Study Of The Effect Of Load Balance In 500 kVA Distribution Transformers In Complex Pt. Perta Arun Gas Area Of 17 Dumai Branch Lhokseumawe City

Rudi Syahputra
1Electric Engineering Study Program – Politeknik Negeri Lhokseumawe

Email: rudi.syahputra75@gmail.com

Abstract. For optimal distribution of electricity to the industry requires transformers as the heart of transmission and distribution. Therefore, the transformer is expected to optimize optimally. Given the hard work of the transformer and to maintain the durability of the equipment, the transformer load cannot exceed the capacity and there is no large load. The supply of electricity that is stable and continuous is a requirement that must be used in electricity needs. In meeting these needs, there is a division of loads that are initially the same because when the same time each which then causes an imbalance that damages the supply of electricity. Load imbalances are things that cause technical losses. In order to achieve a stable supply of electricity and continuity to consumers, it must be overcome. This study aims to determine the magnitude of the load imbalance on the distribution transformer and to determine the losses (losses) caused by the load imbalance in the distribution transformer. The method used is by taking data technically, measuring on secondary side transformers, calculations based on measurement data. The results showed that the percentage of load imbalance in accordance with the calculations during the day was 1.3% and on the same day 7.6% and the difficulty of losses due to the current flowing on the transformer neutral conveyor based on the daytime calculation of 0.17% or 0.79 kW and at night 0.23% or 1,075 kW.

1. Introduction
The distribution system is one of the systems in electric power that has an important role because it is directly related to the use of electrical energy, especially the users of medium voltage and low voltage electricity. Along with the pace of development growth, it is demanded the existence of facilities and infrastructure that support it such as the availability of electricity. Currently, electricity is a major need, both for everyday life and for industrial needs. In meeting the demand for electricity, there is a division of loads that are initially evenly distributed, but because of differences in the time of ignition of each phase of the load, it causes an imbalance of the load which has an impact on the supply of electricity. Load imbalances are things that give rise to technical losses. Load imbalance between each phase (phase R, phase S, and phase T) is what causes the flow of current in the transformer neutral.

1.1 Distribution Network System
The distribution system voltage can be grouped into 2 major parts, namely primary distribution (20kV) and secondary distribution (380 / 220V). The 20 kV distribution network is often called the Medium Voltage Distribution System and the 380/220 V distribution network is often called a secondary distribution network or called the 380 / 220V Low Voltage Network [1]. There are three important parts
of the process of electric power distribution, namely Generation, Distribution and Distribution as shown in Figure 1 [2].

Figure 1. Basic structure of the electrical system

1.2 Working Principles of Transformers

The transformer consists of two coils (primary and secondary) that are inductive. Both of these coils are electrically separated but are magnetically connected via lines that have low reluctance. If the primary coil is connected to a voltage source back and forth, the flux back and forth will appear in the laminated core, because the coil forms a closed network and the primary current flows. Due to the flux in the primary coil, induction occurs in the primary coil and induction occurs in the coil Secondary coils due to the influence of induction from the primary coil or referred to as joint induction (mutual induction) which causes the emergence of magnetic flux in the secondary coil, then the secondary current flows if the secondary circuit is charged so that the electrical voltage can be transferred in whole (magnetization).

\[ e = -N \frac{d\Phi}{dt} \text{ (Volt)} \]  

Where:
- \( e \) = Electromotive force (Volt)
- \( N \) = number of turns (turn)
- \( \frac{d\Phi}{dt} \) = Change in magnetic flux (weber/sec)

Only the alternating current voltage can be transformed by the transformer, whereas in the electronics field, the transformer is used as an impedance coupling between the source and the load to inhibit direct current while still performing alternating current between circuits [3].

1.3 Load Imbalance in the Transformer

Load balance is a condition where all three current/voltage phasors are equal. The three phasors form an angle of 120° to each other. Whereas what is meant by an unbalanced load state is a situation where one or both of the conditions of a balanced condition are not met, there is a possibility of an unbalanced state in the distribution system, namely [1]:

1. The three phasors are equal but do not form an angle of 120° to each other.
2. The three phasors are not the same size but form an angle of 120° to each other.
3. The three phasors are not as large and do not form an angle of 120° to each other.

