Voltage profile evaluation based on power flow analysis using Newton Raphson method: Central and South Sumatera Subsystem

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Abstract. This paper discusses the evaluation of the voltage profile of electric power systems based on power flow analysis by the Newton Raphson method. The aim of power flow analysis is to obtain information about the voltage profile of the system under operating conditions in a steady state in order to evaluate the performance of the electric power system and analyze the conditions of generation and loading of both normal and emergency conditions. The results of the analysis show that there are several load buses which voltage values are below 1.0 pu. In anticipation of a greater voltage drop, reactive power injection is carried out in the form of mounting a certain value capacitor on these buses and obtaining a greater and greater voltage magnitude equal to 1.0 pu.

1. Introduction

An electric power system usually consists of many generators, transformers, active and passive load elements, and interconnected equipment in the transmission network between several buses and even hundreds of buses [1]. This electric power system is used to supply active and reactive electric power to customers who are along the network reliably, economically and sustainably at a certain voltage and frequency levels. This must also be achieved by the absence of generating units that operate on overload conditions continuously and the transmission network that has considerable power losses. Evaluation of voltage profile is carried out to obtain information about system voltage stability under steady-state operation conditions [2]. This information is needed to evaluate the performance of the electric power system and analyze the conditions of generation and loading of both normal and emergency conditions. Another reason is needed to evaluate the stability of the voltage, to see the performance of the electric power system when the electric power system is expanded by adding the transmission network and the load to meet the development of electricity needs of an area. With this evaluation will be guaranteed that the new power system can meet electricity needs economically, efficiently and safely. The electric power system model used in the evaluation of the voltage profile consists of generating units, load elements and transmission lines, each of which is connected to the buses in the system [3]. Also, the representation of the power system model always starts from the inline diagram. Use single line diagrams in evaluating this voltage profile assuming the system is considered balanced. The most important thing from evaluating voltage profile is determining the voltage (V) along with the angle of phase (θ) of each bus [4].
For evaluation of voltage, the profile can be reached in several ways. One of them is by evaluating the voltage profile based on power flow analysis. Many methods are known for power flow analysis including the Gauss-Seidel method, Newton Raphson method and Fast Decouple method [5], [6], [7]. The purpose of this paper was to obtain information on the performance of the voltage profile in the Central and South Sumatra subsystem (Sumbagselteng) based on the power flow analysis by the Newton Raphson method. The problem with this project is

a. Evaluation of voltage profile based on power flow using Newton Raphson method.
b. The discussion of the components of the electric power system is carried out only in connection with the power flow study alone to obtain a mathematical equation that will represent the component in the completion of this power flow calculation.
c. The study of power flow is carried out on the southern Sumatra central electricity system (Sumbagselteng) subsystem.
d. The parameters observed are voltage changes and voltage angle changes for each bus.
e. It is assumed that the voltage on the bus slack is 1.04 pu, the generator bus (PV) is 1.02 pu.
f. It is assumed that the voltage angle for each bus is 0°.
g. Voltage evaluation is performed on the load bus with the expected value between 1.00 pu to 1.05 pu. At this voltage value, the number of losses that occur at the minimum amount of the channel.
h. Voltage repair is done by reactive power injection with capacitor installation.

2. Method
In the initial stage, the numbering of the system is carried out on the system to be analyzed. Buses that are connected to the generator are numbered first after that the bus numbering is continued on load buses, buses that have the largest generating capacity are selected as slack. System data preparation to be analyzed includes data resistance and the capacitance between channels, data tapping transformers, scheduled load data, generation data, phase angle, and bus voltage. Power flow calculation starts with forming network impedance. The network impedance is converted to the admittance network.

Furthermore, the admittance bus matrix is formed from components consisting of tissue admittance, channel capacitance, and transformer tapping changes. The admittance bus matrix formed in a rectangular form is converted into polar shape and separated into conductance components and susceptibility components. Then the active power and scheduled reactive power are calculated on the generator and continued with calculated power calculations. After the calculated power calculation is completed, then proceed with the power mismatch calculation. After the power mismatch is calculated then a Jacobian matrix is formed [8]. This Jacobian matrix consists of 4 submatrices, namely submatrix H, N, M, and L. or \( J_{11}, J_{12}, J_{21}, \) and \( J_{22} \) with other submatrix expressions. After obtaining the price of each element in the Jacobian submatrix, the Jacobian matrix is then formed by combining the four Jacobian submatrices. The Jacobian matrix is then reversed using LU decomposition. Phase angle and voltage magnitude for each new bus. The difference between the phase angle value and the magnitude of the voltage of each bus between the old one and the new one is compared with the predetermined accuracy value. If the accuracy value has not been reached, then the iteration is repeated from the beginning until accuracy is achieved and convergence is achieved. Finally, a voltage evaluation was carried out. The voltage indicator is the voltage value for each load bus in the range between 1.00 pu to 1.05 pu. If the voltage on each load bus is outside the range, then an effort to improve voltage profile is done by injecting reactive power on the bus.

