consists of multiple electricity generating components. In this paper, two types of renewable energy resources, namely solar PV and wind generation, are chosen to supply the hybrid power system.

A longhouse, or 'Rumah Panjang' in the local language, is a timber house raised three to five feet off the ground on stilts. Between 20 – 40 families of the 'Rungus', an ethnic group in the Borneo, residing primarily in northern Sabah, in the area around Kudat, dwell these longhouses. Each family usually have its own apartment while sharing a common living area [5, 6]. Most of these longhouses are located far from the town and reside in the inner part of the jungle. Rural electrification is the process of bringing electrical power to rural and remote areas. The difficulty to extend grid connection through the thick jungle as well as the associated power transmission losses, make the grid power supply in rural areas infeasible and uneconomical. Renewable energy could supply the rural power demand without the consideration of the transmission cost from the grid. Malaysia is an equatorial country which has abundant potential of the RESs [7], whereas Kudat, in particular, located in the northern part of Sabah, possess high wind and solar potentials [8].

A few optimization techniques have been utilized for hybrid system sizing and modelling in the literature, such as graphical construction [9], artificial intelligence [10], dynamic programming [11], linear programming [12], multi-objective design [13], and iterative approach [12, 14]. In this paper, HOMER, a micro-grid analysis tool, is chosen to perform the hybrid system modelling and optimization, in order to model the technical and economic considerations for a hybrid system. Three load profiles, representing various weather conditions; including hot, rainy and normal weather days were developed to represent the annual load curve. Meteorological data of solar irradiation and wind speed were collected at the Kudat area. Simulation results were carried out and compared with the existing diesel power generation option.

The paper is organised as follows. Section 2 outlines the model of the hybrid power system. Section 3 describes system technical modelling in HOMER, whereas Section

4 presents the economic model and life-cycle cost analysis. Section 5 presents the results and Section 6 provides the conclusions.

2. MODELLING OF THE HYBRID POWER SYSTEM

A proper model of the hybrid power system is the first step to obtain credible simulation and analysis results. Technical and financial evaluation techniques are then applied to the developed hybrid model in this paper. The aim to find out the most feasible hybrid system model for the longhouse in Kudat, Sabah. Figure 1 shows the procedure adopted in designing an integrated hybrid power system. The procedure includes load profile development, solar and wind data resources acquisition, finding suitable components and the cost involved, and lastly simulation of designed hybrid system. HOMER (Hybrid Optimization of Multiple Energy Resources) is a software that models the physical behaviour of an energy system and its life-cycle cost. It also provides a chronological simulation and optimization in for designing a combination of RES [**].

2.1 Load Profile Modelling

The load profile of the longhouse in Sabah is modelled with the consideration of the social activities of indigenous people living in this area. Since most of the rural communities of longhouses in Sabah are farmers and beads makers, therefore most of their activities are weather-depended. The load profile is designed based on the weather conditions throughout the year; which can be divided into three categories: hot days, rainy days and normal days. By assuming 20 families in a longhouse, the electrical appliances in a longhouse and the duration for each usage are estimated accordingly. Table 1 indicates typical electrical appliances that could be found in a longhouse with the quantity and usage duration for a normal day. The longhouse has a peak load demand of 16.4 kW and an average of 91.6 kWh/day, with a load factor of 0.232. Figure 2 shows the sample monthly load profile of a longhouse. Three types of daily load curves, shown in Figure 3, are developed based on the usage duration of Table 1.

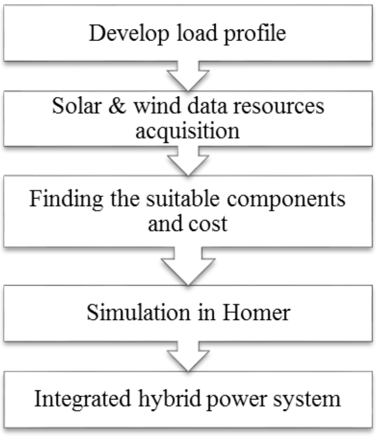


Figure 1. Steps in designing integrated hybrid power system

Table 1. Electrical appliances with the quantity (Qty) and usage duration per day for a normal day

