

# Analysis of the Effect of Load Equalization On Neutral Current at the TP0067 Distribution Substation of PT PLN (Persero) ULP Tanjung Pandan

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Transformer load balancing is a mandatory maintenance activity that is regularly conducted to ensure the optimal performance of distribution systems. This activity serves as an essential effort to minimize neutral current, which contributes to power losses resulting from unbalanced loading conditions in distribution transformers. The load balancing process was carried out at Distribution Substation TP0067, with a capacity of 100 kVA, located within the operational area of PT PLN (Persero) ULP Tanjung Pandan. The procedure commenced with load measurements on each feeder and phase, followed by detailed calculations of the phase load distribution. Based on the analysis results, the phases requiring load transfer to achieve balance were identified. Following the implementation of the load redistribution plan, it is expected that the neutral current will be significantly reduced, thereby reducing power losses and enhancing the overall efficiency and reliability of the distribution system.

**Keywords:** Load Balancing, Neutral Current, Power Losses.

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## 1. Introduction

The increasing economic growth and rapid development rate in Tanjung Pandan City require increasingly large, sustainable electrical power supplies that must be maintained to meet customer energy consumption needs. To achieve this, a reliable power system is required. However, as customer demand increases, the implementation of the power distribution system is inevitably affected by various disturbances, such as electrical load imbalances. Many factors can cause load imbalances, which can lead to various losses in electrical energy distribution. Therefore, to achieve load balance, load equalization can be implemented at distribution substations. An even load will automatically have a small neutral current, thereby reducing losses.

## 2. Literature Review

### Distribution Network

Electric power distribution is the final stage in the delivery of electric power. It is the process of bringing electricity from the electricity transmission system to the electricity consumers. Distribution substations are connected to the transmission system and lower the transmission voltage using transformers. There are 2 types of distribution networks, namely primary distribution and secondary distribution. Primary distribution is a distribution network originating from the transmission network whose voltage is lowered at the Main Substation (GI) to Medium Voltage (TM) with a nominal voltage of 20 kV which is usually called JTM (Medium Voltage Network) while secondary distribution is a distribution network from the distribution substation to be distributed to customers with a low voltage classification of 220 V or 380 V

(inter-phase). The network from the distribution substation is known as JTR (Low Voltage Network), then from JTR it is divided to the customer's house, the line that enters from JTR to the customer's house is called Home Connection (SR).

### Distribution Substation Transformer

A distribution substation is essentially a place where distribution transformers and equipment are installed. As is known, distribution transformers serve to step down medium voltage (20 kV in Indonesia) to low voltage (220/380 V in Indonesia). Thus, distribution transformers serve as a link between the medium-voltage and low-voltage networks.

A transformer is an electrical device that can transfer and change electrical energy from one or more electrical circuits to another electrical circuit with the same frequency, through a magnetic coupling and based on the principle of electromagnetic induction. What is meant by a balanced state is a state in which:

1. All three current/voltage vectors are equal in magnitude.
2. The three vectors form an angle of  $120^\circ$  to each other.

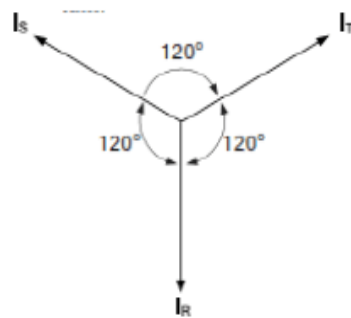


Figure 1. Vector Flow Diagram in a Balanced State

Meanwhile, what is meant by an unbalanced state is a state in which one or both of the conditions for a balanced state are not met. There are three possible unbalanced states, namely:

1. The three vectors are the same size but do not form a  $120^\circ$  angle with each other.
2. The three vectors are not the same size but form an angle of  $120^\circ$  with each other.
3. The three vectors are not the same size and do not form a  $120^\circ$  angle to each other.

