Optimization of Battery Energy Storage System (BESS) sizing for solar power plant at remote area

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Abstract. It is known that the availability of electrical energy will boost economic growth and also industrial growth. However, because the geographical location of the remote area is relatively isolated, the community's energy demand in the area cannot be fulfilled. Until now, the majority of operated power plants are diesel generator by using fossil fuels. Hence, the addition of renewable energy sources (RESs), especially solar energy (PV) and Battery Energy Storage System (BESS) become a choice to reduce the use of fossil fuels. This study discusses the sizing of BESS and PV to obtain an optimized configuration that maximizes the penetration of RESs and minimizes the utilization of diesel generator. The method of this study will be done by using data from the remote area with simulation and computation using HOMER that can get the best configuration of the system. Thus, the results of this study can be implemented in those areas either at the present or in the future.

1. Introduction
Economic and industrial growth is directly proportional to the fulfillment of electricity demand. The unequal availability of fossil fuels and the adversity to provide the electrical networks due to the geographical location made some regions in Indonesia cannot fulfill their electricity demand. The utilization of diesel generators results in a high production cost of electricity. Besides, it may produce high levels of CO\textsubscript{2} emissions, which will impact on the environment. Thus, Renewable Energy Sources (RES) can be deployed to overcome these problems, especially solar energy through the photovoltaic (PV) system, which is already implemented in many areas over two decades [1]. Furthermore, Indonesia is a country with a relatively consistent intensity of solar irradiance throughout the year. The average solar irradiance received in any location Indonesia is 12.38 MJ/m\textsuperscript{2}day or 3.44 kWh/m\textsuperscript{2}day [2].

The application of solar PV system can be combined with the Battery Energy Storage System (BESS) in order to improve the reliability and to reduce the cost of production. The utilization of BESS in PV system will make the supply power steady when a power outage happens or lack of sunlight. Other than that, BESS also has high energy efficiency and good reliability when combined with the PV system [3]. There are several kinds of research previously worked on the BESS sizing in combination with the solar PV system. Chin E. Lin \textit{et al.} (2019) [4] had researched the Philippines. The system consists of PV, wind turbine, Diesel Generator (DG), and BESS. The research was purposed to determine the optimal system components sizing based on system reliability, net present
cost (NPC), and cost of energy (COE). The result showed that this hybrid system was suitable for the applied area and further application for rural and islanding electrification.

There are various methods to find the optimum configuration in systems, such as using software called Hybrid Optimization Model for Electric Renewable (HOMER), which can optimize the component sizing of the system and optimize the economic analysis. Prema V. et al. (2016) [5] proposed the sizing of microgrids for the Indian system using this software. The utility of HOMER was to compare the cost analysis, fuel consumption, and CO$_2$ emission of a hybrid microgrid system with a microgrid that is supplied by only a diesel generator. The hybrid microgrid system configuration used a PV panel, a wind turbine, DG, three strings, Lead Acid Battery, and a converter. It suggested that the hybrid microgrid system would have a lower cost in the next 15 years.

This paper is aimed to study the opportunity to maximize the photovoltaic generator penetration and to minimize the utilization of diesel generator in a remote area, which the expected results are the configuration and the size of PV, battery, and DG. The application of BESS is considered one of the crucial parts to satisfy this objective, where the battery is used for energy management instead of for ancillary service such as frequency regulation. According to the current status of the installation costs of BESS, the application of solar PV systems and BESS still requires high investment. The cost trend is predicted to decrease in a couple of years, while the fuel cost of a diesel generator tends to increase. Therefore, this paper investigates the distinction between the application of diesel generator-PV-BESS in the present time and the application of PV-BESS in the near future. The research uses HOMER to compare the COE in accordance with the time-based cost difference along with other parameter such as the fuel consumption. [6].

This paper is organized as follows: In Section II, the system configuration, load profile of the research object, the solar resources, and the HOMER derivative-free algorithm to determine the BESS size. In Section III, the simulation will be performed, and the results will be presented. Lastly, Section IV will conclude this paper.

2. System configuration & methodology

A grid-on system will be performed in one of the remote areas in eastern Indonesia. The consideration in designing this system involves the system’s sustainability and solar source exploitation. Thus, the system will become reliable. This system configuration can be seen in Figure 1.

