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*Original article*

# Grid Impact Study of Lombok Power System Due to the Integration of Solar Power Plant

Fakhrudin Azhar[1], Fauzan Hanif Jufri[1], Iwa Garniwa[1*]

[1]*Departemen of Electrical Engineering, Faculty of Engineering, Universitas Indonesia*

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**Corresponding author: iwa@eng.ui.ac.id*

***Abstract*—In recent years, the response to climate change and the need for sustainable energy have driven the global energy transition towards renewable energy, particularly Solar Power Plants (SPP). As a tropical archipelagic country with abundant solar energy potential, Indonesia is increasingly committed to integrating renewable energy into the national electricity system. However, integrating SPP also has several drawbacks to the electrical system. For instance, there is an absence of inertia in SPP because the SPP does not contain rotating machines, and the intermittency is due to SPP power production being highly dependent on the availability of sun irradiance. This research analyzes the effects of SPP penetration on the existing electrical system. Newton Raphson load flow, three-phase line-to-ground short circuit, and transient disturbance are used to investigate the impact of SPP penetration. The results show that the SPP penetration enhances the voltage steady state profile due to the additional active power from SPP ( the increasing voltage profile is around 1%). Furthermore, there are no increasing short circuits due to the characteristic of an inverter with no impedance. In addition, the transient response has an effect as SPP has no inertia, indicated by the frequency response that have overshoot around 0.76 Hz. Hence, the system tends to experience swings in conditions.**

***Keywords*— Grid study, Lombok Island, Renewable Energy. Solar Power Plants**

## I. INTRODUCTION

In the first half of 2023, Indonesia's electrification rate will reach 99.7%, with 156 villages still lacking access to electricity. Based on the PLN RUPTL 2021-2030, electricity demand is expected to increase by approximately 4.9% annually. The total electricity demand in 2021 is estimated to be 243 TWh and is expected to increase to 390 TWh by 2030 [2].

To meet the increasing electricity demand yearly, the Indonesian government is enhancing the electricity infrastructure through the additional 20,000 MW and 35 GW programs. The focus of this program is to increase access to electricity through investments in new renewable energy facilities and the expansion of electricity transmission and distribution networks [2].

Presidential Decree Number 5 of 2006 on the National Energy Policy outlines the policies and strategies of the Indonesian government in the energy sector. The adopted guidelines emphasize energy diversification, environmental sustainability, and the optimal utilization of domestic energy resources. The policy was revised in 2014, and a target for a renewable energy mix of 23% was set. Renewable energy development focuses primarily on solar, geothermal, water, and biomass [3].

Although renewable energy has the advantage of providing environmentally friendly and sustainable energy, it also has weaknesses, such as intermittency and low inertia [4], [5]. Renewable energy from solar and wind power comes from various sources. This results in the generated power also being variable. In addition, renewable energy sources (RES) that require converters are also considered non-inertia generators. These two characteristics cause RES to harm the existing electrical system.

The effect of renewable energy intermittency on reactive power is reported in the following study [6]. A study [6] found that the system's reactive power fluctuates due to the intermittency of renewable energy. Therefore, the precise and accurate placement of static VAR compensators is necessary. The intermittent effects of RES were also reported in the study [7]. In that study, it was found that renewable energy has negative effects on the stability of the power system. In addition, the interaction between modes in the power system is more susceptible to occur due to the intermittency of RES. Researchers in the following journal [8] investigated the effects of renewable energy intermittency on small signal stability. In the study, it was found that the intermittent nature of renewable energy.

The low inertia effect of renewable energy power plants using inverters was reported in the following study [9]. The study found that the low inertia caused the power system to experience significant frequency fluctuations. The low inertia characteristic of this renewable energy also presents new challenges to the stability of small signal systems in the power grid, as explained in the following study [10]. Because of these two characteristics of renewable energy, the grid impact study will encounter new challenges and results.

Studies related to grid impact studies on Indonesia's electrical system due to the penetration of renewable energy have been extensively conducted, as in the research conducted by Setiadi [11]. In that study, it was found that installing a 100 MW



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photovoltaic solar power plant would pose new challenges to the 500 kV Java electrical system, particularly regarding small signal stability. The effect of integrating the wind power plant in Sidrap, Sulawesi Island, was reported in the following study [12]. That study found that installing the wind power plant in the Sulawesi electrical system influenced sub-synchronous resonance.

The effect of installing wind farms in the electrical systems of South and West Sulawesi was reported in the following study [13]. In that study, it was found that installing wind power plants (WPP) in the system provided a new effect on the stability of small signals. The study of the effects of installing photovoltaic SPP on the Kalimantan electrical system is reported in this research [14]. The study explains that installing SPP will influence the frequency stability of the Kalimantan electrical system.

The study on carbon emission reduction in the Sumatra electrical system is reported in the following research [15]. The research emphasizes that using nuclear energy and RES can reduce carbon emissions in the Sumatra electricity system. From the above studies, it is known that research on the integration of RES into Indonesia's electricity system has been conducted. One of the islands in Indonesia that also uses renewable energy is Lombok Island.

Lombok, one of the islands in Indonesia known for its natural beauty, will also contribute to the new and renewable energy revolution by integrating Photovoltaic SPP into its electrical system. However, with this step, new challenges related to the stability and reliability of Lombok's electrical system will arise. The study on the effects of installing SPP on the Lombok electrical system is reported in the following research [16]. In that study, voltage stability was examined to see how installing SPP affects Lombok's electrical system.

The power flow study on the Lombok electrical system, considering the integration of SPP, is reported in the following research [17]. Researchers reported the analysis of small signal stability in the Lombok electrical system in the following paper [18]. It was found that if a reduction follows the installation of SPP in diesel power plants, it will lead to a decrease in system performance, especially in small signal stability. However, no research has been conducted that aligns with the standards of the State Electricity Company, called PLN.