#	Electrical appliances	Power consumption (W)	Qty	Usage duration/ day	
				From	To
1	Tube light (inside door)	36	40	1800	0000
2	Tube light (outside door)	36	20	1800	0600
3	Colour TV 19"	80	25	1800	2300
4	Refrigerator	100	5	0000	0000
5	Ceiling fan (inside door)	55	20	1800	0600
6	Ceiling fan (outside door)	55	10	1800	0000
7				1100	1800
8	Radio	50	10	1800	2000
9	Electric Iron	750	5	2000	2200
10	Cooker	1200	4	1100	1200
11			4	1700	1800
12	Washing machine	320	4	2000	2100

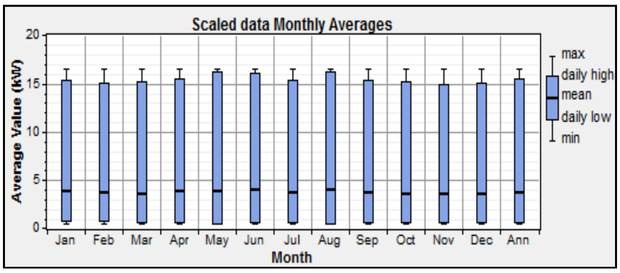


Figure 2. Monthly load profile

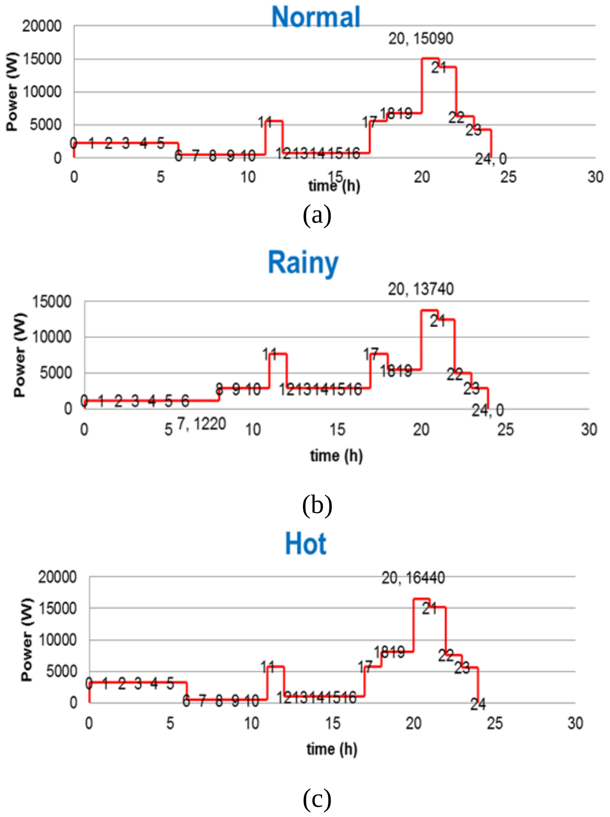


Figure 3. Daily load profile for (a) normal day, (b) rainy day and (c) hot day

The number of hot, rainy and normal days are obtained from the historic weather condition in Kudat for five years from year 2008 to 2012 [15]. Days are classified as hot ones when maximum temperature of the day reaches 30°C and above; rainy days when moderate and heavy rain fall continuously for more than two hours within the period 0800 to 1700, while the rest is classified as normal days, as summarised as in Table 2.

The total consumption throughout a year is calculated. It is equal to the summation of the product of power consumption for each day and the average number of days for hot, rainy and normal days respectively. Hence, total consumption throughout the year is calculated as:

Total Consumption = 84,585 × 176 + 93,350 × 48 + 99,660 × 141 = 33,419.82 kWh/year

3. TECHNICAL MODELLING OF THE HYBRID SYSTEM

In this section, details of the modelling of the hybrid power system's technical operation in HOMER are provided. The system is composed of solar photovoltaic and wind generation as the RES and a single electrical load. Extra components such as battery bank and ac-dc converter are used to make the system more applicable to cope with the intermittency of the renewables. In this paper, the primary load is the electrical demand that the hybrid energy system must supply at once. Any deficiency in the electricity supply will be considered as unmet load.

