

# Analysis of the Relationship Between the Percentage of Load Imbalance and Power Losses in Distribution Transformers at PT. PLN (Persero) ULP Binjai Timur

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Distribution transformer is one of the most important components in the electric power distribution system. Distribution transformers often experience load imbalance problems. One previous study showed that load imbalance can reach 25.6% which contributes to increased power losses. This study aims to analyze the relationship between the percentage of load imbalance and the power losses incurred at PT. PLN (Persero) ULP East Binjai. This study was conducted with a quantitative approach by calculating the percentage of load imbalance and the resulting power losses. Data were collected through direct observation, voltage and current measurements, then calculations and analysis were carried out. The results showed that a greater percentage of load imbalance occurred at night at 12.96% while during the day at 10.03%. And the resulting power losses occurred at night at 853.3 Watts while during the day at 4,386.3 Watts. Thus, it can be concluded that the greater the percentage of load imbalance, the greater the power losses incurred.

**Keywords:** unbalance percentage, load unbalance, power loss, distribution transformer

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## 1. Introduction

A distribution transformer is a crucial component in an electric power distribution system, serving to channel and reduce the voltage from medium voltage to low voltage so that it can be used by consumers as needed. In practical operations, Distribution transformers often face various challenges and disturbances. One of them is load imbalance. According to Sya'roni and Rijanto (2019), the load imbalance condition in transformers can reach 25.6%, which contributes to a significant increase in power losses. PT. PLN (Persero) ULP Binjai Timur is one of the electricity distribution service providers in the East Binjai region that faces load imbalance conditions in distribution transformers. This is the novelty and urgency of this research because there has been no previous research conducted regarding the condition of the percentage of load imbalance and power losses incurred at PT. PLN (Persero) ULP Binjai Timur. Therefore, the purpose of this research is to analyze the relationship between the percentage of load imbalance and power losses in distribution transformers at PT. PLN (Persero) ULP Binjai Timur. It is necessary to determine how the relationship between the percentage of load imbalance and power losses in transformers so that it can provide a real contribution in optimizing the distribution of electrical energy and increasing the reliability of the electricity distribution system in the East Binjai region as emphasized by Yusiran & Hasabudin (2025).

## 2. Literature Review

### Distribution System

The electric power distribution system is a process of distributing electric power from a 150 kV transmission system to consumers, whether using a 20 kV voltage or a 220/380 V voltage.(Tonda et al. 2025)The electricity distribution process starts from the 20 kV substation output to the consumer.(Ramadhan, Lesmana, and Tharo 2024). The system that distributes electric current from the main distribution substation to consumers with good and sustainable service standards is the main objective of the distribution system.(Abendanon Siagian et al. 2023), in order to meet the need for a quality and sustainable electricity supply.

### Distribution Transformer

A transformer is an electromagnetic electrical device that functions to transfer and convert electrical energy from one electrical circuit to another with a different voltage level through electromagnetic induction. With this mechanism, a transformer can change the voltage level, either from high to low or vice versa, according to the needs of the electrical system.(Tonda et al. 2025). One distribution transformer can reduce the voltage from 20 kV to 220/380 Volts for TR users(Anisah 2018)Therefore, the reliability of distribution transformers is the main key in ensuring the continuity of stable and high-quality electrical energy distribution for the increasingly complex economic activities of the community.(Adi Satrio et al., 2023)One of the challenges and disturbances frequently encountered by distribution transformers is load imbalance. Load imbalance is a condition where the current/voltage vector values in each phase (R, S, and T) in a three-phase system are not equal or do not have a phase angle difference of 120° between the phases.(Siregar and Harahap nd)This condition is generally caused by uneven customer distribution, changing electricity consumption patterns, and disruptions to the electricity network.(Muliadi et al. 2022)The impact of this load imbalance significantly affects transformer reliability. Technically, this condition will result in excessive neutral current, potentially increasing power losses and decreasing efficiency in the distribution of electrical energy to consumers.(Afrianda, Samsurizal, and Nurul 2021). Transformer power viewed from the primary voltage side can be written as follows(Ardiansyah and Erivianto nd):

$$S = \sqrt{3} \cdot V \cdot I \quad (1)$$

Where :

