Jurnal Teknologi Elekterika, 2025, Volume 22 (1): 21-27 e-ISSN 2656-0143

# OPTIMIZATION OF SLACK BUS PLACEMENT DURING PEAK LOAD BY CONSIDERING THE VOLTAGE PROFILE OF THE GENERATION BUS IN THE SULSELRABAR ELECTRICITY SYSTEM

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***Abstract***

*This study was carried out to determine the best slack bus placement during peak loads by considering the voltage profile of the generator buses in the South Sulawesi electricity system. Analysis was performed to determine the optimal slack bus placement and its impact on the bus voltage profile. South Sulawesi's electric power system is made up of 29 power-generating units, including PLTA, PLTU, PLTG, PLTGU, PLTMH, PLTD, and PLTB, that operate at a voltage of 150 kV. In addition, 56 substations are linked via a 150 kV transmission network. This study relies on daily operational data from the South Sulawesi system at peak load on September 16, 2022. Using Matlab's Newton-Raphson method to simulate power flow, five scenarios are used to alternately change the generator bus (PV bus) into a slack bus; the generators are PLTA Bakaru, Punagaya PLTU, Jeneponto PLTU, Sengkang PLTU, and Poso PLTA. After running simulations for each generator, it was discovered that Poso PLTA had the voltage profile closest to the standard set by the Minister of Energy and Mineral Resources Regulation number 20 of 2020, which ranges between 0.90 and 1.05 pu. In comparison to the other four slack buses, it had the lowest total power loss of 120,743 MW and 593,764 MW MVAR.*

***Keywords:*** *Slack Deployment Bus, Bus Voltage Profile, Power Flow Simulation, SULSELRABAR Electrical System, Poso Hydroelectric Power Plant*

## I. INTRODUCTION

South Sulawesi's electricity system is large, with 56 buses. The Sulselrabar system is extremely complicated and interconnected from the generating center (PV Bus) to the load center (PQ Bus). In a PV electric power system, a bus can serve as a slack bus (reference bus), which is a bus that contains a generator or generators with the highest capacity among the other generators in the system. Special criteria must be met to select a Slack bus [1] [2].

Slack buses in interconnected systems have a significant impact on the electrical power system's reliability. As a result, careful consideration must be given to the selection of the slack bus to stabilize the system during disturbance conditions, where the slack bus is capable of providing the necessary power.[3].The voltage profile of the generator bus has a significant impact on the effective placement of slack buses in an electric power system. When the Slack Bus is connected to the appropriate generator, it will ensure system continuity and stability [4] [5].

By optimizing the slack bus, the system can deal with disturbances and instability during peak loads, allowing it to operate steadily even when load changes occur [6]. As a result, this study will simulate the optimal placement of slack buses at peak load while taking into account the voltage profile of the generator bus.

## II. LITERATURE REVIEW

### A. Electric Power Systems

The Electric Power System consists of a generating center and a load center connected by a transmission and distribution network to form an interconnected system [7]. Electrical energy is generated by generating canters such as PLTA, PLTU, PLTG, PLTGU, PLTB and PLTS. Then the electrical energy will be transmitted and distributed to load centers [8].

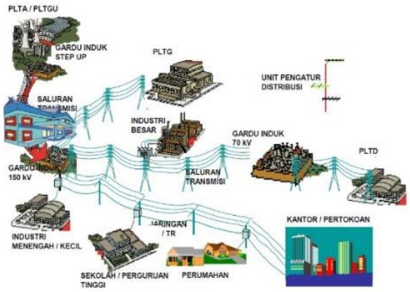



Figure 1. Electric Power Systems

## B. South Sulawesi Electric Power System

Several studies have been carried out on the South Sulawesi electric power system which covers the South, Southeast, and West Sulawesi regions in Indonesia. To improve the stability of interconnected systems, operational efficiency, and stability are of great concern. In-depth analysis needs to be carried out to ensure the reliability and stability of the system as it develops [9].

South Sulawesi's large electricity system requires electricity providers to make efforts to maintain system continuity and stability. Several efforts have been made, such as increasing generating capacity, adding transmission and distribution networks, and improving substation systems and equipment quality. Apart from that, choosing the right slack bus placement can help the stability of the power system[10] [11].

The stability of South Sulawesi's electricity system is the focus of research. Simulated computing systems are a way to see how system stability increases, this shows how advanced computing methods can be used to improve power system stability performance [9] [12].