The study includes power flow and short-circuit studies to assess the system's safety. This research focuses on the effects of integrating SPP into the Lombok electrical system in terms of steady-state voltage, the amount of fault current, and the transient response of the systems.

## II. LOAD FLOW & SHORT CIRCUIT ANALYSIS

### *A. Load Flow Analysis*

The formulations to solve the problems in power flow studies are described as follows: the value of the existing base current is expressed in the following equation [20]:

$$B_p + H_2 = 40. \tag{1}$$

$$I_{base} = \frac{KVA_{base}\ 1\phi}{KV_{base\ line\ to\ netral}} \tag{1}$$

The fundamental impedance value is expressed in the following equation:

$$Z_{base} = \frac{(KV_{base\ line\ to\ netral})^2 x100}{KVA_{base}\ 1\phi} \tag{2}$$

$$Z_{base} = \frac{(KVA_{base\ line\ to\ netral})^2}{MVA_{base}\ 1\phi} \tag{3}$$

The values of bus voltage and current can be calculated and represented by the following admittance matrix equations [21]:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ \dots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & \dots & Y_{1n} \\ Y_{21} & Y_{22} & Y_{23} & \dots & Y_{2n} \\ Y_{31} & Y_{32} & Y_{33} & \dots & Y_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ Y_{n1} & Y_{n2} & Y_{n3} & \dots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \dots \\ V_n \end{bmatrix} \tag{4}$$

$$I_{bus} = Y_{bus} \,.\, V_{bus} \tag{5}$$

where:

$n$ = sum of node
$Y_{11}$ = admittance of node *i*
$Y_{21}$ = admittance of node *i* dan *j*
$V_1$ = voltage phasor of node *i*
$I_1$ = flow current phasor node *i*

From equation 4, the current value can be found using Kirchhoff's law as described by:

$$I_i = y_{i0}V_i + y_{in}(V_i - V_1) + y_{i2}(V_i - V_2) + \dots + y_{in}(V_i - V_n) \tag{6}$$

$$I_i = (y_{i0} + y_{in} + y_{i2} + \dots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \dots - y_nV_n \tag{7}$$

From equation 7, it can be written as:

$$I_i = V_t \sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij}V_j \quad , \ j \neq 1 \tag{8}$$

Then, the equations for the active and reactive can be found by using the equation:

$$P_i + jQ_i = V_i\, I_i^{\,*} \tag{9}$$

So equation 8 can be substituted into equation 9, resulting in:

$$I_i = \frac{P_i - jQ_i}{V_i^{*}} \tag{10}$$

Thus, a relationship equation is obtained between active and reactive power with the admittances in the transmission line:

$$\frac{P_i - jQ_i}{V_i^{*}} = V_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij}V_j \quad , \ j \neq 1 \tag{11}$$

Equation 11 shows that an iteration is needed to find the power flow value occurring at bus *i* because the above equation is a non-linear algebraic equation.


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To calculate load flow, based on reference [6], it is assumed that there is a power flow between two buses (*i* and *j*).

Simplifying the power flow calculation assumes that there is a current flow from bus *i* to bus *j*, so when viewed from bus *j*, the current flow from bus *i* is positive, resulting in the following equation:

$$I_{ij} = I_i + I_{i0} = y_{ij}\left(V_i - V_j\right) + y_{i0}V_i \tag{12}$$

If viewed from the bus i side, the current flow is negative and is represented by the following equation:

$$I_{ji} = -I_i + I_{j0} = y_{ij}\left(V_j - V_i\right) + y_{j0}V_j \tag{13}$$

Then, to calculate the complex power $S_{ij}$ from bus *i* to bus *j* and the complex power $S_{ji}$ from bus *j* to bus *i*, the following equations are used:

$$S_{ij} = V_i I_{ij}^* = V_i\left(V_i^* - V_j^*\right)y_{ij}^* + V_i V_i y_{i0}^* \tag{14}$$

$$S_{ji} = V_j I_{ji}^* = V_j\left(V_j^* - V_i^*\right)y_{ij}^* + V_j V_j y_{j0}^* \tag{15}$$

From equations 14 and 15, the magnitude of the power losses occurring in the transmission line can be determined, which is the algebraic sum of the two equations above, namely:

$$S_{Lij} = S_{ij} + S_{ji} \tag{16}$$

where:
$S_{Lij}$ = power losses in the transmission line (MW)
$S_{ij}$ = transmission line losses *i-j*
$S_{ji}$ = transmission line losses *j-i*

### B. *Short Circuit Analysis*

Short Circuit (SC) occurs when electric current flows through an inappropriate path, usually with very low resistance, causing a huge current surge. This condition can damage electrical equipment and even pose a fire risk. Short circuits are very dangerous in electrical systems because they can disrupt performance and safety. Disruptions in the electrical system that occur when electric current flows from the generator to the consumer are often known as short circuit disturbances. These disturbances can be divided into two main categories: symmetrical and asymmetrical. An example of a symmetrical disturbance is a three-phase symmetrical disturbance, while asymmetrical disturbances include single-phase-to-ground disturbances, phase-to-phase disturbances, and double-to-ground disturbances. The main cause of short circuit disturbances is overload, which leads to current surges and increased temperature, prompting the system's protective devices to cut off the current to prevent further damage.

Generally, short circuit current value in an electrical system can be calculated using the following formula:

**Three-Phase Short Circuit**

When a three-phase short circuit occurs involving all three phases, the magnitude of the three-phase fault current $I_{SC3}$ dapat can be calculated using the following formula:

$$I_{SC3} = \frac{V_{LN}}{X_1} \tag{17}$$

where $V_{LN}$ is the line-to-neutral voltage value and is the positive sequence reactance.