**Figure 1.** System configuration schematic

2.1. Load Data

The load profile of the studied area is presented in Table 1 and Figure 2. The hourly average load is 708.5 kW, and the peak load is 1,348.5 kW. Whereas, the average daily energy consumed is 17,004 kWh/day.
Table 1. Load data used in the simulation

| Metric (Unit) | Average (kW) | Average (kWh/day) | Peak (kW) | Load Factor |
|---------------|--------------|-------------------|-----------|-------------|
| Value         | 708.5        | 17,004            | 1,348.5   | 0.53        |

Figure 2. Daily load profile of the studied area.

2.2. Solar Resource

Global Horizontal Irradiance (GHI) is the total amount of the diffuse radiation incident on a horizontal surface with the direct normal irradiance projected onto the horizontal surface.\[ GHI = Diffuse + DNI \times \cos(z) \], where \( z \) is the solar zenith angle [7]. In this paper, GHI is used as the solar resource radiation. Other than that, there is a Clearness Index (CI), which is the measure of the atmosphere’s clearness [6]. Table 2 and Figure 3 show the monthly average of solar GHI resources in one of the remote areas in eastern Indonesia, with the annual average is 5.92 kWh/m\(^2\)/day. These data are monthly averaged value over 22 years period (July 1983 - June 2005) [8].

Table 2. Monthly GHI and Clearness Index data

| Month      | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Des |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Clearness Index | 0.51 | 0.49 | 0.57 | 0.61 | 0.65 | 0.64 | 0.63 | 0.65 | 0.66 | 0.65 | 0.59 | 0.54 |
| Daily Radiation (kWh/m\(^2\)/day) | 5.52 | 5.34 | 5.98 | 5.9 | 5.71 | 5.3 | 5.38 | 6.09 | 6.74 | 6.95 | 6.38 | 5.8 |

Figure 3. Monthly average solar GHI data

2.3. Derivative-free optimization by HOMER

A system can be designed, optimized, and evaluated technically and financially by using HOMER. A range of input that has been given will be calculated as much as a possible design. When it comes to the optimization process, HOMER determines the optimal size and quantity of the system’s components, also the lowest possible LCOE.

HOMER uses a proprietary derivative-free algorithm to optimize the system by searching for the least cost of the system (COE) [6]. This algorithm is free of derivative calculation and does a direct search method. Therefore, this algorithm can be used when the derivatives of the function are difficult to find and time-consuming [9]. There are many different types of derivative-free optimization, such as Genetic Algorithm, Particle Swarm Optimization, Random Search Method, etc. [10].

Sizing battery charge is the maximum amount of power that the storage bank can absorb. HOMER uses it to decide how much the surplus of RES can be absorbed [6]. The formula is given by the following equation.
is the available energy (kWh) in the storage at the beginning. \( Q \) is the total amount of energy (kWh) in the storage at the beginning. \( C \) is the storage capacity ratio, \( k \) is the storage rate constant, while \( \Delta t \) is the length of the time step. Whereas, the battery discharge power is sized based on the maximum amount of power that the storage bank can discharge. HOMER uses it to obtain whether the battery can fulfill the load on its own [6]. It can be seen in the following equation.

\[
P_{batt, dmax, kbm} = \frac{kQ_1 e^{-k\Delta t} + Qc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})}
\]

(1)

\[
P_{batt, dmax, kbm} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + Qc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})}
\]

(2)

3. Simulation and Result

The simulation is performed by HOMER to obtain the optimized size of the components in the system. Two available control systems are utilized, which are load following (LF) and cycle charging (CC). LF allows the generator to produce the energy based on the required demand and does not allow the generator to charge the BESS. On the other hand, CC controls the generator to operate at its full capacity, and the surplus power is used to charge the BESS. Hence, CC is preferred when renewable energy penetration is minimum, while LF is preferred when the system consists of a lot of renewable energy [6].

The cost information based on the present time entered into HOMER is shown in Table 3.

| Component             | Cost ($) | Lifetime       |
|-----------------------|----------|----------------|
|                       | Capital  | Replacement    | O&M/year |                   |
| PV                    | 400/kW   | 100/kW         | 10/kW    | 25 years          |
| DG                    | 400/kW   | 300/kW         | 0.03/kW  | 30,000 hours      |
| Converter             | 260/kW   | 260/kW         | 7.5/kW   | 15 years          |
| Li-Ion Battery        | 260/kWh  | 260/kWh        | 8.5/kWh  | 10 years          |

The size of the solar PV system is determined heuristically based on the peak load. Hence, it is varied from 2,000 kWp to 6,000 kWp. The size of diesel generator, BESS, and converter are obtained through the HOMER algorithm. The result of the first simulation based on the present status of cost is presented in Table 4.

