

ANALYSIS OF THE EFFECT OF LOAD IMBALANCE ON NEUTRAL CURRENT AND POWER LOSSES IN DISTRIBUTION TRANSFORMER BGLWY1036 SUBSTATION RUMAH TIGA

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ABSTRACT

Load imbalance in an electric power distribution system always occurs and the cause of this imbalance is single-phase loads on low-voltage network customers. As a result of the load imbalance, a current appears in the neutral of the transformer. The current flowing in the neutral of the transformer causes losses, namely losses due to neutral currents in the neutral conductor of the transformer and losses due to neutral currents flowing to the ground.

The additional load on the BGLWY1036 distribution substation in Rumah Tiga village in a period of ± 2 years (2020-2022 which is significant without taking into account the distribution of the transformer load, the impact is felt for consumers, resulting in very large voltage and power losses. Data from measurements during the day and night day (peak load) carried out at the BGLWY1036 distribution substation in Rumah Tiga village, it can be seen that the magnitude of the voltage (V) and current (I), as well as the results of the apparent power calculation (S) are not the same in each phase (L1, L2 and L3).

Based on the results of the analysis, the effect of load imbalance on neutral currents and power losses in the distribution transformer BGLWY1036 Rumah Tiga is obtained (i) power losses due to currents in the neutral conductor (PN) during the day by 8.650% and at night by 10.405 %. (ii) power losses due to neutral current flowing to the ground (PG) during the day is 1.201% and at night is 1.564%.

Keywords: Load Unbalance, Distribution Transformer, Power Losses

INTRODUCTION

Load imbalance in an electric power distribution system always occurs and the cause of the imbalance is in single-phase loads on low-voltage network customers. As a result of the load imbalance, there is a current in the transformer neutral. The current flowing in the neutral of the transformer causes losses, namely losses due to the neutral current in the neutral conductor of the transformer and losses due to the neutral current flowing to the ground.

The addition of loads to the BGLWY1036 distribution substation in Rumah Tiga village within ± 2 years (2020-2022) is significant without taking into account the transformer load sharing, the impact is felt by consumers, resulting in huge voltage and power losses. Measurement data during the day and night (peak load) carried out at the BGLWY1036 distribution substation in Rumah Tiga village, it can be seen that the magnitude of the voltage (V) and current (I), as well as the results of the calculation of apparent power (S) are not the same in each phase (R, S and T).

The measurement data during the day are: (i) voltage, $V_R = 217$ V; $V_S = 218$ V and $V_T = 220$ V. (ii) current, $I_R = 228.3$ A; $I_S = 169.0$ A and $I_T = 92.5$ A. Measurement data at night (peak load) are: (i) voltage, $V_R = 216$ V; $V_S = 217$ V and $V_T = 219$ V. (ii) current, $I_R = 316.2$ A; $I_S = 246.1$ A and $I_T = 119.7$ A. From these results, it can be seen that the load carried by the transformer is not balanced between phases R, S and T, causing a current flowing in the neutral conductor of $I_N = 120.6$ A (during the day) and $I_N = 137.0$ A (night). (data from PT. PLN Area Ambon in 2023).

Based on the problems above, the authors want to conduct research with the title Analysis of the Effect of Load Imbalance on Neutral Currents and Power Losses in Distribution Transformer BGLWY1036 Rumah Tiga.

LITERATURE REVIEW

2.1 Transformer Theory

A transformer is an electrical device that converts alternating current voltage from one level to another by means of a magnetic coupling and is based on the principles of electromagnetic induction. The transformer consists of a core, which is made of plated iron and two coils, namely the primary coil and the secondary coil.

The use of a simple and reliable transformer allows the selection of an appropriate and economical voltage for each need and is one of the important reasons that alternating current is widely used for the generation and distribution of electric power.

