The optimization of hybrid power generator system (PV-Wind turbine) using Homer software

S Suriadi1,*, W I Daru1, R Halid S1, M Syukri1, M Gapy1
1Electrical and Computer Department Engineering Faculty, University of Syiah Kuala, Darussalam Banda Aceh, Indonesia

*E-mail: suriadimali@unsyiah.ac.id

Abstract. There is a higher electricity demand due to increasing population and economic development. Conventional power companies struggle to meet these needs both in generation and distribution. However, the common use of electric and other power generators, driven mostly by fossil fuels, shows certain limitations including decreasing efficiency and energy resources. Therefore, the application of renewable energy sources is greatly significant. The purpose of this research was to analyse the potentials of hybrid power generator system (PV-Wind turbine) and the optimization of electric energy requirement using hybrid optimization model for electric renewable (HOMER) software. The results confirmed this study as useful and a valid reference for government in building power generation systems through renewable energy utilization.

1. Introduction
Indonesia population growth is similar to electric needs [1] known to increase every year as a result of having the highest world population [2]. In order to fulfil the incessant electricity demand, the country can no longer depend on conventional power generator highly driven by fossil fuels. Hence, it is necessary to introduce renewable energy, especially in remote communities [3]. These alternative sources are potentials for stand-alone applications with sufficient system reliability and are also readily available. One major practical approach in employing renewable energy maximally is by using hybrid system, which utilizes the primary energy for similar load [4]. Hybrid generators serve the purpose of providing assurance to primary energy, hence electricity is easily accessible. These systems are effective compared to the use of a single energy source. For instance, the application of wind energy possibly results to electric power instability. However, when two or more energy sources are employed, a more efficient and different situation is achieved. Therefore, one potential method is to utilize hybrid generator system in maximizing the energy from wind speed and solar radiation. This research uses simulation to utilize solar and wind as renewable energy. In order to achieve accurate calculation, HOMER software is employed.

2. Configuration System
A configuration system is required to arrange the generator capacity suitable to supply the load, based on the following:

2.1. Hybrid power generator system (HPGS)
Hybrid system is a combination of renewable and conventional energy resources [5]. This arrangement helps provide increased system efficiency and also balance the high energy demand, particularly targeted at remote communities. In addition, hybrid power generators commonly utilize renewable energy from solar and wind sources and are both operated and connected through the bus, known as a terminal for load distribution. The characteristics of both generator sources are influenced by natural conditions, where the availability of solar and wind energy appears intermittent. Furthermore, solar power
generators function optimally during the day compared to night or cloudy atmosphere [6][7]. However, wind sources operate 24 hours every day, although the influence of wind speed fluctuates regularly. Figure 1 shown the configuration of hybrid generator by using solar and wind turbine.

![Figure 1. PV– Wind Turbine hybrid power generator system [7].](image)

2.1.1. **PV Array**
PV Array is a solar module arranged from certain solar panels, and is combined in series or parallel. The electric power obtains similar direction based on solar radiation intensity which is accepted and then generates direct current (DC).

2.1.2. **Wind turbine**
Wind Turbine is an electric generator known to utilize kinetic energy from the wind and then converts to electricity. This mechanism is installed with long pole in order not to obstruct buildings or trees, hence maximum wind energy is generated.

2.1.3. **Hybrid controller**
Hybrid controllers are designed to integrate power from the wind turbine, PV array and back up batteries [8]. Subsequently, PV-wind charge controllers using buck boost converter are applied as the components of the hybrid controller. The buck boost converter functions to regulate the voltage stability fluctuates.

2.1.4. **Energy Storage**
Energy storage is very significant to hybrid power generator system (HPGS), and performs two primary functions. First, it is used to adapt to instability of electric load and energy from renewable resources. The second objective is to facilitate the control system and entire operations.

2.1.5. **Inverter**
The role of an inverter is to convert direct current (DC) to alternating current (AC). In addition, the quantity of inverter depends on the generator capacity and also the number of applied load.

2.2. **Homer software**
Energy micro-grid software is an international standard application used to optimize the micro-grid design in all fields, commencing from rural electrification, island utility and extends to campus connected with network. This idea was initially developed in Colorado National Renewable Energy Laboratory and was then perfected and distributed by HOMER company in the form of software. HOMER is an optimizing model for hybrid electric power targeted at all renewable energy sources in order to facilitate the generation and distribution of power through a stand-alone application. Therefore, optimal results are achieved in technical feasibility and economic terms [9][10]. HOMER software performs energy balance calculations installed in every configurations system. Then, proper configuration and optimization are also determined, including addressing the electric needs properly with predefined conditions and further predicts adequate installation and operating system. This model also evaluates expenses, including financial, replacement, and maintenance costs, as well as for fuels
and interest. Furthermore, the software models in three critical stages, termed simulation, optimization, and sensitivity processes [11][12].

