Design of Hybrid Power System for Remote Area

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Abstract. This paper describes the results of designing hybrid power system (HPS) for remote area. The design of this system combines three sources of renewable energy, namely wind energy, photovoltaic, and biomass. Design using HOMER software that analyzes system performance from optimization and economic aspect. The design recommendations indicate that all electrical energy demand in the study area is met with 80.27% of total production. The existence of batteries in the system is able to minimize the value of excess electricity.

1. Introduction
In recent years, the concept and movement of renewable energy as a solution to isolated areas has become a warm agenda for discussion. The main motivation is the growing awareness of human to protect the environment by reducing emissions gas and rising fuel prices that drive price increases [1]. In addition, current technological advances have shown that the cost for renewable energy devices has been drastically reduced in recent years [2]. So that renewable energy becomes the right choice to launch electrification program in isolated area in Indonesia especially with Smart Grid concept.

Smart grid is believed to be a future grid that offers increased efficiency, reliability, and environmental friendliness in power generation, transmission, distribution, consumption and management with the advancement of integration in information and communications technology [3]. Smart grids have many new features and advanced capabilities including price dynamics that depend on demand-side management and the high development of the distribution of renewable energy sources [4]. Basically this renewable energy source is dynamic, so the full utilization in renewable energy sources can be achieved by applying hybrid systems.

The renewable hybrid system (SEHT) is composed of two or more conventional energy sources and renewable energy sources or no conventional energy sources that are interconnected in a grid or standalone [5]. Renewable energy systems such as PV, biomass, and wind, or hybrid systems from all three can become a standalone system on the isolated area. This system in addition to reduce the cost of generation and cost of electricity consumption can also create an efficient independent region.

From a wide range of existing software, Hybrid Optimization Model for 2 Electric Renewable (HOMER) is becoming a widely used software for hybrid system optimization. This software can be used for operating strategies of complex system optimization in an easy and economically accurate way [6].

In 2014, this software is used to make electrification design of an isolated area in Karnataka, India. This design incorporates three renewable sources of PV-Biogas-Biomass in a hybrid system [7]. Another research using HOMER is the economic modelling of SEHT for remote areas of Ethiopia by incorporating renewable energy sources of PV-Wind [8], SEHT's research for electrification at an
isolated area in Algeria, North Africa in terms of production power, lifecycle system costs and emissions reductions Greenhouse gases by combining wind-diesel renewable energy sources [9]. Thus, this software is the right software for smart grid system design involving hybrid system from various renewable energy as well as renewable energy with conventional energy.

The study also describes a design by designing a smart grid system model involving optimized hybrid generation at a resort or resort in an isolated area. This research is expected for the development of tourism facilities in an isolated island to improve the welfare of the island community.

2. Methods
The HOMER software can display 3 main principles of simulation, optimization and sensitivity analysis [10]. Hybrid system simulations show the system optimized for different system sensitivity variables [11]. This optimization model in the software allows designers to evaluate offered designs of alternative system configurations based on technical and economic feasibility [12]. The variables that designers can evaluate on optimization and sensitivity analysis algorithms are in the economic and technical aspects of system configuration, uncertain cost calculations, the existence of sources, and other variables [13][14]. HOMER also checks for emissions, system control variables, economics and constraints during hybrid simulations.

2.1. Research Design
This research begins by identifying the load on the case study area. By identifying the load profile, a hybrid system configuration can be determined that will be designed to meet the load requirements based on existing potential. Next, specify the components of the configuration to be designed, the resources, and the load. In addition, there are also operating system requirements such as parameters of economics, optimizations, constraints and control systems that must be met. The next step is to include sensitivity analysis parameters of system configuration in the form of capital cost, replacement cost, and operation and maintenance cost. The last step is to do a calculation that will result in optimization and sensitivity analysis based on predetermined parameters.

2.2. Schematic system
The modelling of this hybrid system consists of several generating components by utilizing existing renewable energy potentials, namely wind turbines, photovoltaic modules, biomass generators, converters, and powered by batteries as energy storage devices (see figure 1).

![Figure 1. Schematic System](image)

2.3. Load profile
This loads comes from an energy audit on designing a Hotel for lodging and tourism needs (see figure 2). Fulfilling the need for electrical energy at Hotel will be managed independently from the
The collaboration of three renewable energies. The hotel is named Hexagon Hotel, with a Hexagonal shape and an area of 0.21 Ha. The hotel consists of 3 types of rooms with a total of 54 bedrooms, 2 swimming pools (one with water boom), 2 restaurants, 3 meeting rooms, 1 fitness centre, 1 children playground, 1 shop and other facilities.

![Figure 2. Daily Load Hexagon Hotel](image-url)

2.4. Renewable energy sources

2.4.1. Solar energy. The annual average of daily radiation produces 5,920 kWh / m² per day (NASA Surface Meteorology and Solar). While the largest sky brightness is in April-October which is generally the dry season in Indonesia (see figure 3).

