Techno-economic analysis of hybrid Diesel-PV-Battery system and hybrid Diesel-PV-Wind-Battery system in Eastern Indonesia

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Abstract. Generally, remote areas in Indonesia apply diesel power plants to provide electricity due to the high cost of grid extensions. The concern of the use of standalone diesel generators is fluctuations in the price of fuel oil, as well as gas emissions resulting from the remnants of combustion. To reduce the use of fossil fuels, it is necessary to use renewable energy which has the potential to be configured hybrid with a diesel generator. This study will discuss the techno and economic analysis of two different hybrid system configurations using the HOMER software. Those hybrid systems are consisting of diesel-PVbattery system and diesel-PV-wind turbine -battery system. There is a reduction in the cost of energy (COE) as the proposed hybrid system is compared with the existing diesel generator system. The COE of the existing system is $0.1968 / kWh, whereas the proposed hybrid diesel-PV-battery system and the hybrid diesel-PV-wind turbine-battery system are $0.1554 / kWh and $0.1555 / kWh, respectively. These optimized results show a reduction in fuel consumption for both hybrid systems configuration by 53.83% and 53.58% when compared to the existing standalone diesel generators. Thus, both hybrid systems have a lower Net Present Cost value of 21.04% and 20.99% when compared to the current standalone diesel generator system. On the other hand, CO₂ emissions generated by the two hybrid system configurations have decreased compared to standalone diesel generators, which were 53.83% and 53.57%, accordingly.

1. Introduction

In general, areas that are not covered by the electricity network are areas that have extreme geographical conditions and poor public utilities. The choice to expand the electricity network to remote areas or distribute it via submarine cables to remote islands requires high costs [1]. One solution in solving electrification problems in remote villages is by using a diesel generator [2]. But the consequences of using diesel generators include dependence on fossil fuels even when fuel prices increase and additional costs for shipping. Besides, the use of diesel generators also harms the surrounding environment due to greenhouse gas emissions that can cause pollution, such as air and noise [3]. On the other hand, electrification has a role in increasing the productivity of community activities and can even become new business opportunities [4].

As a choice besides the use of diesel, which is based on renewable energy technology. Renewable energy-based electrification scheme in an effort to reduce and replace conventional energy in remote areas was in line with the Indonesian government's program based on the vision of 2025: building a new Indonesian strategy that is supporting policies that implement the use of new renewable energy
technologies. In addition, to increase renewable energy-based electrification has been proposed in a draft budget that is coordinated based on central and regional government budget contributions of US$ 43 million in efforts to advance rural electrification [5],[2]. However, the disadvantage of renewable energy sources such as solar and wind is that they are intermittent because they are influenced by weather and climate conditions [6]. Renewable energy generating system technology can be configured either standalone or hybrid [7]. The merger between the diesel power system and the solar power system is done because the solar electric system (photovoltaic) is considered to produce environmentally friendly energy and offers low operational and maintenance costs because this technology does not have involved moving components [8].

Chong Li et al. in their study, explained that solar energy contributes more efficiently to the system in supplying electricity than wind energy [9]. Shaahid et al. [10] in their study demonstrated that the cost of energy production produced from hybrid systems is equal to $0.118/kWh, and the value of COE has increased along with the increased penetration of this hybrid system. Rehman et al. [11] in their study discussed wind power and solar power contributing penetration by 26% and 9% respectively, while diesel power provided 65% to produce the most economical energy production costs of US$ 0.212/kWh with costs diesel fuel of US$0.2/liter. Also, the research of Ngan and Tan et al. [12] explained that the PV-Diesel hybrid power system and the wind-PV-diesel hybrid power system could reduce the use of diesel power, so that fuel consumption and exhaust emissions are reduced.

This research will be discussed using a HOMER simulation to look for potential and design optimization with different scenarios to determine fuel savings when penetration of a renewable energy hybrid system is carried out, as well as to assess the reduction of fuel emissions. Analysis and comparison of different hybrid power generation system configurations will be discussed therein. Various configurations of hybrid power systems include diesel-PV-batteries and PV-diesel-wind turbines-batteries.

The first chapter will discuss the background of topic selection and the study of literature from previous research. Then in chapter two will discuss the research methodology, such as data collection and hybrid components system. Next, in chapter three will discuss the results of simulation and analysis. The last one, chapter five, will discuss conclusions.

2. Methodology

2.1. Daily Load Profile and Renewable Energy Resources

The recorded total daily energy demand of 189,800 kWh/day with an average of 7,908.3 kW and a peak load of 13,989 kW. This number is using secondary data from relevant sources. Random variability (random variability) chosen by 5% is calculated for analysis of timestep and changes from day to day by 5% to make it better. The daily load data is shown in Figure 1. The factors that determine the photovoltaic and wind turbine output power are solar radiation and wind speed. The data used for the HOMER simulation is the average global horizontal radiation for the month and wind speed obtained from NASA's Surface Meteorology and Solar Energy database.