2.3. Analysis of Sensitivity
In sensitivity analysis, the software tends to repeat the optimization process from every single sensitivity variable earlier determined. For instance, if the wind speed is determined as a sensitivity variable, the software simulates toward configuration system to conclude on several wind speeds. The advantages of this application include ease of use, ability to perform simulation then optimization based on a model and automatically determines the optimum configuration with the capacity to supply load at low expenses. Other advantages are the ability to adequately calculate economic parameters, e.g. net present cost (NPC) and cost of efficiency (COE) as the main output.

2.4. PV power system
Solar radiation is converted into DC electric power by PV module. The output power is determined using the equation.

\[ P_{PV} = Y_{PV} f_{PV} \left( \frac{\bar{G}_T}{G_{T,STC}} \right) \left[ 1 + \alpha_p (T_c - T_{c,STC}) \right] \]

Where:
- \( Y_{PV} \) is measured the capacity from PV array, it means the output power is below the standard measurement (kW)
- \( f_{PV} \) is PV (%) derating factor
- \( G_T \) = amount of solar radiation which received by PV array adalah (kW/m²)
- \( G_{T,STC} \) = solar radiation when standard tested (1kW/m²)
- \( \alpha_p \) = load temperature coefficient (%/ºC)
- \( T_c \) = recent PV temperature (ºC)
- \( T_{c,STC} \) = PV standard temperature determined (25ºC)

2.5. Wind turbine power system
The output power from wind turbine is evaluated by the equation.

\[ P_{WTG} = (\frac{\rho}{\rho_0}) P_{WTG,STP} \]

Where:
- \( P_{WTG} \) = Output power from wind turbine (kW)
- \( P_{WTG,STP} \) = overall wind turbine power by using standard temperature and pressure (kW)
- \( \rho \) = current air density (kg/m³)
- \( \rho_0 \) = air density on standard temperature and pressure (1.225/m³)

2.6. Renewable fraction
Renewable fraction is described as the fraction energy sent to the load, and is determined using the equation:

\[ f_{ren} = 1 - \frac{E_{nonren} - H_{nonren}}{E_{served} + H_{served}} \]

Where:
- \( E_{nonren} \) = electric energy production which is not come from renewable energy (kW/yr)
- \( E_{grid,sales} \) = electric energy which sold to net (kWh/yr)(Including \( E_{served} \))
- \( H_{nonren} \) = thermal production which is not included into renewable energy (kWh/yr)
• \( E_{served} \) = total amount of load which is served (kWh/yr)
• \( H_{served} \) = total amount of thermal load which is served (kWh/yr)

3. Methodology
The method used to get the optimization result of hybrid power generator system (HPGS) is simulation using HOMER software. This study applied input data in the form of daily load information, wind speed, and solar radiation intensity. These parameters also covered for optimize hybrid renewable energy process.

3.1 The input of daily load data
The use of HOMER software provides comprehensive data profile on the monthly change of electric load. However, the load profile for tropical locations does not observe any significant change. Significantly due to the absence of climate change. The profile load which is located around Lhoknga Aceh Besar for 24 hours as shown in Figure 2.

Figure 2. Load profile.

Figure 2 shows the daily load used to simulate HPGS for a one year period, and is assumed by using daily random variability of 10%. Subsequently, the average load is then applied at the consumer end in the case of daily generated load data. It is shown in Table 1.

| Table 1. Daily load system |
|---------------------------|
| Electric load system      |
| Average (kWh/d)           | 165.29 |
| Average (kW)              | 6.89  |
| Peak (kW)                 | 24.57 |
| Load Factor               | 0.28  |

Based on Table 1, the average daily absorbed energy was estimated at 165.29 kWh, while the power average of 6.89 kW was used including the peak load valued at 24.57 kW for a one year estimation. Therefore, the load factor is specified at 0.28, and is gotten from the calculation of average and peak load values.

