Analysis of Losses Due to Load Unbalance in a 2000 kVA Transformer at Supermall Mansion 2 Tower Tanglin Surabaya

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Abstract

The load unbalance causes a neutral current, the current flowing in the neutral conductor will cause an increase in losses in the transformer. The greater the losses incurred, the efficiency and reliability of the transformer will decrease. Based on this, a study was conducted on analyzing the losses on distribution transformers at Supermall Mansion 2 Tower Tanglin which aims to determine the percentage value of transformer loading, the value of transformer imbalance, the value of transformer losses, and the value of transformer efficiency. This is done so that the value of the installed transformer does not exceed the applicable SPLN value. During the measurement, it was found that the percentage value of the transformer loading was 38.88% during the daytime and 48.89% at night (maximum SPLN 80%, minimum 40%). The load unbalance value is 11.66% during the daytime and 10.33% at night (SPLN is categorized as good if < 10%). Copper losses (Pcu) are 91.3 kW during the daytime and 94.2 kW at night. The value of losses due to neutral currents is 0.134 kW with a percentage of 0.0071% during the daytime and 0.173 kW with a percentage of 0.0090% at night. The percentage of the current value in the neutral conductor is 26.36% during the day and 24.04% at night (SPLN is categorized as good if < 20%).

Keywords: *Load Unbalanced, Transformer Loading, Transformer Losses*

I. INTRODUCTION

Electric power is now very attached to people's lives. The increase in the use of electric power is increasing along with the times. The provision of reliable and continuous electric power is a requirement that must be met in meeting the demand for electric power. In the electric power system, the transformer itself is a very important component and its condition needs to be considered so that it can support a reliable electric power distribution system. Therefore, the condition of the transformer must continue to be considered so that the reliability of the transformer does not decrease. One of the efforts to maintain the reliability of the transformer is to balance the load between the phases (R, S, T), but in reality an imbalance often occurs. The existence of this load imbalance can occur because the electrical equipment is not turned on simultaneously and electrical installation work that does not pay attention to balance in terms of distribution of electrical loads makes the load of each phase R, S, T unbalanced. This causes the emergence of currents in the neutral conductor which can cause losses. The greater the neutral current of a transformer, the losses incurred will also be greater so that the efficiency and reliability of the transformer will decrease. Based on the problems above, it is necessary to carry out an analysis that aims to calculate the magnitude of the load imbalance between the phases and the resulting losses so that the efficiency value of a transformer can be determined.

In the power distribution system the demand for power by consumers continues to grow. The amount of power requested is not always the same, which causes unequal distribution of the load. This causes the load distribution of each phase to be balanced. However, in reality, the loading of each phase is not always balanced. One of the reasons is the large number of one-phase loads that operate unevenly. Several studies have been conducted on power losses, load imbalance is one of the factors that cause power losses in the line. In order to balance the load by setting up a low-voltage network that can be said to have balanced phases and reduce power losses caused by the emergence of neutral currents, it is necessary to analyze the power system to determine how much of a load unbalance there is on the distribution transformer.

II. MATERIALS AND METHODS

Methods The research was carried out by direct measurement on the 2000 kVA distribution transformer at Supermall Mansion 2 Tower Tanglin, with the steps in carrying out the research, namely: Preparing measuring instruments or research materials, measuring the current of each phase, the phase voltage to neutral, and the neutral current using pliers. amperage.

After the measurement is made, the measurement data is then used to see losses due to unbalanced loading. Then after finishing taking measurements and removing all the tools and materials used and tidying up. From the data obtained during the measurement, the data is analyzed through calculations. The research was conducted in the area of the distribution transformer Supermall Mansion 2 Tower Tanglin which used a measuring instrument to support direct measurement results and analysis of results, specifically ammeters (figure 1), used as an instrument to measure electric current without breaking the power line, to measure voltage or to measure resistance values.