The average annual solar radiation value is 5.05 kWh/m2/day, and the maximum solar radiation recorded in March is 5.25 kWh/m2/day while the minimum solar radiation is recorded in June, which is 4.72 kWh/m2/day. Average annual wind speed data of 3.27 m/s is obtained where the highest value recorded in December was 3.82 m/s, and the lowest value was recorded in May of 2.7 m/s. The solar radiation index data and data of average wind speed for the studied area are shown in Figure 2 below.

2.2. Hybrid System Component

The existing diesel generator system consists of 13 generators with different capacities. Then, the system will be configured in a hybrid with photovoltaic (PV), wind turbine, and battery. The details of each component are shown in Table 1.
3. Simulation and result

Please note that this study uses a load following strategy control. The loading ratio parameter given to the diesel generator (DG) is 30% and the price of diesel fuel is known to be $0.660 (Rp9500) per liter in the study area [18]. The economic parameter inputs provided were the Bank Indonesia benchmark interest rate in May 2020 of 4.50% [19] and the 2020 inflation target of 3% [20]. Resulting in a real discount rate of 1.44%.

### Table 1. Hybrid Components System

| Component       | Capacity   | Cost ($) | Lifetime |
|-----------------|------------|----------|----------|
| Generator MAK [13] | 3×2,544 kW | 0 183.04 | 0.02 20,000 hours |
| Generator DHS [13] | 2×3,100 kW | 0 193.6 | 0.02 20,000 hours |
| Generator CAT [13] | 3×1000 kW | 0 131 | 0.02 20,000 hours |
| Generator TAN [13] | 5×1200 kW | 0 142.59 | 0.02 20,000 hours |
| Converter [14] | 1 kW | 550 450 | 5 15 years |
| PV [14]+Inverter [15] | 1 kWp + 1 kW | 640 + 350 640 + 350 | 15 25 years |
| Wind turbine [16] | 1 kWp | 6760 4595 | 25 20 years |
| Battery [17] | 1 kWh, 167 Ah | 315 300 | 6 12 years |

### Table 2. Size components of different configuration

| Quantity        | Configuration System       |
|-----------------|---------------------------|
|                 | Standalone Generator | Diesel-PV-Battery | Diesel-PV-Wind-Battery |
| Generator (kW)  | 18,732                     | 14,544              | 14,544              |
| PV (kWp) + Inverter (kW) | 0                      | 36,406              | 36,119              |
| Wind turbine (kWp) | 0                       | 0                   | 12                  |
| Battery (kWh)   | 0                         | 49,908              | 49,204              |
| Converter (kW)  | 0                         | 7,321               | 7,442               |

### Table 3. Economic result of three configuration system

| Quantity | Configuration System       |
|----------|---------------------------|
|          | Standalone Generator | Hybrid Diesel-PV-Battery | Hybrid Diesel-PV-Wind-Battery |
| NPC (k$) | $283,965                     | 224,233              | 224,334              |
| LCOE ($/kWh) | 0.1968                | 0.1554               | 0.1555               |
Table 4. The result summary of standalone DG existing and the optimized of hybrid renewable energy system

| Quantity                          | Standalone Generator | Diesel-PV-Battery | Diesel-PV-Wind-Battery |
|-----------------------------------|----------------------|-------------------|------------------------|
| Energy Production (kWh/year)      | 69,277,000           | 85,209,384        | 84,966,188             |
| Generator system (kWh)            | 69,277,000           | 31,504,702        | 31,678,663             |
| PV system (kWP)                   | 0                    | 53,704,682        | 53,280,833             |
| Wind turbine (kWP)                | 0                    | 0                 | 6,692                  |
| Excess Electricity (kWh/year)     | 0                    | 11,161,930        | 10,977,027             |
| CO₂ Emission (kg/year)            | 45,729,050           | 21,114,662        | 21,231,485             |

3.1. Diesel Generator Configuration
Electric production results from the existing diesel generating system is shown in Table 2. From a technical point of view, the TAN generator has the largest electrical energy production of 30,994,962 kWh/year with fuel consumption of 7,696,805 L. Then, the MAK generator produced 20,926,944 kWh/year with 5,221,273 L fuel consumption followed by CAT generator that produced 9,493,615 kWh/year with 2,358,689 L fuel consumption. Finally, the least productive generator in the system is DHS with 7,861,479 kWh/year while consuming 2,098,669 L fuel.