**Interphase Short Circuit**

This short circuit occurs when two phases are involved without being grounded. Magnitude of the inter-phase fault current $I_{SC2}$ can be calculated using the following formula:

$$I_{SC2} = \frac{V_{LL}}{X_1 + X_2} = \frac{\sqrt{3}V_{LN}}{2X_1} = \frac{\sqrt{3}}{2} I_{SC3} \approx 0.866\ I_{SC3} \tag{18}$$

where $V_{LL}$ is line-to-line voltage value and $X_2$ is negative sequence reactance.

**Single Phase Short Circuit to Ground**

This short circuit involves zero-sequence impedance. The magnitude of the single-phase ground fault current can be calculated using the following equation:

$$I_{SC0} = \frac{3V_{LN}}{X_0 + X_1 + X_2 + 3Z_G} \tag{19}$$

If the system uses solid grounding, then $Z_G = 0$

The short-circuit analysis will calculate the short-circuit current levels at each bus/substation in the system before and after the interconnection of the Solar Power Plant. This study was conducted during daytime loads when the solar power plant in the Rote system operates, with all system elements (generation and transmission units) in normal operating conditions, considering that this is the most conservative situation, according to IEC 60909. The purpose of the short-circuit analysis is to evaluate the increase in short-circuit current levels due to the interconnection of the SPP to the system. Figure 1 shows the curve characteristics of each short circuit current.

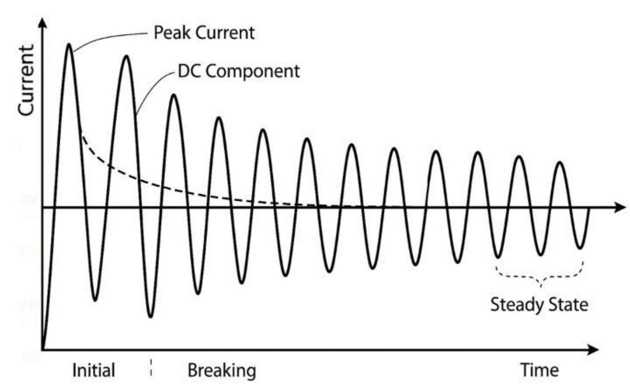


Figure 1 The curve characteristics of short circuit current

The short circuit analysis is based on several parameters, such as initial short circuit current (Ik''/Ikss), peak short circuit current (Ip), and steady-state short circuit current (Ik). The initial short circuit current is the RMS value of the symmetrical AC component of the potential short circuit current(available), which applies to the short circuit now if the impedance remains at the zero-time value. Peak short circuit current is The maximum instantaneous value of the potential (available) short circuit current. A steady state short circuit current is the RMS value of the short circuit current that remains after transient damping.

### *C. The standard for grid study*

In this study, the expected standard output of the research including:

- The voltage at each bus within the system is within the permissible limits as stipulated in the Electricity System Network Regulation (Minister of Energy and Mineral Resources Decree No. 2/2020) and the Electricity Distribution Regulation (Minister of Energy and Mineral Resources Decree No. 04/2009), which states that for 150 kV voltage, the operational voltage limits are +5% and -10%:
- Short circuit current value due to the entry of the solar power plant must not exceed the short-circuit capacity of the equipment in the system. All equipment in the 150 kV system is designed to withstand a current of 63 kA. With that current, the maximum short-circuit current that can be withstood is approximately 138 kA.

## III. SIMULATION AND RESULTS

This paper presents two case studies to examine the effects of integrating SPP into the Lombok 150 kV electrical system. Data were obtained from PT. PLN and also from paper [18]. This system comprises 13 buses, one swing bus, six generator buses, and nine loads. Figure 2 shows the single line diagram of the Lombok 150 kV electrical system. Table 1 shows the load and generation data for Lombok Power Systems (Peak Load), while Table 2 shows the line data of the systems. Certain data cannot be disclosed to the company due to its confidentiality. In addition, the total capacity of the SPP is 30 MW.

