Techno-economic analysis of remote microgrid and high voltage interconnected grid development in isolated area

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Abstract. Seram Island is one of the thousand islands in Indonesia. Due to geographical condition, the power system in Seram Island is currently remain isolated. However, based on Electricity Power Supply Business Plan (RUPTL) 2019-2028, there are power system development plan including 150 kV interconnected grid and several medium-sized power plant in this island. Unfortunately, as demand growth is low, reserve margin in related system tend to be very high, with the average of 182% from year 2019 to 2028. With this circumstance, the development plan based on RUPTL 2019-2028 will not be viable both technically and economically. This study will analyze remote microgrid development as an alternative to high voltage interconnected grid in order to perceive optimum configuration for Seram Island. These two alternatives will be compared both technically and economically. Technical analysis will be conducted using software ETAP 12.6 to investigate power quality and system stability. For economical analysis, several economics parameter will be evaluated as well as Levelized Cost of Electricity (LCOE) to perceive the most economically viable alternative. The result shows that remote microgrid is economically more beneficial to be developed in Seram Island, as well as complying the minimum technical requirement of local grid code.

1. Introduction
Energy is one of the most crucial yet challenging sector, as at least in the past decade there had been major transition particularly in renewable energy deployment. Power sector is the leader of renewable energy utilization, with the electricity generation output of 450 terawatt-hours (TWh) worldwide in 2018 [1]. This strong growth is in line with massive technology development, which will decrease investment and production cost through years. The increase in renewable energy penetration has also affected topology and behavior of power system, particularly for network stability that limits the renewable energy penetration [2]. Renewable energy most likely developed in off-grid system, such as microgrid that usually deployed in remote and small power system.

Microgrid is small-scale power system that is operating independently from, or interconnectable with, main large power system. It is suitable to be applied to centralized and remote area. Microgrid provide alternative solution against diesel-based generation system in remote area. Typically, microgrid comprise 20-25% of renewable energy from total system capacity, but this proportion can be higher in particular system [3]. Microgrid also provide ancillary services for power system management including unit commitment, economic dispatch, voltage and frequency regulation [4]. Moreover, microgrid could become a solution in mitigating green-house gas emissions [5]. Remote area is likely to be found in archipelago area, such as Indonesia.
Indonesia has a huge renewable energy source, particularly for solar energy. The utilization of renewable energy can be a great alternative in small islands. This idea is parallel with government policy, which stated renewable energy will achieve 23% of total energy mix by 2025 [6]. However, penetration of renewable energy is not without challenges. The main concerns are about power system stability and power balance, therefore power system should have adequate reserves that can react immediately when it is needed [7].

One of the isolated islands in Indonesia is Seram. PT PLN (Persero), state-owned utility company has a strategic electricity development plan in Seram, including additional gas engine power plants with total capacity of 40 MW and 150 kV interconnection system [8]. However, due to low demand growth in Seram, the dispatched energy from these power plants will likely not be utilized optimally. As a result, power plants will be operating in low Capacity Factor (CF) which will cause negative impact, both technically and economically.

This study is intended to analyze microgrid as the alternative to planned electricity development in Seram. These two options will be compared both technically and economically. Technical analysis is conducted to investigate power quality and system stability. Moreover, economics parameters as well as Levelized Cost of Electricity (LCOE) will be evaluated to perceive the most economically viable alternative.

2. Methodology

2.1. Simulation Model

Generally, the simulation model is divided into two parts, microgrid modelling and interconnection system modelling. Study case for both alternatives will be in year 2020. Microgrid system is classified into three systems: Masohi, Kairatu, and Piru. Each microgrid consist of wind turbines, PV array, and diesel generators that are connected to AC bus. Existing diesel generators are kept to maintain system quality and stability, particularly in overcoming high power output variability of renewable sources. Microgrid generation capacity optimization is calculated in software HOMER, based on electricity demand in related system. Main parameter of the optimization is LCOE of microgrid system. The system LCOE must be lower than existing power generation cost or Biaya Pokok Penyediaan (BPP) in Seram, that is 20.85 cent USD/kWh [9]. Once LCOE is lower than current BPP, further technical analysis will be conducted using ETAP software. Technical analysis is intended to evaluate quality and stability of microgrid system.