3.2. The input data of wind speed
The HOMER software is used to generate information on wind speed and result of average monthly wind speed based on time, and also serves as parameter in modelling the hybrid power generator system. Based on both results, it can be concluded that the ranges and the percentage of wind speed in Lhoknga Aceh Besar provides an overview of the characteristic of wind speed as shown in Figure 3.
3.3. The input data of solar radiation

The HOMER simulation requires latitude and longitude information in order to ascertain the potentials of solar radiation on certain places. This research area corresponds to the latitude and longitude values of 5°26’ and 95°16’, respectively, and is located within Lhoknga Aceh Besar. The obtained radiation data is as shown in Table 2.

| Months    | Clearness Index | Radiation (kWh/m2/hari) |
|-----------|-----------------|-------------------------|
| January   | 0.57            | 5.39                    |
| February  | 0.577           | 5.75                    |
| March     | 0.557           | 5.79                    |
| April     | 0.542           | 5.64                    |
| Mei       | 0.496           | 5.01                    |
| June      | 0.506           | 4.99                    |
| July      | 0.493           | 4.90                    |
| August    | 0.47            | 4.81                    |
| September | 0.459           | 4.74                    |
| October   | 0.465           | 4.67                    |
| November  | 0.489           | 4.66                    |
| December  | 0.528           | 4.88                    |

3.4 The configuration of HPGS

The analysis of HPGS involves the use of HOMER software, where the configuration consists of certain basic components. Figure 4 shows the configuration of the HPGS design.
3.5. The strategy of HPGS optimization method

There are 2 (two) strategies involved in HPGS optimization in order to service the load, as explained below.

3.5.1. Load following (LF) method

The data above describes certain conditions using the load following (LF) method:

For the first condition, the output energy is sufficient to supply the load and also, the battery does not accept any type of power source. Therefore, the generator is considered non-functional. The second condition shows higher output power is more compared to the load demand, where the energy is then distributed to charge the battery. Therefore, the generator is also non-functional. Furthermore, the third condition provides very low energy, and is not possible to supply the load. Subsequently, two possible events tend to occur. First, provided SOC=SOC_{minimum}, then the generator tends to supply the load (which have been reduced with renewable energy). Diesel generators only achieve this purpose optimally without charging the batteries. Second, provided SOC>SOC_{minimum}, then there is a necessity to analyse in term of expenses incurred in using batteries compared to diesel generator. At higher expenses in operating the generator compared to batteries, the power from batteries (discharge) is applied, if not, the use of diesel generator is allowed.

3.5.2. Cycle charging (CC) method

The first condition of CC strategy shows the renewable energy is sufficient to supply the load and the batteries don’t accept any energy due to the maximum state of charge (SOC). Under this condition, the generator is not operated. The second condition reveals the output of renewable energy is more compared to the load request, hence energy is distributed to charge the batteries. Under this condition, the generator is not also functional. The third condition occurs as the output energy appears very low, and is unable to supply the load demand. There are two possibilities to this occurrence. First, provided SOC=SOC_{minimum}, then the generator operates efficiently to supply the load (which has been decreased with the load of renewable energy). Diesel generator also functions at maximum to deliver the load and charge the batteries. Second, provided SOC>SOC_{minimum}, then there is need for analysis in terms of expenses incurred in using batteries compared to the cost of diesel generator. At higher expenses in maintaining the diesel generator compared to batteries, the power from batteries (discharge) is applied, if it not, the use of diesel generator is allowed.

4. Results and discussion

4.1. The result of simulation by using Load Following method

The simulation result was obtained from HOMER simulation are an optimization based on the components that have been entered into the system. The output of the optimization process is shown in Figure 5.
Figure 5. The results of load following dispatch optimization.

Figure 5 shows the optimization result based on the load following dispatch strategy. The highlighted row signified the best optimization result, where the hybrid system uses photovoltaic (PV) in the amount of 26.1 kW, 1 kW wind turbine with a total of 7 units, and 28 kW diesel generator. Under these circumstances, constant electric power was required to charge 128 unit of batteries at a storage capacity of 83.4 Ah specification, 12 volt DC with 100% SOC, and 40% minimum.

4.2. The simulation result by using Cycle Charging method

The simulation result using cycle charging method as shown in Figure 6

Figure 6. The results of cycle charging dispatch optimization.

Figure 6 represents the optimization result based on cycle charge (CC) dispatch strategy. The marked portion specified the best optimization result, where the hybrid system uses photovoltaic (PV) in the amount of 18.3 kW, 8 unit of 1 kW wind turbine and 28 kW diesel generator. Under these circumstances, continuity electric power was needed, so that it requires 101 unit of batteries with storage capacity similar to aforementioned specifications.
4.3. **HPGS technical comparing analysis based on both dispatch strategies**

In analyzing the optimal results from both strategies, proper attention on energy production and renewable fraction were observed. Subsequently, the economic section was defined based on the net present cost (NPC) value and its influence to the environment. Based on the three components stated, the best simulation approach based on dispatch strategy is the use of load following (LF). This tactic was able to utilize maximum renewable energy with renewable fraction of 75.3% compared to cycle charge (CC) of 58.4%. However, based on NPC, the LF showed lower expense due to the cost influence of generator fuels. Also, the role of diesel generator on CC delivered 34.1% electricity from the total power and the annual fuel consumption was evaluated at 7,766 L. Meanwhile, for LF, the estimated yearly fuel consumption was quantified at 5,606 L, and the operation time (1,586 hours/year) appeared higher compared to CC (1,243 hours/year), as LF only produces sufficient power to distribute to load, while CC generator operates on maximum capacity to supply the load and charge the batteries.

