Electricity and economic valuation of smart grid system on Nusa Penida electricity market

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Abstract. Smart Grid Technology is widely applied in various countries to reduce the basic cost of generation electricity in the region. The existing generation on Nusa Penida Island is only used PLTD, that leads the generation cost are relatively higher, with cost generally Rp.1198,44884 /KWh and more high cost for consumers, to overcome the problems of the system is applied a SG technology, by combined PLTD with photovoltaic (PV) penetration as renewable energy generation and battery energy storage system (BESS) on Nusa Penida grid. This study is analyzed the grid impact and economic value from this technology on Bali, with study case of Nusa Penida island. With used SG concept is Renewable Energy, Storage and Micro Grid Development (RESMG) as base concept of this study. By determined the scenario and conducting the calculation LCOE on PV penetration place, then choose the appropriate scenario there found 3 PV penetration site. With 3-PV penetration site, then calculated the LCOE, and the lower cost is Sakti with Level Cost of Electricity (LCOE) Rp. 780,791591/KWh after PV-penetration on GH-Sakti.

1. Introduction
Smart Grid system (SG) is one of power system grid that made to integrate a continuous power, secure, and efficient supply for consumers. The aim of this system is to stabilize the use of power generation ratio in an effort to stabilize the electrical grid [1].

The existing generation that still exist in Indonesia namely diesel that is not green energy such as at Nusa Penida Island with diesel generation fuel that use is medium fuel oil (MFO) where the fuel is not environmentally friendly that leads the generation cost generally is Rp 1198,44884/kWh and more high cost for consumers. Electricity demand in Nusa Penida island more year more increasing, based growth energy cost over the last 10 year increased 5.65% on Bali distribution system, with unintegrated power grid on Nusa Penida that leads more supply for consumers. Bali electricity demand needs to be increased, it is necessary to increase the energy supply in Bali, if not the energy supply will be less. That’s leads insufficiency of electricity supply in Bali.

The implementation of smart grid can solve Nusa Penida exist problem is to decrease conventional generation ratio (PLTD) with applied the renewable energy (RE) in accordance with the existing potential is solar generation (PLTS). Currently, PLN includes 10 MW hybrid solar plant in Nusa Penida in year 2021 [2]. One of the concepts of SG is Renewable Energy, Storage and Microgrid Development (RESMG), that’s used micro electricity grid, used renewable energy and use a storage.
Microgrid network easy integration applied in Megawatt-Level isolated which is composed photovoltaic (PV)/ wind-power, energy storage, diesel/ gas Power plant, that can solve the less-supply in isolated area [3]. Microgrid system is one of SG concepts that have much benefits of implementing to electricity grid [4]. This paper is shown the result of electricity and economic valuation of smart grid system on Nusa Penida electricity market by implementation SG concepts, is Renewable Energy, Storage and Micro Grid Development (RESMG) on hybrid generation in Nusa Penida.

2. Method
This study starts from defining the purpose of research, review literature, survey, calculating the LCOE and BPP, then electrical system modeling, model validation, simulation to simulation result analysis, then write the result. For analyze the system to optimization generator, done with portrait of electrical system modeling of Nusa Penida on DlgSILENT, modeled on software must be validated according to the real conditions, then determine the solar system (PLTS) and Battery energy storage system (BESS) site penetration to make diesel system into a hybrid system. After that simulated with three conditions, first when only diesel, then the second is PLTD+PV+BESS in unity hybrid system with advance control and communication (ACC) in PED, Suana, and Sakti, which in the simulation there are 3 types of simulation is Load flow analysis, Short circuit analysis and Reability analysis.

