Techno-Economic Evaluation of Hybrid Power System in Rural Area of Sarawak, Malaysia

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Abstract

Electricity access is closely linked to social equity and economic development of a society especially among the rural communities. In this study, we explore the feasibility and potential impacts of a renewable-based hybrid power system that provides clean and affordable electricity to a rural village in Sarawak state of Malaysia. Developed through a case study methodology, this work determines and analyses the potential of natural renewable resources for power generation purpose. According to the results from the resources estimation and surveys done, renewable-based hybrid power system with solar, wind, biomass and hydro has been designed using a techno-economic optimization tool-HOMER software. The improved system also outweighs the existing diesel-fuelled system by saving 37.6 tonnes of greenhouse gases emission and having 52% lower in COE (cost of energy) and NPC (net present cost) despite there is a 6% annual capacity shortage. Based on the existing socio-economic status and the feedback from local community towards power generation issues, potential benefit of renewable-based hybrid power system on achieving sustainability and improving living standard of local community have been accomplished.

Keywords
Photovoltaic, Wind, Sustainability, Capacity shortage

1. Introduction

Energy demand has been rising exponentially over the years to fulfill the energy requirements in this economically-link and modern society. However, in Malaysia, energy poverty and lack of electricity generation in the rural area especially is exacerbating the poverty in this developing nation. In recent years, Malaysia has achieved 96.86% of 24-hour electricity access and the electricity coverage in Peninsular Malaysia is the highest at 99.72% as compared to Sarawak (88.01%) and Sabah (92.94%) (Islam et al. 2010). Recently, renewable energy sources (RES) arise to become a potential alternative of replacing the conventional electricity generation sources (coal, natural gas, diesel etc.) as well as reducing global warming and fuel cost to the minimum (Energy Commission 2016; Sovacool and Drupady 2011).

Renewable energy is able to contribute significantly to meeting the power demand. It is mostly accessible in isolated areas; thus, it has high potential to supply electricity to such areas (Khor and Lalchand 2014; Ong et al. 2011). Many advanced countries willing to spend extravagantly on renewable energy and the development of its technology (Fadaeenejad et al. 2014). The renewable energy resources that have been established are solar photovoltaic (PV), wind, and hydro and biomass.

Therefore, the main goal of this study is to analyze the economic feasibility of a designed renewable-based hybrid power system to meet the load demand of the selected area of study, in comparison with the existing off-grid diesel-fueled power generation system.

2. Methodology

2.1 System Description

In this paper, hybrid power system models have been designed using HOMER to evaluate the cost and ability of different models to meet the load demand. HOMER requires some input data to obtain the optimized results for different combinations which are described in the following section (Rahman et al. 2013).

2.2 Load Profile

In this paper, the average energy consumption by the selected area is recorded at 678kWh/day. Figure 1 shows the daily average load profile in which 17:00 to 22:00h time period is found as peak demand. In this case, 84 kW is considered as peak load consumption. The monthly average load in the selected area is shown in Figure 2.

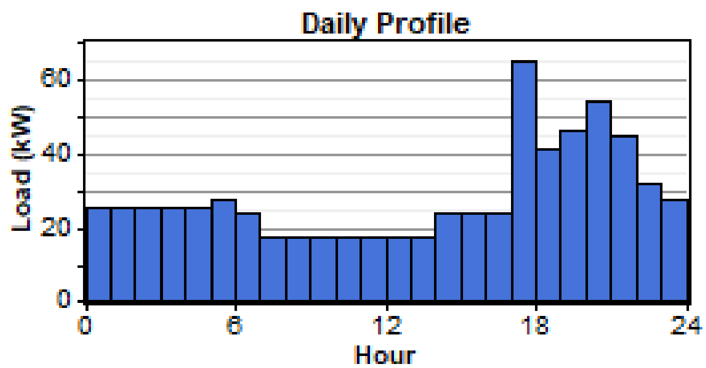

Figure 1. Load profile (daily)

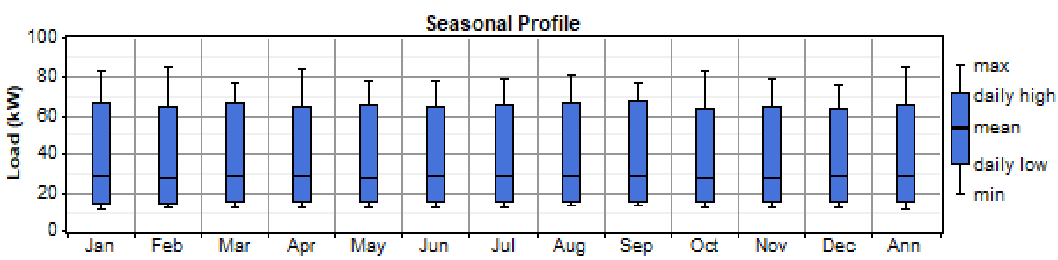

Figure 2. Load for a year (monthly average)