Figure 1. Digital Ampere Meter

In carrying out this research, researchers collected data at Supermall Mansion 2 Tower Tanglin. Data collection techniques were obtained from sources in research, namely:

1. Primary data is data obtained from research objects by means of direct measurements to retrieve the necessary data, namely:
   a. Current data flowing in each phase (phase R, phase S, phase T, and phase N). This data is needed to determine the average current flowing in each phase, while the neutral current data is needed to determine the amount of power loss that occurs in the distribution transformer.
   b. The voltage data contained in this Distribution transformer is the voltage flowing in each phase and the working voltage contained in the transformer. Voltage data is needed to find out how much the peak load current is on the transformer
   c. The resistance data (R) needed is the resistance data on the neutral conductor of the distribution transformer to analyze losses due to neutral currents in the neutral conductor.
2. Secondary data is data that comes from sources or references used in the calculation of this final assignment, the reference used is the Electricity Company Standard (SPLN No.17 of 2014).

A. Unbalanced Load Condition

As a result of the load unbalance between each phase on the secondary side of the transformer (R, S, T) current flows in the neutral channel of the transformer. The current flowing in the neutral conductor of this transformer causes losses (losses). Losses in the neutral conductor of this transformer are formulated as follows:

$$P_N = I_N^2 \times R_N \quad (1)$$

Where,

P_N = Losses in the neutral conductor (Watts)
I_N = Current in the neutral conductor (Ampere)
R_N = Resistance of neutral conductor (Ohm)

Figure 2. shows a vector diagram of currents in a balanced state. Here it can be seen that the sum of the three current vectors (I_R, I_S, I_T) is equal to zero so that no neutral current (I_N) appears.

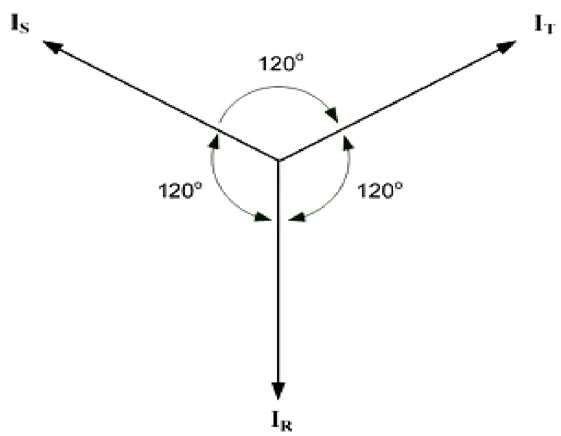

Figure 2. Vector Diagram Balanced Condition

Meanwhile, Figure 2 shows an unbalanced current vector diagram. Here it can be seen that the sum of the three current vectors (I_R, I_S, I_T) is not equal to zero so that a quantity appears, namely the neutral current (I_N), which depends on how big the unbalance factor.

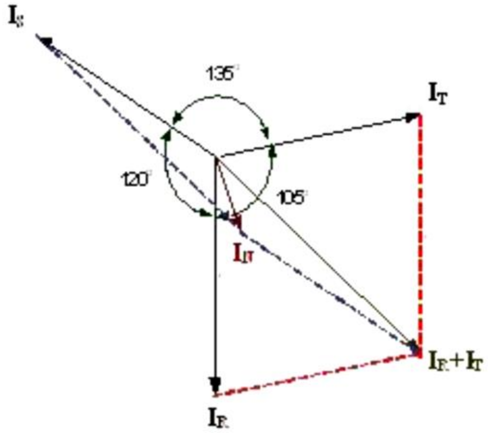

Figure 3. Vector Diagram Unbalanced Condition

B. Distribution and Power Loss

For example a power of P is distributed through a channel with a neutral conductor, if in this power distribution the phase currents are in a balanced state, then the amount of power can be expressed as follows:

$$P = 3 \times V \times I \times Cos\varphi \quad (2)$$

Where,

P = True Power (Watt)
V = Voltage Phase-Netral (Volt)
I = Phase Current (Ampere)
Cos φ = Power Factor

