Analysis of power loss on the addition of new networks in Malang transmission system

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Abstract. Power loss problems in Malang transmission line system can occur due to high voltage drops in a long distance transmission lines and can be attributed to large loads resulting to high current flowing in the lines. Not only this setback can contribute to the decrease power transfer in the demand side, but it also can impair the conductor line over time owing to the excessive heats. To mitigate this problem, new networks or current distribution scheme are offered to reduce the excessive power loss and additionally to meet the load demands. This study aims to investigate and calculate the power losses in the transmission system before and after the networks are employed. The mathematical analysis of the power loss is presented in this paper and subsequently verified through simulation. The data used in this study are obtained from the State Electricity Utility (PLN) of Malang Raya. The results of this study indicate that before the addition of the network, Malang Transmission System experienced a significant power loss that is equal to 598.2 kW in six lines, including Bus 1 – LW at 125.5 kW, Bus 1 – PKS 164 kW, PKS – KA 1 kW, LW – KA 12.1 kW, KA – SKL 50 kW, and STM – KA 245.6 kW. After the addition of four new networks, the power loss is considerably reduced to 355.7 kW in 10 lines, including Bus 1 – LW 67.9 kW, Bus 1 – PKS 52.6 kW, PKS – KA 1.6 kW, LW – KA 0.3 kW, SKL – KA 0.1 kW, STM – KA 88.3 kW, LW – SKL 0.4 kW, PKS – LW 0.2 kW, STM – PKS 57.2 kW, and STM – SKL 87.1 kW.

1. Introduction

The process of channelling power to the electric power system starts from the generation, then distributed through the transmission network system, then distributed to customers or the community through the distribution network system. Furthermore, to support the increasing electrical energy needs, the fulfilment of electrical power needs in each load must be served appropriately, both from the adequacy of power supply and from the balance of load power in the distribution system [1]. Fulfilment of electricity needs can be carried out properly, if supported by adequate infrastructure. Thus the interconnection system needs to be implemented properly to obtain an adequate power supply as needed. In addition, the operation of the electric power system must also be able to overcome the disturbances and problems that exist, so that the process of channelling electric power is not hampered and runs safely and reliably [2–3].

Therefore, to serve the entire load area it is necessary to do equal distribution of electricity usage, so that the condition of the whole system can be balanced. In addition, operationally, it must also be able to compensate for changes in the burden of conditions that are increasing at any time. This dynamic...
condition of load changes causes the supply of electrical power to be maintained very well and sufficient to serve all loads that are scattered at each center of the load. With a load that is spread in various locations and a large enough load can cause electrical power to be sent through a channel far enough, this will cause problems, such as power loss on the system [4-5]. Nevertheless, there were noteworthy studies in recent years which purportedly to investigate and devote to this particular problems [6-13]. In such efforts, many presented different approaches, including optimal power flow [6], controllable shunt reactors [7], modern devices and methods [8], voltage monitoring and optimization [9], tie-line reconstructions and planning [10-14].

In this paper, analysis on the power losses of Malang Transmission System is proposed, with reconstructions of the networks using additional tie-lines, as previously mentioned in [13]. The transmission power loss calculation is demonstrated and corroborated through simulation. The reconfiguration of Malang Transmission System shows promising results, leading to significant power loss decrease almost half of the initial total loss.

2. Main Theory
The calculation of power loss both in the existing network topology and the subsequent addition of new networks are based on the power flow theory [3] and analyzed in the following subsections.

2.1. Power Flow
Calculation of power flow and voltage in the electric power system is a very important part in determining the power loss, this can be done on the entire network represented in a single phase circuit. Furthermore, each bus is categorized based on four conditions namely voltage (V), active power (P), reactive power (Q) and phase angle (δ). So it is known the name of the reference bus (swing bus), load bus (load bus) and generator bus (generator bus).