## C. Classification of Electric Power System Buses

The electric power system states that every electric power system has a module or bus, which accommodates the power flow process which includes the angle and magnitude of the potential difference, active and reactive power flow, and everything necessary for process stability. Based on these objectives, there are three types of buses used in the operation of the Electric Power System, namely Generation Bus (PV bus), Load Bus (PQ bus), and Reference Bus (slack bus)[13].

1. Generator Bus (PV Bus)
   The voltage bus, also called the generator bus or PV bus, has active power whose power can be controlled by setting the prime mover and has a constant voltage. The phase angle and the amount of reactive power must be considered because only the voltage and active power are known[14].
2. Load Bus (PQ Bus)
   In an electric power system, a bus with known active power (P) and reactive power (Q) is called the PQ bus or load bus. The load, or final stage, of an electric power system is represented by this bus. The PQ bus has active power (P) and reactive power (Q) as its parameters. In power flow analysis, the size of the load installed on the bus determines how much power flows[14].
3. Slack Bus
   The term "slack bus" can be used to refer to any number of bus generators (PV Bus). The slack bus can be used to supply active (P) and reactive (Q) power shortages in the system. The best method for identifying slack buses is to analyze daily operating data from each bus that may be identified as a slack bus[14].

## D. Voltage Profile

When load conditions change or the power system experiences power losses, the voltage profile shows the voltage at nominal voltage. The voltage must remain within the standard 0.95 – 1.05 pu. This means that if the voltage is lower than 0.95 pu, it is considered low voltage, while if it is higher than 1.05 pu, it is considered overvoltage [15].

Minister of Energy and Mineral Resources Regulation number 20 of 2020 applies that the voltage on 70 kV and 150 kV systems must be maintained at +5% and -10% of the nominal system voltage[16].

## E. Power Flow Study

Power flow is a calculation for calculating current, active power, voltage, and reactive power in the distribution of an electric power system. Current electric power network system problems can be resolved or overcome by conducting a power flow analysis. This problem is caused by several different things, and of course, has different approaches[17].

There are 4 methods used in calculating power flow, namely:

Gauss Seidel, The Gauss-Seidel method is used to solve systems of linear equations. The latest values of other variables are used to calculate the new value of each variable at each iteration. Although this method is easy and simple to implement, convergence is slow and not always guaranteed for all types of systems[9] [18].

Decoupled, the power flow equations are broken down into two simpler sets using the Decoupled approach, one for the voltage angle and one for the voltage magnitude. Compared with Newton Raphson, this method has lower computational complexity but lower accuracy[18].

Fast Decoupled, Fast Decoupled is a variation of the Decoupled strategy that is more effective by speeding up convergence. Although assumptions can reduce errors in some situations, this method is very efficient in terms of the amount of computing time spent and memory used [2] [19].

Newton Rapshon, Newton Raphson's method is a calculation that solves non-linear equations from a single starting point. When compared with other methods, the Newton-Raphson method will be more effective and practical for large-scale electric power systems because it requires fewer iterations than other methods.[20].

In this research, the Newton-Raphson method is used to calculate the power flow of a large system.

The steps for completing the power flow using the Newton-Raphson method are:

1. Line impedance is converted to admittance with the equation

$$y_i = \frac{1}{Z_i} = \frac{1}{R + jX} = \left(\frac{R}{R^2 + X^2}\right) + j\left(\frac{-X}{R^2 + X^2}\right) \quad (2.1)$$

2. Arranging the Y bus Matrix

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} = \begin{bmatrix} Y_{11} & -Y_{12} & -Y_{13} \\ -Y_{21} & Y_{22} & -Y_{23} \\ -Y_{31} & -Y_{32} & Y_{33} \end{bmatrix} \quad (2.2)$$

3. Calculate active power on buses 2 and 3 and reactive power on bus 2. (Initial voltage estimation$V_2^{(0)} = 1.0 + j0.0$)

$$P_i\& = \sum_{j=1}^{n} |V_2||V_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (2.3)$$

$$Q_2\& = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (2.4)$$

4. Constructing the Jacobian Matrix [J] The Jacobian matrix consists of the partial derivatives of P and Q with respect to each variable. The magnitude and phase angle of the voltage ($\delta j$) assumed as well as active power ($Pi$) and reactive power ($Qi$) which is calculated to obtain the elements of the Jacobian. After that, the value of the change in voltage $\Delta|$ will be obtained$Vi|$, and changes in voltage phase angle ($\Delta\delta j$). The following is the matrix form of the Jacobian.