The simulations are conducted at off peak load. The object of this study System Development is based on RUPTL (PT. PLN, 2019 - 2028) to make the diesel hybrid system by combined diesel power plant (PLTD) as existing generation with solar generation (PLTS) with storage (BESS) thus become solar hybrid system. This study was conducted in May 2019 with a survey method where the survey was conducted at Nusa Penida island. This study is conducted at Nusa Penida Hybrid Renewable Energy Power Plant (REPP) target COD year 2021. There are 3 sited simulated in this study is Site 1 – Ped, located 4.5 km from PLTD Kutampi, Site 6 – Suana, located 7.3 km from PLTD Kutampi, Site 7– Sakti, Located 14.5 km from PLTD Kutampi

3. Result and discussion
The result and discussion is shown LCOE before and after renewable energy (RE) penetration, operation mode, load flow (LF), short circuit (SC) and reability analysis.

3.1. LCOE before and after RE penetration
The first calculation is assumed a Level Cost of Electricity (LCOE) from before and after RE penetration, namely:

| Penetration    | LCOE (Rp/kWh) |
|----------------|---------------|
| Non Penetration| 1198,44884    |
| Site 1         | 825,4611268   |
| Site 6         | 782,1823497   |
| Site 7         | 780,7915914   |

Table 1 explains the result of calculation that shows LCOE before RE penetration is equal Rp 11198,44884 while the lowest LCOE after RE penetration result are at Site 7 (GH Sakti) is equal Rp 780,7915914.

3.2. Operation mode
The operation mode before and after RE penetration is:
Figure 1 shows the operation mode when only using diesel power plant to covers load demand of Nusa Penida consumers. The operation mode will change after the PV penetration. Figure 2 shown the different operation mode when only use diesel power plant (PLTD) with operation mode after RE penetration become hybrid system. PV penetration is supply the system only when the daylight that leads the LCOE cost lower for consumers.

3.3. Load Flow (LF)

Load flow analysis Load flow analysis is an estimate bus node voltage, active and reactive power flow through every branches, currents through each branch, branch losses and transformer loading [5-7].

The simulation was performed a daylight because PV penetration is only use when daylight, it defines load flow result analysis before and after PV penetration. Table 2, shown the result of load flow analysis.

| Analysis Type          | PLTS Capacity (MW) | Available Power (MW) | Maximum Voltage (p.u) | Minimum Voltage (p.u) | Loading (%) | Losses (%) |
|------------------------|--------------------|----------------------|-----------------------|------------------------|-------------|------------|
| Before Penetration     | -                  | 10.84                | 1.00                  | 0.91                   | 10.49       | 3.2        |
| After Penetration site 1 | 7 MW               | 10.94                | 1.00                  | 0.91                   | 10.49       | 4.11       |
| After Penetration site 6 | 7 MW               | 11.01                | 1.00                  | 0.91                   | 10.49       | 4.72       |
| After Penetration site 7 | 7 MW               | 11.05                | 1.00                  | 0.91                   | 10.49       | 5.06       |

Table 2 explains with 7 MW solar PV that injected to Nusa Penida, shows increase available power from before penetration and shows increase losses as far as the distribution line on grid.

3.4. Short Circuit (SC)

Short Circuit analysis is performed to verify that the maximum short-circuit current that may be experienced in the grid before and after the PV Penetration remain at acceptable levels [8-10]. Short circuit analysis is an estimate short circuit level on Nusa Penida Grid when only use diesel as existing power plant and after PV penetration. The summarized of SC before and after PV penetration, namely:

| Location    | Before Site 1 | After Site 6 | After Site 7 |
|-------------|---------------|--------------|--------------|
| PLTD Kutampi| 1,254         | 0,714        | 0,552        |
| Site PV     | 1,008         | 0,710        | 0,534        |
Table 3 define maximum short circuit on Nusa Penida system in under the breaking current rating (12.5 kA) where the circuit breaker is able to interrupt the short circuit current, without being destroyed or causing an electric arc with unacceptable duration. The short circuit level decreases than before PV penetration. It is because short circuit contributed from Nusa Penida Hybrid-renewable energy power plant, and the system can safety use 12.5 kA circuit breaker.

