Optimization of Hybrid Renewable Energy in Sarawak Remote Rural Area Using HOMER Software

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***Abstract*—In past few years, there has been a huge concern about decentralized electricity supply in Sarawak, Malaysia. Renewable energy resources can be seen as an alternative energy to capture the remote rural electrification's problems. Installing and operating a renewable energy generation is not difficult but it requires cautious step as to make sure maximum use of energy can improve the electrification. Therefore, the aim of this paper is to critically analyze five types of optimized hybrid renewable energy systems in term of financial and power production using HOMER software. This paper approaches four renewable energy resources, namely solar, hydro, wind and biomass in three remote rural areas located in Limbang, Kapit and Sri Aman regions. Different combination of solar PV system, micro-hydro generator, wind turbine and biomass generator together with battery storage and converter were studied. The optimization between these different sizes of system was built based on energy demand satisfaction, system cost and carbon gas emission. Comparison between operational of behaviors hybrid renewable energy systems with stand-alone diesel generator only were also carried out to elucidate the effects on investment cost and environment. The results revealed that hybrid hydro with battery system is seen to be the cheapest system and has the best technical performance in all locations. Solar PV and biomass generator system were combined with hydro generator as a back-up power. It is also found that hybrid renewable energy is more cost-effective and reduce of carbon emission compared to stand-alone diesel generator.**

***Keywords*—HOMER, hybrid renewable energy resources, remote rural area, net present cost, initial cost, operating cost.**

I. INTRODUCTION

Electricity energy has been one of backbones of supporting socio-economic development to a modernize country as growing financial in industries and development in the standards of living is the reason of rising in energy consumption. Fossil fuels energy such as coal and natural gas of conventional energy contribute to greenhouse impact and start to appreciate natural resources in order to help electrification in some inaccessible rural areas. Based on the current rising trend of fuel prices in the world market, Malaysia government perceived the potential of renewable energy as an alternative option to make sure the sustainability of energy resources [1].

Sarawak has a low electrification access in Malaysia which most of them are living in unreachable electric grid of rural areas. The statistic in 2013 has stated that the Malaysia's electricity access rate had reached to 96.86%. The percentage contribution of electricity in Peninsular Malaysia, Sabah and Sarawak are 99.72%, 92.92% and 88.01%, respectively [2]. In 2016, SEB has identified 4,316 villages that consist of 40,000 homes in rural area have not received 24-hour electricity yet [3]. The lack of electricity intensifies the poverty where the developing countries have high demand for electricity. However, the government state and villagers are expected to have positive social economic impacts in the future.

The renewable energy resources is an alternative energy to capture the remote rural electrification's problems since the off-grid hybrid renewable energy focusing in rural area is to reduce the poverty rate. The combination of two or more hybrid renewable energy eventually give advantages in supporting the shortcoming of electrical energy and give strength to unpredictable renewable energy resources [4]. However, a major problem with this kind of application is to find the optimum hybrid energy that can satisfy customers' demand with minimum cost. This problem can be overcome by doing a deep research on the potential of renewable energy system.

The main objective of this work is to simulate hybrid renewable energy sources which consist of PV system, micro-hydro, wind turbine, and biomass generator at Sarawak rural remote area. This work also compares the cost for hybrid renewable energy sources with stand-alone diesel generator of electricity source only.

II. METHOD

A. HOMER software

HOMER that stands for Hybrid Optimization of Multiple Electric Renewables is a software developed by the National Renewable Energy Laboratory (NREL), US to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone and distributed generation applications. HOMER calculates the mathematical data and generates results of feasible configurations sorted by Net Present Cost (NPC) to compares various design configurations on the basis of operational and economic rates. The possible system configurations can evaluate from HOMER's optimization and sensitivity analysis.