One method of power flow that is widely used is the Newton-Raphson method, because the iteration is shorter and the computation process is faster. Furthermore, in this method, the equation of active power (P) and reactive power (Q) on bus p is seen in Equation 1.

\[ P_p - jQ_p = E_p I_p \]  (1)

2.2. Malang Raya Transmission System General Overview
Transmission lines in the Malang area are generally radial in shape, because networks in Malang Raya use one channel that is connected directly to each substation and then channelled to the load through a distribution network. Furthermore, to support the process of channelling electrical power to the transmission line substation, it is necessary to use an ASCR-HAWK type conductor, namely aluminium reinforced steel conductor (ASCR) with a voltage of 150 kV [5,14]. Overall, the transmission system uses a conductor measuring 477 mm²/mcm in a cross-section area of 241.50 mm² aluminium and a steel cross-sectional area of 39.34 mm². In addition, the type current capacity of the conductor is 600 A with a maximum temperature of 75 °C at 40°C and a DC resistance at 20°C is 0.1196 Ω/km, and works at a frequency of 50 Hz with a weight of 977 kg/km.

2.3. Power Loss Overview
The transmission line has four parameters that affect its ability to function as part of a power system namely resistance, conductance and capacitance. Furthermore, each transmission line can be approached by the length, which is long, medium and short. In the transmission line besides voltage drop, power losses also occur. This power loss reflects the wasted power, resulting in the power received at the receiving side is smaller than the power sent at the sending side. This discharge is converted into heat in the transmission system over a period of time. So that the energy received at the receiving side is smaller than the energy sent. In general, this power loss is caused by resistance in the conductor and corona power.
To determine the power loss from the network can be modeled as follows. Consider the line connecting the two buses $i$ and $j$ in Figure 1. The line current $I_{ij}$, measured at bus $i$ and defined positive in the direction

\begin{equation}
I_{ij} = I_i + I_\ell + y_{ij}(V_i - V_j) + y_{\ell o}V_i
\end{equation}

Similarly, the line current $I_{ji}$ measured at bus $j$ and defined as positive in the direction from bus $j$ to bus $i$ is given by

\begin{equation}
I_{ji} = -I_i + I_\ell + y_{ij}(V_j - V_i) + y_{\ell o}V_j
\end{equation}

The complex power $S_{ij}$ from bus $i$ to $j$ and $S_{ji}$ from bus $j$ to bus $i$ are denoted as follow

\begin{equation}
S_{ij} = V_i I_{ij}^*
\end{equation}

\begin{equation}
S_{ji} = V_j I_{ji}^*
\end{equation}

The power loss in line $i$ to $j$ is the algebraic sum of the power flows determined from (4) and (5), thus can be derived as follows

\begin{equation}
S_{L,ij} = S_{ij} + S_{ji}
\end{equation}

3. Results
Before analyzing the calculation of power loss network, the data depicted are the following:

3.1. Single Line Diagram of Initial Network

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Single line diagram of initial network}
\end{figure}
3.2. Single Line Diagram of New Network

Figure 2 shows the original transmission system, whereas Figure 3 shows the modification by adding new lines to the existing ones. Discussion of the transmission line transformation are discussed in detail in [14], in which the original networks are suffered from significant voltage drop in each buses. Therefore, this paper deals with the analysis of the line power losses and derive the comparison between the network before and after modifications are employed.

3.3. Bus and Transmission Line Data
In Table 1, the bus voltage on the initial network in the Malang area at peak load. It is seen that the voltage condition has decreased significantly (according to the standard [2]), thus this decrease greatly affects the sender of power from bus 1 to bus 2, resulting in power losses on the line.

| Bus Name | Voltage Bus (pu) |
|----------|------------------|
| Bus 1    | 1 L 0°          | 1.0 + j0        |
| Bus LW   | 0.99133 L -0.738° | 0.991248 - j0.012769 |
| Bus PKS  | 0.98933 L -0.929° | 0.9892 - j0.01604 |
| Bus SKL  | 0.98466 L -1.23° | 0.984433 - j0.021137 |
| Bus KA   | 0.98866 L -0.969° | 0.988519 - j0.01672 |
| Bus STM  | 1 L 0°          | 1.0 + j0        |

Figure 3. Single line diagram of new network (after additional networks)
Table 2. Bus voltage of new network

| Bus Name | Voltage Bus (pu) |
|----------|-----------------|
| Bus 1    | 1 $\angle$ 0°   |
| Bus LW   | 0.9938 $\angle$ -0.549° |
| Bus PKS  | 0.9940 $\angle$ -0.528° |
| Bus SKL  | 0.9934 $\angle$ -0.567° |
| Bus KA   | 0.9933 $\angle$ -0.585° |
| Bus STM  | 1 $\angle$ 0°   |

Table 2 shows the bus voltage after adding tie line network. It can be seen that the change in voltage starts to improve where each bus has a voltage close to the value of 1 $\angle$ 0. Thus, the power loss that occurs in each line can be reduced and the power can be sent as needed. After the data has been fulfilled, the power loss value calculation can be done with several stages:

3.3.1. Determine the value of admittance

The value of admittance is obtained from converted of line impedance $Z^{-1}$.