S : Transformer Power (kVA)

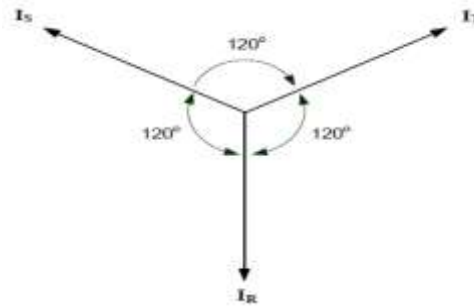
V : Transformer Primary Side Voltage (kV)

I : Current (A)

### Load Imbalance

Load imbalance is a condition in which there is a difference in the magnitude of the load or current passing through each phase in a three-phase electrical power system.(Anang Dasa Novfowan, Mochammad Mieftah, and Wijaya Kusuma 2021). Balanced load condition is a condition where(Ruliyanto 2020):

- a. The three vectors (R, S and T) of current/voltage are the same size.
- b. The three vectors (R, S and T) form an angle of 120° to each other.

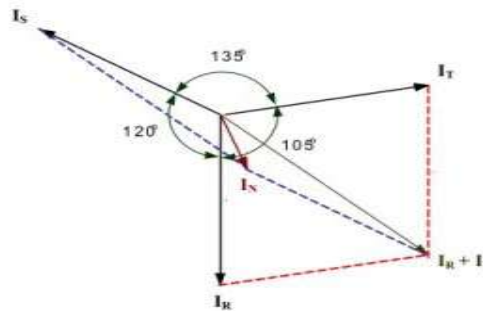


Source: Rulianto (2020).

**Figure 1.** Balanced State Flow Diagram Vector

Meanwhile, the condition of an unbalanced load is where one of the conditions for a balanced load is not met. (Soares Mariano Simoes frangino and Budiono Gatot 2024):

- a. The three vectors (R, S and T) are the same size but do not form a 120° angle.
- b. The three vectors (R, S and T) are not the same magnitude but form an angle of 120°.
- c. The three vectors (R, S and T) are not the same size and do not form an angle of 120°.



**Figure 2.** Unbalanced State Flow Diagram Vector

To determine how large the percentage of load imbalance is, the first step is to calculate the average current using the following formula: (Rohmat and Riyadi 2023).

$$\text{Average} = \frac{IR + IS + IT}{3} \tag{2}$$

Then the step taken is to find the coefficients a, b, and c. These coefficients are the comparison between I in each phase (R, S, T) with the average I. (Sutama and Sari 2023). The following equation states the relationship between these coefficients and the currents of each phase.

$$\begin{aligned} IR &= a. \text{ On average, then } a = \frac{IR}{\sqrt{\text{rata-rata}}} \\ IS &= b. \text{ Average, then } b = \frac{IS}{\sqrt{\text{rata-rata}}} \\ IT &= c. \text{ On average, then } c = \frac{IT}{\sqrt{\text{rata-rata}}} \end{aligned} \tag{3}$$

Then to calculate the percentage of load imbalance, it can be calculated using the formula (Aini et al., 2021):

$$\text{Imbalance}(\%) = \frac{(|a-1| + |b-1| + |c-1|)}{3} \times 100\% \tag{4}$$

Where :

- IR : R phase current value
- IS : S phase current value

IT : Phase current value T

### Power Losses Due to Neutral Current in Transformer Neutral Conductor

One of the main causes of power loss is uneven load distribution.(Sam & Gunawan, 2025). The current flowing through the neutral wire in a transformer with a three-phase star configuration with four wires is known as neutral current.(Istoni Reza & Gunawan Andi, 2021). The magnitude of the load imbalance is related to the amount of current passing through the neutral cable.(Zebua et al., 2021). Current flows into the neutral wire due to the uneven loading between the three phases. This current results in power losses along the neutral wire.(Jatmiko et al., 2024). The power loss in the neutral conductor of this transformer can be calculated using the following formula(Ginting, 2022):

$$P_N = I_N^2 \cdot R_N \quad (5)$$

Where :