3.1 Solar PV Model

Solar radiation data, serving as an indication of the amount of solar radiation to the earth's surface in a typical year, is required to model a solar PV system. These data vary remarkably by location, as it depends greatly on climate and latitude. The solar radiation data and clearness index, a measure of the atmosphere clearness ranging from zero to one, is obtained via HOMER online resources [16, 17]. The data are based on solar radiation of latitude 6°53′ North and longitude 116°50′ East (Kudat), with time zone (GMT+08.00). Figure 4 shows the monthly averaged solar radiation data and clearness index of Malaysia, where the average daily radiation equals to 5.012 kWh/m^2/day and a clearness index of 0.505.

Table 2. Summary of hot days, rainy days and normal days from year 2008 to 2012 and the average

Year	Hot days	Rainy days	Normal days
2008	140	63	162
2009	149	50	166
2010	146	33	186
2011	134	52	179
2012	138	44	183
Average	141	48	176

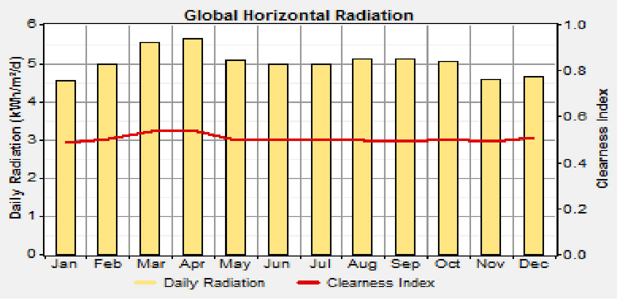


Figure 4. Monthly averaged solar radiation data and clearness index

The output power of photovoltaic (PV) array is given as equation below [16, 18]:

$$P_{Output} = f_{PV} Y_{PV} \frac{I_R}{I_S} \tag{1}$$

Where f_{PV} is the PV derating factor; Y_{PV} is the PV array rated capacity in kW, I_R is the solar radiation radiated on the PV array surface in kW/m^2, I_S is the standard radiation amount to rate PV array capacity in kW/m^2. The derating factor defines the deviation of PV array from the ideal performance caused by several effects. These include wire losses, dust on PV panels, increased temperature and etc. The PV array rated capacity or peak capacity is the amount of power a PV array would generate under standard conditions of 25°C panel temperature and 1 kW/m^2 radiation.

In the modelling of the PV array, one important assumption is that the maximum power point tracker (MPPT) is present in the system. Hence, the output of the PV array will be consistent, even if the voltage of the system varies throughout the operation. PV panels sizing is calculated using PV calculator [19]. Finally, the selected PV panel is a polycrystalline type with maximum power of 240 W, maximum power voltage of 30.6 V, maximum power current of 7.84 A, efficiency of 14.7% and the derating factor is 77%. The lifetime of the PV module is 25 years with a tilt angle of 45°.

3.2 Wind Turbine Generator Model

Wind resource data are also based on the wind speed throughout the year in Kudat, Sabah, Malaysia. Synthetic hourly wind speed data are generated from January to December, with four advanced parameters: Weibull shape factor, autocorrelation factor, diurnal pattern strength and hour of peak wind speed [20]. Another important parameter is the anemometer height, at which wind speed data are measured or estimated. The difference between turbine hub height and anemometer height can lead to imprecise results. Therefore, an extrapolation using the logarithmic law or power law is included for the wind speed adjustment at different levels of height.

Four steps are involved in the process to determine the output power of the wind turbine for each hour. These are:

(i) Average wind speed for a particular hour at the anemometer height is determined using wind resource data;

(ii) The corresponding wind speed at the turbine's hub height is calculated using the extrapolation logarithm law;
(iii) Wind turbine power curve is used to calculate the output power at different wind speeds;
(iv) The output power is multiplied by the air density ratio, defined as the ratio of actual air density to the standard air density, which is assumed to be constant throughout the year.

The wind data is synthesized based on the Weibull parameters measured at height 80 m with the scale parameter, K = 2.15 and shape parameter, c = 7.51 m/s. Extrapolation of this value for the hub height at 12 m is calculated and the new scale parameter, K = 1.76 and shape parameter c = 4.80 m/s with an average wind speed of 4.269 m/s, where the autocorrelation factor is 0.76 and diurnal pattern strength is 0.218. Figure 5 shows the wind speed probability density function. The 12m hub height wind turbine has a lifetime of 15 years, cut-in speed of 3.5 m/s, rated speed of 12 m/s and a cut-out speed of 25m/s. Figure 6 displays the power curve of the rated 10 kW FD 8.0 wind turbine.