Due to variations in loads between phases or the nature of loads in a manufacturing process that loads each phase at different times, the presence of multiple loads between phases that are not properly distributed or balanced causes confusion. In 95% of the measurement time, 10% is the maximum allowable average stress strain (Rusliadi, R., et al., 2022). The neutral wire of the transformer appears to have current flowing between the three phases. Power losses in the distribution network will increase due to the current flowing through the neutral wire of the transformer, which will have a significant negative impact on consumers and PLN. The average current is the phase current in a balanced state according to the load coefficient equation a = b = c = 1. So, convention can be used to calculate the equation:

$$I_R = \text{a}.I_R \quad \text{jadi} \quad \text{a} = I_R/I_{avg} \quad (3)$$

$$I_S = \text{b}.I_S \quad \text{jadi} \quad \text{b} = I_S/I_{avg} \quad (4)$$

$$I_T = \text{c}.I_T \quad \text{jadi} \quad \text{c} = I_T/I_{avg} \quad (5)$$

While the magnitude of the coefficients a, b, and c is equal to one if the state is balanced. Consequently, the following formula can be used to calculate the average (%) as follows (Bactiar, A., et al., 2021)

$$\frac{(a-1)+(b-1)+(c-1))}{3} x\ 100\% \quad (6)$$

Where,

a = Coefficient of phase current R
b = Coefficient of phase current S
c = Coefficient of phase current T

C. Copper Losses in Transformer

The copper losses occur due to the resistance in the winding. Copper losses will be directly proportional to the size of the load so that increasing the load current will increase copper losses as well. To minimize copper losses, a copper wire whose cross section is large enough to carry the required electric current must be taken. These copper losses can be written in the following equation.

$$P_{cu} = I^2_P \text{ x } R_P + I^2_S \text{ x } R_S \quad (7)$$

Where,

P_{cu} = Copper Losses (Watt)
Ip = Primary Current (ampere)
Is = Secondary Current (ampere)
Rp = Resistance of Primary Turn (ohm)
Rs = Resistance of Secondary Turn (ohm)

D. Core Loss in Transformer

Core losses (Pc) are classified into two parts, namely hysteresis losses and eddy current losses. So the core loss can be written in the equation

$$Pi = Ph + Pe \quad (8)$$

Where :

Pc = Core loss (kW)