Figure 2. Phasor current diagram

Figure 2 (a) shows the phasor of the current diagram in a balanced state. Here it is seen that the sum of the three current phasors (IR, IS, IT) is equal to zero so that no neutral current (IN) appears. Whereas in Figure 2 (b) shows the phasor of an unbalanced current diagram. Here it can be seen that the sum of the three current phasors (IR, IS, IT) is not the same as zero so that a quantity that is a neutral current (IN) appears, the amount depends on how much the imbalance factor is. [4]

1.4 Calculation of Full Load Current Transformer

Transformer power, when viewed from the side of high voltage (primary), can be formulated as follows:

\[ S = \sqrt{3} \cdot V \cdot I \]  

(2)

Where:
- \( S \): Power transformer (kVA)
- \( V \): Transformer (kV) primary side voltage
- \( I \): Current mesh (A)

So that to calculate the full load current (full load) can use the formula:

\[ I_{FL} = \frac{S}{\sqrt{3}V} \]  

(3)

where:
- \( I_{FL} \): Full load current (A)
- \( S \): Power transformer (kVA)
- \( V \): Voltage of transformer secondary side (kV)

1.5 Load Imbalance Calculation

The average current can be calculated using the equation [5]:

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

(4)

Where the magnitude of the phase current in a balanced state (I) equals the magnitude of the average current, the coefficients a, b, and c are obtained by:
In a balanced state, the magnitude of the coefficients \( a \), \( b \) and \( c \) is one. Thus the average load imbalance (\%) is:

\[
\frac{|a-1| + |b-1| + |c-1|}{3} \times 100 \%
\]  

(8)

1.6 Calculation of Losses Due to Neutral Flow in the Carrying Neutral Transformer

As a result of the load imbalance between each phase on the secondary side of the transformer (phase R, phase S, phase T) flows the current in the transformer neutral. The current flowing in the transformer neutral conductor causes losses. [1] Losses in this transformer neutral conductor can be formulated as follows:

\[
P_N = I_N^2 \cdot R_N
\]  

(9)

where:

\( P_N \): Losses on transformer neutral conductors (watts)

\( I_N \): Current flowing in the transformer neutral (A)

\( R_N \): transformer neutral delivery resistance (\( \Omega \))

Whereas losses due to neutral currents flowing to the ground can be calculated by formulating the following:

\[
P_G = I_G^2 \cdot R_G
\]  

(10)

where:

\( P_G \): losses due to neutral currents flowing to the ground (watts)

\( I_G \): neutral currents flowing to the ground (A)

\( R_G \): transformer neutral earthing prisoners (\( \Omega \))

2. Methodology

The method used in this study is to make direct measurements on the secondary side of the distribution transformer. The data collected through direct on-site measurement includes technical data of 500 kVA distribution transformer, measurement of an unbalanced load in daytime conditions (at 10.00 wib) and at night (21.00). Furthermore, from the measurement data, calculations are performed to determine the transformer loading capacity, load imbalance, losses due to neutral currents on neutral conductors, and losses due to neutral currents flowing to the ground.

3. Results and discussion

The following results of measurements were carried out on two measurement conditions, namely measurements during the day (table 1) and night (Table 2).
Table 1. Measurement of unbalanced load at noon at 10:00 a.m.

| Phase | I (A) | Vp-n (V) | S (kVA) | Cos φ |
|-------|-------|----------|---------|-------|
| R     | 80,6  | 219      | 17,65   | 0,92  |
| S     | 62    | 218      | 13,51   | 0,92  |
| T     | 89,2  | 218      | 19,44   | 0,92  |
| In (A) | Ig (A) | Rg (Ω) |         |       |
| 37    | 0,4   |          |         | 4,5   |

Table 2. Measurement of unbalanced load at night at 9:00 p.m.

| Phase | I (A) | Vp-n (V) | S (kVA) | Cos φ |
|-------|-------|----------|---------|-------|
| R     | 137,7 | 218      | 30,01   | 0,92  |
| S     | 119,3 | 219      | 26,12   | 0,92  |
| T     | 147,3 | 218      | 32,11   | 0,92  |
| In (A) | Ig (A) | Rg (Ω) |         |       |
| 43,1  | 0,6   |          |         | 4,5   |

To clarify the measurement results it is necessary to describe the current flow scheme on the secondary side of the transformer during the day and night. Figure 3 shows the IN current is smaller than in Figure 4 caused by the loading factor at night is greater.