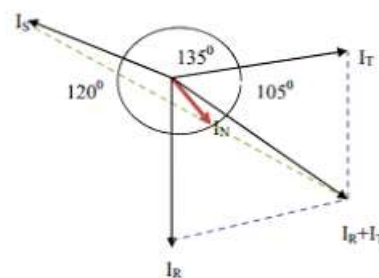


Figure 2. Vector Flow Diagram in an Unbalanced State

### 3. Methods

This research was conducted at PT. PLN (Persero) Bangka Belitung Region UP3 Belitung ULP Tanjungpandan at Substation TP0067 100 KVA located on Jalan Sijuk, Aik Seru, Sijuk District, Belitung Regency, Bangka Belitung Islands. The data source obtained for this research is transformer data at the TP0067 substation, namely direct measurement data of the TP0067 transformer load before and after transformer load equalization.

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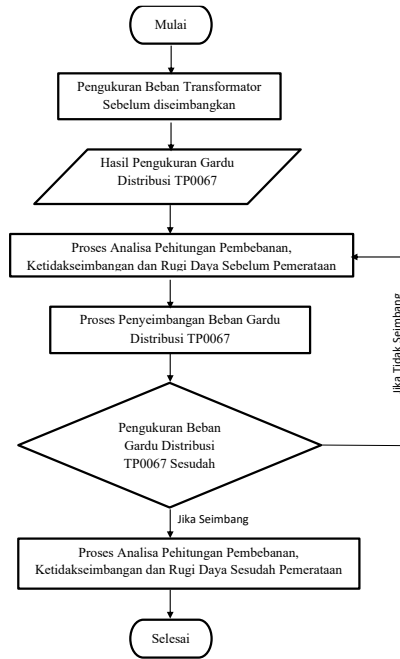


Figure 3. Final Project Research Flowchart

#### 4. Results and Discussion

##### Results

Load balancing is an activity that consists of initial measurements, equalizing the load of each unbalanced (unbalanced) phase, to the final measurement. aims to ensure that the current in the neutral reduced, so that losses arising from the neutral current are reduced. Load balancing is carried out on low voltage cables (TR) or on house connections (SR). Transformer load measurements at PLN ULP Tanjungpandan revealed an unbalanced load at distribution substation TP0067, requiring load equalization. The transformer load measurements were conducted on Thursday. July 10, 2025 at 7:36 PM WIB. The transformer load data is as follows:

Table 1. Results of Voltage and Current Measurements at Substation TP0067

| Parameters measured | Voltage (V) | Current (A) |      |   |
|---------------------|-------------|-------------|------|---|
|                     |             | R           | S    | T |
| RN                  | 235         |             |      |   |
| SN                  | 235         |             |      |   |
| TN                  | 234         |             |      |   |
| Hospital            | 406         |             |      |   |
| ST                  | 407         |             |      |   |
| TR                  | 407         |             |      |   |
| Major A             | -           | 3           | 8    | 7 |
|                     |             | 5.7         | 0.4  | 5 |
| Total               | -           | 3           | 8    | 7 |
|                     |             | 5.7         | 0.4  | 5 |
| Neutral             | -           |             | 72.4 |   |

From the measurement results, it was concluded that there was a load imbalance in each phase with the smallest phase in phase R and the largest phase in phase S. The magnitude of the load imbalance is

$$I_{rata-rata} = \frac{I_R + I_S + I_T}{3}$$

$$= \frac{35,7 + 80,4 + 75}{3}$$

$$= \frac{191,1}{3}$$

$$= 63,7A$$

$$a = \frac{I_R}{I_{rata-rata}} = \frac{35,7}{63,7} = 0,56$$

$$b = \frac{I_S}{I_{rata-rata}} = \frac{80,4}{63,7} = 1,26$$

$$c = \frac{I_T}{I_{rata-rata}} = \frac{75}{63,7} = 1,17$$

$$\% \text{ ketidakeimbangan} = \frac{(|a - 1| + |b - 1| + |c - 1|)}{3} \times 100\%$$