2.2 Calculation of Transformer Full Load Current

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

$$S = \sqrt{3} \cdot V \cdot I \text{ (VA)} \dots \dots \dots (1)$$

Where:

S = Transformer power (kVA)

V = Transformer primary side voltage (kV)

I = Mains current (A)

So to calculate the full load current, you can use the formula:

$$I_{FL} = \frac{S}{\sqrt{3} \cdot V} \text{ (Ampere)} \dots \dots \dots (2)$$

Where :

I_{FL} = Full load current (A)

S = Transformer power (kVA)

V = Voltage of the secondary side of the transformer (kV)

2.3 Losses (losses) due to the existence of a neutral current in the neutral conductor of the transformer.

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

$$P_N = I_N^2 \cdot R_N \text{ (Watts) (3)}$$

Where:

P_N = Loss of power in the neutral conductor of the transformer (watts)

I_N = Current flowing in the transformer neutral (A)

R_N = Transformer neutral conductor resistance (Ω)

While losses caused by neutral currents flowing to the ground (ground) can be calculated with the following formulation:

$$P_G = I_G^2 \cdot R_G \text{ (Watts) (4)}$$

Where:

P_G = Power loss due to neutral current flowing to ground (watts)

I_G = Current flowing into the ground (A)

R_G = transformer neutral earthing resistance (Ω)

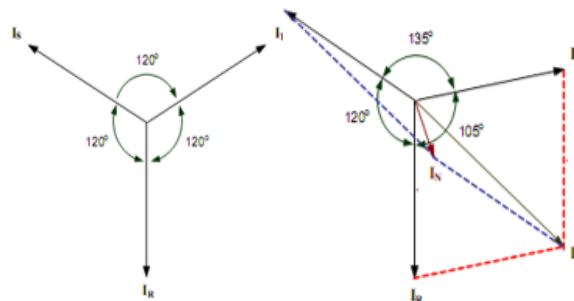
2.4 Load Unbalance

A state of balance is a state in which:

- The three phases have the same magnitude of the current/voltage vector.
- The three phases have mutual vectors that form an angle of 120° with each other.

Meanwhile, what is meant by an unbalanced state is a condition in which one or both of the conditions for a balanced state are not met. There are 3 possible unbalanced conditions, namely:

- The three phases have the same vector size, but do not form an angle of 120° with each other.
- The three phases have vectors that are not the same size, but form an angle of 120° to each other.
- The three phases have vectors that are not the same size and do not form an angle of 120° with each other.



Gambar 1. Vektor Diagram Arus
(Julius Sentosa Setiadji, dkk, 2006:69)

Figure 1(a) 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. Meanwhile, Figure 1(b) shows an unbalanced current diagram vector. 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) whose magnitude depends on how big the imbalance factor is.

2.5 Delivery and Disadvantages

For example, a power of P is channeled 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:

$$P = 3.V.I.Cos\varphi \text{ (Watts)} \dots\dots\dots (5)$$

with:

P = Power at the sending end

V = Voltage at the sending end

cos φ = Power factor

The power to the receiving end will be less than the power to the sending end, because there is shrinkage in the channel. If (I) is the magnitude of the phase current in a power distribution equal to P in a balanced state, then in the same power distribution but with an unbalanced state the magnitude of the phase currents can be expressed by the coefficients a, b and c as follows:

$$[IR] = a[I]$$

$$[IS] = b[I] \dots\dots\dots (6)$$

$$[IT] = c[I]$$

where IR, IS and IT are the currents in the R, S and T phases, respectively.

If the power factor in the three phases is considered the same even though the magnitude of the current is different, the amount of power supplied can be expressed as:

$$P = (a + b + c) \times [V] \times [I] \cdot \cos\varphi \dots\dots\dots (7)$$

If equation (7) and equation (5) state that the power is the same, then from the two equations the requirements for the coefficients a, b, and c can be obtained, namely:

$$a + b + c = 3 \dots\dots\dots (8)$$

where in a balanced state, the value of $a = b = c = 1$

2.6 Electrical Power

The unit for electric power in the SI and metric systems is the watt. One watt is defined as something equal to the work done at the rate of one joule every second.