Figure 3. Current flow scheme of the transformer secondary side during the day
3.1 Distribution Transformer Technical Data

In this test, the transformer technical data was taken by conducting a field survey. Here is the distribution transformer data as shown in the Name Plate.

| Factory Name | Trafo-union |
|--------------|-------------|
| Group Vector | Dyn5        |
| Power Capacity | 500 kVA   |
| Phase        | 3 fasa     |
| Primer Voltage L-L | 20 kV    |
| Secondary Voltage L-L | 400 V   |
| Primary Current | 14.43 A   |
| Secondary Current | 722 A    |
| Impedance    | 6%         |
| Incoming Cable | XLPE 95   |
| Outgoing Cable | NYFGBY 50 |

Figure 4. Current flow scheme of transformer secondary side at night

Figure 5. 500 kVA capacity distribution transformer
3.2 Used Load Current
To determine the used load current on the transformer using measurement data in Tables 1 and 2 are as follows:

a. During the day (10:00 a.m.)
$$I_{\text{Used Load}} = \frac{S}{\sqrt{3} \cdot V} = \frac{50,6 \text{ kVA}}{\sqrt{3} \times 400 \text{ V}} = 73,03 \text{ A}$$

b. at night time (9.00 p.m.)
$$I_{\text{Used Load}} = \frac{S}{\sqrt{3} \cdot V} = \frac{88,24 \text{ kVA}}{\sqrt{3} \times 400 \text{ V}} = 127,36 \text{ A}$$

3.3 Full Load Current
Full load current ($I_{\text{FL}}$) is obtained based on the transformer power capacity as shown in table 3 which is 500 kVA.
$$I_{\text{FL}} = \frac{S}{\sqrt{3} \cdot V} = \frac{500 \text{ kVA}}{\sqrt{3} \times 400 \text{ V}} = 721,68 \text{ A}$$

3.4 Analysis of Transformer Loads
a. Daytime measurement
To determine the average percentage of loading during the day, first calculate the percentage of performance load based on measurement data in Table 4.1 is $I_R = 80.6$ A, $I_S = 62$ A, $I_T = 89.2$ A:
$$\%_B = \frac{I_{\text{ph}}}{I_{\text{FL}}} \times 100\%$$
$$\%_{BR} = \frac{80.6}{721.68} \times 100\% = 11.16\%$$
$$\%_{BS} = \frac{62}{721.68} \times 100\% = 8.59\%$$
$$\%_{BT} = \frac{89.2}{721.68} \times 100\% = 12.36\%$$
The average loading percentage is
$$\frac{\%_{BR} + \%_{BS} + \%_{BT}}{3} = \frac{11.16+8.59+12.36}{3} = 10.703\%$$

b. Night measurements
To determine the average percentage of loading at night, first calculate the percentage of performance load based on measurement data in Table 4.2 is $I_R = 137.7$ A, $I_S = 119.3$ A, $I_T = 147.3$ A:
The average loading percentage is \( \%_B = \frac{I_{ph}}{I_{FL}} \times 100 \% \)

\[ \%_{BR} = \frac{137.7}{721.68} \times 100 \% = 19.08 \% \]

\[ \%_{BS} = \frac{119.3}{721.68} \times 100 \% = 16.53 \% \]

\[ \%_{BT} = \frac{147.3}{721.68} \times 100 \% = 20.41 \% \]

The average loading percentage is

\[ \frac{\%_{BR} + \%_{BS} + \%_{BT}}{3} = \frac{19.08 + 16.53 + 20.41}{3} = 18.67 \% \]

From the calculation above, it can be seen that at (WBP = Peak Load Time) the percentage of loading for the Dumai area is the 17-branch distribution transformer complex of PT. PAG Lhokseumawe, the highest load value occurred at night which is 18.67%.