$$= \frac{(|0,56 - 1| + |1,26 - 1| + |1,17 - 1|)}{3} \times 100\%$$

$$= \frac{0,44 + 0,26 + 0,17}{3} \times 100\%$$

$$= \frac{0,87}{3} \times 100\%$$

$$= 29\%$$

The magnitude of the load imbalance in a balanced state is less than 15%, while the calculation results show that the load imbalance value at the TP0067 distribution substation is 29%, this shows that the TP0067 distribution substation is in an unbalanced state. Due to the current flowing through the neutral conductor, there is unused power. The amount of unused power, or losses, before load equalization can be seen in the following calculation:

$$R_N = \text{Resistansi} \times \text{Panjang saluran}$$

$$= 0,69 \times 1,34$$

$$= 0,138 \Omega$$

$$P_N = I_N^2 \times R_N$$

$$= 72,4^2 \times 0,138$$

$$= 723,36 W$$

From the calculation results, the power losses were obtained as much as 723.36 W, so to reduce the load imbalance and power losses, load equalization is necessary.

### Load Equalization Plan

Load equalization at distribution substations is done by moving customer house connections from phases that have a larger load to phases that have a smaller load, this aims to ensure that the load between phases is as close as possible to the same or in a balanced state. In direction A, a load of 17 A will be transferred from the S phase to the R phase, then a load of 12 A from the T phase to the R phase. For more clarity, please see table 2 below:

**Table 2.** Load Equalization Plan at Distribution Substation TP0067

| No    | Major | Current Before Equalization |        |      | Flow After Equalization |         |         |
|-------|-------|-----------------------------|--------|------|-------------------------|---------|---------|
|       |       | R                           | S      | T    | R                       | S       | T       |
| 1     | A     | 37.5 A                      | 80.4 A | 75 A | 64 A                    | 67.15 A | 61.75 A |
| TOTAL |       | 37.5 A                      | 80.4 A | 75 A | 64 A                    | 67.15 A | 61.75 A |

By estimating the load of 6 customers from phase S to phase R and 5 customers from phase T to phase R, with the following data:

- a. From the customer data that is planned to be moved, it can be seen that the total power is 18.92 A. Meanwhile, if the average usage is 70%, the total is 13.25 A. So all the planned S phase customers can be moved to the R phase.

**Table 3.** List of customers who will be moved from Phase S to Phase R

| NO | IDPEL        | NAME              | SUBSTATION | TARIFF | POWER | CURRENT |
|----|--------------|-------------------|------------|--------|-------|---------|
| 1  | 163000001133 | MULIYADI          | TP0067     | R1     | 450   | 2       |
| 2  | 163000043666 | ARI OKTA ANDRIA I | TP0067     | R1     | 450   | 2       |
| 3  | 163000046459 | TITIN SUMARNI     | TP0067     | R1MT   | 900   | 4       |
| 4  | 163000001327 | MURDIANI          | TP0067     | R1MT   | 900   | 4       |
| 5  | 163000010341 | DEDI SAPUTRA      | TP0067     | R1MT   | 900   | 4       |
| 6  | 163000031143 | ANTON DARMAWAN    | TP0067     | R1MT   | 900   | 4       |

- b. From the customer data that is planned to be moved, it can be seen that the total power is 18.92 A. Meanwhile, if the average usage is 70%, the total is 13.25 A. So all the planned T phase customers can be moved to the S phase.

