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Analysis of Load Imbalance in Tarakan Distribution Transformer of PT PLN (Persero) Sukarami Customer Service Unit

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ABSTRACT: Load imbalance in an electric power distribution system always occurs and the cause of this imbalance is unbalanced single-phase loads on low voltage network customers. As a result of this load imbalance, a current arises in the neutral of the transformer, which can cause power losses. The aim of the research is to analyse the load imbalance of the Distribution Transformer PC0044, PC0074, PC0088, PC0129, PC1319 on the Tarakan Feeder of PT PLN (Persero) Sukarami Customer Service Unit. The results of the research show that the highest peak load percentage occurs on the PC1319 Distribution Transformer, namely 93.0874%, and based on PLN ED Decree No. 0017.E/DIR/2014, transformer loading. The largest percentage of load imbalance occurs in the PC0044 Distribution Transformer, namely 38.0952%, and based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the bad category because the load imbalance is ≥ 25%. The largest percentage of power losses due to neutral current in the transformer neutral conductor occurs in the PC0044 Distribution Transformer, namely 2.6737%, and based on PLN ED Decree No. 0017.E/DIR/2014, the neutral current TR is included in the good category because the power losses due to the neutral current in the transformer neutral conductor are <10%. The largest percentage of power losses due to neutral current flowing to the ground occurs in the PC0044 Distribution Transformer, namely 5.0784%.

KEYWORDS: Load Imbalance, Power Losses, Neutral Current, Distribution Transformer

I. INTRODUCTION

The presence of electricity is a fundamental need in human life, which cannot be ignored. It has become a primary need for humans, especially with technological advances, where electric power is the main driver in operating various devices supporting human life, both in households and in industrial contexts. One of the crucial elements in electric power infrastructure is the distribution transformer [1].

Distribution transformers are components used to distribute electricity from substations to load centres or consumers. In three-phase four-wire distribution transformers, load imbalance often occurs. Load imbalance is caused by different loads on each phase of the secondary side of the transformer, namely phase R, phase S, and phase T. Load imbalance between phases causes neutral current to flow in the transformer. The flowing neutral current can cause power loss in the transformer, namely power loss due to the neutral current in the neutral conductor of the transformer, and power loss due to neutral current flowing to the ground. If there is a large load imbalance, the neutral current that appears is also large, and the power loss due to the neutral current flowing to the ground is even greater [2-4].

Based on these problems, the purpose of this study is to analyse the load imbalance in Distribution Transformers PC0044, PC0074, PC0088, PC0129, PC1319 Tarakan Transmission Line PT PLN (Persero) Sukarami Customer Service Unit. The parameters to be analysed include determining the percentage of loading on each transformer, load imbalance on the transformer, power loss due to neutral current in the neutral conductor of the transformer, and power loss due to neutral current flowing to the ground. The benefit of this research is that the loading on Distribution Transformers PC0044, PC0074, PC0088, PC0129, PC1319 Tarakan Feeder can be balanced and the same in each phase in order to reduce power losses contained in Distribution Transformers PC0044, PC0074, PC0088, PC0129, PC1319 Tarakan Feeder.

II. RESEARCH METHODS

2.1. Time and Place of Research

The implementation of the research began in February to March 2023. The research site is PT PLN (Persero) Sukarami Customer Service Unit (ULP) located at Jalan Kelapa Gading Km 9, RT. 1, Karya Baru Village, Alang-Alang Lebar District, Palembang City, South Sumatra 30961. The object of research is load imbalance in five distribution transformers of Tarakan Feeder, namely PC0044, PC0074, PC0088, PC0129, PC1319.

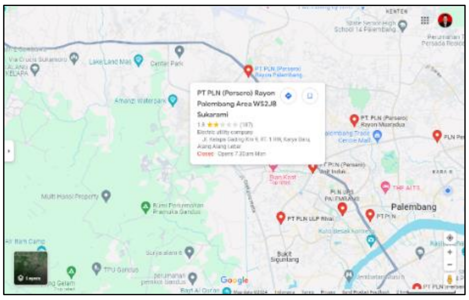


Figure 1. Research Location

2.2. Research Stages

Distribution transformers are devices used to transport electrical energy from substations to the point of consumption or load. Usually, distribution transformers are placed close to consumer locations, in contrast to transmission transformers which are generally located near power plants or in large transformer stations. A transformer is a device consisting of two or more coils connected to each other through a common magnetic field. When one of the coils, usually the primary coil, is connected to an alternating voltage source, there will be a magnetic flux that depends on the primary voltage and the number of turns. The flux will then connect the other coil, which is the secondary coil, and generate a voltage in it, the value of which depends on the number of turns in the secondary coil [2-4].

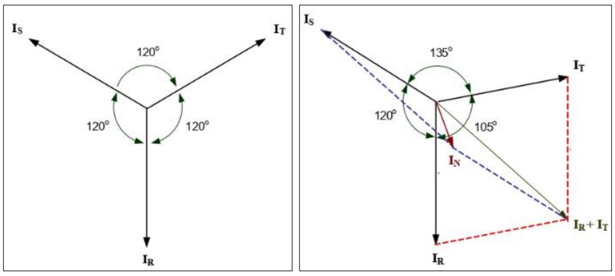
In three-phase distribution transformers with four wires, load imbalance often occurs. This imbalance is triggered by different loads on each phase on the secondary side of the transformer, namely phase R, phase S, and phase T. The load imbalance between phases results in neutral current flow in

The transformer. This neutral current flow can cause power losses in the transformer. One of the common problems in three-phase systems is load imbalance, which is often caused by the dominance of the load on one phase over the other. If there is load imbalance in all three phases, it can produce current flow in the neutral wire, and the load angle difference between phases is not equal to 120°. What is meant by a balanced state is a state in which (Figure 2a) [5-7]:

1. All three current/voltage vectors are equal
2. The three vectors form a 120° angle with each other

Meanwhile, an unbalanced state is a state in which one or both of the conditions of an equilibrium state are not met (Figure 2b). There are three possible unbalanced states, namely [5-7]:

1. The three vectors are equal but do not form a 120° angle with each other
2. The three vectors are not equal in magnitude but form a 120° angle with each other
3. The three vectors are not equal and do not form a 120° angle with each other.