2.1. Power Flow Method
Power system reliability can be known if the voltage across all nodes is known. One of the most common power system conditions of concern is power flow. The power flow on the network or exactly in the net branches is calculated if the voltage in each net node is known. So the main problem of calculating power flow is to calculate the voltage in each node if the injection current at each node is known. If \( \mathbf{I} \) know, then the system of linear equations \( \mathbf{YV} = \mathbf{I} \) can be solved for voltage vectors

\[ \mathbf{YV} = \mathbf{I} \]
but in the electric power network, especially in calculating the power flow is usually not known current injection but power injection.

2.2. Bus Classification

Also, the power system in each bus or node is presented in four variables which include active power (P), reactive power (Q), magnitude voltage (V) and phase angle (δ). Power flow equations solve two of the four variables mentioned above, and the remaining two must be solved using the power flow equation. In general, buses can be classified into three categories. In each bus, category two of the four variables are known while the other two variables are calculated by the power flow equation. The three categories include

1. Load Bus (P-Q Bus), in this bus active power injection (P) and reactive power, are known while magnitude (V) and phase angle (δ) are calculated.

2. Generating Bus (Bus P-V), in this bus, the active power injection (P) and the voltage magnitude (V) are known while the phase angle (δ) and reactive power injection (Q) are calculated. The concept of the P-V bus or the generating bus allows the reactive power injection (Q) not to be determined because it is to the P-V bus that the reactive power losses incurred in the network are inflicted after the voltage has been calculated and the reactive power injection (Q) is knotted itself.

3. Slack Bus, on this bus the voltage magnitude (V) and voltage phase angle (δ) is known while active power injection (P) and reactive power (Q) are calculated. The concept of bus slack allows an unspecified active power (P) injection to be needed because it is to this node that all active losses incurred in the network are inflicted after the voltage has been calculated and the active power injection is knotted itself.

2.3. Newton Raphson Method

By classifying the equations of active power on the one hand and the equations of reactive power on the other side while the stress variables are also grouped separately from the groups of voltage angles which are concisely stated from the formula of Taylor series approximation around the estimated value of a certain voltage, the magnitude of the voltage correction is when k can be obtained by completing the following equation (1) system

\[
\begin{bmatrix}
\frac{\partial P_1}{\partial \delta_1} & \ldots & \frac{\partial P_1}{\partial \delta_n} & |V_1| & \frac{\partial P_1}{|V_1|} & \ldots & |V_n| & \frac{\partial P_n}{|V_n|} \\
\vdots & J_{11} = H & \vdots & \vdots & J_{12} = N & \vdots & \vdots & \vdots \\
\frac{\partial P_1}{\partial \delta_2} & \ldots & \frac{\partial P_1}{\partial \delta_n} & |V_2| & \frac{\partial P_2}{|V_2|} & \ldots & |V_n| & \frac{\partial P_n}{|V_n|} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\frac{\partial Q_1}{\partial \delta_2} & \ldots & \frac{\partial Q_1}{\partial \delta_n} & |V_2| & \frac{\partial Q_2}{|V_2|} & \ldots & |V_n| & \frac{\partial Q_n}{|V_n|} \\
\vdots & J_{21} = M & \vdots & \vdots & J_{22} = L & \vdots & \vdots & \vdots \\
\frac{\partial Q_1}{\partial \delta_2} & \ldots & \frac{\partial Q_1}{\partial \delta_n} & |V_2| & \frac{\partial Q_2}{|V_2|} & \ldots & |V_n| & \frac{\partial Q_n}{|V_n|} \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
\end{bmatrix}
\begin{bmatrix}
\Delta \delta_1 \\
\vdots \\
\Delta \delta_2 \\
\vdots \\
\Delta \delta_n \\
\Delta V_1 \\
\vdots \\
\Delta V_n \\
\Delta Q_1 \\
\vdots \\
\Delta Q_n \\
\end{bmatrix}
= 
\begin{bmatrix}
\Delta P_2 \\
\vdots \\
\Delta P_n \\
\Delta Q_2 \\
\vdots \\
\Delta Q_n \\
\end{bmatrix}
\]