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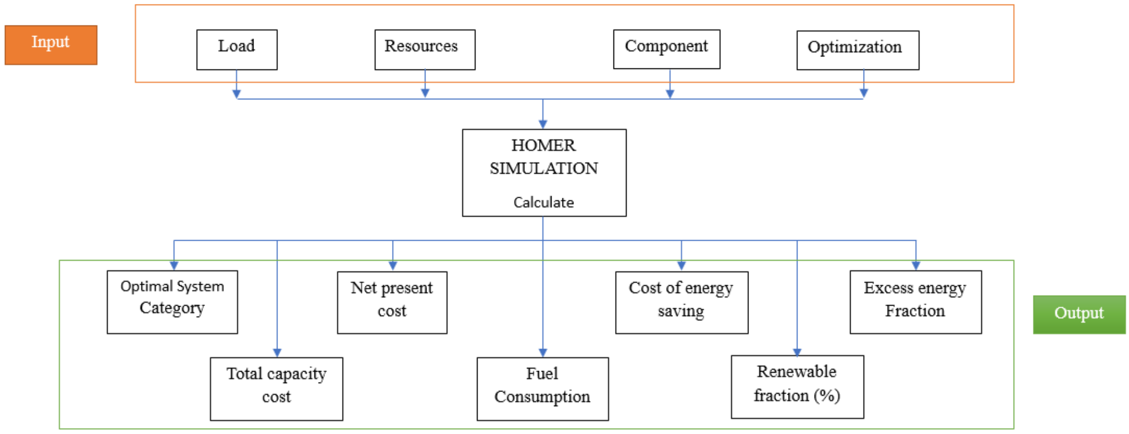

Fig. 1. HOMER simulation concept [5-6].

Fig. 1 shows the HOMER simulation concept in hybrid renewable energy sources simulation. Three cores of capability of HOMER software which consists of simulation, optimization and sensitive analysis. The simulation simulates all potential combinations of components depending on the different scenarios. HOMER filter and optimize the best configuration and then it displays a list of configurations sorted according to lifecycle cost.

As a case study, three remote rural areas in Sarawak have been selected, namely Limbang (A), Kapit (B), and Sri Aman (C) as shown in Fig. 2. All of three locations have solar, hydro, wind, and biomass energy resources, however the effectiveness of each energy is depending on the geographical area.

B. *Load Profile*

The daily load profile is based on typical daily load at Malaysian village household [7-8]. Fig. 3 shows the detail load profile in one day for typical household in village and typical electricity consumption is depicted in Table 1 [9]. The scenario of load consumption in one rural area is assumed to have 100 houses with average load specification. Therefore, load profile in HOMER is increased by a factor of 100. In addition, the average of load and peak load are 844 kWh/day and 103 kW, respectively. A day-to-day and time-step-to-step in HOMER is set as 2% as to consider the effect of randomness. The random variables are percentage to obtain a more realistic load data.

C. *Renewable energy resource data*

For hybrid renewable energy simulation of PV, micro-hydro, wind, and biomass, some important data are required, namely average solar irradiation, water flow rate, wind speed, and capacity of empty fruit bunch (EFB) for biomass resource at each location.

The solar irradiation and wind speed data can be directly accessed from NASA surface meteorology and solar energy website by inserting the location's coordinates of each location in HOMER software. The data obtained consists of daily solar irradiation, clearness index and air temperature. The water flow rate data for each location were obtained from SEB R&D data [10]. Biomass energy resource can be harnessed from various types of biomass residue. In this work, empty fruit bunch (EFB) which is the leftover of the fresh fruit bunch (FFB) of palm oil is chosen as the biomass fuel in Malaysia. This is due to the fact that Malaysia is one of the biggest palm oil producers with abundance supply of palm oil residue to be harnessed. The EFB residue quantity can be calculated which is found to be 23% from the FFB [11]. Throughout the calculation, it is assumed that only 80% of the available EFB in the location is used for the site. In summary, the data of solar irradiation including PV data, water flow rate, and EFB capacity of each location can be seen in Table II.

Fig. 4 shows the schematic diagram of the system simulated in HOMER, whereby the components are connected to either AC or DC bus. With AC output being produced, biomass generator is connected to the AC bus and can directly supply AC load. Meanwhile, both PV module and wind turbine which are generating DC power are connected to the DC bus. The battery storage stores the DC power whenever there is excessive electricity produced, while the converter functions by converting DC power from the PV and wind turbine to the AC power to serve load. Table III shows the output capacity rate in kWh for each component of renewable energy sources which are used in this simulation. For each component, cost of capital, replacement and operating and maintenance (O&M) are taken into consideration.