Watts are also defined as the energy released or the work done every second by a constant current of 1 ampere flowing at a voltage of 1 volt, or

$$P = I.V.Cos\varphi \text{ Watts} \dots\dots\dots (9)$$

The fact that the watt is a unit of power or rate of doing work cannot be overemphasized. Keep in mind that the current in amperes is the rate of flow of electricity or equal to the number of coulombs per second, so the power formula can be written:

$$Daya.dalam.watt = \frac{Coulomb}{Sekon} \times Volt \dots\dots\dots (10)$$

In other words, the watt is a measure of the speed at which an electric charge moves through a potential difference. From Ohm's law ($V = IR$), this value of V can be distributed into equation (9), so that another useful power formula is obtained

$$P = I \times V = I \times IR = I^2 \times R \dots\dots\dots (11)$$

The third power formula can be derived from the fact that $I = V/R$ by Ohm's law. Substitute into equation 11

$$P = \frac{V \times V}{R} = \frac{V^2}{R} \dots\dots\dots (12)$$

2.7 Power Loss On Line

When current flows through the resistance, the resistance becomes hot or it is said that electrical energy is converted into heat energy. The rate of conversion of electrical energy into heat

is called power and the method used to determine this power is, in other words, the rate of energy released in resistance is proportional to the square of the current.

Because the conductors of a transmission or distribution circuit have resistance, they heat up when current flows through them. The heat or heat is removed or lost to the surrounding air, this is called a loss in the channel.

This power loss is proportional to the square of the current flowing. For this reason, it is more efficient to deliver power with the smallest possible current so that the power loss is minimal. Power loss based on line resistance on transmission and distribution lines is expressed by the following equation:

- For three phase

$$P_l = 3.I^2, R.l \text{ (Watts) (13)}$$

- For one phase

$$P_l = .I^2, R.l \text{ (Watts) (14)}$$

METHOD

3.1 Research Locations

This research was carried out at PT. PLN (Persero) Ambon Area, feeder Wayame 1, especially at substations and low voltage distribution network (secondary) 380/220volt distribution substation BGLWY1036 Lorong Service Desa Rumah Tiga.

3.2 Types of Research Data

The type of data needed to perform a calculation analysis, as follows:

3.2.1 Primary Data

The data obtained from the measurement results, namely:

- Distribution transformer data for the BGLWY1036 Rumahtiga substation.
- Current and voltage data, distribution substation BGLWY1036 Rumahtiga.

3.2.2 Secondary Data

Data obtained from references (books, journals, and PLN), namely:

- Transformer specification data
- Standard data types and sizes of channels/cables

3.3 Variable Analysis of Research Results

The variables used in analyzing the results of this study are as follows:

Table 3.1 Variable Analysis

No	Variabel	Simbol	Satuan
1	Ketidakseimbangan beban trafo		%
2	Losses akibat adanya arus pada penghantar netral trafo	P_N	Watt
3	Losses akibat arus netral yang mengalir ke tanah	P_G	Watt

RESULTS AND DISCUSSION

4.1 Research Results

The results of the study were obtained from (i) data sources from PT (Persero) PLN Ambon Branch, (ii) measurements at the end of the conductor. The results and data obtained are May 2023.

4.1.1 Description of the BGLWY1036 Substation for Three Houses

Factory Made: Sintra

Type : Outdoors

Power : 100 kVA

Working Voltage : 20 kV / 400 V

Current: 5 – 250 A

Relationship : Dyn5

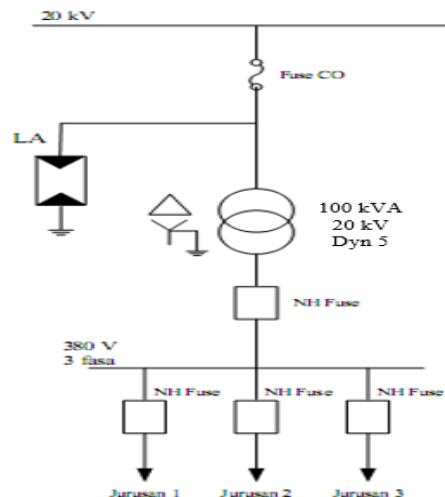
Impedance : 4%

Number of Transformers: 1 x 3 phase

4.1.2 Distribution and Single Line Transformers



Gambar 4.1. Trafo Distribusi 100 kVA
(Sumber : PT. PLN Area Ambon, 2023)