Ph = Hysteresis Loss

Pe = Loss of eddy current

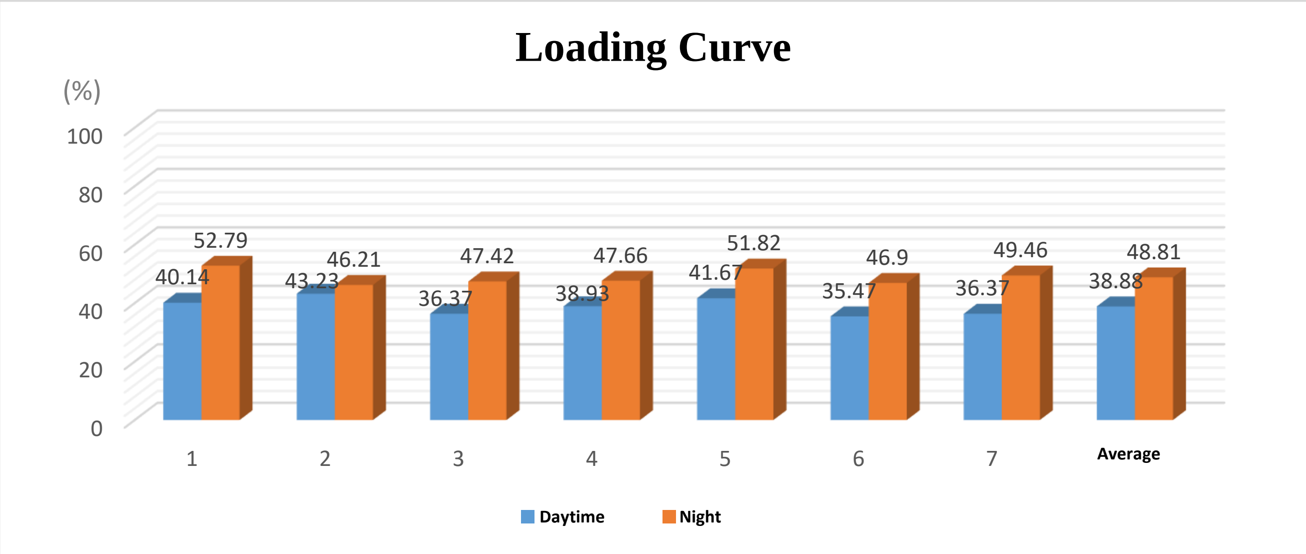

Figure 2. Load Percentage in Transformer on Supermall Mansion 2, Tower Tanglin

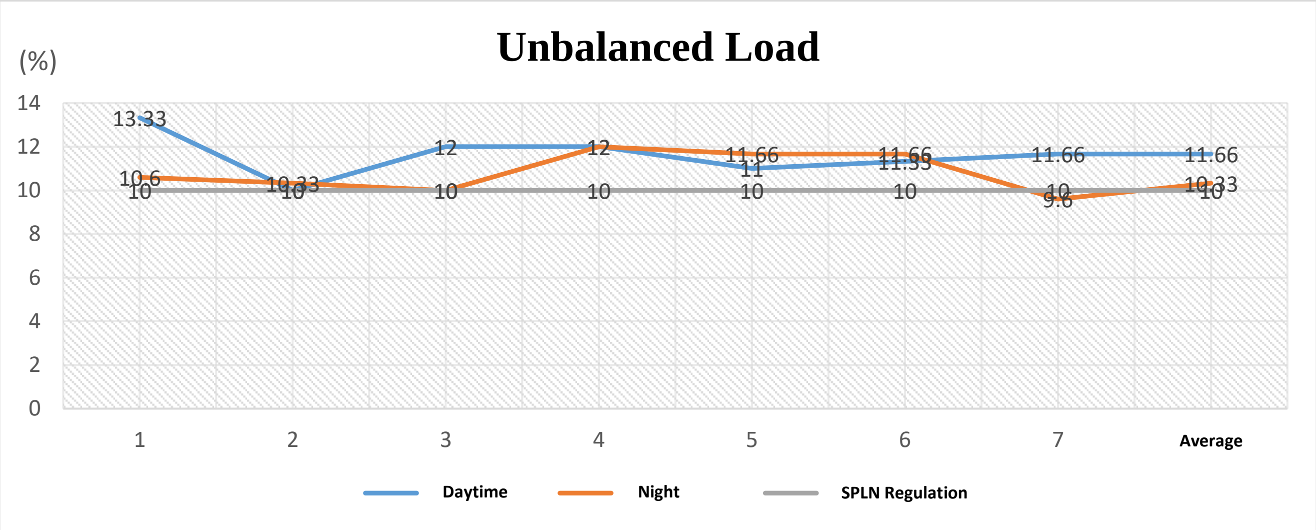

Figure 3. Unbalanced Load Percentage in Trasnformer on Supermall Mansion 2, Tower Tanglin

III. Results and Discussions

This research was conducted to determine the percentage of loading, the percentage of unbalanced load, the percentage due to the neutral current in the transformer, copper loss, core loss, and the efficiency percentage of the transformer. Table 1 is the average distribution transformer current data for 7 days which is the subject of current research. The measured current is the current flowing in the secondary winding of the transformer in each phase R, S, and T.

Table 1. Average Current for 7 Days

Phase	Current (Ampere)	
	Daytime	Night
R	341,71	427,57
S	439,85	543
T	341	438,57

A. Load Unbalance Analysis on Transformers

According to regulation SPLN 17 of 1979, distribution transformers are endeavored not to be loaded more than 80% or below 40%. From the figure 2, the percentage of load current in the Distribution Transformer at Supermall Mansion 2 Tanglin Tower for 7 days with an average of 38.88% during the daytime and 48.89% at night. The percentage of current loading on the Transformer for 7 days with an average value of 38.88% during the daytime is categorized as bad, and at night 48.89% is still categorized as well.

From the figure 3, the average value of unbalance during (7 days) is 11.66% during the daytime and 10.33% at night. Meanwhile, according to SPLN No. 17 of 2014 is categorized as good if the transformer load unbalance value is < 10%. The unbalance in Supermall Mansion 2 Tower Tanglin is categorized as sufficient.