Table 3. Value of line impedance and admittance

| Line      | Impedance (pu) | Admittance (pu) |
|-----------|----------------|-----------------|
| Bus 1 - LW| 0.0166 + j0.0538 | 5.2366 - j16.9716 |
| Bus 1 - PKS| 0.0128 + j0.0525  | 4.3855 - j17.9794 |
| PKS - KA  | 0.0053 + j0.0216  | 10.7146 - j43.6672 |
| LW - KA   | 0.0165 + j0.0536  | 5.246 - j17.0417 |
| SKL - KA  | 0.0108 + j0.0263  | 13.3608 - j32.5362 |
| STM - KA  | 0.0147 + j0.0475  | 5.9457 - j19.2125 |
| LW - SKL  | 0.01 + j0.026     | 13.1578 - j34.2105 |
| PKS - LW  | 0.0078 + j0.0252  | 11.2101 - j36.2173 |
| STM - PKS | 0.0234 + j0.0662  | 4.7464 - j13.42799 |
| STM - SKL | 0.0209 + j0.0543  | 6.9122 - j16.0399 |

Table 3 shows the impedance and admittance value that is owned by each line both the initial line and the new line. The unit of value is already per unit (pu). Impedance values are obtained from data retrieval on the line with the formula $Z = R + jX$. To determine the value of admittance can be calculated with the formula $1/Z$.

3.3.2. Determine Bus Voltage

This stage determines the voltage on each bus and determines the difference between buses i and j. The following calculations are comprised in Table 4 and 5.

Table 4. Initial network voltage difference value

| Lines      | Voltage Difference (pu) |
|------------|-------------------------|
| Bus 1 - LW | 0.008752 + j0.012769    |
| Bus 1 - PKS| 0.0108 + j0.01604       |
| PKS – KA   | 0.000681 + j0.000679    |
| LW – KA    | 0.002729 + j0.003951    |
| KA – SKL   | 0.004085 + j0.004417    |
| KA – STM   | 0.015567 + j0.021137    |
Table 5. New network voltage difference value

| Line                  | Voltage Difference (pu) |
|-----------------------|-------------------------|
| Bus 1 - LW            | 0.006246 + j0.009522    |
| Bus 1 - PKS           | 0.006022 + j0.00916     |
| PKS - KA              | 0.00071 + j0.000982     |
| LW - KA               | 0.000456 + j0.00062     |
| SKL - KA              | 0.000033 + j0.000312    |
| STM - KA              | 0.006752 + j0.010142    |
| LW - SKL              | 0.000423 + j0.000308    |
| PKS - LW              | 0.000203 + j0.000362    |
| STM - PKS             | 0.006042 + j0.00916     |
| STM - SKL             | 0.006649 + j0.009831    |

3.3.3. Determine Line Current of $I_{ij}$ and $I_{ji}$

This stage determines the current value of each bus $i \rightarrow j$ and otherwise bus $j \rightarrow i$ by using Eq. 2 and Eq. 3.

Table 6. Initial network flow value data

| Line                  | $I_{ij} = Y_{ij}(V_i - V_j)$ (pu) | $I_{ji} = -I_{ij}$ (pu) |
|-----------------------|-----------------------------------|-------------------------|
| Bus 1 - LW            | 0.262541 - j0.081669              | 0.262541 + j0.081669    |
| Bus 1 - PKS           | 0.335753 - j0.123834              | 0.335753 + j0.123834    |
| PKS - KA              | 0.036947 - j0.022462              | 0.036947 + j0.022462    |
| LW - KA               | 0.081648 - j0.02578               | 0.081648 + j0.02578    |
| KA - SKL              | 0.198291 + j0.073896              | 0.198291 + j0.073896    |
| KA - STM              | 0.498651 - j0.173407              | 0.498651 + j0.173407    |