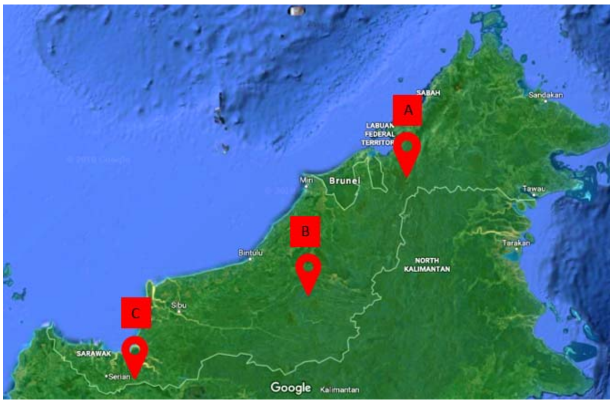

Fig. 2. Case study location for hybrid renewable energy simulation: (A) Limbang, (B) Kapit, and (C) Sri Aman.

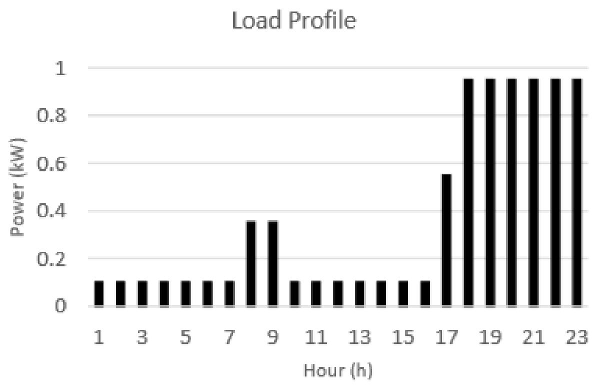

Fig. 3. Load profile for typical a household in village [7-8].

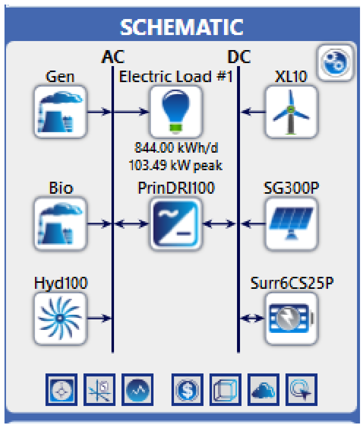

Fig. 4. Schematic diagram of hybrid model in Homer.

TABLE I. TYPICAL ELECTRICITY CONSUMPTION OF HOUSEHOLD VILLAGE IN MALAYSIA [9]

Appliances	Wattages (W)	Hours of use (h)	Daily load demand (kWh/day)	Annual load demand (kWh/year)
9 lamp	9 x 40	6	2.16	788.4
1 TV	80	6	0.48	175.2
1 refrigerator	100	24	2.40	876.0
4 fan	4 x 100	5	2.00	730.0
1 washing machine	250	2	0.50	182.5
Total			7.54	2752.1

TABLE II. RENEWABLE ENERGY RESOURCE DATA FOR EACH LOCATION

Location	(A) Limbang 4°12.1'N, 115°34.4'E	(B) Kapit 2°39.0'N 113°44.4'E	(C) Sri Aman 1°12.5'N, 110°55.6'E
Average Solar irradiation (kWh/m^2/day)	5.05	4.84	4.62
PV area (m^2)	2024.58	2112.42	2213.01
PV peak power (kWp)	374.55	390.80	409.41
Number of PV modules (unit)	1249	1303	1364
Water flow rate (m^3/s)	5.2164	0.3466	0.4010
Wind speed (m/s)	2.690	2.260	3.120
Empty fruit bunch (EFB) (t/ha/day)	838.98	287.28	238.03

TABLE III. THE CAPACITY RATE FOR EACH COMPONENT OF HYBRID RENEWABLE ENERGY SOURCES

Component	Capacity (kWh)
Peimar SG 360M solar panel	1
Generic Hydro 100 kW	100
Bergey Excel 10 wind turbine	10
HAITAI Biomass generator	100
Princeton DRI-100 inverter	100
Surrette 6CS25P battery	6.91

III. RESULTS AND DISCUSSION

The model components, namely diesel generator, PV solar system, hydro turbine system, wind system, biomass generator, converter and battery are simulated for three selected regions, which are Limbang, Kapit and Sri Aman. Five feasible system types are discussed in term of economic and technical point of views, which are hydro with battery and converter (Hbc), hydro and biomass with battery and converter (HBbc), hydro and solar with battery and converter (HPbc), biomass with battery and converter (Bbc), and hydro + wind with battery and converter (HWbc).