2.3 Solar Radiation, Wind Speed, Biomass and Hydro Resources Availability

The data of average annual solar radiation and wind speed is obtained from NASA surface meteorology and are recorded at 5.05 kWh/m^2/day and 2.12 m/s as shown in Figure 3 and 4 below. As used in HOMER, the latitude and longitude of Kampung Seberang Kedai, Limbang are 4.75" N and 115.01" E respectively. As for biomass and hydro resources, the scaled annual average data were obtained from on-site survey and interviews and are 0.1 ton/day and 2.17 L/s respectively as shown in Figure 5 and 6.

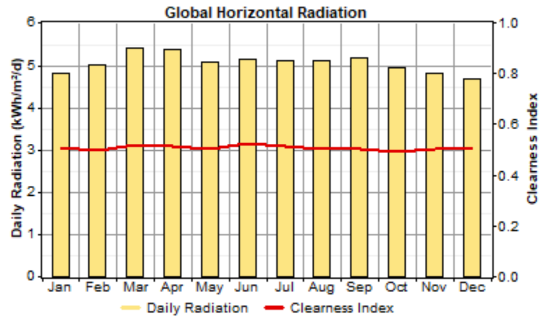

Figure 3. Monthly solar radiation

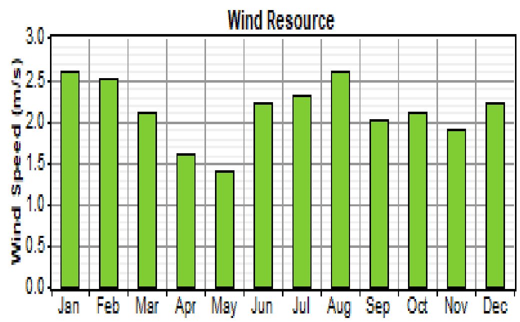

Figure 4. Monthly wind speed

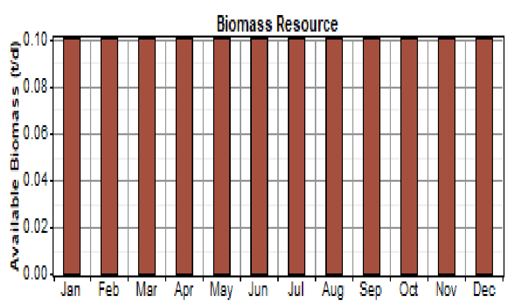

Figure 5. Monthly biomass resources

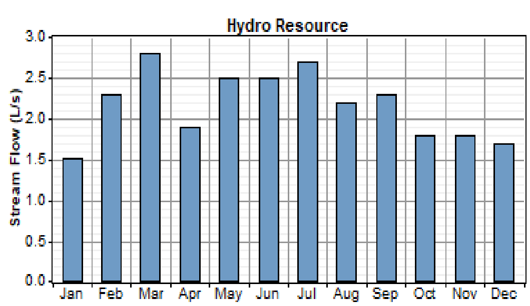

Figure 6. Monthly hydro resources

2.4 HOMER software

HOMER is a software developed by the National Renewable Energy Laboratory (NREL) in the United States (US) (Cader et al. 2016). Generally, it is used for design and analysis of hybrid power system. In this study, the electric load, renewable energy resources data, component details and costs are provided as input data to HOMER (Vijeyan et al. 2017).

2.5 Cost analysis by HOMER

Net Present Cost (NPC): Net Present Cost indicates all the installation and operation cost of the designed hybrid system throughout its project lifetime and is calculated as in equation (1) (Fadaeenejad et al. 2014):

$$NPC = \frac{TAC}{CRF(i, Rprj)} \qquad (1)$$

where, TAC, CRF, I and Rprj represent total annualized cost (RM), capital recovery factor, interest rate (%) and project lifetime (year), respectively.

Total Annualized Cost*:* Total annualized cost (TAC) is the sum of annualized costs of every equipment of the power system including capital, operation and maintenance cost, replacement and also fuel cost (Rezzouk and Mellit 2015).

Capital Recovery Factor: Capital Recovery Factor (CRF) is a ratio used to calculate the present value of a series of equal annual cash flows [10].

$$CRF = \frac{i \times (1+i)^n}{(1+i)^{n-1}} \qquad (2)$$

where, n and i represents the number of years and annual real interest rate, respectively.

Annual Real Interest Rate: Annual real interest rate is a function of the nominal interest rate and its equation is shown in equation (3).

$$i = \left(\frac{i' - F}{1+F}\right) \qquad (3)$$

where, i, i' and F is the real interest rate, nominal interest rate and annual inflation rate, respectively.