$$[J] = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_4} & \frac{\partial P_2}{\partial |V|_2} & \cdots & \frac{\partial P_2}{\partial |V|_4} \\ \vdots & J_{11} & \vdots & \vdots & J_{12} & \vdots \\ \frac{\partial P_4}{\partial \delta_2} & \cdots & \frac{\partial P_4}{\partial \delta_4} & \frac{\partial P_4}{\partial |V|_2} & \cdots & \frac{\partial P_4}{\partial |V|_4} \\ \frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_4} & \frac{\partial Q_2}{\partial |V|_2} & \cdots & \frac{\partial Q_2}{\partial |V|_4} \\ \vdots & J_{21} & \vdots & \vdots & J_{22} & \vdots \\ \frac{\partial Q_4}{\partial \delta_2} & \cdots & \frac{\partial Q_4}{\partial \delta_4} & \frac{\partial P_4}{\partial |V|_2} & \cdots & \frac{\partial Q_4}{\partial |V|_4} \end{bmatrix} \quad (2.5)$$

Where,

- Off-diagonal element type from J11

$$\frac{\partial P_i}{\partial \delta_j} = -\left| Y_{ij} V_i V_n \right| \sin(\theta_{in} + \delta_n - \delta_i)$$

- Diagonal type element from J11

$$\frac{\partial P_i}{\partial \delta_i} = \Sigma_{\substack{n=1 \\ n\neq 1}}^{N} \left|Y_{ij} V_i V_n\right| \sin(\theta_{in} + \delta_n - \delta_i) = \sum_{\substack{n=1 \\ n\neq 1}}^{N} \frac{\partial P_i}{\partial \delta_n}$$

- Off-diagonal element type from J21

$$\frac{\partial P_i}{\partial |V_j|} = \left| Y_{ij} V_i \right| \cos(\theta_{in} + \delta_n - \delta_i)$$

- Diagonal type element of J21

$$\frac{\partial P_i}{\partial |V_j|} = 2|V_i|G_{ii} + \Sigma_{\substack{n=1 \\ n\neq 1}}^{N} \left| Y_{ij} V_n \right| \cos(\theta_{in} + \delta_n - \delta_i)$$

- Off-diagonal type element of J12

$$\frac{\partial Q_i}{\partial \delta_j} = -\left| Y_{ij} V_i V_n \right| \cos(\theta_{in} + \delta_n - \delta_i)$$

- Diagonal type of element J12

$$\frac{\partial Q_i}{\partial \delta_i} = \Sigma_{\substack{n=1 \\ n\neq 1}}^{N} \left|Y_{ij} V_i V_n\right| \cos(\theta_{in} + \delta_n - \delta_i) = -\sum_{\substack{n=1 \\ n\neq 1}}^{N} \frac{\partial Q_i}{\partial \delta_n}$$

- Off-diagonal type of element J22

$$\frac{\partial Q_i}{\partial |V_j|} = \left| Y_{ij} V_i \right| \cos(\theta_{in} + \delta_n - \delta_i)$$

- Diagonal type of element J22

$$\frac{\partial Q_i}{\partial |V_j|} = 2|V_i|B_{ii} + \Sigma_{\substack{n=1 \\ n\neq 1}}^{N} \left| Y_{ij} V_n \right| \cos(\theta_{in} + \delta_n - \delta_i)$$

5. Load and generator in units:

$$S_2^{sch} = -\frac{P + jQ}{Nb} ..pu$$
$$P_3^{sch} = \frac{Vn}{Vb} = ..pu \quad (2.6)$$

6. Remaining power (residual power)

$$\Delta P_i^{(k)} = P_i^{sch} - P_i^{(k)}$$
$$\Delta Q_i^{(k)} = Q_i^{sch} - Q_i^{(k)} \quad (2.7)$$

7. Repeat steps 4 to 6, until required $\epsilon$ fulfilled
   The above process is called iteration, where this process will continue to repeat until the power is active ($\Delta Pi$) and reactive power ($\Delta Qi$) has reached the predetermined convergent value. In general, the convergent value ranges from 0.01 to 0.0001