Fig. 5. Shows the production of electrical energy for each system. Note that for all five systems in three different locations, the hydro energy is found as the highest power production per year. In Limbang, the water flow rate at Pa'beluyu river has potential to generate over 742 kW/day and produce 5,605 MWh/year. For this reason, a bulk hydro turbine can be built in Limbang river and supply to another rural area. Contrary to Limbang, Wong Kepayang river in Sri Aman has potential to generate 59 kW/day. Since the peak load of a village is expected up to 100 kW/day, hydro energy need a battery for storage as the system is not capable to supply sufficient electricity at one time. Meanwhile, the 50 kW biomass generator is expected to generate 308,13kWh/year with 1,304 L/year regardless in different EFB residue in three locations. This is because the biomass generator is operating at the maximum power that adequate to light up the whole remote rural area without

have any excess electricity. In this case, biomass generator has to be upgraded if the village grows up after 25 years.

The cost analysis is start with net present cost (NPC), initial and operating cost of each hybrid renewable systems as shown in Fig. 6. As can be seen from the figure, Hbc system has the lowest investment with $468,651 over 25 years with $329,000 of initial cost. The operating cost of Hbc also comes as the cheapest as hydro energy source is free and the system only need to be upgraded after 25 years. The installation stand-alone Bbc system is low with cost of $468,283. However, Bbc has the highest operating cost among five hybrid renewable systems because it need to buy biomass fuel to burn up the generator. The HWbc comes as the most expensive investment with $841,731 for 25 years. While, in this case, the operating cost is low because solar and wind energy sources are free. Thus, the most optimized hybrid renewable systems are hydro with battery and converter (Hbc).

This work also compared the five optimized systems with stand-alone diesel generator. The economic and technical potential of five hybrid renewable energy systems were simulated in HOMER software is analyzed in terms of the cost expensed as well as the electricity production. A 120 kW of genset is needed to supply local household electrical demand. Hence, operation of the generator is scheduled to operate 24 hours/day. The comparison of Hbc, HBbc, Bbc, HPbc and HWbc systems to stand-alone diesel generator are categorized according to NPC, initial/capital and operating cost as illustrated in Fig. 7. It is found that diesel generator has the highest investment among the six systems. The first optimized hybrid is Hbc system which invested about $468,651 for 25 years, meanwhile the NPC of diesel generator is about hundred times, which is $46,189,380. This shows that hybrid renewable energy systems can be saved over 60% compared to invest the stand-alone diesel generator in one remote rural area. With regards to this matter, the cost of electricity if using diesel generator is $11.60 for every kWh used.

Biomass generator and diesel generator are analyzed in term of gas emission. The comparison of carbon emission and other gasses is shown in Table IV. It is found that the biomass generator produce carbon dioxide (CO_2) gas about 1,846 kg/year, which is very low if compared to 350,587 kg/year of CO_2 produced by diesel generator. It is clearly showed that diesel generator has emitted many greenhouse gases to atmosphere. These gases are released during the combustion of diesel to generate electricity. This is because diesel is made of hydrocarbon (HC) which convert into water (H_2O) and carbon dioxide (CO_2). Also, diesel generator emitted carbon monoxide (CO), sulfur dioxide and nitrogen oxides gases which can contribute to air pollution and global warming. In contrast, biomass residue is made from carbohydrate (CHO). The reason that biomass is a low carbon fuel is because biomass breathes carbon dioxide and stores it in its tissue. It is proved that using renewable energy sources can help to minimize the greenhouse gases and the air become cleaner.