### 3.5 Load Imbalance Analysis

#### a. At noon

Using equation (4) and based on the data in Table 1 we can determine the average current:

\[ I_{Average} = \frac{I_R + I_S + I_T}{3} \]

\[ I_{Average} = \frac{80.6 + 62 + 89.2}{3} = 77.26 A \]

By knowing the average value of the secondary current, we can use equations (5), (6) and (7) to be able to know the magnitude of the coefficients \(a\), \(b\) and \(c\), where the magnitude of the phase current is in a balanced state (I) equal to the amount of average current the day.

\[ I_R = a \cdot I \text{ then: } a = \frac{I_R}{I} = \frac{80.6}{77.26} = 1.04 A \]

\[ I_S = b \cdot I \text{ then: } b = \frac{I_S}{I} = \frac{62}{77.26} = 0.8 A \]

\[ I_T = c \cdot I \text{ then: } c = \frac{I_T}{I} = \frac{89.2}{77.26} = 1.15 A \]

In equilibrium, it can be seen that the coefficients \(a\), \(b\) and \(c\) are 1. Thus, the average load imbalance (\%) by using equation (8) is:

\[ \text{Average imbalance} = \left\{ \left| \frac{a-1}{3} \right| + \left| \frac{b-1}{3} \right| + \left| \frac{c-1}{3} \right| \right\} \times 100 \% \]

\[ \text{Average imbalance} = \left\{ \left| \frac{1.04-1}{3} \right| + \left| \frac{0.8-1}{3} \right| + \left| \frac{1.15-1}{3} \right| \right\} \times 100 \% \]

Average imbalance = 13 %
b. At night
Using equation (4) and based on the data in Table 2 we can determine the average current:

\[ I_{\text{Average}} = \frac{I_R + I_S + I_T}{3} \]

\[ I_{\text{Average}} = \frac{137.7 + 119.3 + 147.3}{3} \]

\[ I_{\text{Average}} = 134.76 \text{ A} \]

By knowing the average value of the secondary current, we can use equations (5), (6) and (7) to be able to know the magnitude of the coefficients a, b and c, where the magnitude of the phase current is in a balanced state (I) equal to the amount of average current the day.

\[ I_R = a \text{. I} \]

then: \[ a = \frac{I_R}{I} = \frac{137.7}{134.76} = 1.02 \text{ A} \]

\[ I_S = b \text{. I} \]

then: \[ b = \frac{I_S}{I} = \frac{119.3}{134.76} = 0.88 \text{ A} \]

\[ I_T = c \text{. I} \]

then: \[ c = \frac{I_T}{I} = \frac{147.3}{134.76} = 1.09 \text{ A} \]

In equilibrium, it can be seen that the coefficients a, b and c are 1. Thus, the average load imbalance (%) by using equation (8) is:

\[ \text{Average imbalance} = \frac{|a-1|+|b-1|+|c-1|}{3} \times 100 \% \]

\[ \text{Average imbalance} = \frac{|1.02-1|+|0.88-1|+|1.09-1|}{3} \times 100 \% \]

Average imbalance = 7.6 %

From the above calculation, it can be seen that both during the day and at night, the average percentage of load imbalance ranges from 7.6 - 13%. This is due to the uneven use of load among consumers in the R, S and T phases.

3.6 Analysis of Losses Due to Neutral Flow on Neutral Transformers
a. At noon
By using equation (9) and measurement data in Table 1, losses due to neutral currents on transformer neutral conductors can be calculated, namely:

\[ P_N = I_N^2 \cdot R_N \]

\[ = 37^2 \cdot 0.579 \]

\[ = 792.6 \text{ watt} \approx 0.79 \text{ kW} \]

Where is the transformer active power (P)

\[ P = S \cdot \cos \varphi \text{, where } \cos \varphi \text{ is used is } 0.92 \]

\[ P = 500 \cdot 0.92 \]

\[ = 460 \text{ kW} \]

