Optimal sizing and sensitivity analysis of Hybrid Renewable Energy Systems: A case of Ur island in Indonesia

I A Aditya*, S Aisyah and A A Simaremare
PLN Research Institute Jl. Durentiga No 102, Jakarta, Indonesia

*indra.aditya@pln.co.id

Abstract. This study presents the design optimization and sensitivity analysis of the hybrid renewable energy system (HRES) for Ur island in Indonesia. The Ur Island is a remote island where local residents unreachable by electrical network systems but has potential to utilize the solar Photovoltaic (PV) and wind energy. The analysis of the hybrid systems is modeling in the Hybrid Optimization Model for Electric Renewable (HOMER) to find out the most cost-effective configurations for electricity requirement of 234 kW h/day primary load with 25.6 kW peak load. The results show that system with the configuration of PV-Wind-Diesel-battery delivers the best optimal design for Ur island in terms of cost of energy (COE) and Total Net Present Cost (TNPC). In addition, the impact of solar radiation, wind speed, diesel price, O&M cost, investment cost and replacement cost are identified by carrying out the sensitivity analysis.

1. Introduction
The government has set target for Indonesia electrification ratio at 100% in 2020 with higher contribution of renewable energy [1]. As laid out in Indonesia National Energy Planning (RUEN) which support Sustainable Development Goals 7 (SDG7) and Paris Agreement (NDC), the share of renewables is aimed to increase 25% in the country’s energy mix by 2025, compared to the current amount at 14% [1].

PLN as an Indonesian state-owned company tasked with supplying the electricity needs for the public interest (public service obligation/PSO). Since Indonesia is a vast archipelago consisting of approximately 17,500 islands, the geographic conditions and the resident distribution are the biggest challenges in providing electricity for outermost, remote, and underdeveloped (3T) regions. This situation makes local residents unreachable by electrical network systems. Energy potential in 3T regions can be utilized to provide electricity. The energy potentials are solar, wind, biomass, and micro-hydro energy.

Ur Island was one of the outermost island in the Kei Islands, Maluku which was bordered by Utir Island in the south and Manir Island in the east. It took around ± 2 hours by small boat from Kei Kecil Island to Ur Island. This island did not have access to electricity but PLN is planning to provide the electricity from diesel generator with rated capacity 25 kW. Diesel generator is inexpensive to install but expensive to operate and maintain for 3T regions.

The objective of this paper is to determine the best configuration of hybrid renewable energy system to meet the load requirement on specific area that can offer the lowest amount of Total Net Present Cost (TNPC). The rest of paper is organized as follows. Section 2 describes the methodology. Resources and
simulation model are given in section 3 and 4 respectively. Result and discussion are provided in section 5. Finally, conclusions are drawn in Section 6.

2. Methodology
The analysis of the hybrid systems was modeling in the Hybrid Optimization Model for Electric Renewable (HOMER) software to find out the most cost-effective configurations [2]. HOMER simulated the operation systems of a simplified model for every possible combination of components entered and rank the systems according to user-specified criteria, such as Cost of Energy (COE) or total Net Present Cost (NPC). Some publications about designing a hybrid system have been proposed [3-5] and Comparative economic analysis on a distributed generation power system [6-8]. Figure 1 illustrates an architecture of HOMER software [9-11].

![Figure 1. Architecture of HOMER software.]

3. Resources

3.1. Electric load
The load at Ur island is assumed to be constant and there was no load growth. This island is a fisherman village which has about 200 houses. In this study, 10% of day to day and 20% of time to time step random variability are used in order to account the variation in daily load energy consumption. The scaled annual average is 234 kWh/day and the peak load is 25.6 kW. The load profile of this island shown in Figure 2.

![Figure 2. The daily load profile.]

3.2. Solar and wind energy potential
In this study, solar radiation and wind speed data has been taken from NASA (National Aeronautics and Space Administration) surface and solar energy database. The latitude and longitude for this island are
(5°50'54.4"S) and (132°32'47.92"E), respectively. Wind speed data obtained at 50 m above the surface of sea level, as shown in Figure 3. The figure shows that the wind speed ranges from 3.71 to 7.6 m/s. The highest wind speed occurs in July. Monthly average solar radiation and clearness index data are shown in Figure 4. As it can be seen, the solar radiation is high, especially between September and October. For this location, the average daily radiation is 5.57 kWh/m²/day and the average annual clearness index is 0.56.

![Figure 3. Wind speed (monthly average).](image)

![Figure 4. Solar radiation and clearness index (monthly average).](image)

4. Simulation model
In this study, the configuration of the hybrid PV array, wind turbine, diesel generator and battery system using HOMER software was shown in Figure 5. For economic analysis, the following estimated values were used.
4.1. Photovoltaic array
The capital cost of the PV system is USD 550/kWp with 25 years’ lifetime. The replacement cost is assumed at the same as the capital cost. The Operation and maintenance (O & M) cost is considered as USD 11/year/kWp.

4.2. Wind turbine
This study has selected AWS HC as wind turbine in this system. Its rated power is 1.5 kW with 12 meters’ hub height. It has the cut-in speed of 2.2 m/s and rated wind speed of 10.7 m/s. In addition, lifetime of the turbine is 20 years. The capital cost is USD 3,600 with the replacement cost is considered as the same price as capital cost. The O & M cost is USD 100/year/unit.