**Table 4.** List of customers who will be moved from Phase T to Phase R

| NO | IDPEL        | NAME                 | SUBSTATION | TARIFF | POWER | CURRENT |
|----|--------------|----------------------|------------|--------|-------|---------|
| 1  | 163000032624 | EGY RIARZI PRABASENA | TP0067     | R1MT   | 900   | 2       |
| 2  | 163000035578 | BELITUNG RESIDENCE   | TP0067     | R1MT   | 900   | 2       |
| 3  | 163000044467 | KUTOT                | TP0067     | R1MT   | 900   | 2       |
| 4  | 163000110979 | ISAAC                | TP0067     | R1MT   | 1300  | 4       |
| 5  | 163000144461 | ISMAD ZENAWI         | TP0067     | R1MT   | 1300  | 4       |
| 6  | 163000596639 | MULIYADI             | TP0067     | R1MT   | 1300  | 6       |

From the load equalization plan data, the magnitude of the load imbalance that occurs can be seen in the following calculation:

$$I_{rata-rata} = \frac{I_R + I_S + I_T}{3}$$

$$= \frac{64 + 67,15 + 61,75}{3}$$

$$= \frac{192,9}{3}$$

$$= 64,33 \text{ A}$$

$$a = \frac{I_R}{I_{rata-rata}} = \frac{64}{64,3} = 0,99$$

$$b = \frac{I_S}{I_{rata-rata}} = \frac{67,15}{64,3} = 1,04$$

$$c = \frac{I_T}{I_{rata-rata}} = \frac{61,75}{64,3} = 0,96$$

$$\% \text{ ketidakseimbangan} = \frac{(|a - 1| + |b - 1| + |c - 1|)}{3} \times 100\%$$

$$\begin{aligned}
 &= \frac{|0,99 - 1| + |1,04 - 1| + |0,96 - 1|}{3} \times 100\% \\
 &= \frac{0,01 + 0,04 + 0,04}{3} \times 100\% \\
 &= \frac{0,09}{3} \times 100\% \\
 &= 3\%
 \end{aligned}$$

From the results of the load equalization plan calculations, the load imbalance was found to be 3%, so it can be concluded that the load equalization plan is in accordance with the target, namely a load imbalance of less than 15%.

**After Load Equalization**

The results of the load equalization carried out on Thursday, August 7, 2025 can be seen in the following table:

**Table 5. Load Equalization Results at the TP0067 Distribution Substation**

| MAJOR | Current Before Equalization |        |      | Flow After Equalization |        |        |
|-------|-----------------------------|--------|------|-------------------------|--------|--------|
|       | R                           | S      | T    | R                       | S      | T      |
| A     | 35.7 A                      | 80.4 A | 75 A | 77.8 A                  | 72.6 A | 82.3 A |
| TOTAL | 35.7 A                      | 80.4 A | 75 A | 77.8 A                  | 72.6 A | 82.3 A |

After the load equalization was carried out, there was a visible difference between before and after the load equalization, which was originally R = 35.7 A to 77.8 A, S = 80.4 A to 72.6 A, and T = 75 A to 82.3 A. From the load equalization data, the magnitude of the load imbalance that occurs can be seen in the following calculation:

$$\begin{aligned}
 I_{rata-rata} &= \frac{I_R + I_S + I_T}{3} \\
 &= \frac{77,8 + 72,6 + 82,3}{3} \\
 &= \frac{232,7}{3} \\
 &= 77,56 \text{ A} \\
 a &= \frac{I_R}{I_{rata-rata}} = \frac{77,8}{77,56} = 1,003 \\
 b &= \frac{I_S}{I_{rata-rata}} = \frac{72,6}{77,56} = 0,936 \\
 c &= \frac{I_T}{I_{rata-rata}} = \frac{82,3}{77,56} = 1,061
 \end{aligned}$$

$$\begin{aligned}
 \% \text{ ketidakeimbangan} &= \frac{(|a - 1| + |b - 1| + |c - 1|)}{3} \times 100\% \\
 &= \frac{|1,003 - 1| + |0,936 - 1| + |1,061 - 1|}{3} \times 100\% \\
 &= \frac{0,003 + 0,064 + 0,061}{3} \times 100\% \\
 &= \frac{0,128}{3} \times 100\% \\
 &= 4,26\%
 \end{aligned}$$

The neutral current in a distribution transformer is the result of the vector sum of the currents in each phase. The current flowing in the neutral can be calculated using equation 2.8.