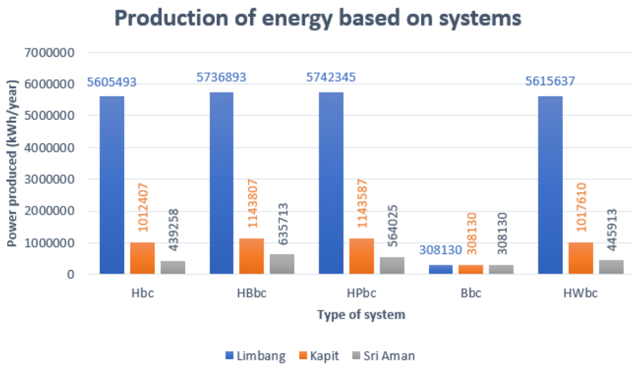

Fig. 5. Production of electrical energy based on the different type of systems.

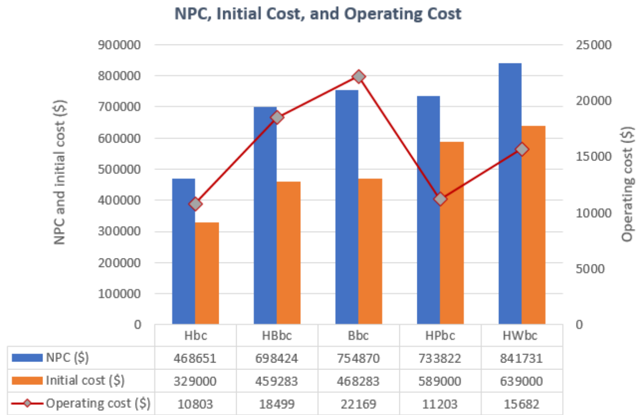

Fig. 6. Total cost for the different type of systems.

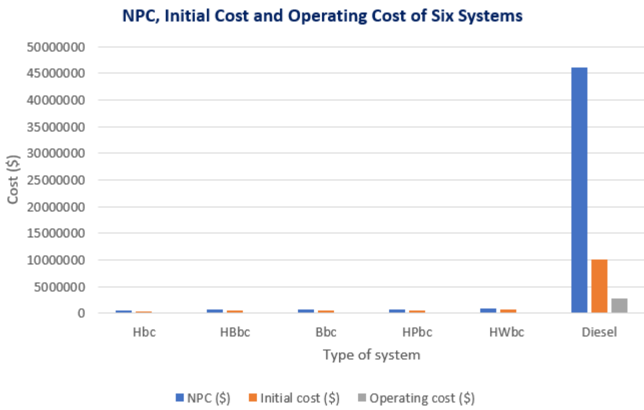

Fig. 7. Comparison of total cost with stand-alone diesel generator only.

TABLE IV. COMPARISON OF GAS EMISSION

Gas Type	Biomass (kg/year)	Diesel (kg/year)
Carbon dioxide	1,846	350,587
Carbon monoxide	2.07	2,210
Unburned hydrocarbons	0	96.4
Particulate matter	0	13.4
Sulfur dioxide	0	859
Nitrogen oxide	1.29	2,076

IV. Conclusion

This paper investigated the current potential of solar, hydro, wind and biomass renewable energy in remote rural area in Sarawak, Malaysia using HOMER software. Three remote rural areas located in Limbang, Kapit and Sri Aman region have been selected in this work. It is found that the renewable energy systems are totally relied on the solar irradiation level, flow of water stream, wind speed as well as biomass residue quantity at one location. As the conclusion, this work demonstrated that hydro energy has the biggest potential to supply electricity to the whole remote rural area. It seems from the fact that Sarawak has mountainous topography and high rainfall rate that provide such abundance water resources to sustain the hydroelectricity in remote rural area.

The second major finding is Sarawak has intermediate solar and biomass energy has potency to generate power as back up electricity. One of the most significant finding to emerge from this work is wind energy has not feasible to be utilized in Sarawak as average of wind speed below than 4 m/s. In addition, installing and operating a wind turbine requires a huge investment. Lastly, renewable energy systems are cheaper and supply green electricity compared to diesel generator. It is proven that renewable energy-based systems are not cost-competitive against stand-alone diesel generator only.

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