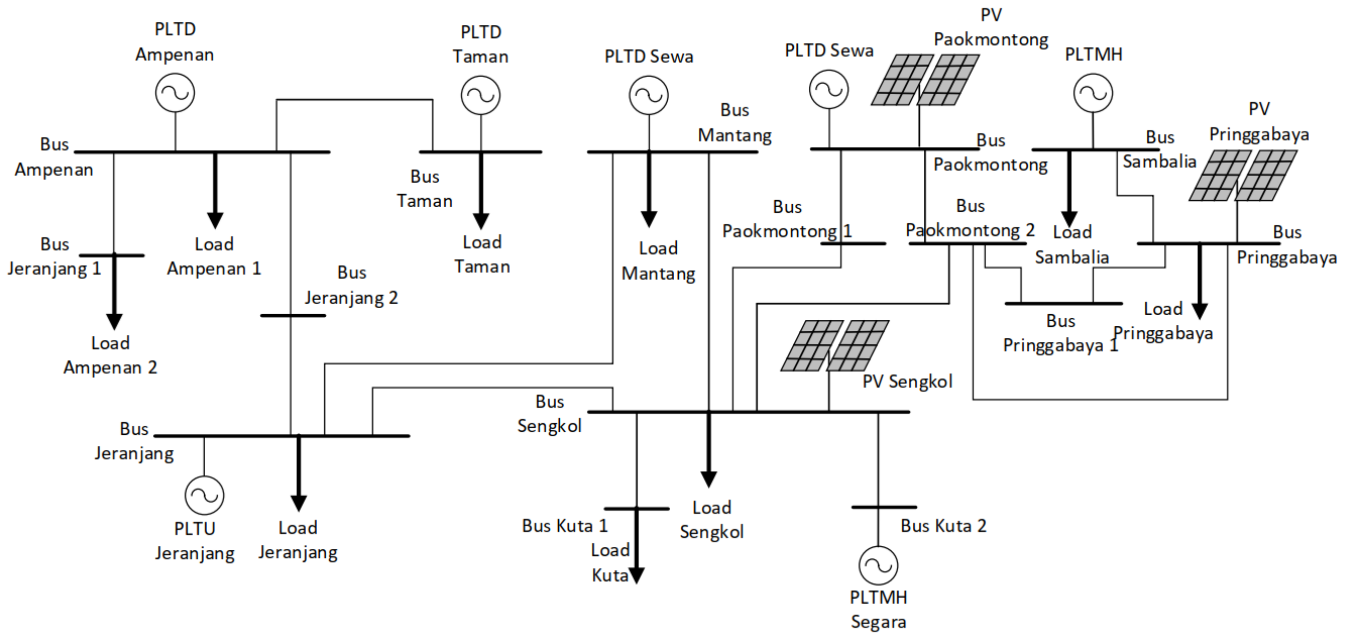

Figure 2. Single line diagram of Lombok 150 kV with SPP

Table 1. Generator and Load Data in Lombok kV

| Bus | Generation | | Load | |
|---|---|---|---|---|
| | P (MW) | Q (Mvar) | P (MW) | Q (Mvar) |
| Ampenan | 0 | 0 | 24.76 | 3.26 |
| Jeranjang | 0 | 0 | 46.19 | 9.68 |
| Jeranjang 1 | 0 | 0 | 34.11 | -10.46 |
| Jeranjang 2 | 0 | 0 | 0 | 0 |
| Kuta 1 | 0 | 0 | 3.9 | -0.14 |
| Kuta 2 | 0 | 0 | 0 | 0 |
| Mantang | 0 | 0 | -0.06 | -0.23 |
| Paokmotong | 0 | 0 | 0 | 0 |
| Paokmotong 1 | 0 | 0 | 0 | 0 |
| Paokmotong 2 | 0 | 0 | 0 | 0 |
| LV Paokmotong | 10 | 0 | 0 | 0 |
| Pringgabaya | 0 | 0 | 5.34 | 0.18 |
| Pringgabaya 1 | 0 | 0 | 0 | 0 |
| Pringgabaya 2 | 0 | 0 | 0 | 0 |
| LV Pringgabaya | 5.34 | 0 | 0 | 0 |


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| Bus | Generation | | Load | |
|---|---|---|---|---|
| | P (MW) | Q (Mvar) | P (MW) | Q (Mvar) |
| Sambalia 1 | 0 | 0 | 1.61 | 0.72 |
| Sambalia 2 | 0 | 0 | 0 | 0 |
| Sengkol | 0 | 0 | 5.35 | 6.38 |
| LV Sengkol | 10 | 0 | 0 | 0 |
| Taman | 0 | 0 | 3.22 | 4.59 |
| Ampenan Diesel Power Plant | 16.3 | 2.32 | 0 | 0 |
| Paokmotong Diesel Power Plant | 4.8 | 0.68 | 0 | 0 |
| Lease Diesel Power Plant | 66.6 | 9.49 | 0 | 0 |
| Taman Diesel Power Plant | 2 | 0.28 | 0 | 0 |
| Micro Hydro Power Plant | 2.3 | 0 | 0 | 0 |
| Segara Micro Hydro Power Plant | 0.64 | 0.09 | 0 | 0 |
| Jeranjang Steam Power Plant | 33.89 | 6.75 | 0 | 0 |

Table 2. Line Data in Lombok

| Line | R (ohm) | X (ohm) | Length (km) |
|---|---|---|---|
| Ampenan – Jeranjang 1 | 1.42009 | 2.9015 | 3.5 |
| Ampenan – Jeranjang 2 | 3.04305 | 6.2175 | 7.5 |
| Ampenan – Taman | 2.069274 | 4.2279 | 5.1 |
| Jeranjang 1 – Jeranjang 2 | 1.42009 | 2.9015 | 3.5 |
| Mantang - Jeranjang | 14.60664 | 29.844 | 36 |
| Paokmotong – Paokmotong 2 | 0.933202 | 1.9067 | 2.3 |
| Paokmotong – Pringgabaya 1 | 7.262746 | 14.8391 | 17.9 |
| Paokmotong – Pringgabaya 2 | 7.262746 | 14.8391 | 17.9 |
| Paokmotong1 – Paokmotong | 1.01435 | 2.0725 | 2.5 |
| Pringgabaya - Pringgabaya 1 | 0.5274619 | 1.0777 | 1.3 |
| Pringgabaya - Pringgabaya 2 | 0.568036 | 1.1606 | 1.4 |
| Pringgabaya – Sambalia 1 | 6.0861 | 12.435 | 15 |
| Pringgabaya – Sambalia 2 | 6.0861 | 12.435 | 15 |
| Sengkol - Jeranjang | 16.29695 | 33.29762 | 40.166 |
| Sengkol – Kuta 1 | 4.787732 | 9.7822 | 11.8 |
| Sengkol – Kuta 2 | 4.787732 | 9.7822 | 11.8 |
| Sengkol - Mantang | 13.02425 | 26.6109 | 32.1 |
| Sengkol – Paokmotong 1 | 15.78329 | 32.2841 | 38.9 |
| Sengkol – Paokmotong 2 | 15.78329 | 32.2841 | 38.9 |

The first case study will conduct a load flow analysis to see the steady-state voltage response of the system after the SPP is installed. The second case study observes how the total fault current appears after the solar power plant is installed in the existing system. The third case study is a transient analysis. In this case, we can see Bali's performance in the transient domain.