Cost of Energy (COE): It is the average cost per kWh of useful electrical energy produced by the system and is calculated (Rahman et al. 2017).

$$COE = \left(\frac{TAC}{LPrim,AC + Lprim,DC}\right) \qquad (4)$$

Where, $L_{Prim,\,AC}$ and $L_{prim,\,DC}$ are AC primary load and DC primary load, respectively.

2.6 Simulation Model

The components are chosen from HOMER to perform simulation. Figure 7 shows the existing off-grid diesel generator system with battery. Figure 8 shows the designed hybrid power system design using HOMER which consists of PV array, wind turbine, biomass generator, diesel generator, hydropower generator, converter and battery(Tan 2014).

To evaluate the system performance under different conditions, HOMER simulates the above two arrangement at the same area and same load based on different cost parameters such as the installation cost, operation and maintenance cost, replacement cost and cost of energy.

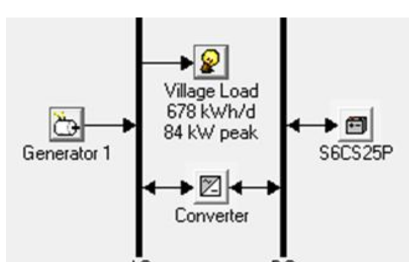

Figure 7. Existing power system

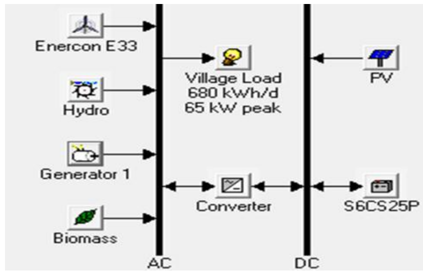

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Figure 8. Designed hybrid power system

Photovoltaic Array
Name: Jinko Eagle (72 PID free polycrystalline 72-cell module). Its efficiency can reach up to 15% and lifetime about 25 years. The capital of this PV array is estimated at RM9000 per kW and operation and maintenance of RM50 per year.

Wind Turbine
In this study, up to three wind turbine of model Enercon E33 with rated power 330kW each have been input in HOMER. Hub height designed for this model is 25m and with lifetime of 15 years. The capital and O&M cost of each wind turbine is RM350,000 and RM1000/year respectively. Figure 9 below shows the power curve of the Enercon E33 wind turbine (Rehman and Sahin 2012).

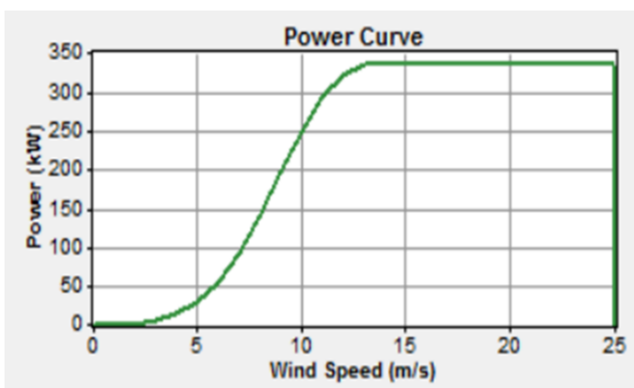

Figure 9. Power curve of Enercon E33

Diesel and Biomass Generator
For this study, the diesel and biomass generator are utilizing the same brand of generator which is Cummins generator. This type of generator has a high efficiency of up to 60%. The price of a generator in the market ranges from RM15,000 to RM20,000 for a 30kW generator. As the input in HOMER, diesel generator of rated power 30kW, 60kW, 90kW have been selected and biomass generator of rated power 10kW, 20kW, 30kW have been selected. HOMER will be able to provide a more optimum results with flexibility given to the input data for each component (Rahman et al. 2014).

Converter
Name: Platinum R3 system converter, manufactured by Generic. Its efficiency is about 85% with optimal reliability and lifetime of 15 years. The price of RM820/ kW has been chosen and inverted of 40kW is selected for this study which is large enough to handle the total amount of watts used at a time. The operation and maintenance cost is about RM30/year.

Battery Storage
Name: Surrette 6CS25P with battery capacity of 6.94 kWh and lifetime of 12 years. This type of batteries can perform full depth of discharge and they are priced at RM5000 per unit in the market. They are arranged in a string and each string has about 10 batteries. The sizes of batteries that were considered in this study ranges from 50 to 250 units since there is no any limitation on number of batteries that can be stacked together (Rehman and Sahin 2012).