$$\begin{aligned}
 \overline{I_N} &= \overline{I_R} + \overline{I_S} + \overline{I_T} \\
 &= 77,8\angle 0^\circ + 72,6\angle 120^\circ + 82,3\angle 240^\circ \\
 &= 77,8(\cos 0^\circ + j\sin 0^\circ) + 72,6(\cos 120^\circ + j\sin 120^\circ) + 82,3(\cos 240^\circ + j\sin 240^\circ) \\
 &= 77,8(1 + j0) + 72,6(-0,5 + j0,86) + 82,3(-0,5 - j0,86) \\
 &= 77,8 + j0 - 36,3 + j62,423 - 41,15 - j70,778 \\
 &= 0,35 - j8,535 \\
 |I_N| &= \sqrt{(0,35)^2 + (-8,835)^2} \\
 &= \sqrt{0,1225 + 78,057} \\
 &= \sqrt{78,179725} \\
 &= 8,841 \text{ A} \\
 \theta &= -\frac{b}{a} \\
 \theta &= -\frac{(-8,835)}{(-0,35)} \\
 &= -25,2428 \\
 \theta &= \tan^{-1} \times (-25,2428) \\
 &= -87,73^\circ \\
 &= 272,27^\circ \\
 \overline{I_N} &= 8,841\angle 272,27^\circ
 \end{aligned}$$

After the load equalization was carried out, the calculation of the current flowing in the neutral conductor was reduced by 63.559 A, which was originally 72.4 A to 8.841 A. Due to the current flowing through the neutral conductor, there is unused power. The amount of unused power, or losses, after load equalization can be seen in the following calculation:

$$\begin{aligned}
 R_N &= \text{Resistansi} \times \text{Panjang saluran} \\
 &= 0,69 \times 1,34 \\
 &= 0,138 \Omega \\
 P_N &= I_N^2 \times R_N \\
 &= 8,841^2 \times 0,138 \\
 &= 10,78 \text{ W}
 \end{aligned}$$

After the load is equalized, the power losses due to the current flowing in the neutral conductor which was originally...723,36W decreased by 712.58 W to 10.78 W.

### Discussion

After the calculation, the following values were obtained:

**Table 6.** Current Results at Distribution Substation TP0067

| Phase | Current             |                   |                    |
|-------|---------------------|-------------------|--------------------|
|       | Before equalization | Equalization plan | After equalization |
| R     | 35.7 A              | 64 A              | 77.8 A             |
| S     | 80.4 A              | 67.15 A           | 72.6 A             |
| T     | 75 A                | 61.75 A           | 82.3 A             |
| N     | 72.4 A              | 4.66 A            | 8.84 A             |

**Table 7.** Results of losses due to neutral current at the TP0067 distribution substation

|                               | Before equalization | Equalization plan | After equalization |
|-------------------------------|---------------------|-------------------|--------------------|
| Losses due to neutral current | 723.36 W            | 2.99 W            | 10.78 W            |

**Table 8.** Results of the percentage of imbalance

|            | Before equalization | Equalization plan | After equalization |
|------------|---------------------|-------------------|--------------------|
| %imbalance | 29%                 | 3%                | 4.26%              |

After calculations were carried out, it was found that the load imbalance on the TP0067 distribution transformer resulted in a current flowing in the neutral conductor of 72.4 A. This neutral current resulted in power losses in the transformer of 723.6 W. If the load transfer is in accordance with what has been planned in the table, the current flowing in the neutral conductor can be reduced to 4.66 A. The decrease in the current in the neutral conductor can also reduce the power losses in the transformer to 2.99 W. However, the data obtained after the load equalization in the field still shows that there is a current flowing in the neutral conductor of 8.84 A and there are power losses in the transformer of 10.78 W. This is influenced by the non-linear load installed on the distribution transformer. The appearance of neutral current in a transformer can be caused by two factors: load imbalance and the influence of non-linear loads. Furthermore, field conditions are not always consistent with theory. Load equalization is performed by moving the household connections from the phase with the highest load to the phase with the lowest load, resulting in equal or nearly equal load values for all three phases. The purpose of load equalization is to reduce neutral currents and power losses in the transformer and to prevent transformer failures due to unbalanced loads.