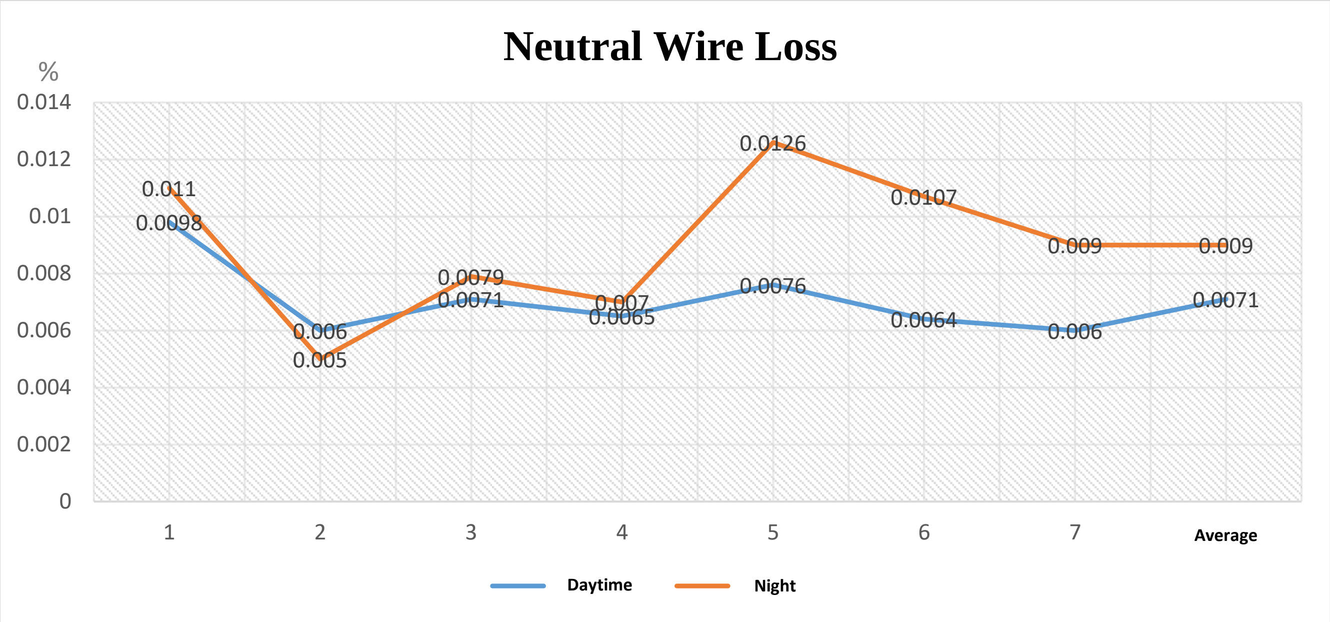

Figure 4. Neutral Wire Loss in Transformer on Supermall Mansion 2, Tower Tanglin

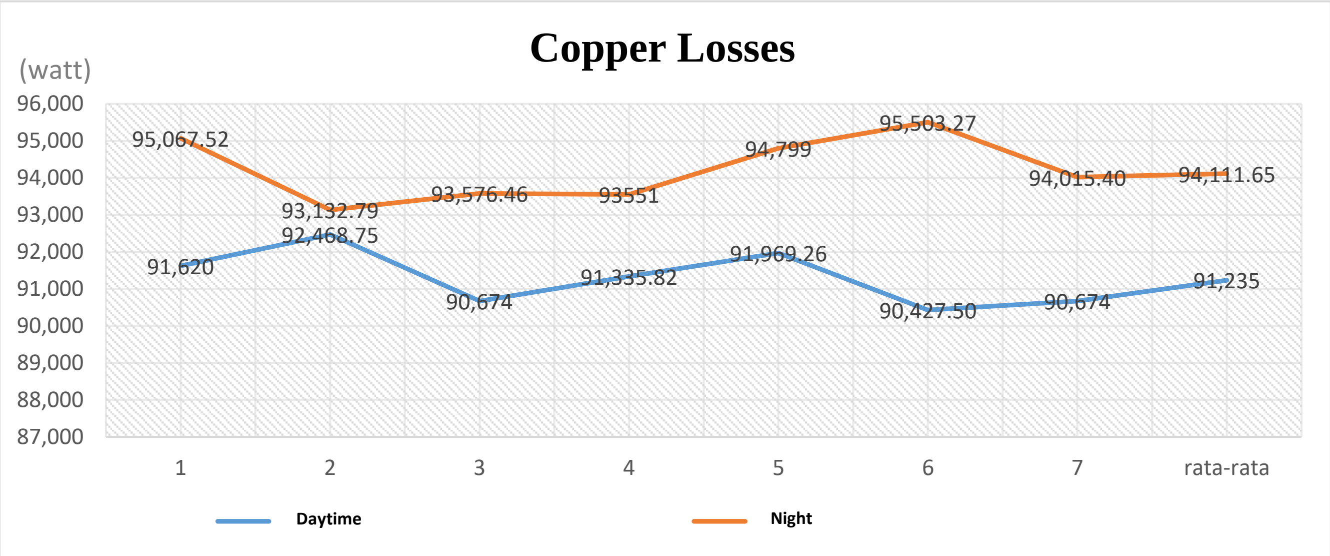

Figure 5. Copper Loss in Transformer on Supermall Mansion 2, Tower Tanglin

B. Identification of Neutral Wire Loss

From the measurement results, and calculated using equation (1), losses due to neutral currents in the neutral conductor of the transformer can be known. Figure 4 shows that the value of losses due to neutral current (Pn) for 7 days with an average of 0.134 kW with a percentage of 0.0071% during the day and 0.173 kW with a percentage of 0.0090% at night. The more neutral current that flows in the neutral wire of the transformer (In), the more losses in the neutral wire of the transformer (Pn). With increasing neutral currents and losses in the transformer, the efficiency of the transformer decreases.

C. Identification of Copper Losses

Copper loss can be calculated using equation (7), while core loss can be calculated using equation (8). Because the transformer is in operation, the core loss of the transformer is obtained from the nameplate data. The graphic above shows that the value of copper losses (Pcu) for 7 days with an average of 91,234 watts (91.3 kW) during the day and 94,111 watts (94.1 kW) at night. The