- PN: power loss (loss) in the neutral conductor (W)
- IN : current flowing on the neutral side (A)
- RN : neutral conductor resistance ( $\Omega$ /km)

### Power Loss Due to Neutral Current Flowing to Ground

In addition to the current in the neutral conductor, the current that arises due to load imbalance also flows to the ground through the grounding conductor.(Soares Mariano Simoes frangino & Budiono Gatot, 2024). To calculate the power losses that occur, you can use the following formula:(Science, 2022):

$$P_G = I_G^2 \cdot R_G \quad (6)$$

Where :

- PG: power loss due to neutral current flowing to the ground (W)
- IG: current flowing in the grounding conductor (A)
- RG : grounding resistance ( $\Omega$ )

## 3. Research Methods

This research is designed for quantitative research that focuses on numerical data and statistical analysis to determine the relationship between the percentage of load imbalance and power losses caused by distribution transformers in the PT. PLN (Persero) ULP Binjai Timur area.

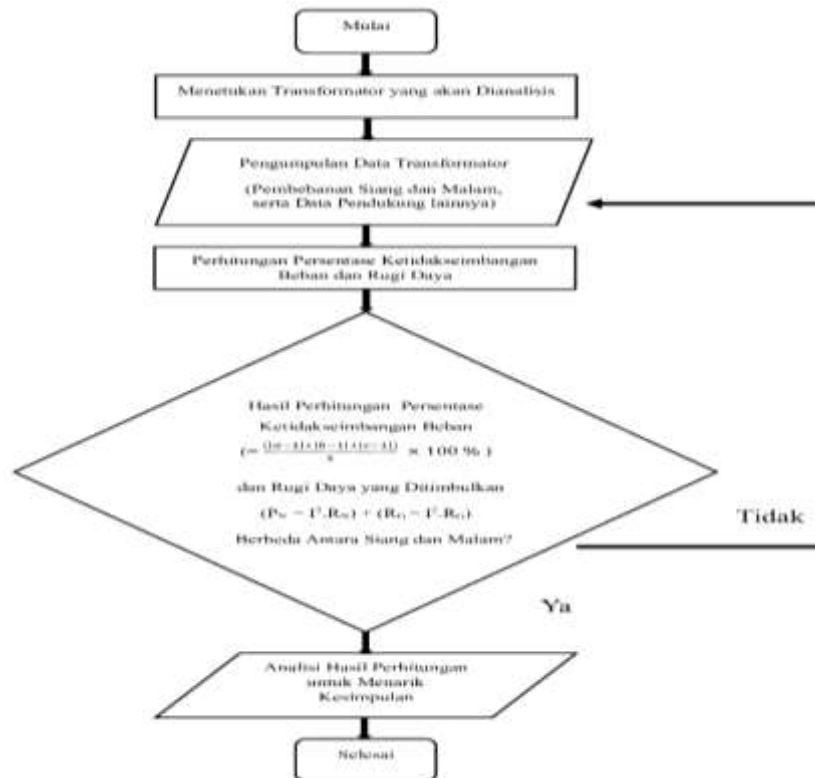


Figure 3. Flowchart System

Variables Analyzed

- a. Load imbalance (%).
- b. Power loss in the neutral conductor of a transformer caused by load imbalance (Watts).
- c. Power loss due to neutral current flowing to ground (Watts)

Data collection technique

- a. Interview with the East Binjai ULP to determine the condition of transformer loading in the field.
- b. Observation of daily load measurements for the selection of transformers to be studied.
- c. Measurement of technical variables required for research (current, voltage, and resistance).

Data analysis

- a. Calculating the percentage of distribution transformer load imbalance.
- b. Calculate power losses arising from load imbalance in distribution transformers.
- c. Draw conclusions about the relationship between the percentage of load unbalance and power losses incurred in distribution transformers.