3.3 Battery and Converter

A battery is a device capable of storing electricity, when supply exceeds demand, and discharging to produce electricity when needed. A few battery properties are essential to determine the capability of the battery. These properties are the battery nominal voltage, round-trip efficiency and minimum state of charge. The round-trip efficiency is the factor to determine the efficiency of charging or discharging, while minimum state of charge represents the lower limit of battery level. The battery lifetime is independent of the cycle depth, and can be calculated as follows [16]:

$$R_{bat} = \min\left(\frac{N_{bat}Q_{lifetime}}{Q_{input}}, R_f\right) \tag{2}$$

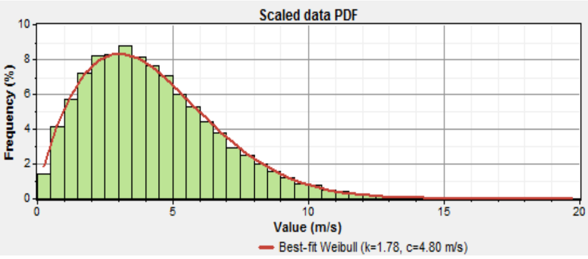


Figure 5. Wind speed probability density function

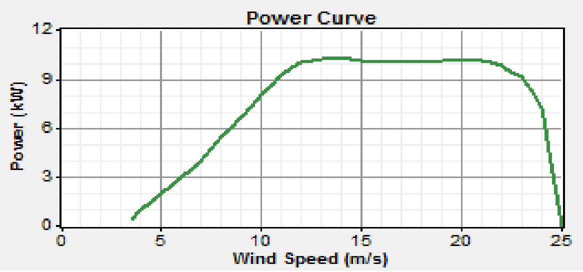


Figure 6. FD 8.0 power curve

where N_{bat} is the number of batteries; $Q_{lifetime}$ is the lifetime of a battery; Q_{input} is the annual amount of energy cycles in the battery; R_f is the float life of the battery. There is an additional operation cost required which is the marginal cost of energy, defined as the sum of the battery wear cost and the battery energy cost. The battery wear cost is calculated using the following [16]:

$$C_{BW} = \frac{C_{rep}}{N_{bat}Q_{lifetime}\sqrt{\eta_{rt}}} \tag{3}$$

where C_{rep} is the replacement cost; N_{bat} is the number of batteries; $Q_{lifetime}$ is the lifetime of a battery; η_{rt} is the round-trip efficiency. The battery energy cost is calculated as the total charging cost of the battery divided by the amount of energy put into the battery (over the years).

The battery selected in this paper is a deep cycle lead-acid type which is suitable to be used for off-grid electrification. It has a nominal capacity of 1000 Ah with 2 V nominal voltage. Its round-trip efficiency is 85%, minimum state of charge equal to 30%, maximum charge current of 202 A and has weight of 62 kg per battery. Twelve batteries are connected in series to get a 24 V battery bank for this system. Pure sinusoidal inverter is selected for this hybrid system because it will not cause any damage to the electrical appliances. It has an efficiency of 90%, input voltage of 24 V, output voltage of 230 V, output frequency of 50 Hz and a range of output power from 1 – 200 kW.

On the other hand, the only technical properties of the converter in HOMER simulation is the capacity, whereas the economic properties of the converter considered are the capital and replacement cost, operation and maintenance cost as well as its expected lifetime in years.

4. ECONOMIC MODELLING

In HOMER, economic modelling applies life-cycle cost analysis. Costs such as the capital costs, replacement costs, maintenance costs and revenues from selling electricity to the grid and salvage value obtained at the end of the project lifetime, need to be included. The salvage value is calculated as [16]:

$$S = C_{rep}\frac{R_{re}}{R_{com}} \tag{4}$$

where C_{rep} is the component replacement cost; R_{re} is the component remaining lifetime; R_{com} is the component lifetime.