Gambar 4.2. Single line trafo distribusi 100 kVA
(Sumber : Gilbert V. Titaley, 2023)

4.1.3 Measurement Data

Table 4.1. Measurement results of the 100 kVA distribution transformer during the day

Phasa	S (kVA)	Vp (Volt)	I (Ampere)	Cosφ
R	28,61	216	132,43	0,82
S	26,17	218	120,12	0,84
T	17,68	220	80,35	0,85
I_N	106,75 A			
I_G	54,64 A			
R_G	0,3420 Ω			

Sumber : PT. PLN Area Ambon, 2023.

Table 4.2. Measurement results of the 100 kVA distribution transformer at night

Phasa	S (kVA)	Vp-n (Volt)	I (Ampere)	Cosφ
R	36,70	216	142,48	0,81
S	31,70	217	129,94	0,82
T	26,21	219	95,27	0,84
I_N	117,08 A			
I_G	62,34 A			
R_G	0,3420 Ω			

Sumber : PT. PLN Area Ambon, 2023.

4.1.4 Current flow scheme

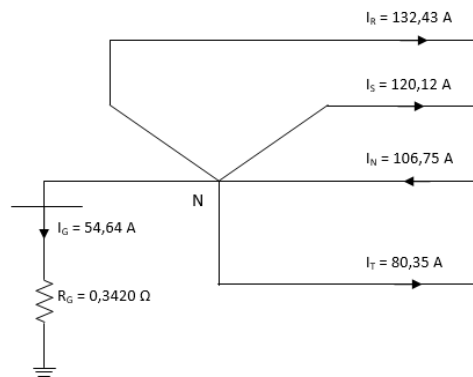


Figure 4.3 Schematic of Current Flow on the Secondary Side of the Transformer during the Day.
(Sumber : Gilbert V. Titaley, 2023)

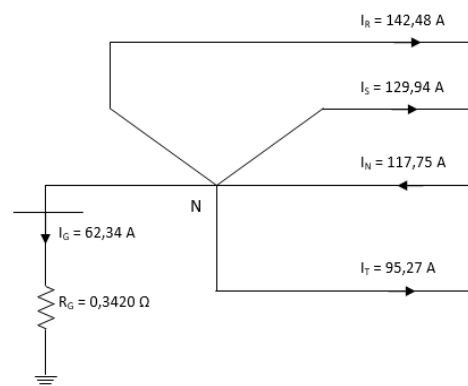


Figure 4.4 Schematic of Current Flow on the Secondary Side of the Transformer at Night.
(Sumber : Gilberth V. Titaley, 2023)

4.2 Discussion

4.2.1 Transformer Loading

a. Transformer Full Load Current

Calculate the full load current of the distribution transformer, using equation (2):

$$S = 100 \text{ kVA}$$

$$V = 0.38 \text{ kV phase - phase}$$

$$I_{FL} = S / (\sqrt{3} \cdot V) = 100000 / (\sqrt{3} \times 380) = 152.11 \text{ A}$$

b. Transformer average current

At noon

$$I_R = 132.43 \text{ A}; I_S = 120.12 \text{ A}; I_T = 80.35 \text{ A}$$

$$I_{rata-rata} = \frac{I_R + I_S + I_T}{3} = (132.43 + 120.12 + 80.35) / 3 = \mathbf{110.97 \text{ A}}$$

