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Voltage stability assessment of the Southern Sulawesi power system in Indonesia for 2020 by using modal analysis

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Abstract. This paper presents the voltage stability analysis assessment of the Southern Sulawesi power system in Indonesia for the year 2020, considering the load increase every year, the addition of new power plants as well as the large additional load of smelter industries in the Bantaeng Regency. The voltage stability method used in this paper is the modal analysis method. Modal analysis method uses the Jacobian reduction matrix resulting from the Newton-Raphson power flow analysis. Modal analysis produces eigenvalues for each load bus in the system. The bus with the smallest eigenvalue becomes the focus in determining the stability of the system. Then bus participation factor is determined to obtain the most influential bus to improve the stability. The results of this study confirm that by 2020, the Southern Sulawesi power system will be in a stable condition, with the smallest eigenvalue of 5.8 in bus Pare-Pare while bus Barru has the highest bus participation factor.

1. Introduction

Modal analysis method is a static (steady-state) voltage stability analysis technique that aims to calculate the eigenvalue of each load bus from a Jacobian reduction matrix system which is a representation of the change of reactive power injected to a load bus to the voltage change [1]. The modal analysis is based on the Jacobian reduction matrix obtained from the power flow analysis using the Newton-Raphson method [2]. The eigenvalues in the modal analysis technique give an indication of the stability level of a system. When the eigenvalues become higher, the system becomes more stable. Eigenvalues near zero or negative give an indication that the system is unstable or close to an instability condition. The calculation of the bus participation value in the modal analysis technique provides information about the effectiveness of reactive power change on a bus by observing the voltage change in the load bus [3]. Hence by using this method then we can identify whether a bus is prone to instability.

The development of the industrial sectors of a country becomes one of the factors to consider the country as a developed country. However, the industry will not be able to develop well if it is not balanced with adequate electrical power resources, because industry operations require a large power supply. Furthermore, most industries use inductive loads such as electric motors on both a small and large scale. If the available power supply is not sufficient to supply the inductive loads then the industry will not be able to perform properly. And when this event happens in a large industry and the systems



are still forced to operate, then system imbalance might happen and disrupt the whole system causing the significant change of voltage and/or frequency resulting in a voltage or frequency instability condition [4-6] and possibly the worst case that it can cause cascading failures that might lead to load shedding [7] or blackout.

One of the regencies in the South Sulawesi Province that is currently building big industries is the Bantaeng Regency. The Bantaeng Regency is one of the districts in South Sulawesi that has many large industries and currently are building new smelters. There are several companies that are planning the construction of these smelters in Bantaeng. Until 2020, the smelter industries development planning will need electrical power of 610 MVA. Currently, the existing available power in the Southern Sulawesi power system is approximately 1350 MW with a peak load of around 1050 MW. Therefore, with a large addition of power needed and also considering the load addition into the system, then it is important to assess the stability [8-12] and transmission congestion [13-15] of the Southern Sulawesi power system by 2020. The additional power generation up to 2020 will also be considered in this study.

2. Modal analysis method

Modal analysis method was first introduced by Gao, Kundur and Morrison who formulated a way to predict the voltage collapse of the system based on the Jacobian reduction matrix obtained from the power flow study using the Newton-Raphson method [1]. The basis of the modal analysis method is to compute the eigenvalues of each load bus and eigenvectors value of the Jacobian reduction matrix system. Eigenvalue provides an illustration of the change in reactive power to the changes in voltage. The power flow equation uses the Newton-Raphson method as follows:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} \quad (1)$$

where $\begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix}$ is the Jacobian matrix

By assuming $\Delta P = 0$, then we will obtain the Jacobian reduction matrix as follow:

$$J_R = J_4 - J_2 J_1^{-1} J_3 \quad (2)$$

J_R is the Jacobian reduction matrix of the system

The matrix J_R represents a linear relationship between the voltage changes to the reactive power injection change on a bus. Eigenvalues and eigenvectors of the Jacobian reduction matrix are used for voltage stability analysis. Voltage instability can be identified by the eigenvalues of a Jacobian reduction matrix [16]. The analysis of the results of eigenvalues as follows:

$$J_R = \xi \lambda \eta \quad (3)$$

Where ξ is the right eigenvector matrix of the J_R ; η is the left eigenvector matrix of the J_R ; λ is the diagonal eigenvalues matrix of J_R .

The system's stability based on the strength of the load bus can be identified from the state of each bus based on its eigenvalues. If all eigenvalues are positive ($\lambda > 0$) then the system is said to be stable, whereas the system is said to be unstable if there is at least one negative eigenvalue ($\lambda < 0$).

The lowest eigenvalue contained in the load bus is an indication of the proximity of the system to instability. Furthermore, the determination of the participation of any bus that is critical to an unstable condition is very important. This is why the participation factor method is produced. The bus participation factor explains the large contribution of changes in a bus to the stability condition so that the bus that has the greatest participation value is the most influential bus in a system [17]. If ξ^k and η^{ki} , which is the right eigenvector and the left eigenvector, respectively, for the eigenvalue λ_i of the J_R matrix, then the participation factor of bus k for eigenvalues λ_i is defined as,

$$P_{ki} = \xi_{ki} \cdot \eta_{ki} \tag{4}$$

For all small eigenvalues, the bus participation factor can determine the mechanism of a bus to an unstable state.