Net present cost (NPC) is used in calculating the life-cycle cost of the project, in which future cash flows of total costs and revenues are discounted back to the present using discounted rate. The total annualized cost is used to determine the NPC and the levelised cost of energy. It totals up all the costs used in the project minus the revenue obtained at the end of the project. The total NPC can be calculated as [16]:

$$C_{NPC} = \frac{C_{tot\,ann}}{f\left(i, R_{pro}\right)} \tag{5}$$

where C_{totann} is the total annualized cost; i is the annual interest rate, R_{pro} is the project lifetime; $f(i, R_{pro})$ is the capital recovery factor given the equation as follow [16],

$$f\left(i,N\right)=\frac{i(i+1)^N}{(i+1)^N-1} \tag{6}$$

where N is the number of years. In order to determine the levelised cost of energy, the following formula is used [16]:

$$LCOE=\frac{C_{tot\,ann}}{E_{load}+E_{grid}} \tag{7}$$

where E_{load} is the total load demand per year; E_{grid} is the total energy sold to the grid per year. The minimum net present cost is chosen for different configurations of the system while the levelised cost of energy is used to compare the cost of different systems. Technical and economic considerations are modelled using the HOMER software and simulation of the designed hybrid system is carried out.

5. RESULTS AND DISCUSSIONS

After gathering all required data, a complete off-grid hybrid system configuration which consists of PV arrays, wind turbines and batteries is modelled. An inverter is included in this model as a device to convert electric power from DC to AC to supply the load. Figure 7 shows the configuration of the off-grid hybrid PV/Wind/Storage system in HOMER.

A lifetime of 25 years is selected for this system and the optimization results are obtained with HOMER technical analysis simulation. After the simulation is completed, the lowest life-cycle cost is determined in Table 3, which shows the optimal components quantity, size, capital, replacement and operation and maintenance cost of the hybrid system. Most of the components selected are in US dollar and they are converted back to Malaysian Ringgits (RM) by multiplying the values with 4 which equals to the current currency exchange rate (as of July 2015).

The proposed integrated hybrid off-grid system is compared with the diesel generation power system, for the electrification of the longhouse, to verify the effectiveness and the feasibility of the proposed hybrid system. Two 10 kW CSC Power diesel generators are implemented, where one generator will run the base load for 24 hours, while the other diesel generator is used to serve the peak load. A diesel generator has a capital and replacement cost of RM 26,000. It has a lifetime of 20,000 operating hours and the diesel fuel price at current rate is RM 1.90/liter. Table 4 displays the optimization result of net present value and levelised cost of energy (LCOE) for the hybrid system and off-grid diesel system configuration. From Table 4, the total net present value and the LCOE of a hybrid system that consists of PV panels, wind turbines, batteries and converter is lower than the diesel electrification for a longhouse. This proves that the hybrid system is more economically feasible than the diesel electricity generation, with the additional benefit of environmental friendliness, since the renewable hybrid system does not contribute to any greenhouse gasses emission.

Figure 8 shows the production percentage of PV arrays and wind turbine and excess electricity at different hub heights (12 m, 30 m and 50 m). The production ratio of the wind turbine, excess electricity and unmet electric load are further investigated. Results show that the production ratio of wind generation increases with the increase in tower hub height. This is mainly due to the more energy generated with higher wind speed at higher heights. It is also observed that excess electricity is not much affected with the increase in hub height, while the unmet electric load shows a significant reduction, from 10.2 kWh/yr to 0.813 kWh/yr, when the hub tower is located at an increased height. Hence, the wind turbine is recommended to be installed at hub height more than 30 m. Although current state of technology development still does not support small wind turbine of more than 30 m height, with technology advancement, small wind turbine hub height of 30 m may possibly be available in future.

Furthermore, when the proposed hybrid system is applied to a large load demand that comprises few longhouses, installation of a medium wind turbine with a hub height of more than 30 m or even 50 m could be warranted.

Table 3. Components quantity and capital, replacement and operation and maintenance (O&M) cost of the hybrid system

Item	Quantity	Size	Capital (RM)	Replacement (RM)	O&M (RM)
PV array	6	0.24kW	1,128	1,128	0
Wind turbine	3	10kW	29,430	29,430	589
Inverter	8	2.5kW	2,000	2,000	0
Battery	144	1000Ah	1,200	1,200	12
Wind controller	12	24V	800	800	8
Solar controller	12	24V	1,440	1,440	14

Table 4. The net present value and levelised cost of energy for hybrid system and diesel electrification

Diesel Generator (10kW)	PV (kW)	Wind Turbine (10kW)	Battery (2V, 1000Ah)	Converter (kW)	Total Net Present Value (RM)	LCOE (RM/kWh)
-	36	1	144	20	524,305	**1.22**
2	-	-	-	-	667,961	**1.56**