increasing current flowing in the copper winding due to excessive loading causes an increase in copper loss in the transformer. The amount of copper loss always changes depending on the applied load, this loss reaches its maximum value at peak load.

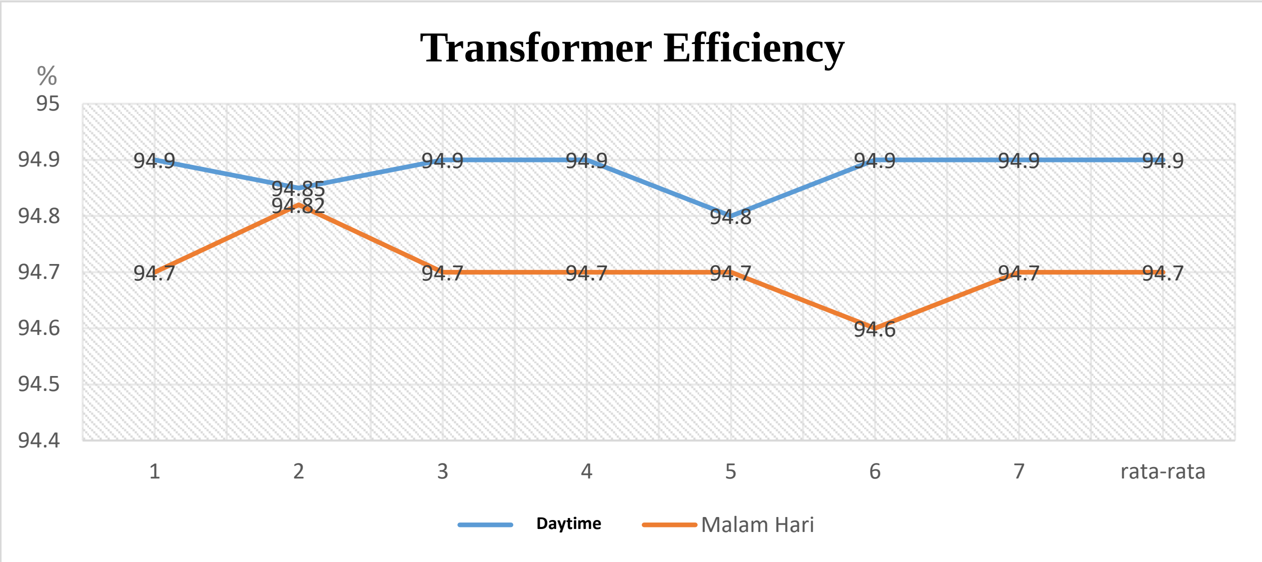

Figure 6. Transformer Efficiency on Supermall Mansion 2, Tower Tanglin

D. Determination of Transformer Efficiency

Transformer efficiency is the ratio of output power and input power, where the size of the efficiency of the transformer is affected by the size of the load. Efficiency is also affected by the losses contained in the transformer. After knowing how much loss there is in the transformer then the overall loss is added to the output power so that the input power of the transformer can be known. The efficiency value can be calculated by dividing the output power by the input power of the transformer. A good transformer efficiency value is 100%, but conditions in the field have power losses which can cause the transformer to heat up so that the efficiency value of the transformer will decrease. As shown in Figure 6, the average value of the transformer is 93.25% during the daytime and 94.7% at night. So the smaller the losses generated, the greater the efficiency value of the transformer.