4. Results and Discussion

Data collection

Based on the observations, the transformers to be analyzed are as follows.



Source: Research documentation (2025).

**Figure 1.** 160 kVA Distribution Transformer

**Table 1.** Transformer Name Plate Data to be Analyzed

Transformer Brand	Trafindo
Power	160 kVA
Primary Voltage	20000 Volt
Secondary Voltage	400 Volt
Loss Without Reason	300 W
Burdened Loss	2000 W
Cooling Type	ONAN
Vector Group	Yzn5
Neutral Conductor	A3CS 70 mm
Grounding Resistance	2.1 $\Omega$
Neutral Conductor Resistance	Resistance of AAACS type conductor with a diameter of 70 mm is 0.443 $\Omega$ /km <a href="https://unifibercable.com/products/overhead-insulated-cable/a3cs-aaacs-cable-indonesia.html">(<a href="https://unifibercable.com/products/overhead-insulated-cable/a3cs-aaacs-cable-indonesia.html">https://unifibercable.com/products/overhead-insulated-cable/a3cs-aaacs-cable-indonesia.html</a>)</a>

Based on load measurements carried out on September 9, 2025 on a 160 kVA distribution transformer, the following data was obtained.

**Table 2.** Results of Voltage Measurements During the Day and Night

Voltage	Day (Volt)	Night (Volt)
RN phase	228	225
SN phase	226	222
TN Phase	229	227

**Table 3.** Results of Current Measurements During the Day and Night

Current	Day (Ampere)	Night (Ampere)
R Phase	85.6	163.3
S phase	63.3	111.5
T phase	74.5	135.7
N Conveyor	39.9	90.3
Grounding	8.4	19.2

### Calculation of Load Imbalance Percentage

Before calculating the percentage of load imbalance during the day, the first thing to do is calculate the average current based on equation (2) as follows.

$$\text{Average} = \frac{IR+IS+IT}{3} = \frac{85,6+63,3+74,5}{3} = 74.4$$

SoAverage = 74.4

Then, after finding the average current, the next step is to find the values of the coefficients a, b, and c based on equation (3) as follows.

$$a = \frac{IR}{\sqrt{\text{rata-rata}}} = \frac{85,6}{74,4} = 1,150$$

$$b = \frac{IS}{\sqrt{\text{rata-rata}}} = \frac{63,3}{74,4} = 0,850$$

$$c = \frac{IT}{\sqrt{\text{rata-rata}}} = \frac{74,5}{74,4} = 1,001$$

And the percentage of load imbalance based on equation (4) during the day is as follows.

$$\text{Imbalance}(\%) = \frac{(|1,150-1|+|0,850-1|+|1,001-1|)}{3} \times 100 \%$$

$$= \frac{0,301}{3} \times 100 \%$$

$$= 10.03\%$$

So the percentage of load imbalance during the day is 10.03%.

### Calculation of the Percentage of Load Imbalance at Night

Before calculating the percentage of load imbalance at night, the first thing to do is calculate the average current based on problem (2) as follows.

$$\text{Average} = \frac{IR+IS+IT}{3} = \frac{163,5+111,5+135,7}{3} = 136.9$$

SoAverage = 136.9

Then, after finding the average current, the next step is to find the values of the coefficients a, b, and c based on equation (3) as follows.

$$a = \frac{IR}{\sqrt{\text{rata-rata}}} = \frac{163,5}{136,5} = 1,194$$

$$b = \frac{IS}{\sqrt{\text{rata-rata}}} = \frac{111,5}{136,5} = 0,814$$

$$c = \frac{IT}{\sqrt{\text{rata-rata}}} = \frac{135,7}{136,5} = 0,991$$

And the percentage of load imbalance at night based on equation (4) is as follows.

$$\text{Imbalance}(\%) = \frac{(|1,194-1|+|0,814-1|+|0,991-1|)}{3} \times 100 \%$$

$$= \frac{0,389}{3} \times 100 \%$$

$$= 12.96\%$$

So the percentage of load imbalance at night is 12.96%.