4.4. **Sensitivity results**

Sensitivity results are represented in the form of an optimized graph type. Figure 7 shows the LF strategy consisting of four configurations.

![Figure 7. The results of sensitivity on LF strategy.](image1)

![Figure 8. The results of sensitivity on CC strategy.](image2)
Figure 7 expands the analysis of sensitivity by using diesel cost and wind speed on LF. The type of generator -PV-wind- batteries are considered for use as the cost of diesel extended to 1.6 $/L with wind speed requirement at an average of 5 m/s. For generator-PV-battery with diesel price of 0.50 $/L up to 1.67 $/L, the average of wind speed appeared below 5 m/s, while PV-Wind battery was used for maximum wind speed and diesel cost at 7.99 m/s and 1.4 $/L, respectively. Based on Figure 8, generator-PV-wind- battery configuration obtained maximum energy under the conditions of diesel price at 1.5 $/L and wind speed of 5 m/s. The generator-PV- battery was used with diesel price from 0.50 $/L up to 1.5 $/L and wind speed under 5 m/s. Also, the PV-wind- battery was used as the wind speed approached 7.99 m/s with diesel price at 1.2 $/L.

5. Conclusion

Based on results and discussion, the simulation of HPGS (PV – wind turbine) using Homer software revealed the load following (LF) strategy as the best compared to cycle charge (CC). The load following dispatch optimization to supply a load of 165.29 kWh/day at Lhoknga Aceh Besar was obtained at the combination of 26.1 kW PV, 7 kW wind turbine, 28 kW generator, 138 units of battery, and 13.8 kW converter to produce NPC $371,049 and COE $0.481 per kWh. Obviously, the LF dispatch optimization is more economical with the smaller total NPC and the COE then CC dispatch optimization. Based on results simulation the NPC and COE of the CC dispatch optimization are respectively $374,163 and $0.485 per kWh. Furthermore, the use of HPGS based on both dispatch strategies tend to potentially produce the power to meet annual electricity demand, where LF acquired a total power of 72,535 kWh/year, while CC was estimated at 73,747 kWh/year. Based on the renewable fraction from both strategies, the highest value of 75.3% occurred with LF and involved less battery activities. This condition showed greater energy was produced by the LF system compared to the energy needed to supply load. Meanwhile, CC was estimated at 58.4% renewable fraction.

References
[1] Perusahaan Listrik Negara (PLN) 2018 Rencana Usaha Penyediaan Tenaga Listrik (RUPTL) 2018-2027. Jakarta: Perusahaan Listrik Negara. (in Bahasa Indonesia).
[2] Daryanto Y 2007 Kajian Potensi angin Untuk Pembangkit Listrik Tenaga Bayu. Yogyakarta: Balai PPTAGG - UPT-LAGG. (in Bahasa Indonesia).
[3] Herlina 2009 Analisis Dampak Lingkungan dan Biaya Pembangkit Listrik Tenaga Hibrida di Pulau Sebesi Lampung Selatan. Tesis. Jakarta: Universitas Indonesia. (in Bahasa Indonesia).
[4] Quaschning V 2005 Understanding Renewable Energy Systems. London, VA: Earthscan.
[5] Aderemi B A, Chowdhury S P, Olwal T O, Abu-Mahfouz A M 2018 Energies. 11 1572.
[6] Ren, Y., Suganathan P N, Srikanth N 2015 Renew. Sustain. Energy Rev. 50 82-91.
[7] Sharif M S E, Khan M M Z, Moniruzzaman M, Bose A 2017 Am. J. Mod. Energy 3 121-130.
[8] Aziz A S, Tajuddin M F N, Adzeman M R, Ramli M A, Mekhilef S 2019 Sustainability 11 683.
[9] Slameto A 2015 Data Manajemen dan Teknologi Informasi. 16 1-10. (in Bahasa Indonesia).
[10] Gilman P, Lambert T. 2005. Homer the micro power optimization model software started guide. National Renewable Energy Laboratory of United States Government.
[11] Suriadi, Taib S, Shawal J M 2013 Proc. Aceh Dev. Int. Conf. 3 103-109.
[12] Suriadi, Aqsa A S H, Ramdhani H S, Syukri M, Gapy M 2019 Prosiding Seminar Nasional dan Ekspo Teknik Elektro. 7 pp. 42-46. (in Bahasa Indonesia).