3. Results and analysis

The analysis in this study considers the growth of the residential load and the additional industry load planning, as well as an average power generator addition. Based on the Power Supply Business Plan of PT. PLN (Persero), Indonesian State Electricity Company, sales of electricity in the Sulawesi Island grew on an average of 11.5% per year, while the average generator capacity increased only 2.7% per year [18].

By considering the load growth of the large smelter industry addition and additional power generation, then the voltage profile for the Southern Sulawesi power system in 2020 can be predicted. Figure 1 shows the forecasted voltage magnitude for the Southern Sulawesi power system in 2020.

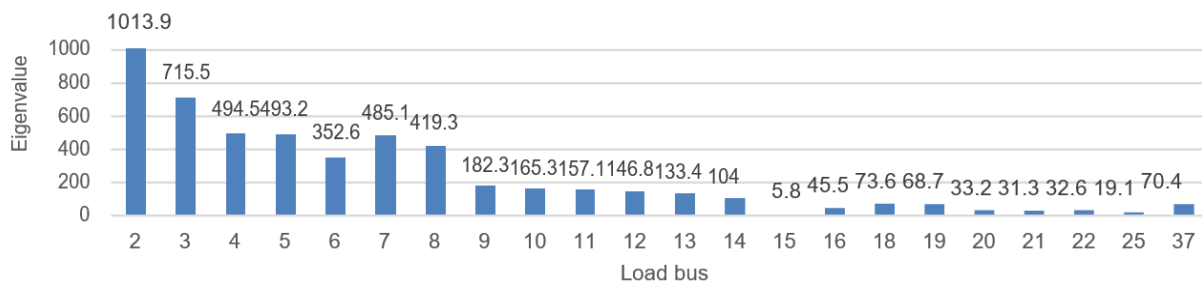


Figure 1. Eigenvalues for all load buses of the Southern Sulawesi power system in 2020.

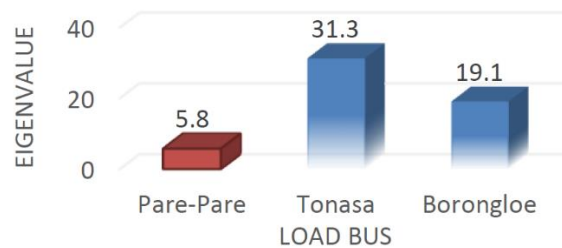


Figure 2. Three smallest eigenvalues of the Southern Sulawesi power system in 2020.

From figure 2 it can be concluded that since all eigenvalues are positive, the Southern Sulawesi power system in 2020 is in a stable condition. However, the load bus with the smallest eigenvalue must also be considered. From figure 3, bus Pare-Pare in 2020 is the load bus with the smallest eigenvalue (5.8) as indicated in the red bar. The smallest eigenvalue of a power system indicates the proximity of the system to instability. Then, the bus participation factors need to be calculated to determine the mechanism of stability. The bus participation factor informs the contribution of changes in a bus to the stability condition so that the bus that has the greatest participation value is the most influential bus in the system. The bus participation factors are calculated with respect to the smallest eigenvalue. This bus participation factor is used to determine the weakest bus of the system. Figure 4 shows the five largest bus participation factors with respect to the smallest eigenvalue, which is bus Pare-Pare.

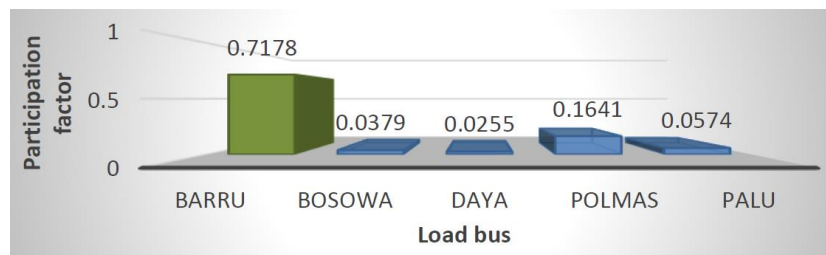


Figure 3. Largest bus participation factor with respect to the smallest eigenvalue

From figure 3, bus Barru has the highest participation factor of 0.7178, which means that bus Barru is the most influential bus towards the weakest bus of Pare-Pare in 2020. By performing modal analysis, then the power utility of the Southern Sulawesi power system can use the results of the research in future planning of the system. Since the matrix represents a linear relationship between the voltage changes to the reactive power injection change on a bus, therefore, its results can become the basis for reactive power compensating devices allocation [19, 20].

4. Conclusion

This paper assesses the voltage stability analysis of the Southern Sulawesi power system in Indonesia for the year 2020, considering the load increase every year, the addition of new power plants as well as the large additional load of smelter industries in the Bantaeng Regency. By using the power flow analysis and modal analysis, the results of this study confirm that by 2020, the Southern Sulawesi power system will be in a stable condition. This can be observed by the voltage magnitudes at all buses that are within the voltage stability limit and all eigenvalues that are positive. Bus Pare-Pare has the smallest eigenvalue of 5.8, while bus Barru has the highest bus participation factor, which means that bus Barru has the biggest influence in improving the system stability with respect to the weakest bus, which is bus Pare-Pare.

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