### *A. Load Flow Analysis*

In this case, a comparison was made of the voltage levels on the 150 kV Bus before and after installing the SPP in the Lombok system. This study assesses the safety of installing solar power plants (SPP) in the Lombok electrical system. Table 1 compares the system's steady-state voltage before and after the installation of the SPP.

Table 3. Voltage Profile on bus 150 kV

| Name of Bus | Before SPP (kV) | After SPP (kV) | Name of Bus | Before SPP (kV) | After SPP (kV) |
|---|---|---|---|---|---|
| Ampenan | 147.33 | 147.97 | Paokmotong 2 | 148.38 | 150.41 |
| Jeranjang | 147.92 | 148.56 | Pringgabaya | 148.25 | 150.41 |
| Jeranjang 1 | 147.20 | 147.84 | Pringgabaya 1 | 148.26 | 150.41 |
| Jeranjang 2 | 147.73 | 148.37 | Pringgabaya 2 | 148.26 | 150.41 |
| Kuta 1 | 148.07 | 149.43 | Sambilia 1 | 148.29 | 150.44 |
| Kuta 2 | 148.22 | 149.58 | Sambilia 2 | 148.25 | 150.41 |
| Mantang | 149.91 | 149.88 | Sengkol | 148.19 | 149.54 |
| Paokmotong | 148.42 | 150.47 | Taman | 147.15 | 148.79 |
| Paokmotong 1 | 148.41 | 150.41 | | | |

From the simulation results, it is known that there is an increase in the voltage profile at the 150 kV buses in the Lombok electrical system. This voltage increase occurs due to the additional active power provided by the SPP. This additional power causes the system to experience a reduction in power losses. So that the load can receive power more optimally. However, this increase in voltage profile does not violate the limits set by the Ministry of Energy and Mineral Resources through its grid code.

Table 4. Generator Active Power

| Name of Generator | Before PV Connected | | | After PV Connected | | |
|---|---|---|---|---|---|---|
| | P (MW) | Q (MVar) | % | P (MW) | Q (MVar) | % |
| Jeranjang SP | 33.89 | 6.75 | 59.50 | 14.63 | 14.92 | 36.20 |
| Taman DPP | 2.00 | 0.28 | 30.50 | 2.00 | 0.28 | 30.50 |
| Paokmotong DPP | 4.80 | 0.68 | 40.40 | 4.80 | 0.68 | 40.40 |
| Ampenan DPP | 16.30 | 2.34 | 40.40 | 16.30 | 2.34 | 40.40 |
| Lease DPP | 66.60 | 9.49 | 40.40 | 66.60 | 9.49 | 40.40 |
| Segara MHPP | 0.64 | 0.09 | 40.40 | 0.64 | 0.09 | 40.40 |
| MHPP | 2.30 | 0.00 | 70.50 | 2.30 | 0.00 | 70.50 |

Table 4 shows each generator's active and reactive power and loading percentages before and after the integration of SPP. The results show that when SPP is integrated into the system, the loading percentages of the Jeranjang steam power plant are reduced. Only the Jeranjang steam power plant reduces the loading percentage because the Jeranjang is the slack bus. From these results, it is noticeable that adding SPP could reduce the stress of the Jeranjang steam power plant if the uncertainty is not considered.

### *B. Short Circuit Analysis*

In this section, an analysis will be conducted on the total short-circuit current on the 150 kV bus after installing the SPP into the existing system. The Lombok system will be subjected to two types of disturbances: the first is a single-phase-to-ground fault, and the second is a three-phase-to-ground fault. These disturbances are selected because single-phase ground faults often occur in the field, while three-phase ground faults significantly affect the system. Tables 3 and 4 show the short circuit currents due to single-phase and three-phase-to-ground faults.


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Table 5. Short Circuit Current Due to a Single Phase to Ground Fault

| Cubicle ID | Breaking Capacity Ik" (kA) | Before PV Connected | | | After PV Connected | | | Increase in Ik" |
|---|---|---|---|---|---|---|---|---|
| | | Ik" (kA) | Ip (kA) | Ik (kA) | Ik" (kA) | Ip (kA) | Ik (kA) | |
| Ampenan | 138 | 3.70 | 8.36 | 3.70 | 3.70 | 8.36 | 3.70 | 0.000446 |
| Jeranjang | 138 | 4.57 | 10.71 | 4.57 | 4.57 | 10.71 | 4.57 | 0.000973 |
| Jeranjang 1 | 138 | 3.30 | 7.24 | 3.30 | 3.30 | 7.24 | 3.30 | 0.000351 |
| Jeranjang 2 | 138 | 4.23 | 9.72 | 4.23 | 4.23 | 9.72 | 4.23 | 0.000747 |
| Kuta 1 | 138 | 2.45 | 4.96 | 2.45 | 2.46 | 4.96 | 2.46 | 0.001710 |
| Kuta 2 | 138 | 2.47 | 5.01 | 2.47 | 2.47 | 5.01 | 2.47 | 0.001714 |
| Mantang | 138 | 5.50 | 13.76 | 5.50 | 5.50 | 13.76 | 5.50 | 0.001210 |
| Paokmotong | 138 | 2.25 | 4.61 | 2.25 | 2.25 | 4.62 | 2.25 | 0.002827 |
| Paokmotong 1 | 138 | 2.24 | 4.57 | 2.24 | 2.24 | 4.57 | 2.24 | 0.002689 |
| Paokmotong 2 | 138 | 2.25 | 4.59 | 2.25 | 2.25 | 4.60 | 2.25 | 0.002779 |
| Pringgabaya | 138 | 1.88 | 3.77 | 1.88 | 1.89 | 3.77 | 1.89 | 0.002200 |
| Pringgabaya 1 | 138 | 1.88 | 3.77 | 1.88 | 1.89 | 3.77 | 1.89 | 0.002183 |
| Pringgabaya 2 | 138 | 1.88 | 3.77 | 1.88 | 1.89 | 3.77 | 1.89 | 0.002181 |
| Sambilia 1 | 138 | 1.51 | 2.96 | 1.51 | 1.51 | 2.96 | 1.51 | 0.001383 |
| Sambilia 2 | 138 | 1.48 | 2.88 | 1.48 | 1.48 | 2.88 | 1.48 | 0.001372 |
| Sengkol | 138 | 3.39 | 7.25 | 3.39 | 3.39 | 7.26 | 3.39 | 0.003214 |
| Taman | 138 | 3.19 | 6.95 | 3.19 | 3.19 | 6.95 | 3.19 | 0.000317 |
| Maximum Increase in Ik” | | | | | | | | 0.028298 |