So, the percentage losses due to neutral currents in the transformer neutral conductors during the day are:

\[ \% P_N = \frac{P_N}{P} \times 100 \% \]
\[
\% P_N = \frac{0.79 \text{ kW}}{460 \text{ kW}} \times 100 \% = 0.17 \%
\]

b. At night

By using equation (9) and measurement data in Table 2, losses due to neutral currents on transformer neutral conductors can be calculated as follows:

\[
PN = I_N^2 \cdot R_N = 43.1^2 \cdot 0.579 = 1075.5 \text{ watt} \approx 1.075 \text{ kW}
\]

So the percentage losses due to neutral currents in transformer neutral conductors at night are:

\[
\% P_N = \frac{P_N}{P} \times 100 \%
\]

\[
\% P_N = \frac{1.075 \text{ kW}}{460 \text{ kW}} \times 100 \% = 0.23 \%
\]

3.7 Analysis of Losses Due to Neutral Current Flowing to the Ground

a. At noon

Using equation (10) and measurement data in Table 1, losses due to neutral currents flowing to the ground \((I_g)\) can be calculated as follows:

\[
PG = I_G^2 \cdot R_G = 0.4^2 \cdot 4.5 = 0.72 \text{ watt} \approx 0.00072 \text{ kW}
\]

So the percentage losses due to neutral currents flowing to the ground during the day are:

\[
\% P_G = \frac{P_G}{P} \times 100 \%
\]

\[
\% P_G = \frac{0.00072 \text{ kW}}{460 \text{ kW}} \times 100 \% = 0.000156 \%
\]

b. At night

Using equation (10) and measurement data in Table 2, losses due to neutral currents flowing to the ground \((I_g)\) can be calculated, namely:

\[
PG = I_G^2 \cdot R_G = 0.6^2 \cdot 4.5 = 1.62 \text{ watt} \approx 0.00162 \text{ kW}
\]

So the percentage losses due to neutral currents flowing to the ground at night are:

\[
\% P_G = \frac{P_G}{P} \times 100 \%
\]

\[
\% P_G = \frac{0.00162 \text{ kW}}{460 \text{ kW}} \times 100 \% = 0.000352 \%
\]
Table 3. Loss on 500 kVA Distribution Transformers

| No | RN (Ω) | Time | Unbalanced Load (%) | IN (A) | IG (A) | PN (kW) | PN (%) | PG (kW) | PG (%) |
|----|--------|------|---------------------|--------|--------|---------|--------|---------|--------|
| 1  | 50 mm²| Noon | 13                  | 37     | 0,4    | 0,79    | 0,17   | 0,0072  | 0,00015 |
| 2  | Night | 7,6  | 43,1                | 0,6    | 1,075  | 0,23    | 0,00162| 0,00035 |
| 3  | 70 mm²| Siang| 13                  | 37     | 0,4    | 0,55    | 0,11   | 0,0072  | 0,00015 |
| 4  | Malam | 7,6  | 43,1                | 0,6    | 0,74   | 0,16    | 0,00162| 0,00035 |

Table 3 shows that the greater the neutral current flowing in the transformer neutral (IN) conductor, the greater the loss in the transformer neutral (PN) conductor. Similarly, if the greater the neutral current flows to the ground (IG), the greater the losses due to neutral currents flowing to the ground (PG). With the greater neutral currents and losses in the transformer, the transformer efficiency drops. If the size of the neutral conductor wire is made the same as the conductor wire (70 mm²), the neutral current losses will decrease.

4. Conclusion
To overcome the load imbalance, it is necessary to measure the distribution transformer periodically (check the load). By knowing the distribution transformer load, especially on one phase load consumers, we can find out the percentage of load imbalance on the transformer. If the percentage of load imbalance has a value of 20%, it is necessary to carry out a balanced load sharing action to the maximum extent possible. The greater the load imbalance on the distribution transformer, the more neutral currents flowing to the ground and transformer losses. One way to overcome neutral current losses is to replace the size of the neutral conductor cable from 50 mm² to 70 mm². The reason why this action must be taken is to minimize the unbalanced load on the distribution transformer, besides that this action can reduce losses caused by unbalanced load on the distribution transformer and also achieve a stable and continuous electricity supply to consumers.

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