![Figure 3. The annual average of Solar Radiation](image-url)

2.4.2. Wind energy. Average monthly wind speeds at 50m above the earth's surface. From these data, the annual average of wind speed is 4.260 m / s (NASA Surface Meteorology and Solar). While the highest wind speed is in July – August (see figure 4).
2.4.3. Biomass energy. With potential biomass existing in the case study sites to produce 5,770 MWe in 1 year, it is estimated that there are about 290 tons of Biomass potential in one month (Directorate of Bio, EBTKE, ESDM, Indonesia). The greatest potential is obtained from municipal waste. Biomass Potential has not been utilized either on grid or off grid (see figure 5).

3. Results and discussion

3.1. Components

3.1.1. Photovoltaic. Capital cost of solar PV system with a capacity of 10 kW reaches $ 3,897 / kW which is included with the cost of installation, transportation and system balance. The O / M cost is assumed to be $ 21 / year (NREL Government, Distributed Generation Renewable Energy Estimate of Costs, updated on February 2016). The recommended use of PV systems in this design is 33 years with an 80% derating factor estimate as a consideration of effects of dust, and temperature (see figure 6).
3.1.2. **Wind turbine.** Capital cost of a 10 kW wind turbine system reaches $6,118 / kW which is included with installation, transportation and system balance. The O / M cost is assumed to be $35 / year. The cost information is obtained from NREL Government, Distributed Generation Renewable Energy Estimate of Costs which is updated on February 2016. The life of the recommended wind turbine system in this design is 19 years (see figure 7).

3.1.3. **Generator biomass.** For this biomass power system, a biogas generator of 50 kW will be used with a capital cost of $5,792 / kW and an estimated O / M cost of $0.011 / h. This cost information is obtained from NREL Government. The use life of this generator reaches 245,280 hours or about 28 years with the standard deviation of 8 years (see figure 8).
3.1.4. Converter. The recommended converter in design is a two-way or two-directional converter, which can be operated either as an inverter or a rectifier. Figure 4.7 shows the input details of the converter. The converter efficiency is assumed 95% for the inverter and 85% for the rectifier. The initial cost for the converter is $900 / kW at an O&M cost of $10 / year. It is based on information from WHOLESALE SOLAR that was updated in May 2016 (see figure 9).

3.1.5. Battery. Recommended storage battery is flooded/wet lead acid battery from IND13-6V type Trojan. The cost of capital and replacement for this battery is $1,135.75 with lifespan of 10 years (EcoDirect 2016). This battery is designed with 100% initial state of charge and 20% minimum state of charge. For battery life is generally determined based on the number of discharge / charge cycle (see figure 10).
3.2. Variable optimization and sensitivity

It takes a lot of information to get the simulation results, in addition to the previously described parameters. To produce the sensitivity analysis, the economic parameters are so influential that the accuracy of the cost of each component is very important. The research project is designed for 25 years, with the nominal discount rate and inflation rate of 6.75% and 3.33% (Bank Indonesia, 2016), respectively. For constraints systems, the maximum annual shortage capacity is assumed to be 20% with minimum renewable energy penetration of about 10%. This assumption is because the designed hybrid system does not connect the available grid, in other words the role of renewable energy becomes the main resource as a power supplier at Hexagon Hotel (see Table 1).

Table 1. Value of the Overall Optimization Variables

| Variable Optimization | Bio Generator Capacity (kW) | IND13-6V Strings (#) | G10 Quantity (#) | PV Capacity (kW) | Converter Capacity (kW) |
|------------------------|-----------------------------|----------------------|------------------|------------------|------------------------|
|                        | 0                           | 0                    | 0                | 0.0              | 0.0                    |
|                        | 5                           | 377                  | 500              | 645.2            | 95.95                  |
|                        | 10                          | 754                  | 1000             | 1290.4           | 191.90                 |
|                        | 50                          | 1500                 | 2000             | 1935.6           | 287.85                 |
|                        |                              |                      | 2500             | 2580.8           | 383.80                 |
|                        |                              |                      | 2500             | 3226.0           | 479.75                 |
|                        |                              |                      | 3000             | 3871.2           | 575.70                 |
|                        |                              |                      | 3500             | 4516.4           | 671.65                 |
|                        |                              |                      | 4000             | 5161.6           | 767.60                 |
|                        |                              |                      | 4500             | 5806.8           | 863.55                 |
|                        |                              |                      | 5000             | 6452.0           | 959.50                 |
3.3. Optimization result

Based on the calculations made by HOMER software, six hybrid power plant configurations were obtained with only one sensitivity analysis result. From the simulation results, some of the offered configurations are sorted by the lowest NPC. The best option of this analysis is aimed at the configuration of PV, wind and biomass systems equipped with a system of overlays and batteries (see figure 11).

![Figure 11. Optimization Result](image)

3.4. Sensitivity analysis

Can be seen from the best configuration in Figure 12, the NPC of the system is $759,478 or Rp 10,121,763,816.65 with Cost of Electricity (CoE) of $0.0341 / kWh and Operating and Maintenance Cost (O/M) of $2,132 per year. Based on the sensitivity analysis, the increase of electricity requirement will affect the operational cost, total NPC and also CoE. So it is with its resources. The greater the potential resources used, the fewer components used. This will reduce the total number of NPCs in the system.