Based on the simulation results, the configuration of the standalone DG system obtained an NPC value of $283,964,500. Initial capital for the diesel generator system is assumed to be $0 because the generator components are available beforehand so there is no need to allocate costs for purchases. The largest NPC value comes from the TAN generator because the generator produces the largest amount of electricity and operates most of the time. The existing standalone DG system obtained a Cost of Energy (COE) value of $0.1968/kWh with an operating cost of $13,633,080.

3.2. Hybrid Diesel-PV-Battery Configuration
Based on the optimal combination of 5.05 kWh/m² per-day global average solar radiation, a $0.66/L diesel price shows optimization results in the form of 36.4 MWp PV, 49,908 total batteries, and 7,321 kW converter. In Table 2 is shown the optimization of power generation system with a hybrid diesel PV battery configuration. It is known that the system can rely on power from PV sources to supply loads when the high availability of solar radiation. Then the generator will operate when the power generated by the PV is insufficient or not available.

The simulation results show that PV penetration of 36.4 MWp (63% renewable penetration) can produce electrical energy of 53,704,682 kWh/year. The impact of the use of PV causes monthly electricity production from generator components to decrease. TAN generators experienced a decrease in energy production to 17,102,401 kWh/year with material consumption also decreasing to 4,329,175 L. However, TAN generators continued to produce the largest production.

Then, the MAK generator also experienced a decrease in electrical energy production to 5,146,532 kWh/year with fuel consumption of 1,319,134 L. Furthermore, the CAT generator and DHS generator also experienced a decrease in electrical energy production to 3,162,573 kWh/year and 6,093,206 kWh/year with fuel consumption of 789,156 L and 1,584,101 L. However, the impact of using PV and batteries has succeeded in reducing NPC and COE compared to the existing diesel generator system to 21.0350% and 21.0365% with an operating cost of $8,086,884, which is lower than the existing diesel generator system.

3.3. Hybrid Diesel-PV-Wind Turbine-Battery Configuration
In Table 2 is shown that the system can rely on power from PV sources to supply loads when the high availability of solar radiation. However, wind turbine components only produce small amounts of energy due to the low wind speed available in this area. Then the generator will operate when the power generated by PV and wind turbine is insufficient or not available.

Simulation results show that PV penetration of 36.12 MWp (62.7% PV penetration) can produce electrical energy of 53,280,833 kWh/year. Also, wind turbine penetration of 12 kW can produce electric energy production of 6,692 kWh/year (0.00788% wind penetration). The impact of the use of
PV and wind turbine causes monthly electricity production from generator components to decrease. TAN generators experienced a decrease in energy production to 16,987,832 kWh/year, with material consumption also decreasing to 4,299,380 L.

Then, the MAK generator also experienced a decrease in electrical energy production to 5,210,153 kWh/year with fuel consumption of 1,334,790 L. Furthermore, the CAT generator and DHS generator also experienced a decrease in electrical energy production to 3,172,009 kWh/year and 6,308,669 kWh/year with fuel consumption of 791,448 L and 1,640,321 L.

However, the impact of using PV, wind turbine, and batteries has succeeded in reducing NPC and COE compared to the existing diesel generator system to 20.999% and 20.985% with an operating cost of $8,108,964, which is lower than the existing diesel generator system but higher than PV–diesel–battery

3.4. Emissions
It can be seen that the application of the hybrid energy system has succeeded in reducing the use of fossil fuels which also has an impact on gas emissions resulting from residual combustion. Where the Hybrid diesel-PV–battery system and hybrid diesel-PV–wind–battery system have succeeded in reducing CO2 gas emissions by 53.83% and 53.57% of the total emissions generated from the standalone diesel generator system. So that the application of hybrid energy system technology is considered more environmentally friendly

4. Conclusion
The study shows that the first hybrid system that consists of solar-diesel-battery has the cheapest energy generation costs with a value of $0.1554/kWh. On the other hand, the cost of the existing standalone diesel generator system and the hybrid diesel-PV–wind turbine–battery system are $0.1968/kWh and $0.1555/kWh respectively. The penetration of renewable energy from the configuration of the hybrid diesel-PV–battery system and hybrid diesel-PV–wind turbine–battery system has succeeded in reducing the use of diesel fuel by 53.83% and 53.59% compared with the standalone diesel generator system. Also, the lowest NPC value obtained by the configuration of a hybrid diesel-PV–battery is $224,232,492 then followed by the hybrid diesel-PV–wind turbine–battery and standalone diesel generator with the cost of $224,333,554 and $283,964,500. Hybrid renewable energy systems, both diesel-PV–batteries and diesel-PV–wind turbine–batteries, are predicted in reducing CO2 emissions by 53.8% and 53.6% compared to existing standalone diesel generators.

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