At night

$$I_R = 142.48 \text{ A}; I_S = 129.94 \text{ A}; I_T = 95.27 \text{ A}$$

$$I_{rata-rata} = \frac{I_R + I_S + I_T}{3} = (142.48 + 129.94 + 95.27) / 3 = \mathbf{122.56 \text{ A}}$$

c. Transformer Loading Percentage

At noon

$$\%_{TL} = \frac{I_{rata-rata}}{I_{FL}} \times 100\% = \frac{110.97}{152.11} \times 100\% = \mathbf{72.95\%}$$

At night

$$\%_{TL} = \frac{I_{rata-rata}}{I_{FL}} \times 100\% = \frac{122.56}{152.11} \times 100\% = \mathbf{80.57\%}$$

From the calculation above it can be seen that at night (WBP = Peak Load Time) the loading percentage is quite high, namely 80.57%.

4.2.2 Transformer Load Unbalance

At noon

By using equation (6), the magnitude of the coefficients a, b, and c can be known, where the magnitude of the phase current in a balanced state (I) is equal to the magnitude of the average current (Iaverage).

$$I_R = a \cdot I_{average}, \text{ then } a = \frac{I_R}{I_{rata-rata}} = \frac{132.43}{110.97} = 1.193$$

$$I_S = b \cdot I_{average}, \text{ then } b = \frac{I_S}{I_{rata-rata}} = \frac{120.12}{110.97} = 1.082$$

$$I_T = c \cdot I_{average}, \text{ then } c = \frac{I_T}{I_{rata-rata}} = \frac{80.35}{110.97} = 0.724$$

In a balanced state, the magnitude of the coefficients a, b and c is 1. Thus, the average load unbalance (in %) is:

$$= \{|a-1| + |b-1| + |c-1|\} / 3 \times 100\%$$

$$= \{|1.193-1| + |1.082-1| + |0.724-1|\} / 3 \times 100\% = \mathbf{18.39 \%}$$

At night

By using equation (6), the magnitude of the coefficients a, b, and c can be known, where the magnitude of the phase current in a balanced state (I) is equal to the magnitude of the average current (I_{average}).

$$I_R = a \cdot I_{\text{average}}, \text{ then } a = \frac{I_R}{I_{\text{rata-rata}}} = \frac{142,48}{122,56} = 1.163$$

$$I_S = b \cdot I_{\text{average}}, \text{ then } b = \frac{I_S}{I_{\text{rata-rata}}} = \frac{129,94}{122,56} = 1.060$$

$$I_T = c \cdot I_{\text{average}}, \text{ then } c = \frac{I_T}{I_{\text{rata-rata}}} = \frac{95,27}{122,56} = 0.777$$

In a balanced state, the magnitude of the coefficients a, b and c is 1. Thus, the average load unbalance (in %) is:

$$= \{|a-1| + |b-1| + |c-1|\} / 3 \times 100\%$$

$$= \{|1.163-1| + |1.060-1| + |0.777-1|\} / 3 \times 100\% = \mathbf{14.85 \%}$$

From the calculation above, it can be seen that both during the day and at night, the load imbalance is still within tolerance of the maximum load imbalance value assumed by PLN, which is 20%. (I Gede Budiya, et al. 2021, p. 286)

4.2.3 Losses Due to Current in the Transformer Neutral Conductor

A. Neutral Conductor Cross-sectional Area 50 mm²

At noon

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$I_N = 106.75 \text{ A}; R_N = 0.6452 \Omega; P_N = I_N^2 \times R_N \\ = [106.75]^2 \times 0.6452 = \mathbf{7352.42 \text{ Watts} \approx 7.352 \text{ kW}}$$

where is the active power of the transformer (P):

$$P = S \times \cos \phi,$$

where the $\cos \phi$ used is 0.85 and the apparent power of the transformer (S) = 100 kVA

$$P = 100 \times 0.85 = \mathbf{85 \text{ kW}}$$

Thus, the percentage of losses due to current in the neutral conductor of the transformer is:

$$\%P_N = \frac{P_N}{P} \times 100\% = \frac{7,352}{85} \times 100\% = \mathbf{8.650 \%}$$