3.5. Electrical analysis

The amount of electricity generated reaches 1,648,385 kWh per year. PV became the largest supplier in this case, as it produced 1,301,158 kWh per year or 78.93% of total electricity production. PV is expected to be a substitute for the grid that supplies the load demand on the object of study continuously. The electricity contributed by the biomass generator reaches 250,468 kWh per year, equivalent to 15.19% of the total electricity production from the system. On the other hand, biomass generator is considered to supply the load demand during peak load time, i.e., at 02.00 WIB until 06.00 WIB and at 19.00 WIB until 21.00 WIB. While the wind turbine into a complementary supply that produces 96,759 kWh per year which is equivalent to 0.058% of the total production of electrical systems. In addition, there is energy stored in the battery that is equal to 708,072 kWh per year. While the total main load that needs to be met is 1,323,217 kWh per year. Therefore, the overall load can be fulfilled by a system with an excess power of 118,337.6 kWh per year which is equivalent to 7.17% of the total production wasted into excess electricity.

3.6. Economic analysis

The best configuration shows that the CoE reaches $0.0341 / kWh or about Rp 454.43 / kWh. This figure is far below the current base rate of Indonesian electricity which is priced at $0.11 or Rp 1,467.28 / kWh (PLN, April 2017). Price details per April 2017 are attached to Appendix D. Based on these figures, if this Hotel is connected to the PLN grid, the cost of electricity bill at Hexagon Hotel at full expense can reach Rp 201,553,528,6 / month. Meanwhile, with this hybrid system, the cost of electricity
that needs to be issued is Rp 62,422,966.25 / month. That is, the system is able to suppress and save electricity budget of Rp 139,130,528.3 / month. This shows that the use of renewable energy as an alternative energy with the configuration generated in the case study area can reduce the electricity cost of the grid. Therefore, the best configuration is feasible to be realized in order to meet the needs of electrical load on the object of study.

4. Conclusion
The design recommendations indicate that all electrical energy demand in the case study area can be fulfilled with 80.27% of total production and can in the presence of a battery of the system can store energy so as to suppress the excess electricity value. In addition to optimization results, the proposed system is also based on sensitivity analysis that is influenced by operational costs, capital cost, and also CoE. The greater the potential of resources used, the fewer components necessary so that the total NPC will decrease significantly. From an economic point of view, this simulation can reduce CoE to 1/3 or up to only 30.9% of the electricity base rate in Indonesia today. This shows that this system can be realized, because it has benefits both on aspects of electricity and financial aspects.

References
[1] H S Farmad and S Biglar 2012 Integration of demand side management, distributed generation, renewable energy sources and energy storages CIRED 2012 Work. Lisbon 29-30 May 2012 1–4
[2] Markovic M, Nedic Z and Nafalski A 2016 Comparison of microgrid solutions for remote areas in Electrical Power and Energy Conference (EPEC), 2016 IEEE 1-5
[3] H Farhangi 2010 The path of the smart grid IEEE Power Energy Mag. 8 1 18–28
[4] X Guan, Z Xu and Q S Jia 2010 Energy-efficient buildings facilitated by microgrid IEEE Trans. Smart Grid 1 3 243–252
[5] Hurtado 2015 Optimization of a hybrid renewable system for high feasibility application in non-connected zones Appl. Energy 155 308–314
[6] Razak 2010 Optimal sizing and operational strategy of hybrid renewable energy system using HOMER PEOCO 2010 - 4th Int. Power Eng. Optim. Conf. Progr. Abstr. 495–50
[7] Rajanna 2014 Optimal Modeling of Solar / Biogas / Biomass based IRE System for a Remote Area Electrification 6th IEEE Power India Int. Conf. (PIICON), 2014
[8] G Bekeleaa and G Bonenya 2012 Design of a photovoltaic-wind hybrid power generation system for Ethiopian remote area Energy Procedia 14 0, pp. 1760–1765, 2012.
[9] Himri 2008 Techno-economical study of hybrid power system for a remote village in Algeria Energy 33 7 1128–1136
[10] O Hafez and K Bhattacharya 2012 Optimal planning and design of a renewable energy based supply system for microgrids Renew. Energy 45 7–15
[11] B U Kansara and B R Parekh 2011 Modelling and simulation of distributed generation system using HOMER software 2011 Int. Conf. Recent Adv. Electr. Electron. Control Eng. IConRAeCE’11 - Proc. 328–332
[12] P R Bhattarai and S Thompson 2016 Optimizing an off-grid electrical system in Brochet, Manitoba, Canada Renew. Sustain. Energy Rev. 53 709–719
[13] Kumar A 2013 In search of an optimization tool for renewable energy resources: Homer vs. in-house model 2013 IEEE Electr. Power Energy Conf. EPEC 2013 1–7
[14] Abdullah AG, Risdiyanto A, Nandiyyanto AB. Hybrid Energy System Design of Micro Hydro-PV-biogas Based Micro-grid. InIOP Conference Series: Materials Science and Engineering 2017 Mar (Vol. 180, No. 1, p. 012080). IOP Publishing.