### Calculation of Power Losses Due to Load Imbalance

#### 1. Power Losses in Transformer Neutral Conductor

Based on equation (5), the power losses in the neutral conductor due to daytime are as follows:

$$IN = 39.9 \text{ A}$$

$$RN = 0.443 \Omega$$

$$\begin{aligned} P_N &= I_N^2 \cdot R_N \\ &= 39.92 \cdot 0.443 \\ &= 705.2 \text{ Watts} \\ &= 0.7052 \text{ kW} \end{aligned}$$

#### 2. Power Losses Due to Current Flowing to the Ground

Based on equation (6), the power losses due to current flowing to the ground are as follows:

$$\begin{aligned} I_G &= 8.4 \text{ A} \\ R_G &= 2.1 \Omega \\ P_G &= I_G^2 \cdot R_G \\ &= 8.4^2 \cdot 2.1 \\ &= 148.1 \text{ Watts} \\ &= 0.1481 \text{ kW} \end{aligned}$$

#### 3. Power Losses in Transformer Neutral Conductor

Based on equation (6), the power losses in the neutral conductor due to load imbalance at night are as follows:

$$\begin{aligned} I_N &= 90.3 \text{ A} \\ R_N &= 0.443 \Omega \\ P_N &= I_N^2 \cdot R_N \\ &= 90.3^2 \cdot 0.443 \\ &= 3,612.2 \text{ Watts} \\ &= 3.6122 \text{ kW} \end{aligned}$$

#### 4. Power Losses Due to Current Flowing to the Ground

Based on equation (6), the power losses due to current flowing to the ground at night are as follows:

$$\begin{aligned} I_G &= 19.2 \text{ A} \\ R_G &= 2.1 \Omega \\ P_G &= I_G^2 \cdot R_G \\ &= 19.2^2 \cdot 2.1 \\ &= 774.1 \text{ Watts} \\ &= 0.7741 \text{ kW} \end{aligned}$$

From the results of the calculation of the percentage of imbalance and power loss load caused during daytime conditions, an imbalance of 10.03% was obtained and caused power losses of 705.2 Watts on the neutral conductor and power losses due to current flowing to the ground of 148.1 Watts. So the total power loss incurred is 853.3 Watts or 0.8533 kW. Meanwhile, at night, an imbalance of 12.96% was obtained and resulted in power losses of 3,612.2 Watts on the neutral conductor and power losses due to current flowing to the ground amounting to 774.1 Watts. So the total power loss incurred is 4,386.3 Watts or 4.3863 kW. From the calculation results, it was found that the percentage of load imbalance that occurs between day and night is different, with the percentage of imbalance at night being greater, namely 12.96% than during the day, namely 10.03%. In addition to the percentage of load imbalance, it was also found that the number of power losses incurred is greater at night, namely 4,386.3 Watts than during the day, namely 853.3 Watts. Thus, the relationship between the percentage of load imbalance and the resulting power losses can be illustrated by the following graph.

## 5. Conclusion

The percentage of load imbalance that is greater occurs at night is 12.96% while during the day it is 10.03%. Power losses caused by load imbalance that are greater occur at night is 4,386.3 Watts or 4.3863

kW while during the day it is 853.3 Watts or 0.8533 kW so it can be concluded that the greater the percentage of load imbalance between the R, S, and T phases, the greater the power losses incurred or can be said to be directly proportional. This can be seen from the results of calculations of day and night conditions, namely daytime conditions with a load imbalance percentage of 10.03% causing a power loss of 853.3 Watts or 0.8533 kW and a load imbalance percentage of 12.96% with power losses caused by 4,386.3 Watts or 4.3863 kW at night. Based on these conclusions, it is recommended that PT. PLN (Persero) ULP Binjai Timur regulate balancing activities and redistribute loads to reduce the percentage of load imbalance and power losses. Further research is expected to conduct a more in-depth analysis and involve all distribution locations of PT. PLN (Persero) ULP Binjai Timur to obtain more accurate results.

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