## III. RESEARCH METHODS

MATLAB is used to simulate the Slack Bus selection procedure that is being investigated in this study. The procedure is broken down into several steps, the first of which is coding all types of buses. The purpose of this step is to ensure that all types of buses are coded in the program that will be executed in MATLAB. One goes to the Slack Bus, two to the PV Bus, and three to the PQ Bus. This code simplifies MATLAB power flow processing. Second, read the bus type to see if the photovoltaic bus with code 1 has the most generating power. After selecting each PV bus, MATLAB will calculate power flow. Step 3 displays power flow analysis results. Each generator selected as the Slack Bus will reveal its power flow, voltage profile, and power losses in this step. After that, the results will be transferred into software to simplify analysis. In light of the fact that some earlier studies did not address the topic of daily peak load data, this investigation makes use of daily load operation data from the SULSELRABAR system. For the purpose of this study, the data that was examined were the peak load data from Friday, September 16, 2022.

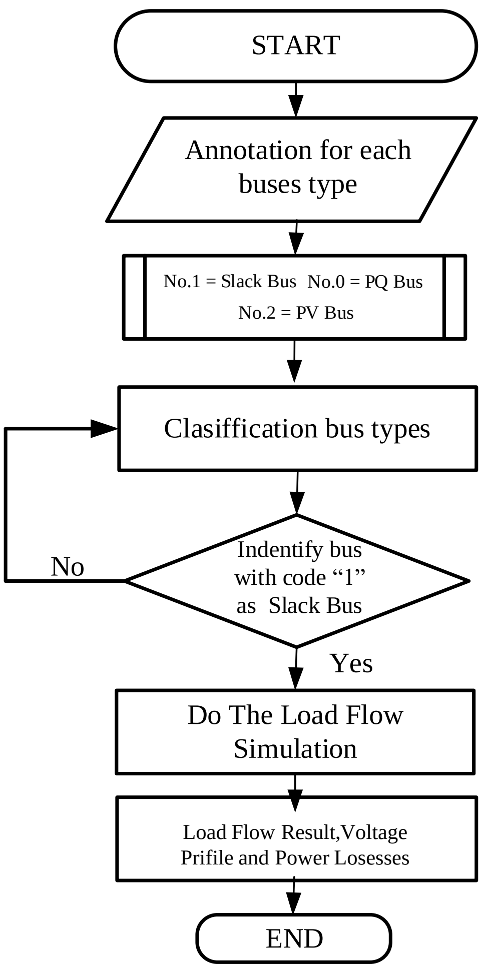



Figure 2. Slack Bus Selection Process

## IV. RESULTS AND DISCUSSION

### A. Voltage Profile Simulation

To get the best Voltage Profile in the South Sulawesi electricity system, five generator selection scenarios (PV Bus) were carried out to be used as slack buses. The generator selected to be a slack bus candidate is the generator with the largest generating capacity. The power plants are PLTA Bakaru 126 MW, PLTU Punagaya 203.94 MW, PLTU Jeneponto 433.58 MW, PLTGU Sengkang 281 MW, PLTA Poso 512.5 MW. Of the five selected generators, a power flow simulation was carried out at each generator, and the result of the simulation was the voltage profile of each bus in pu values

Figure 3 shows the simulation results for the five slack bus candidates. According to the simulation for buses 40 and 55, the slack bus candidates Bakaru, Punagaya, Jeneponto, and Sengkang have very small voltage drops from the nominal voltage value. Meanwhile, the Poso slack bus has a consistent voltage on each bus, making the Poso PLTA the ideal slack bus candidate. In comparison to the other four power plants, Poso PLTA's voltage profile is closest to the ESDM Ministerial Regulation Number 20 of 2020 standards of +5 percent and -10 percent of the nominal system voltage.

When the system was operating under peak load conditions, the voltage profile on the 56 system buses was 0.90 - 1.05 p.u. when the Poso PLTA was selected as the best slack bus. This was in comparison to the voltage profiles from the other four candidates for the slack bus.

### B. Selected Slack Bus Power Losses Results

According to the findings of this study, the total power loss value will be relatively low if the voltage profile is in a stable condition and is relatively close to the nominal voltage value. Specifically, as shown in Figure 4. For the Poso slack bus, the results of the smallest power loss are 120,743 megawatts and 593,764 megavolt-ampere-hours. This is directly proportional to the results of the voltage profile, where the Poso slack bus also has a voltage profile value for each bus that is stable and at the standard that was determined beforehand.