Table 6. Short Circuit Current Due to a Three-Phase to Ground Fault

| Cubicle ID | Breaking Capacity Ik" (kA) | Before PV Connected | | | After PV Connected | | | Increase in Ik" |
|---|---|---|---|---|---|---|---|---|
| | | Ik" (kA) | Ip (kA) | Ik (kA) | Ik" (kA) | Ip (kA) | Ik (kA) | |
| Ampenan | 138 | 3.28 | 7.41 | 3.28 | 3.28 | 7.41 | 3.28 | 0 |
| Jeranjang | 138 | 3.99 | 9.36 | 3.99 | 3.99 | 9.36 | 3.99 | 0 |
| Jeranjang 1 | 138 | 2.96 | 6.50 | 2.96 | 2.96 | 6.50 | 2.96 | 0 |
| Jeranjang 2 | 138 | 3.72 | 8.55 | 3.72 | 3.72 | 8.55 | 3.72 | 0 |
| Kuta 1 | 138 | 2.29 | 4.62 | 2.29 | 2.29 | 4.62 | 2.29 | 0 |
| Kuta 2 | 138 | 2.30 | 4.66 | 2.30 | 2.30 | 4.66 | 2.30 | 0 |
| Mantang | 138 | 4.73 | 11.84 | 4.73 | 4.73 | 11.84 | 4.73 | 0 |
| Paokmotong | 138 | 2.09 | 4.27 | 2.09 | 2.09 | 4.27 | 2.09 | 0 |
| Paokmotong 1 | 138 | 2.08 | 4.24 | 2.08 | 2.08 | 4.24 | 2.08 | 0 |
| Paokmotong 2 | 138 | 2.08 | 4.26 | 2.08 | 2.08 | 4.26 | 2.08 | 0 |
| Pringgabaya | 138 | 1.76 | 3.53 | 1.76 | 1.76 | 3.53 | 1.76 | 0 |
| Pringgabaya 1 | 138 | 1.76 | 3.53 | 1.76 | 1.76 | 3.53 | 1.76 | 0 |
| Pringgabaya 2 | 138 | 1.76 | 3.53 | 1.76 | 1.76 | 3.53 | 1.76 | 0 |
| Sambilia 1 | 138 | 1.43 | 2.80 | 1.43 | 1.43 | 2.80 | 1.43 | 0 |
| Sambilia 2 | 138 | 1.41 | 2.74 | 1.41 | 1.41 | 2.74 | 1.41 | 0 |
| Sengkol | 138 | 3.07 | 6.58 | 3.07 | 3.07 | 6.58 | 3.07 | 0 |
| Taman | 138 | 2.87 | 6.25 | 2.87 | 2.87 | 6.25 | 2.87 | 0 |
| Maximum Increase in Ik” | | | | | | | | 0 |

The table shows an increase in short-circuit current in Ik, Ik", and Ip. This occurs because the solar power plant uses an additional transformer to raise the voltage to 150 kV. This additional transformer creates an extra short-circuit current in the system. For PV plants, because the inverter has no impedance, the PV plant does not provide short-circuit current to the system. The short-circuit current provided by the SPP is the same as that provided by the transformer. However, the increase in short-circuit current is relatively small and does not exceed the maximum short-circuit current limit of 150 kV equipment, around 138 kA. Therefore, it can be concluded that integrating solar power plants (SPP) will not significantly impact the breaking capacity of equipment at the 150 kV voltage level. Therefore, there is no need to replace equipment when the solar power plant is installed in the Lombok 150 kV electrical system.

### *C. Transient Stability Analysis*

In this section, the transient response of Lombok power systems is investigated. This assessment aims to investigate the stability of Lombok power systems due to the integration of SPP in a transient domain. Bus Ampenan is used to investigate the transient response of Lombok power systems. The load flow analysis shows that this bus has the lowest voltage compared to other buses. Increasing the load capacity on one load by up to 20% is carried out to excite the transient response of Lombok



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power systems. Frequency and voltage response are used to investigate the transient stability of Lombok power systems. Figs 3 and 4 show the transient response of Ampenan frequency and voltage.