For interconnection system, modelling will be conducted to analyze system viability both technically and economically. The input data will be processed to analyze financial performance as well as technical aspect. For technical analysis, the method and simulation process are similar to microgrid system. The result then will be compared to microgrid system result. Criteria of selected alternative for Seram Island is the one with lower LCOE and fulfill technical requirement in accordance with grid code standard. Analysis process in this study is shown in Figure 1.

![Figure 1. Analysis Process](image)

2.2. Financial Analysis

In conducting financial analysis, there are two main parameters to measure financial viability of both alternatives, they are Net Present Value (NPV) and Levelized Cost of Electricity (LCOE). Financial formulas are based on standard financial calculation [10],[11]. Nominal discount rate as financial input
assumption is calculated based on Weighted Average Cost of Capital (WACC), which is defined as follows:

\[
WACC = (E \times K_e) + [(D \times K_d) \times (1 - t)]
\]  
(1)

Where E is percentage of equity used for funding, \(K_e\) is cost of equity, D is percentage of debt used for funding, \(K_d\) is cost of debt, and t is corporate tax rate.

The discount rate is taken into calculating NPV of each alternative. NPV is essential consideration in determining financial viability of the project. Positive NPV depict profitable project, as lower or negative value represent less attractive or even not feasible project. NPV is calculated as follows:

\[
NPV = \sum_{t=1}^{n} \frac{C_t}{(1 + i)^t}
\]  
(2)

Where \(C_t\) is cash flow during single period t, i is discount rate, and t is time periods.

LCOE, the determining factor of alternative viability is calculated based on project costs and electricity production during lifetime of plant or system. The LCOE value represents electricity tariff of related system, therefore it should be lower than existing BPP. Otherwise, the additional system or plant will increase system BPP. LCOE is defined as follows:

\[
LCOE = \frac{\sum_{t=1}^{n} I_t + M_t + F_t}{\sum_{t=1}^{n} E_t}
\]  
(3)

Where \(I_t\) stands for investment in year t, \(M_t\) is operations and maintenance costs in year t, \(F_t\) is fuel costs in year t, \(E_t\) is electricity generation in year t, i is discount rate, and n is lifetime of the system.

2.3. Technical Analysis

Technical analysis is intended to evaluate power system performance, particularly in terms of quality and stability. Power system of both alternatives are modelled using ETAP software. Load flow analysis is conducted to analyse power system quality, including voltage level and losses. Parameters of the power system must comply with related grid code requirement.

Stability of power system is analysed by conducting transient stability simulation. Inertia constant (H) of wind turbine is modelled, as penetration of wind power generation will release kinetics energy from its rotating mass during fault condition. The inertia constant can be calculated using following equation [12].

\[
H = \frac{J \omega_m^2}{2S}
\]  
(4)

Where J is inertia of the machine, \(\omega_m\) is the rotational speed of the machine, and S is the nominal apparent power of the generator. Process of simulation is carried out by performing 3-phase fault at wind turbine bus and fault will be cleared in 120 ms, as stated in grid code. The system is considered stable if frequency is able to recover and maintain between 47.5 Hz – 52 Hz after fault is cleared.

3. Results

3.1. Financial Result

Financial modelling is started with determining the value of WACC. Percentage of equity funding is assumed 30% of total project cost, with cost of equity of 10%, while debt percentage is 70%. Corporate tax rate to be used in this study is 25% and interest rate is 7%. Exchange rate used in this study is IDR 14,234 [13]. According to equation (1), value of discount rate is 6.68%. Interconnection
System analysis is conducted by evaluating economic viability of committed power plants, they are gas engine power plant (PLTMG) Seram Peaker and Seram 2, with capacity of 20 MW for each plant. Due to similar size, result of interconnection system is represented by one of PLTMG only. The approach is to yield minimum LCOE by setting IRR slightly higher than discount rate, so that the projects are considered profitable.