The Jacobian matrix obtained is then reversed to the Jacobian loop using one of the matrix inverse methods [9] [10]. The phase angle and voltage magnitude of each new bus can be found using the following equation (2)
The multiplication results obtained are then separated into parts $\Delta \delta_i$ and $\Delta |V|/|V|$ and obtained the following equations (3) and (4)

$$
\Delta \delta_i^{(k+1)} = \delta_i^{(k)} + \Delta \delta_i^{(k)} \quad (3)
$$

$$
|V|^{(k+1)} = |V|^{(k)} + \Delta |V|^{(k)} = |V|^{(k)} \left(1 + \frac{\Delta |V|^{(k)}}{|V|^{(k)}}\right) \quad (4)
$$

Wherever

$\Delta \delta_i$ : Changes in the bus voltage phase angle to $i$

$\Delta |V|$ : Change the bus voltage magnitude to $i$

3. Result and Discussion

3.1. Electrical Data

The electrical data used in this study are the Central and South Sumatra Sumatran subsystem electrical data (Sumbagselteng). For maps and diagrams, the Central and South Sumatra (Sumbagselteng) subsystem electricity section is shown in Figure 1 and Figure 2.
3.2. Calculation Results and Voltage Profile Analysis

This section calculates and analyzes the voltage profile for the Southern Central Sumatra subsystem electricity system (SumbagSelteng). The results of the voltage evaluation on the Central and South Sumatra subsystem (SumbagSelteng) show that there are several load buses in the Central and South Sumatra subsystem (SumbagSelteng) which have voltage values below 1.00 pu shown in Table 1. The following.

Table 1. Bus Data with Less Than 1 Pu Value

| Bus Number | Bus Name          | Voltage Value (pu) |
|------------|-------------------|--------------------|
| 25         | GI Bagan Batu     | 0.9860             |
| 26         | GI Duri           | 0.9770             |
| 27         | GI Dumai          | 0.9610             |
| 39         | GI Muaro Bungo    | 0.9670             |
| 40         | GI Bangko         | 0.9410             |
| 44         | GI Lubuk Linggau  | 0.9900             |
| 62         | GI Sribawono      | 0.9980             |

Also, information on channel losses for the Central and South Sumatra subsystem (SumbagSelteng) was also obtained where active power losses were 104.6220 MW and reactive power losses of -127.5320 MVAR.

For the voltage values on the buses shown in Table 1, to reach 1.00 pu or more as well as reduced channel losses, it is carried out by reactive power injection with the installation of capacitors on buses where the voltage has decreased. The calculation of the installed capacitor capacity is done by...
simulation. By simulating the capacitor, capacity is obtained which must be installed, and the calculation results are shown in Table 2. below

| Bus Number | Bus Name     | Voltage Value (pu) | MVAR     |
|------------|--------------|--------------------|----------|
| 25         | GI Bagan Batu | 0.9988             | 1.0000   |
| 26         | GI Duri      | 0.9976             | 5.0000   |
| 27         | GI Dumai     | 0.9980             | 8.0000   |
| 39         | GI MuaroBungo| 0.9950             | 15.0000  |
| 40         | GI Bangko    | 0.9978             | 25.0000  |
| 44         | GI Lubuk     | 0.9989             | 10.0000  |
|            | Linggau      |                    |          |
| 62         | GI Sribawono | 0.9995             | 2.0000   |

With active power losses of 100.3770 MW and reactive power losses of -185.5060 MVAR.

4. Conclusion
The results of the evaluation of the voltage profile in the Central and South Sumatra subsystem (SumbagSelteng) show that seven load buses have voltage values below 1.00 pu. To improve the voltage value on the seven buses, reactive power injection is carried out by installing the capacitor, and the result of the reactive power injection causes the voltage value on the seven buses to increase. For the Central and South Sumatra subsystem (SumbagSelteng), buses in the subsystem have negative phase angles and positive phase angles. For negative phase angles, it shows that these buses have a lagging power factor and absorb reactive power from the system while for positive phase angles, indicating that these buses have power factors overtaking and supplying reactive power to the system. The further research should also be carried out in changing load conditions so that the stability performance is more reliable and stable and to improve the voltage on each bus; it should also be done with a transformer tap setting.

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