Table 7. New network flow value data

| Line                  | $I_{ij} = Y_{ij}(V_i - V_j)$ (pu) | $I_{ji} = -I_{ij}$ (pu) |
|-----------------------|-----------------------------------|-------------------------|
| Bus 1 - LW            | 0.194311 - j0.056142              | 0.194311 + j0.056142    |
| Bus 1 - PKS           | 0.191101 - j0.068101              | 0.191101 + j0.068101    |
| PKS - KA              | 0.050489 + j0.020482              | 0.050489 + j0.020482    |
| LW - KA               | 0.012938 - j0.004518              | 0.012938 + j0.004518    |
| SKL - KA              | 0.010595 - j0.003095              | 0.010595 + j0.003095    |
| STM - KA              | 0.0234999 - j0.069422             | 0.0234999 + j0.069422   |
| LW - SKL              | 0.016103 - j0.010418              | 0.016103 + j0.010418    |
| PKS - LW              | 0.015386 - j0.003294              | 0.015386 + j0.003294    |
| STM - PKS             | 0.151678 + j0.037655              | 0.151678 + j0.037655    |
| STM - SKL             | 0.203647 - j0.038695              | 0.203647 + j0.038695    |

Table 6 describe the value of the existing line current in the initial Malang transmission system. Calculation of current $I_{ij}$ by multiplying the value of admittance by the value of the difference in the line voltage and current $I_{ji}$ is the value of $-I_{ij}$. Subsequently, Table 7 indicates the current value in the new network. It appears that the current value in the new network is smaller than the current in the initial network. This is because in the new network the current is decreased because there are four additional networks, so it can be ascertained that the power losses in the lines are small.
3.3.4. Calculate the value of power $S_{ij}$ and $S_{ji}$

At this stage the power calculation is sent on the $ij$ channel and the power received on the $ji$ line using Eq. 4 and Eq. 5.

**Table 8. Initial network power calculation value**

| Line         | $S_{ij} = V_i I_{ij} \times (\text{pu})$ | $S_{ji} = V_j I_{ji} \times (\text{pu})$ |
|--------------|------------------------------------------|------------------------------------------|
| Bus 1 - LW   | $0.262541 + j0.081669$                   | $0.261286 - j0.077602$                  |
| Bus 1 - PKS  | $0.335753 + j0.123834$                   | $0.334113 - j0.117111$                  |
| PKS - KBA    | $0.036908 + 0.021627$                    | $0.036898 - 0.021586$                   |
| LW - KBA     | $0.081263 + j0.024512$                   | $0.081142 - j0.024119$                  |
| KBA - SKL    | $0.19725 + j0.069732$                    | $0.19675 - j0.068554$                   |
| KBA - STM    | $0.495915 + j0.163079$                   | $0.498371 - j0.173407$                  |

Table 8 shows the value of the power sent and the power received at the poor transmission lines before the tie line network is carried out. Furthermore, the difference will be calculated between the power sent and the power received, so as to get the results of loss of power on the line.

**Table 9. New network power calculation value**

| Line         | $S_{ij} = V_i I_{ij} \times (\text{pu})$ | $S_{ji} = V_j I_{ji} \times (\text{pu})$ |
|--------------|------------------------------------------|------------------------------------------|
| Bus 1 - LW   | $0.194311 + j0.056142$                   | $0.193632 - j0.053941$                  |
| Bus 1 - PKS  | $0.191101 + j0.068101$                   | $0.190575 - j0.065939$                  |
| PKS - KA     | $0.050372 + 0.019896$                    | $0.050356 - 0.019832$                   |
| LW - KA      | $0.01292 + j0.004366$                    | $0.012917 - j0.004346$                  |
| SKL - KA     | $0.010494 - j0.003179$                   | $0.010493 + j0.003182$                  |
| STM - KA     | $0.0234999 + j0.069422$                  | $0.234116 - j0.06657$                   |
| LW - SKL     | $0.016102 + j0.010102$                   | $0.016098 - j0.01019$                   |
| PKS - LW     | $0.015323 + j0.003133$                   | $0.015321 - j0.003127$                  |
| STM - PKS    | $0.151678 + j0.037655$                   | $0.151106 - j0.036038$                  |
| STM - SKL    | $0.203647 + j0.038695$                   | $0.202778 - j0.036436$                  |

In Table 9 is a calculation of the value of the power sent and received on the addition of a new network. The same is true in Table 8 but in this new network it has 10 transmission channels while the Initial network has 6 transmission channels.