For microgrid system, LCOE and IRR is calculated based on typical investment and O&M cost for related power plant [14,15], which is simulated in HOMER software. Result of financial analysis is shown in Table 1.

Table 1. Result of financial analysis.

|                | 150 kV Interconnection | Masohi Microgrid | Kairatu Microgrid | Piru Microgrid |
|----------------|------------------------|------------------|-------------------|---------------|
| NPV (USD)      | 33,552                 | 27,809.033       | 15,259,155        | 11,644,382    |
| Payback Period (years) | 13.7               | 8.1              | 8.8               | 8.7           |
| IRR (%)        | 6.69                   | 13.2             | 12.1              | 12.3          |
| LCOE (cent USD/kWh) | 30.28              | 19.36            | 20.38             | 19.56         |

It can be seen from Table 1 that LCOE of all microgrid system is below existing BPP in Seram Island. Moreover, the NPV is positive and IRR is acceptable for typical project. Otherwise, the LCOE of interconnection system is higher than existing BPP to keep the project profitable. Therefore, microgrid alternative is more economically viable to be deployed.

3.2. Technical Result

Modelling of interconnection system is provided in accordance with RUPTL 2019-2028, with all related power plants, substations, and transmission lines. Peak load in Seram system along from Masohi to Piru is 17 MW. Meanwhile, microgrid system utilize 20 kV distribution lines to evacuate energy dispatched from generation plants. Load flow analysis is conducted to evaluate system quality of each alternative. Result of load flow analysis is shown in Table 2.

Table 2. Result of load flow analysis.

|                  | 150 kV Interconnection | Masohi Microgrid | Kairatu Microgrid | Piru Microgrid |
|------------------|------------------------|------------------|-------------------|---------------|
| Lowest Voltage (kV) | 154.2                 | 18.8             | 19.2              | 18.8          |
| Highest Voltage (kV) | 155.7                 | 19.9             | 19.6              | 19.9          |
| Losses (%)       | 0.25                   | 0.6              | 0.5               | 0.5           |

Voltage level of all alternatives are still in the range of +5, -10%, complying with grid code requirement. As well as system losses is still far under standard maximum limit. Therefore, deployment of both interconnection and microgrid system will not cause any detrimental impact to system quality.

In conducting transient stability analysis, voltage and frequency stability at PLTMG Seram 2 and related substations are examined to evaluate system stability during major fault occurred at PLTMG Seram 2 bus and after fault is cleared. For microgrid system, observed buses are conducted at diesel generator, wind turbine, and PV power plant bus. Result for voltage stability and frequency stability are shown in Figure 2 and Figure 3, respectively.
From Figure 2 and Figure 3 it can be seen that either interconnection system and microgrid system are able to recover from major fault. However, it should be taken into account to control power generation from rotating generator at microgrid system, particularly diesel power plant as the largest unit size. This matter is intended to keep the system stable, as both oversupply and lack of supply can lead to system instability.

4. Conclusion

In this study, comparison between interconnection system as planned in Electricity Power Supply Business Plan (RUPTL) 2019-2028 and microgrid system comprising of solar PV plant, wind power generator, and diesel generator is provided. From economic analysis, it is found that PLTMG Seram peaker and PLTMG Seram 2 yield LCOE of 30.28 cent USD/kWh which is higher than existing BPP (20.85 cent USD/kWh). LCOE value of interconnection system is high due to low demand that cause power plants cannot dispatch the energy optimally. Therefore, interconnection facilities are not viable to be built in Seram. Otherwise, microgrid system provide lower LCOE than BPP, as well as keeping the project profitable. Masohi microgrid yield 19.36 cent USD/kWh, Kairatu microgrid 20.38 cent USD/kWh, and Piru microgrid 19.56 cent USD/kWh. For technical analysis, both interconnection and microgrid system are able to meet power system quality requirement, as well as keep the system stable under major fault circumstance. Therefore, it can be concluded that microgrid development is more feasible and profitable to be deployed in Seram Island.
Figure 3. Frequency Stability (a) Interconnection system (b) Masohi Microgrid (c) Kairatu Microgrid (d) Piru Microgrid.

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