4.3. Power converter
There are three different sizes of power converter that used in this system which are 18 kW, 36 kW and 54 kW. The capital cost and replacement costs for 1 kW converter is USD 1,000. The O & M cost is considered as USD 10/year/kW. Its efficiency is about 98 % with 10 years of lifetime.

4.4. Battery
The study has chosen Generic lead acid as the type of battery that used for the system. The capital cost and the replacement cost of the battery is USD 150 with the capacity 1 kWh. O & M cost is USD 15/year. The battery stack is containing several numbers of batteries and 24 batteries is considered as a string.

4.5. Diesel generator
The capital cost of diesel generator is USD 4,500 with a capacity of 25 kW. The replacement cost was assumed equal to capita cost. The maintenance of generator is every 18,000 hours with down time 168 hours. The intercept and the slope were 0.825 L/hr and 0.273 L/hr/kW respectively. The O & M cost was fixed at USD 0.6/hour. The fuel price was USD 1.075/liter.

5. Results and discussion
HOMER shows the optimization results of the hybrid renewable energy system in terms of cost and technical aspects. In Table 1, a detailed list has been presented about size of various components and cost of five cases including capital cost, operating cost, NPC, COE. The simulation showed that the combination of a PV array[ (85.8 KW)], 9 unit wind turbine (13.5 kW), a diesel generator (25 kW) and 240 batteries is economically the most feasible with COE USD 0.276/kWh and a minimum NPC (Net Present Cost) of USD 414.951, without any annual energy shortage.

![Figure 5. The configuration of hybrid energy system.](image-url)
However, the TNPC and COE will become expensive when diesel generator was excluded in the system. By referring to the load profile given in Figure 2 the peak load occurs at night when the PV was not available. At this time, the battery will supply the load, since PV was not available. If battery was insufficient or unavailable, the diesel generator will take over the task. Since the diesel generator was not available, the hybrid system required additional PV array and battery storage to provide the electricity at night. This scenario will increase the cost TNPC due to the extremely high initial capital cost for battery and PV array.

### Table 1. HOMER simulation results.

| No. | CS6X 325P | CS6X 325P inv | AWS 1.5 kW | Diesel Gen | LA ASM | Converter | Dispatch | NPC | COE | Operating Cost | Initial Capital | Renewable Frac. | Total Fuel |
|-----|-----------|---------------|------------|------------|--------|-----------|----------|-----|-----|----------------|----------------|----------------|------------|
| 1   | 85.8      | 210           | 7          | 25         |        | 284       | LF       | 414.551 | 0.276 | 14.916 | 152.664 | 95.6               | 1.454     |
| 2   | 150       | 210           | 7          | 25         |        | 284       | LF       | 482.680 | 0.322 | 18.019 | 184.182 | 93.4               | 2.175     |
| 3   | 143       | 210           | 5          | 25         |        | 488       | CC       | 488.567 | 0.326 | 18.591 | 196.824 | 100                | -         |
| 4   | 150       | 210           | -          | -          |        | -         | CC       | 488.567 | 0.326 | 18.591 | 196.824 | 100                | -         |
| 5   | -         | -             | -          | -          |        | -         | CC       | 749.792 | 0.499 | 41.248 | -       | 0                  | 30.806    |

From the Figure 6 it could be seen that the total production of the hybrid renewable energy system and load consumption were 164,283 kWh/yr and 85,410 kWh/yr respectively. In this scenario, the percentage of renewable energy contribution was 95.6 %. The PV array produced 138,128 kWh/yr that was 84.1% of the total energy served. The remaining 13.6% and 2.28 % of the total energy were served by wind turbine and the diesel generator respectively. This system produced 69,136 kWh/yr excessive energy which was 42.1% of total energy production.

![Figure 6. The production and consumption simulation.](image)

#### 5.1. Sensitivity analysis

In this simulation, sensitivity analysis was performed based on considering the uncertain parameters. HOMER showed how the cost of the system changes with a fluctuation in solar radiation, wind speed, diesel price, O & M cost, capital cost and replacement cost. In Figure 7, the spider graph sensitivity analysis measured the impact on COE as a result changing the parameters within the given range [9]. Y-axis represent the COE and x-axis represent the value relative to base case. Its showed that the battery cost (O & M, capital and replacement) and wind speed have the largest overall impact on COE. The battery cost had positive affect on COE when it increases. Conversely, the wind speed was seen to have the largest negative impact on COE while increasing. The diesel price was found to have the smallest effect on COE as illustrated by the smallest slope.
6. Conclusion
The optimization result showed that hybrid renewable energy system applicable to be used as an off-grid system in Ur Island, Maluku. The combination of PV array, wind turbine, diesel generator, battery storage and converter brings to the COE value of USD 0.276/kWh and TNPC value of USD 414.951. It is observed that COE of hybrid system with diesel generator is less than hybrid system with 100% renewable energy because it need extra battery and PV array to provide the electricity at night. The results obtained from the sensitivity analysis indicated how wind speed and battery cost had largest impact on COE. Detailed modelling is needed because renewable energy penetration in such amount can cause stability problem to the system.

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