3.5. Reliability analysis

Reliability analysis in this analysis is an estimate transient and frequency reability of power system with small disturbances that shown after penetration, where the solar panel is covered with clouds [11,12]. The duration solar panel covered by clouds of influence with the land area of solar panel itself. Intermittent condition is when solar panel covered with clouds, where power system have small disturbances that shown after penetration, that leads solar radiation falls from 100% to 25% in PV PP area. The condition on figure below is the situation when solar panel falls from every site after penetration, namely:

![Figure 3. Solar radiation decrease 75%](image)

Figure 3. Solar radiation decrease 75%.

Figure 3 Show the situation when solar panel decrease 75%. When solar radiation decrease that leads same situation of active power, the duration of solar radiation decrease is calculating assumed square 9.55 ha land area for 7 MW solar panel, equals:

\[ s = \sqrt{95500m^2} = 309.03 \ m \]  

With 18 m/s wind speed condition in Nusa Penida, that leads decrease of active power with calculated equals is:

\[ m = \frac{P_{PLTS}}{s} \times V_a \]  
\[ m = \frac{7}{309.03} \times 18 = 0.407 \approx 0.41 \ MW/s \]  

Then the calculated of when the solar radiation fall from 100% to 25%, the duration of solar radiation falls is:

\[ t = \frac{P_{PLTS} \times 0.75}{m} \]  
\[ t = \frac{7 \times 0.75}{0.41} = 12.8 \ s \approx 13 \ sekon \]  

The duration of solar radiation falls from 100% to 25% in 13 seconds, and simulation result on figure below:
Figure 4. The frequency of system.

Figure 5. Active power (MW)-PED.

Figure 4 shows the decrease of frequency system to 49.75 Hz, then have increase to 49.76 Hz Where the result of fluctuation frequency is under minimum UFR rating, then Nusa Penida electric system after PV penetration is stable. When the solar radiation falls from 100% to 25%, the active power of PV Power Plant falls is on Figure 5 that show the active power of PV Power Plant falls to 1.12 MW, then increase to 1.38 MW. Where the radiation falls to 25% from 100%. On this condition will be handled by Battery Energy Storage System (BESS) as a frequency regulator by supply power to Nusa Penida Grid, namely:

Figure 6. Active power BESS (MW)-PED.

Figure 6 shows with 6 MW of BESS can handle the Intermittent condition and BESS supply 5.85 MW active power to Nusa Penida electric system. BESS handle the condition by supply the active power as a frequency regulator.

4. Conclusion
The conclusion of this study is:

- Based on this study different mode of operation condition between only use diesel power plant (PLTD) as existing generation to supply all electricity demand with the mode of operation after PV penetration on PED, Suana and Sakti, where on daylight diesel power plant (PLTD) is off and all electricity demand is supply from solar generation (PLTS). Intermittent condition will be handled by Battery Energy Storage System (BESS) as a frequency regulator.
- Optimal active power when only use diesel power plant (PLTD) is 10.84 MW. Then, optimal active power after PV penetration on site 1 (PED) is 10.94 MW, on Site 6 (Suana), and on Site 7(Sakti) is 11.05 MW. Interconnection of Nusa Penida REPP Solar Hybrid in Site 1 has a lowest losses value 3.33%. After Nusa Penida Hybrid REPP Penetration, the short circuit current level
falls than before RE Penetration. When solar radiation falls to 25%, there is a violation occurs at the frequency limit (f<49.5 Hz).

- Injection of PV penetration based on RUPTL [13] is conducted at Nusa Penida 10 MW Hybrid Renewable Energy Power Plant (REPP) target COD year 2021 to minimizes the Leveled Cost of Electricity (LCOE). After Nusa Penida Hybrid REPP Penetration, the LCOE level falls than before RE Penetration, with generally cost that only use diesel power plant (PLTD) assumed Rp 1198,44844 and more lowest cost after PV penetration with cost on site 1-PED is Rp 825,4611268, on site 6-Suana is Rp 782,1823497 and onsite 7-Sakti is Rp 780,7915914.

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