At night

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$I_N = 117.08 \text{ A}; R_N = 0.6452 \Omega; P_N = I_N^2 \times R_N \\ = [117.08]^2 \times 0.6452 = \mathbf{8844.23 \text{ Watts} \approx 8.844 \text{ kW}}$$

Thus, the percentage of losses due to current in the neutral conductor of the transformer is:

$$\%P_N = \frac{P_N}{P} \times 100\% = \frac{8,844}{85} \times 100\% = \mathbf{10.405 \%}$$

B. Neutral Conductor Cross-sectional Area 70 mm²

To minimize losses due to current in the neutral conductor of the transformer, calculations are carried out using a neutral conductor cross-sectional area of 70 mm².

At noon

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$I_N = 106.75 \text{ A}; R_N = 0.4608 \Omega; P_N = I_N^2 \times R_N \\ = [106.75]^2 \times 0.4608 = 5251.075 \text{ Watts} \approx 5.251 \text{ kW}$$

where is the active power of the transformer (P):

$P = S \times \cos \varphi$, where the $\cos \varphi$ used is 0.85 and the apparent power of the transformer (S) = 100 kVA

$$P = 100 \times 0.85 = 85 \text{ kW}$$

Thus, the percentage of losses due to current in the neutral conductor of the transformer is:

$$\%_{PN} = \frac{P_N}{P} \times 100\% = \frac{5,251}{85} \times 100\% = 6,178 \%$$

At night

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$P_N = I_N^2 \times R_N = 117,08^2 \times 0,4608 = 6316.52 \text{ Watt} \approx 6.317 \text{ kW}$$

where is the active power of the transformer (P):

$P = S \times \cos \varphi$, where the $\cos \varphi$ used is 0.85 and the apparent power of the transformer (S) = 100 kVA

$$P = 100 \times 0.85 = 85 \text{ kW}$$

Thus, the percentage of losses due to neutral currents in the neutral conductor of the transformer is:

$$\%_{PN} = \frac{P_N}{P} \times 100\% = \frac{6,317}{85} \times 100\% = 7.431 \%$$

C. Neutral Conductor Cross-sectional Area 95 mm²

To minimize losses due to current in the neutral conductor of the transformer, calculations are carried out using a neutral conductor cross-sectional area of 70 mm².

At noon

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$I_N = 106.75 \text{ A}; R_N = 0.3096 \Omega$$

$$P_N = I_N^2 \times R_N = 106,75^2 \times 0,3096 = 3528.066 \text{ Watt} \approx 3.528 \text{ kW}$$

where is the active power of the transformer (P):

$P = S \times \cos \varphi$, where the $\cos \varphi$ used is 0.85 and the apparent power of the transformer (S) = 100 kVA

$$P = 100 \times 0.85 = 85 \text{ kW}$$

Thus, the percentage of losses due to current in the neutral conductor of the transformer is:

$$\%_{PN} = \frac{P_N}{P} \times 100\% = \frac{3,528}{85} \times 100\% = 4.115 \%$$

At night

From the measurement table, and by using equation (3), the amount of losses due to currents in the neutral conductor of the transformer can be calculated, namely:

$$P_N = I_N^2 \times R_N = 117,08^2 \times 0,3096 = 4243.912 \text{ Watt} \approx 4.244 \text{ kW}$$

where is the active power of the transformer (P):

$P = S \times \cos \varphi$, where the $\cos \varphi$ used is 0.85 and the apparent power of the transformer (S) = 100 kVA

$$P = 100 \times 0.85 = 85 \text{ kW}$$

Thus, the percentage of losses due to neutral currents in the neutral conductor of the transformer is:

$$\%_{PN} = \frac{P_N}{P} \times 100\% = \frac{4,244}{85} \times 100\% = 4.993 \%$$