## 5. Conclusion

The conclusion of this paper are: The load imbalance on the TP0067 distribution transformer results in a current flowing in the neutral conductor of 72.4 A, which can cause power losses of 723.36 W. When the load on the TP0067 distribution transformer has been balanced or nearly balanced, the current flowing in the neutral conductor drops from the original 72.4 A to 8.841 A, this can also reduce power losses from the original 723.36 W to 10.78 W. There is a difference between the current results before and after load equalization, before load equalization the measurement results obtained were R=35.7 A, S=80.4 A, T=75 A, N=72.4 A, then after equalization it became R=77.8 A, S=72.6 A. T=82.3 A, N=8,841 A. The PLN ULP Tanjung Pandan Engineering Team should provide outreach to PBPD (New Installation and Power Addition) officers regarding the installation or addition of new customers so they can coordinate and balance the load on the substation when new customers are added. Furthermore, distribution substations should be remeasured at least once every three months to determine the condition of the transformer for overload, high load imbalance, and so on.

## 6. References

- Andinata, Yoffi, Amani Darma Tarigan, Muhammad Imam Nur Iman Yy. (2024). Analysis The Effect of Transformer Load Balancing on the Mg0045 160 Kva Distribution Substation against Losses. *Tambusai Journal of Education*, Vol. 8, No. 1, 2024. Matter.8929-8943.
- Dahlan, M. (2005). The Effect of Load Imbalance on Neutral Current and Losses in Distribution Transformers. Kudus: ISSN 6870.

- Aryza S et al (2024) A ROBUST OPTIMIZATION TO DYNAMIC SUPPLIER DECISIONS AND SUPPLY ALLOCATION PROBLEMS IN THE MULTI-RETAIL INDUSTRY. *Eastern-European Journal of Enterprise Technologies*, 129(3).
- Kadir, A. (2000). Distribution and Utilization of Electric Power. Jakarta: University of Indonesia.
- Marsudi, D. (2006). Operation of Electric Power Systems. Yogyakarta: Graha Ilmu.
- PT PLN (Persero). (2010). Book 4: Standards for Distribution Substations and Switching *Substation Construction*. Jakarta: PT PLN (Persero).
- PT PLN (Persero). State Electricity Company Standard 50. Jakarta: PT PLN (Persero).
- PT PLN (Persero). (2007). State Electricity Company Standard SPLN D3.002-1 2007. Jakarta: PT PLN (Persero).
- PT PLN (Persero). Distribution Transformers at PT PLN UP3 Semarang. Semarang: *FTI-UJ Journal*, 3(1).
- Tarigan, Adisastra Experience, Hamdani, and Novi Kristiani Sidabalok. (2025). *Load Distribution to Reduce Power Loss in Distribution Transformer at PT PLN (PERSERO) ULP Lembayung. Journal of Information Technology, computer science and Electrical Engineering*, Vol. 2, no. 2, June 2025, pp. 58~64.
- Tharo, Zuraidah, et al. (2018). *An Effect of Unbalanced Load Usage of Electrical Equipment. International Journal for Innovative Research in Multidisciplinary Field*, Vol. 4, No. 10, October 2018, pp. 192-196.
- Tarigan, Amani Darma, Zuraidah Tharo, Rahmadsyah Pulungan. (2018). Effect of Use Unbalanced Load on Electrical Equipment Lifespan. *Jurnal Ilmiah Abdi Ilmu*, Vol. 11, no. 1, October 2018. Pg. 115-120.
- Wibowo, Pristisal, Solly Ariza. (2018). *A Quality Distribution Networks with Unbalanced Load Management Distribution Transformer. International Journal for Innovative Research in Multidisciplinary Field*, Vol. 4, No.10, October 2018, pp. 161-163.