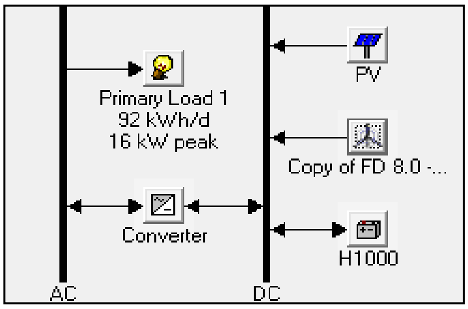
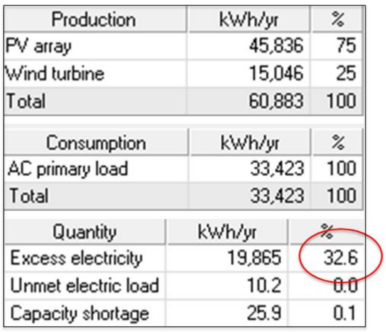


Figure 7. Configuration of off-grid hybrid PV/Wind/Storage system in Homer

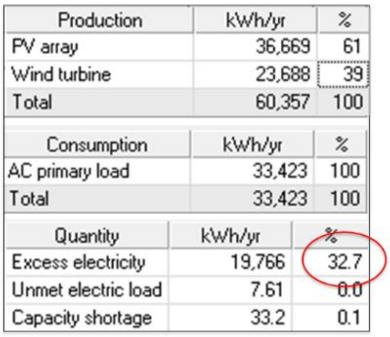


Production	kWh/yr	%
PV array	45,836	75
Wind turbine	15,046	25
Total	60,883	100

Consumption	kWh/yr	%
AC primary load	33,423	100
Total	33,423	100

Quantity	kWh/yr	%
Excess electricity	19,865	32.6
Unmet electric load	10.2	0.0
Capacity shortage	25.9	0.1

(a) Hub height of 12 m

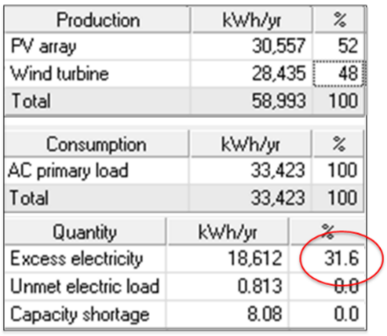


Production	kWh/yr	%
PV array	36,669	61
Wind turbine	23,688	39
Total	60,357	100

Consumption	kWh/yr	%
AC primary load	33,423	100
Total	33,423	100

Quantity	kWh/yr	%
Excess electricity	19,766	32.7
Unmet electric load	7.61	0.0
Capacity shortage	33.2	0.1

(b) Hub height of 30 m



Production	kWh/yr	%
PV array	30,557	52
Wind turbine	28,435	48
Total	58,993	100

Consumption	kWh/yr	%
AC primary load	33,423	100
Total	33,423	100

Quantity	kWh/yr	%
Excess electricity	18,612	31.6
Unmet electric load	0.813	0.0
Capacity shortage	8.08	0.0

(c) Hub height of 50m

Figure 8. The production ratio of PV array and wind turbine and excess electricity at different hub heights

6. CONCLUSION

An integrated hybrid power system that consists of PV arrays, wind turbines and batteries is successfully modelled for a longhouse in Kudat, Sabah, Malaysia. The system configuration satisfies both the technical and financial constraints where the total net present cost is RM524,305 and the levelised cost of energy (LCOE) is RM1.22/kWh for 25 years of project lifetime. Compared with diesel-fuelled system, the net present cost and LCOE of the hybrid system is lower. This subsequently proves that the hybrid power system is economically feasible to serve a longhouse in Sabah. The hybrid system has an added value of being environmentally friendly, since it did not produce any greenhouse gasses. This, in turn, will help to combat environmental damages such as the global warming. The analysis indicates that the best hub height for the wind turbine is 50 m. This was substantiated with the reduction in excess electricity and unmet electric load. Nonetheless, small wind turbines are not feasible to be installed at more than 30 m based on current state of technology development. In future, with the advancement in technology, higher hub height of small wind turbine may be available for installation. This will expectedly provide a better performance. Besides, excess electricity generated from the proposed hybrid power system can be sold back to the grid in future, after the extension of the power system grid to rural areas, along with the projected growth and development in Malaysia.