3.3.5. Power Losses $S_L$ Calculation

At this stage the power loss calculation is calculated using Eq. 6. The results of the calculation is shown in the following Table 10.

**Table 10. Initial network power loss value**

| Line         | $S_{L,ij} = S_{ij} + S_{ji}$ (pu) | Losses (kW) |
|--------------|----------------------------------|-------------|
| Bus 1 - LW   | $0.001255 + j0.004067$            | 125.5       |
| Bus 1 - PKS  | $0.00164 + j0.006723$             | 164         |
| PKS - KA     | $0.00001 + j0.000041$             | 1           |
| LW - KA      | $0.000121 + j0.000393$            | 12.1        |
| KA - SKL     | $0.000484 + j0.001178$            | 50          |
| KA - STM     | $0.000883 + j0.002852$            | 245.6       |

In Table 10, it appears that there are significant power losses in the Initial transmission network. This shows that, there is a large amount of electrical energy discharged when peak load occurs. Seen that experienced the greatest power loss that is channeling Sutami (STM) to Kebonagung (KA) amounted to 245.6 kW. This might be due to the distance that is too far and the burden of Kebonagung is quite large. In this network system, it can be seen that the total power loss in all lines is 598.2 kW.
As in Table 11, that the power loss in the system by adding a new network is smaller than the original system configuration. The total power loss in this system is 355.7 kW, smaller than the previous power loss 598.2 kW.

Figure 4. Power loss distribution for each line of new and old Malang Transmission System Network

Figure 4 shows a comparison between the 6 initial lines and the 6 final lines where the end line has decreased power loss, whereas the losses for the 4 new lines are explained using the Table 12.
Table 12 explains that the power loss in the 4 lines addition networks in the Malang transmission system is very small compared to the 6 lines in the Initial network. So that when compared with the total of the two schemes, the addition of the Malang transmission network system greatly reduces the power loss in the Malang transmission system.

4. Conclusion
Based on the results of analytical calculations of power losses in the Malang Transmission System, it can be concluded that in the Initial transmission network there was a significant power loss of 598.2 kW. Whereas on the transmission network that has been done by adding a new network has a smaller power loss of 355.7 kW. So that the addition of a new network to the Malang transmission system is highly recommended for State Electricity Company (PLN) to reduce the power losses that occur.

References
[1] May T W, Yeap Y M and Ukil A 2016 Region 10 Conference (IEEE) pp 637-641
[2] Transmission and Distribution Committee 2018 Guide for Identifying and Improvement Voltage Quality in Power System IEEE Standard 1250
[3] Saadat H 1999 Power System Analysis (WCB/McGraw-Hill)
[4] Reddy V V, Yesuratnam G and Kalavathi M S 2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (IEEE) pp 70-76
[5] Agustina M and Afandi A N 2019 Frontier Energy System and Power Engineering 1(2) pp 30-35.
[6] Granada M, Rider M J, Mantovani J R and Shahidehpour M 2008 Transmission and Distribution Conference and Exposition: Latin America (IEEE) pp 1-6
[7] Smirnov A A and Smolovik S V 2005 Russia Power Tech (IEEE) pp 1-5
[8] Gashimov A M, Babayeva A R, Khidirov F L and Nayir A. Modern Electric Power Systems (IEEE) pp 1-5
[9] Li H, Bose A and Venkatasubramanian V M 2015 IEEE Trans Smart Grid 7 2 pp 785-793
[10] Pourakbari-Kasmaei M, Rider M J and Mantovani J R 2016 IET Generation, Transmission & Distribution. 10 2 pp 299-309
[11] Zheng X, Chen Y, Chen H, Zhang Y, Zhu J, Chen J and Xuan P 2017 IEEE Trans. Emerg. Sel. Topics Power Electron. 6 3 pp 1095-1103
[12] Liu C, Wang J, Fu Y and Koritarov V 2014 IET Generation, Transmission & Distribution 8(6) pp 1082-1089
[13] Elhassan M E, Rahim Y H and Abbas A Y 2017 International Conference on Communication, Control, Computing and Electronics Engineering (IEEE) pp 1-4
[14] Chanif M N, Widodo P, Rahmawati Y, Fadlika I, Apiyanto A E and Afandi A N 2019 International Conference on Electrical Engineering and Informatics (IEEE) pp 348-353

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