E. Discussion

Load imbalance that affects neutral wire loss is a problem that occurs in three-phase power systems that have a neutral wire used to connect electrical equipment to the ground. Load imbalance occurs when the electrical loads connected to each phase are not evenly balanced. This unbalanced loading can cause unbalanced currents to flow through the neutral wire. As a result, the power losses that occur in the neutral wire are greater than if the load is balanced. These power losses can be in the form of conduction losses and induced losses in the neutral wire.

Conduction losses occur due to the unbalanced flow of current in the neutral wire, causing resistance in the wire. Induction losses occur due to the presence of a magnetic field generated by an unbalanced current in the neutral wire. These power losses can lead to decreased power system efficiency, excessive heat on the neutral wire, and reduced system power capacity. In addition, unbalanced loading can cause the neutral voltage to become unstable, which can affect the operation of electrical equipment and cause interference with the system.

Copper loss is the power loss that occurs in the transformer due to the resistance of the copper coil used in the construction of the transformer. This copper loss arises because the current flowing through the copper coil produces a voltage drop due to the copper resistance. The effect of copper loss on transformer efficiency is very significant. Copper loss results in a decrease in the actual power that can be used by the load, thereby reducing the efficiency of the transformer. The greater the copper loss, the lower the transformer efficiency. Transformer efficiency is measured by comparing the output power to the input power. The output power is the power supplied to the load, while the input power is the power supplied to the transformer. The greater the copper loss, the more power is lost in the form of heat, so the output power will be less than the input power. This results in a decrease in transformer efficiency.

In addition, copper loss can also cause an increase in transformer temperature. When current flows through the copper coil, the copper resistance causes the coil to heat up. If the copper loss is too high, the temperature of the transformer may rise above safe limits, which can result in damage to the insulation of the transformer and shorten its operational life. To increase the efficiency of the transformer, it is necessary to make several efforts. One way is to use a conductor material that has a low resistance, such as high-quality copper. In addition, it is also necessary to pay attention to the design of the transformer windings to reduce the current path length and the associated copper resistance. In some cases, the use of alternative conducting materials such as aluminum may be considered to reduce copper losses, although aluminum has a higher resistance than copper.

In the transformer industry, efficiency is very important because it is directly related to operational and environmental costs. More efficient transformers result in lower power losses and minimize environmental impact. Therefore, reducing copper loss is an important factor in increasing transformer efficiency. From the results of this study, it can be a material consideration for the Supermall Mansion 2 Tower Tanglin, especially in the electricity department to pay more attention to the load between phases (R, S, T) on the distribution transformer in order to avoid a greater load imbalance, and if this occurs, there will be large losses (losses) that arise which cause the efficiency of the transformer to decrease.

IV. CONCLUSION

Based on the results of observations made at the transformer section of the Supermall Mansion 2 Tower Tanglin Surabaya when measuring the load. The percentage of loading current in the Distribution Transformer at Supermall Mansion 2 Tower Tanglin for 7 days with an average of 38.88% during the daytime is categorized as bad, and at night 48.89% is still categorized as well. The average value of load imbalance for (7 days) is 11.66% during the daytime and 10.33% at night which is categorized as sufficient. Value of copper losses (Pcu) for 7 days with an average of 91,234 watts (91.2 kW) during the day and 94,111 watts (94.1 kW) at night. As for the value of losses due to neutral current (P_N) for 7 days with an average of 0.134 kW with a percentage of 0.0071% during the daytime and 0.173 kW with a percentage of 0.0090% at night. The average efficiency value of the transformer at Supermall Mansion 2 Tower Tanglin for (7 days) is 93.25% during the daytime and 94.7% at night.

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