4.2.4 Losses Due to Neutral Current Flowing to the Ground

Losses due to neutral currents flowing to the ground during the day can be calculated using equation (4), namely:

At noon

$$P_G = I_G^2 \times R_G, \text{ where } I_G = 54.64 \text{ A and } R_G = 0.3420 \Omega$$

$$= 54,64^2 \times 0,3096 = 1021.051 \text{ Watts} \approx 1.021 \text{ kW}$$

Thus the percentage of losses is:

$$\%_{PG} = \frac{P_G}{P} \times 100\% = \frac{1,021}{85} \times 100\% = 1.201 \%$$

At night

$$P_G = I_G^2 \times R_G \text{ where } I_G = 62.34 \text{ A and } R_G = 0.4320 \Omega$$

$$= 62.34^2 \times 0,4320 = 1329.106 \text{ Watts} \approx 1.329 \text{ kW}$$

Thus the percentage of losses is:

$$\%_{PG} = \frac{P_G}{P} \times 100\% = \frac{1,329}{85} \times 100\% = 1.564 \%$$

4.2.5 Comparison of Losses in Distribution Transformers Using Neutral Conductor Cross-sectional Areas of 50 mm², 70 mm² and 95 mm²

In this section, a comparison of the results of calculating losses in distribution transformers is given for the use of neutral conductor cross-sectional areas of 50 mm², 70 mm² and 95 mm²

Tabel 4.3 Perbandingan losses pada trafo distribusi 100 kVA

R _N (Ω)	Waktu	Ketidak- seimbangan Beban (%)	I _N (A)	P _N (kW)	P _N (%)	I _G (A)	P _G (kW)	P _G (%)
0,5882 (50 mm ²)	Siang	18,39	106,75	7,352	8,650	54,64	1,021	1,201
	Malam	14,85	117,08	8,844	10,405	62,34	1,329	1,564
0,4202 (70 mm ²)	Siang	18,39	106,75	5,251	6,178	54,64	1,021	1,201
	Malam	14,85	117,08	6,316	7,431	62,34	1,329	1,564
0,3096 (95 mm ²)	Siang	18,39	106,75	3,528	4,151	54,64	1,021	1,201
	Malam	14,85	117,08	4,243	4,993	62,34	1,329	1,564

4.3 Analysis of Calculation Results

In Table 4.3 it can be seen that the greater the neutral current flowing in the transformer neutral conductor (I_N), the greater the losses in the transformer neutral conductor (P_N). Likewise, if the greater the neutral current flowing to the ground (I_G), the greater the losses due to the neutral current flowing to the ground (P_G).

With greater neutral currents and losses in the transformer, the efficiency of the transformer decreases. If the size of the neutral conductor wire is made the same as the phase conductor wire (70 mm²), then the neutral current losses will be smaller

CLOSING

5.1. Conclusion

Based on the data analysis above, it can be seen that the effect of load imbalance on neutral currents and power losses at the BGLWY1036 Rumah Tiga distribution transformer can be summarized as follows:

1. Losses (losses) of power due to currents in the neutral conductor (PN)
 - During the day, power losses due to currents in the neutral conductor (PN) are 8.650%.
 - At night the power loss due to the current in the neutral conductor (PN) is 10.05%.
2. Losses (losses) of power due to the neutral current flowing to the ground (PG)
 - During the day, power losses due to neutral currents flowing to the ground (PG) are 1.201%.
 - At night the power loss due to neutral current flowing to the ground (PG) is 1.564%.

5.2. Suggestion

Based on the discussion and analysis of the results and conclusions, it is recommended as follows:

1. One way to overcome neutral current losses is to equal or exceed the size of the neutral and phase conductors.
2. Pay attention to the distribution of the load on the transformer, so that the loading of each phase is the same.
3. For additional loads in the future, it is necessary to pay attention to the installed transformer capacity, with the aim that the load usage does not exceed the transformer capacity.

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