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REFERENCES

[1] C. W. Forsberg, "Sustainability by combining nuclear, fossil, and renewable energy sources," *Progress in Nuclear Energy*, vol. 51(1), no. 1, pp. 192-200, 2009.

[2] S. Shafiee and E. Topal, "When will fossil fuel reserves be diminished?," *Energy Policy*, vol. 37(1), pp. 181-189, 2009.

[3] B. Atilgan and A. Azapagic, "Life cycle environmental impacts of electricity from fossil fuels in Turkey," *Journal of Cleaner Production*, vol. 106, pp. 555-564, 2015.

[4] N. L. Panwar, S. C. Kaushik, and S. Kothari, "Role of renewable energy sources in environmental protection: A review," *Renewable and Sustainable Energy Reviews*, vol. 15(3), pp. 1513-1524, 2011.

[5] *Kota Belud & Rungus Longhouse Experience*. 2017. [Online]. Available: http://www.discoverytours.com.my/index.php?option=com_content&view=article&id=36&Itemid=39

[6] G. Appell. *Rungus Dusun. Encyclopedia of World Cultures Supplement*. 2017. [Online] Available: http://www.encyclopedia.com/doc/1G2-3458100084.html

[7] J. O. Petinrin and M. Shaaban, "Renewable energy for continuous energy sustainability in Malaysia," *Renewable and Sustainable Energy Reviews,* vol. 50, pp. 967-981, 2015.

[8] K. M. Nor, M. Shaaban, and H. Abdul Rahman, "Feasibility assessment of wind energy resources in Malaysia based on NWP models," *Renewable Energy,* vol. 62, pp. 147-154, 2014.

[9] B. S. Borowy and Z. M. Salameh, "Methodology for optimally sizing the combination of a battery bank and PV array in a wind/PV hybrid system," *IEEE Transactions on Energy Conversion,* vol. 11(2), pp. 367-375, 1996.

[10] Y. Hongxing, Z. Wei, L. Lin, and F. Zhaohong, "Optimal sizing method for stand-alone hybrid solar-wind system with LPSP technology by using genetic algorithm," *Solar Energy,* vol. 11(2), pp. 367-375, 2008.

[11] A. R. De and L. Musgrove, "The optimization of hybrid energy conversion systems using the dynamic programming model—Rapsody," *International Journal of Energy Research,* vol. 12(3), no. 3, pp. 447-457, 1988.

[12] W. D. Kellogg, M. H. Nehrir, G. Venkataramanan, and V. Gerez, "Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/PV systems," *IEEE Transactions on Energy Conversion*, vol. 13(1), no. 1, pp. 70-75, 1998.

[13] R. Yokoyama, K. Ito, and Y. Yuasa, "Multiobjective Optimal Unit Sizing of Hybrid Power Generation Systems Utilizing Photovoltaic and Wind Energy," *Journal of Solar Energy Engineering,* vol. 116(4), no. 4, pp. 167-173, 1994.

[14] W. Zhou, C. Lou, Z. Li, L. Lu, and H. Yang, "Current status of research on optimum sizing of stand-alone hybrid solar–wind power generation systems," *Applied Energy,* vol. 87(2), no. 2, pp. 380-389, 2010.

[15] *Forecast, Current condition, History and averages from Kudat Airport, Sabah, Malaysia (6.9200ºN, 116.8300ºE).* 2017. [Online]. Available: http://weatherspark.com/#!graphs;ws=34020

[16] T. Lambert, P. Gilman, and P. Lilienthal, *Micropower system modeling with Homer.* in Integration of Alternative Sources of Energy, F. A. Farret and M. G. Simoes, Eds., New Jersey: John Wiley & Sons. Inc, 2006, pp. 379-418.

[17] (2017). *HOMER - Hybrid Renewable and Distributed Generation System Design Software*. Available: http://www.homerenergy.com/

[18] S. G. Fikari, "Modeling and Simulation of an Autonomous Hybrid Power System," Master Programme in Energy Technology M.S. Thesis, Uppsala Universitet, 2015.

[19] *PV*SOL online - a free tool for solar power (PV) systems*. 2017. [Online]. Available: http://pvsol-online.valentin-software.com/#/

[20] *The Swiss wind power data website: power calculator*. 2017. [Online]. Available: http://www.wind-data.ch/tools/powercalc.php?lng=en