3. Results and Discussion

Figure 10 and 11 below illustrates the optimization for the existing off-grid diesel generator system and the hybrid power system. For the existing diesel power generation system, as shown in in Figure 10, the minimum COE obtained from the simulation result is RM1.591/kWh and total NPC is recorded at RM5,547,622. In this scenario, there is no any renewable energy utilized in power generation and hence, the renewable fraction is definitely a zero. The dispatch strategy is cycle charging which means the means the batteries are charged simultaneously by the generator as the load is being served, so that the charged batteries can be used to support the extra demand.

	DGen (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	DGen (hrs)	Batt. Lf. (yr)
	100	150	50	CC	$ 830,000	334,727	$ 5,547,622	1.591	0.00	0.00	131,948	8,760	12.0

Figure 10. Screenshot of simulation result of off-grid diesel power generation system

For the optimized renewable energy-based hybrid power system as shown in Figure 11, which is the PV-Diesel-Biomass system, the simulated result for COE is RM0.774 per kWh and total NPC of RM2,588,665 which is both more than 50% lesser than the existing off-grid diesel power generation system. In term of dispatch strategy, this system uses load following which means whenever a generator operates, it only able to produce sufficient power to meet the primary load demand in the village and the charging of batteries will be done by renewable power sources.

	PV (kW)	E33	Hydro (kW)	DGen (kW)	Biom (kW)	S6CS25P	Conv. (kW)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Biomass (t)	DGen (hrs)	Biom (hrs)	Batt. Lf. (yr)
	80			30	20	50	40	LF	$ 1,045,600	109,484	$ 2,588,665	0.774	0.56	0.06	42,902	36	5,423	2,105	12.0

Figure 11. Screenshot of simulation result of proposed hybrid PV-Diesel-Biomass system

From Figure 12 below, it can be seen that the total production of the proposed hybrid model is 272,811 kWh/year and consumption by the load is 237,350 kWh/year. The monthly average electricity production from different units using the proposed components is also shown in Figure 12.
The capacity shortage of the proposed hybrid power system is recorded at 6% which means there are chances that the selected village will face power shortage throughout the year. However, this 6% of capacity shortage is still within the acceptable range despite it is high compared to the existing diesel power generation system.

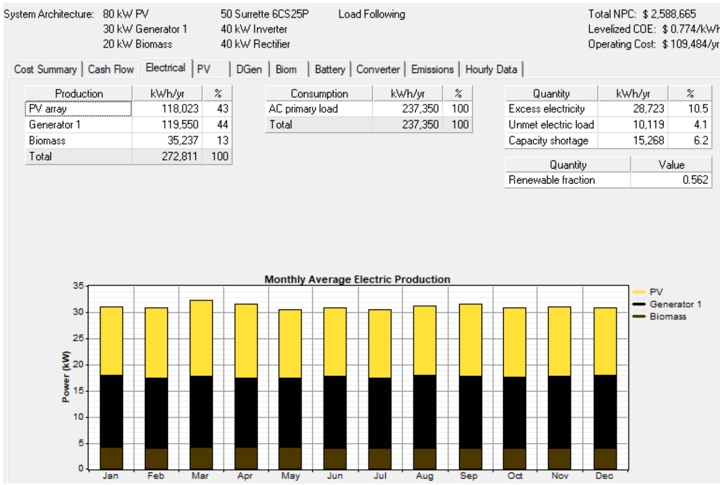

Figure 12. Monthly average electricity production using proposed hybrid system

Environmental wise, the proposed hybrid power system produces much lower emission (about 68% less in Carbon dioxide emission) if compared to the existing system as shown in Table 1 and 2 below.

Table 1. Emission from proposed system

Pollutant	Emission (kg/yr)
Carbon dioxide	112,982
Carbon monoxide	279
Unburned fuel	30.9
Particulate matter	21
Sulfur dioxide	227
Nitrogen oxides	2,490

Table 2. Emission from existing system

Pollutant	Emission (kg/yr)
Carbon dioxide	347,070
Carbon monoxide	857
Unburned fuel	94.9
Particulate matter	64.6
Sulfur dioxide	697
Nitrogen oxides	7,644

4. Conclusions

This paper presents a comparative analysis between an off-grid diesel power generation system and renewable-based hybrid power system in selected village of Sarawak, Malaysia. The optimization result portraits that the renewable-based hybrid (PV-Wind-Diesel) is more economic and environmentally friendly compared to the conventional diesel power generation system for the same load demand. From the simulation result, it is also investigated that the NPC of the optimized system is 50% lower than the existing system. Even though the existing system wins at electrical aspect with 0% capacity shortage, the optimized hybrid power system still outweighs in other aspect such as NPC, COE, renewability, environmental friendliness which are more important in a long term basis. Therefore, it can be said that the optimized renewable-based hybrid power system (PV-Diesel-Biomass) is the most suitable and cost effective system compared to the existing system and other optimized hybrid power system. The research objectives and aim for this project have been achieved.

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