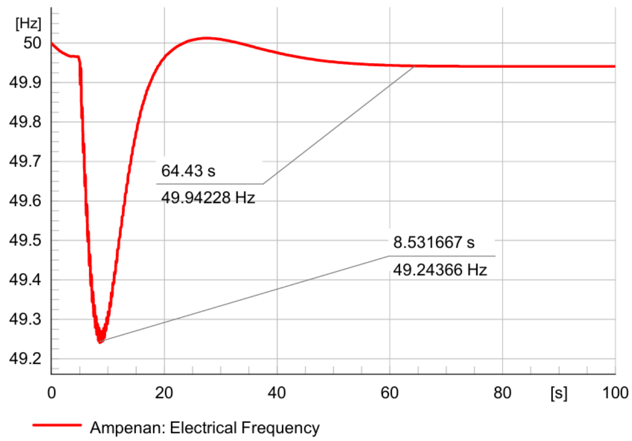

Figure 3. Ampenan frequency transient response

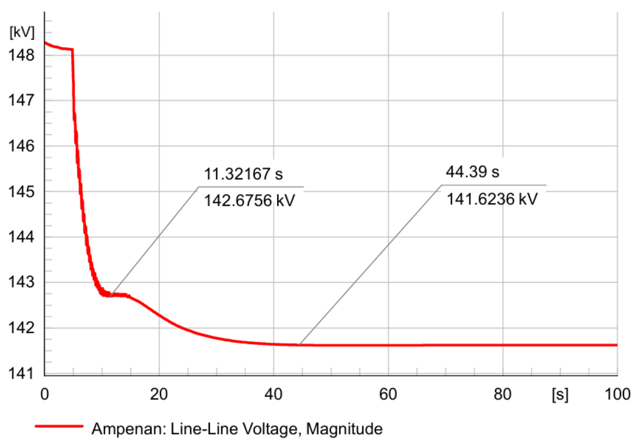

Figure 4. Ampenan voltage transient response

From the results, it is noticeable that when there is a disturbance in the system, both frequency and voltage experience undershoot. However, the undershoot is still above the minimum standard from ESDM (the frequency overshoot is around 0.76 Hz while the voltage is around 7.32 volt). Hence, it can be stated that although the SPP is installed in the Lombok systems, the Lombok system is still robust enough to handle the transient disturbance. Furthermore, the dynamic response of the reference power plant need to be investigate to analysed how the response of the reference power plant against the disturbance. Fig 5 and 6 shows the active and reactive power transient response of reference power plant due to the increasing load capacity. It is found that the power plant increase their active and reactive power to control the frequency and the voltage of the systems.

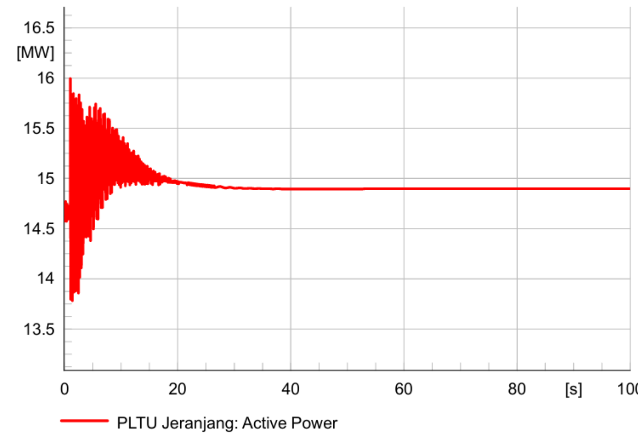

Figure 5. PLTU Jeranjang active power transient response

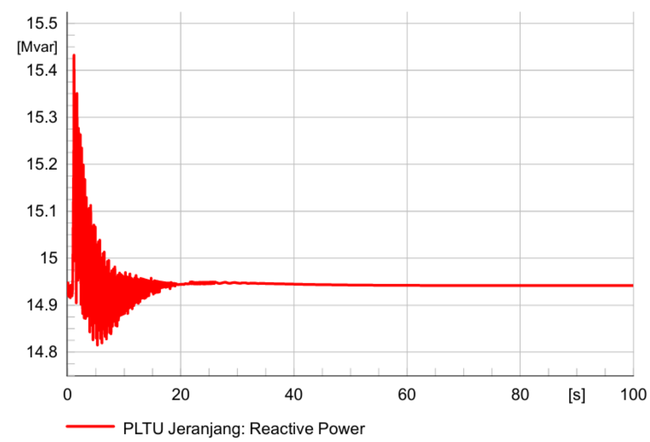

Figure 6. PLTU Jeranjang reactive power transient response

For further clarification, another disturbance can be emulated to the system. The disturbance that will be emulated to the system is a generator trip. The generator that will be trip is PLTD Ampenan. Fig 7 shows the frequency response of Lombok power systems, while Fig 8 shows the voltage response of Lombok power systems. The results show that the overshoot that emerges in the system is still achieving the ESDM standard (the frequency undershoot is around 0.83 Hz while the voltage is around 11 volt). Hence, it can be stated that the integration of SPP does not significantly affect the system performance since the system is quite large. Furthermore, the dynamic response of the reference power plant need to be investigate to analysed how the response of the reference power plant against the disturbance. Fig 9 and 10 shows the active and reactive power transient response of reference power plant due to the increasing load capacity. It is found that the power plant increase their active and reactive power to control the frequency and the voltage of the systems.



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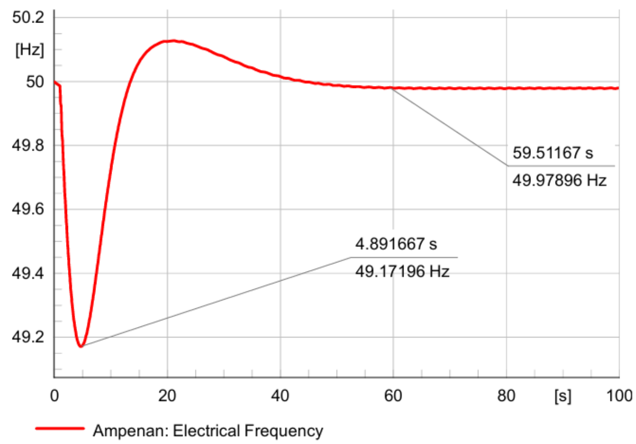