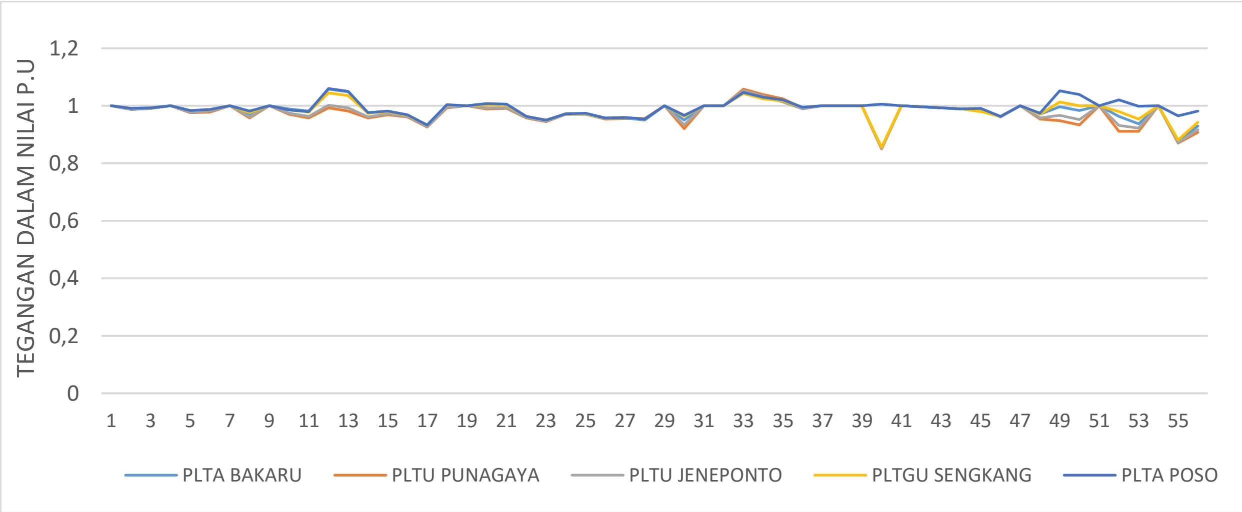
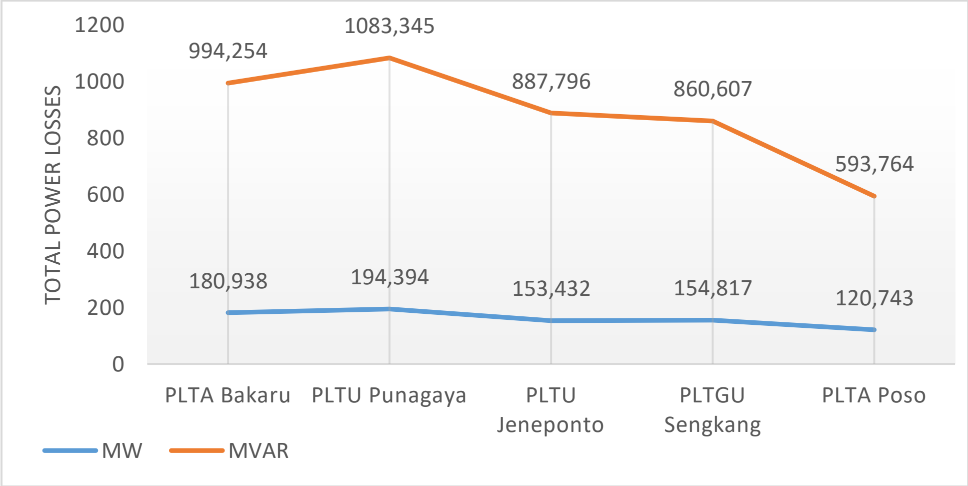



Figure 3. The Slack Bus Candidate Result




Picture 4. Total Power Loss at Selected Slack Bus

## V. CONCLUSION

Based on the results of the simulation that has been carried out, it can be concluded that:

1. The PLTA Poso was chosen as a slack bus because its voltage profile is closest to the ESDM Ministerial Decree number 20 of 2020, which is 0.90 - 1.05 p.u.
2. In comparison to the other four slack buses, the Poso bus experiences the least power losses when the slack bus is positioned on it. The total system power loss on the Poso bus is 120,743 MW and 593,764 MVAR.

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