| Components (kW)     | Cost ($) | Total fuel (L/year) |
|---------------------|----------|---------------------|
| PV 2,000 1,500 6,138 1,147 15.4M 0.191 843,486 |
| 3,000 1,500 11,888 1,380 14.3M 0.178 466,585 |
| 4,000 1,500 15,536 1,617 13.1M 0.164 194,347 |
| 4,000 0 126,004 5,098 62.3M 0.782 0 |
| 5,000 1,500 15,394 1,456 13.0M 0.161 127,318 |
| 5,000 0 35,173 3,070 20.2M 0.253 0 |
| 6,000 1,500 15,766 1,510 13.1M 0.163 78,749 |
| 6,000 0 28,259 2,572 17.3M 0.217 0 |

It shows that the systems with a generator have lower COE compare to the ones without a generator. For the system with 6,000 kW of PV, 1,500 kW of generator, and 15,766 kW of BESS, the COE is 0.163 USD and the total fuel consumption is 78,749 L/year. Meanwhile, for the system with the same PV size but not using a generator, the COE is 0.217 USD and zero fuel consumption. The differences between these two types of configuration are very significant, and it makes the system with
a generator look more profitable than the system without a generator because of the low COE. However, the installation costs of PV and BESS are predicted to decrease in the future. By 2010, the utility-scale system is estimated to reduce between USD 3,600 to USD 4,000/kW, and by 2020 will reduce to USD 1,800/kW. Also, as low as USD 1,060 to USD 1,380/kW by 2030 [19]. From that downward trend, the price of PV will decline by 34% for approximately the next two years. Therefore, it is worth analyzing the optimized system configuration when considering this trend.

The result of the second simulation based on the predicted cost is presented in Table 5. It shows that the COE of three different PV sizes is 0.576 USD for 4,000 kW, 0.189 USD for 5,000 kW, and 0.160 USD for 6,000 kW. Referring to the downward trend, in the next three years, the PV and BESS installation costs will decrease by 36%. Comparing to the data from the first simulation in Table 4, the system with 6,000 kW of PV, 1,500 kW of generator, and 15,766 kW of BESS has the COE of 0.163 USD. Meanwhile, with a downward trend of 36% in the next three years, COE of the system with 6,000 kW PV, 2,388 kW BESS, and without a generator will be lower than the system from the first simulation. The difference is 0.003 USD, which means in 2023, the system with 6,000 kW PV, 2,388 kW BESS, and without a generator will be more profitable than the one with a generator in the present. This is also supported by zero fuel consumption in the predicted system configuration. So, the increase in the price of fossil fuels will not affect the system.

From both simulations that have been done, it is obtained that installing PV with the size of 6,000 kW, BESS size 2,388 kW, and without a generator will save the installation cost even more. It is referring to the downward trend which lead to the decline of installation cost by 36% in the next three years. Other than that, by not using a generator, the system will not be affected by the price of fossil fuels that tends to increase over time. System with 6,000 kW of PV, 2,388 kW of BESS, and without a generator may seem more expensive in the present, but it will be profitable in the near future.

| Table 5. The result of the simulation based on the prediction cost |
|---------------------------------------------------------------|
| Components (kW) | Cost ($) | Total fuel (L/year) |
| PV | DG | Li-Ion | Converter | NPC | COE | |
| 4,000 | 0 | 126,029 | 5,073 | 45.8M | 0.576 | 0 |
| 5,000 | 0 | 35,365 | 2,914 | 15.0M | 0.189 | 0 |
| 6,000 | 0 | 28,388 | 2,123 | 12.7M | 0.160 | 0 |

4. Conclusion
Optimization by using HOMER was performed in this study to find the optimum configuration that maximizes the penetration of renewable energy such a solar photovoltaic system and minimizes the utilization of diesel generator. The simulation is done to investigate the distinction between the application of diesel generator-PV-BESS in the present time and the application of PV-BESS in the near future. The result shows that when simulation uses the present status of cost, the system with a generator has lower COE compare to the one without a generator. However, the installation costs of PV and BESS are predicted to decrease in the future because of the downward trend. Another result shows that when simulation uses prediction cost, which tends to decrease by 36% in the next three years, the COE of the system without a generator will be lower than the system with a generator in the present. So, installing a system without a generator with a slightly higher COE will be profitable in the next couple of years and it is also supported by zero fuel consumption so that the increase in the price of fossil fuels will not affect the system.

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