Figure 7. Ampenan frequency transient response due to the generator outage

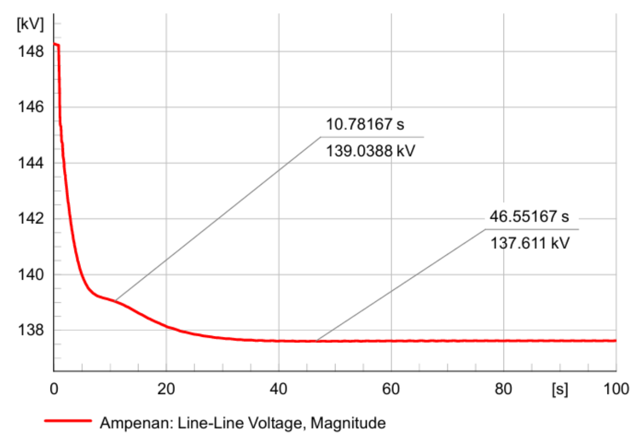


Figure 8. Ampenan voltage transient response due to the generator outage

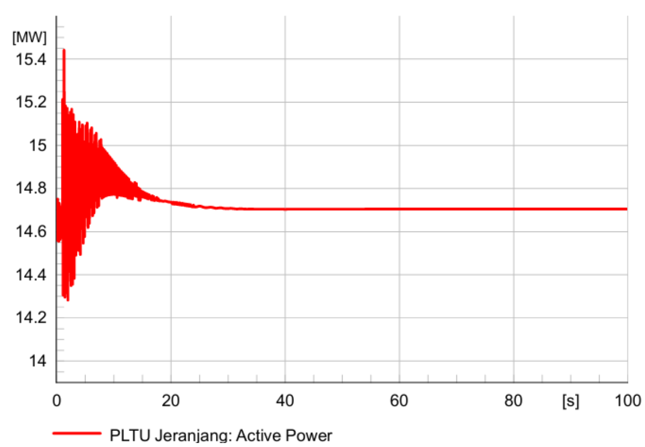


Figure 9. PLTU Jeranjang active power transient response due to the generator outage

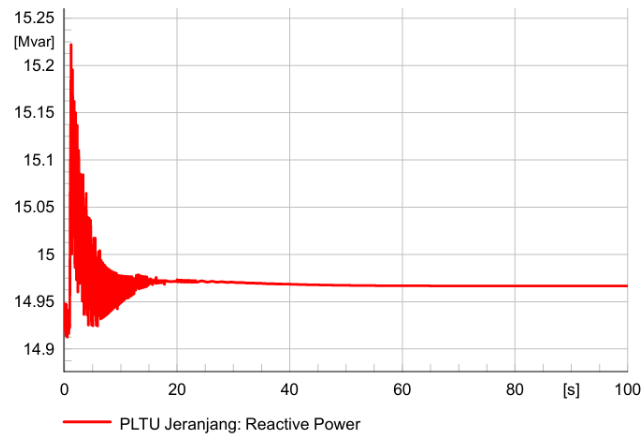


Figure 10. PLTU Jeranjang reactive power transient response due to the generator outage

## IV. CONCLUSION

This paper discusses the impact study of installing solar power plants (SPP) on the Lombok electrical system. This paper aims to analyze whether the installation of SPP may affect the operation of the Lombok 150 kV electrical system. Power flow, short circuit, and transient studies were used as case studies to see how the installation of SPP affects the 150 kV Lombok electrical system. From the simulations conducted, it was found that the addition of SPP to the Lombok electrical system does not adversely affect its operation. These findings are evident from the steady-state voltage levels at each 150 kV bus in the Lombok electrical system, which remain within the permitted operational range (±5%). In addition, the short-circuit current that arises from the addition of the SPP is still below the breaking capacity of the 150 kV level equipment. Thus, it can be concluded that the Lombok system will operate normally in steady-state conditions when the SPP is integrated into the existing system. In addition, it is noticeable that both frequency and voltage transient responses are still achieving the ESDM standard (the frequency overshoot is around 0.76-0.83 Hz while the voltage is around 7.32-11 volt). Further research needs to be done on other devices that can enhance the transient performance of Lombok Power Systems.

## ACKNOWLEDGMENT

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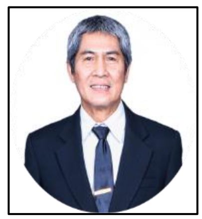
**Fakhrudin Azhar, ST.,** was born in Gresik on December 22, 1990. He graduated with a Bachelor’s in Electrical Engineering from the Faculty of Industrial Technology at Institut Teknologi Sepuluh Nopember Surabaya in 2013. He is a candidate for a Master's Degree in the Department of Electrical Engineering at the University of Indonesia, Depok, Indonesia, focusing on power systems and intelligent systems.

**Fauzan H. Jufri** earned his Bachelor's degree in Electrical Engineering from Universitas Indonesia, Indonesia, in 2008, Master's degree in Energy Systems Research from Ajou University, Korea, in 2018, and Doctoral degree in Electrical Engineering from Universitas Indonesia, Indonesia, in 2023.
He is a senior researcher at Universitas Indonesia, focused on design, modeling and simulation for power system protection, control, and stability. His research interests include the development and deployment of advanced and intelligent power system infrastructures.



**Iwa Garniwa MK** earned his Bachelor’s, Master’s, and Doctoral degree in Electrical Engineering from Universitas Indonesia, Indonesia. He is currently a professor at the Department of Electrical Engineering, Universitas Indonesia.He has contributed in various research projects related to energy and power system in Indonesia. His research interests include the power quality, high voltage engineering, and renewable energy deployment.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