(a) (b)

Figure 2. Vector Current Diagram

Figure 2(a) shows the vector current diagram 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 no neutral current appears. Whereas Figure 2(a) shows the vector current diagram in an unbalanced state. 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 large the unbalance factor is [5-7].

2.2.1. Full Load Current on Transformer

Transformer power when viewed from the low voltage side (secondary) can be determined using the following equation [8]:

$$S = \sqrt{3}\, V\, I \qquad (1)$$

Then the *full load* current in the transformer can be determined using the following equation [8]:

$$I_{FL} = \frac{S}{\sqrt{3}\, V} \qquad (2)$$

Description:

S = Transformer power (kVA)

V = Transformer secondary side voltage (kV)
I_{FL} = Full load current (A)

2.2.2. Transformer Loading

Transformer loading under unbalanced load conditions is equal to the average current magnitude. The average current in the transformer can be determined using the following equation [1]:

$$I_{average} = \frac{I_R + I_S + I_T}{3} \quad (3)$$

Then, the transformer loading percentage can be determined using the following equation [1]:

$$I_{loading}\ (\%) = \frac{I_{average}}{I_{FL}} \times 100\ \% \quad (4)$$

2.2.3. Load Imbalance on Transformers

For example, power of P is channelled 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 [2]:

$$P = 3\ V\ I \cos\phi \quad (5)$$

Description:
P = Power at the send end (W)
V = Voltage at the send end (V)
$\cos\phi$ = Power factor

If I is the magnitude of the phase current in the power distribution by 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 coefficient a, b, and c as follows [9]:

$$I_R = a \times I_{average} \text{ then } a = \frac{I_R}{I_{average}} \quad (6)$$

$$I_S = b \times I_{average} \text{ then } b = \frac{I_S}{I_{average}} \quad (7)$$

$$I_T = c \times I_{average} \text{ then } c = \frac{I_T}{I_{average}} \quad (8)$$

With I_R, I_S, and I_T are the phase currents R, S, and T. The power factor ($\cos\phi$) the three phases are considered the same even though the magnitude of the current is different, the amount of power supplied can be expressed as follows [8]:

$$P = (a + b + c)\ V\ I \cos\phi \quad (9)$$

If equation (9) and equation (5) express the same magnitude of power, then from the two equations can be obtained the requirements for the coefficients of a, b, and c namely: $a + b + c = 3$ in the unbalanced state, while in the balanced state the coefficient value of $a = b = c = 1$. Then the average current magnitude of load imbalance can be expressed in percentage (%), namely [3]:

$$I_{load\ imbalance}\ (\%) = \frac{\{|a-1| + |b-1| + |c-1|\}}{3} \times 100\% \quad (10)$$

2.2.4. Power Loss Due to The Presence of Neutral Current in the Transformer Neutral Conductor

As a result of unbalanced loading in each phase, current will flow in the neutral conductor. If there is a resistance value in the neutral conductor and the current is flowing, the neutral conductor will have a voltage that causes the voltage in the transformer to be unbalanced. The current flowing along the neutral conductor will cause power losses along the neutral conductor of [1,3]:

$$\Delta P_N = {I_N}^2\ R_N \quad (11)$$

Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is [1,3]:

$$\Delta P_N\ (\%) = \frac{\Delta P_N}{P} \times 100\ \% \quad (12)$$

Description:
ΔP_N = Power loss at the neutral conductor of the transformer (W)
I_N = Current flowing in the neutral conductor of the transformer (A)
R_N = Resistance at the neutral conductor of the transformer (Ω)
$\Delta P_N\ (\%)$ = Percentage of power loss at the neutral conductor of the transformer (%)

2.2.5. Power Loss Due to Neutral Current Flowing to Ground

This power loss occurs due to the neutral current flowing or heading to the ground, the amount can be calculated using the following formula [3-4,7]:

$$\Delta P_G = {I_G}^2\ R_G \quad (13)$$

Then the percentage of power loss due to neutral current flowing to the ground is [3-4,7]:

$$\Delta P_G\ (\%) = \frac{\Delta P_G}{P} \times 100\ \% \quad (14)$$

Table 2. Distribution Transformer Load Measurement Results on Tarakan Feeder

Distribution Transformer	Transformer Capacity (kVA)	Measurement Time	I_R (A)	I_S (A)	I_T (A)	I_N (A)	I_G (A)	R_N (Ω)	R_G (Ω)	V_{P-P} (V)	V_{P-N} (V)	Cos ϕ
PC0044	100	07/02/23 18.45	37	125	97	61	31,9	0,6842	4,53	404	229	0,91
PC0074	315	07/02/23 20.15	128	113	108	37	19,4	0,6842	3,73	402	235	0,90
PC0088	160	07/02/23 19.55	82	68	66	43	22,5	0,6842	4,96	407	236	0,92
PC0129	200	07/02/23 17.50	105	185	136	79	41,4	0,6842	4,86	402	232	0,91
PC1319	200	07/02/23 19.00	271	240	280	43	22,5	0,6842	4,74	408	237	0,92

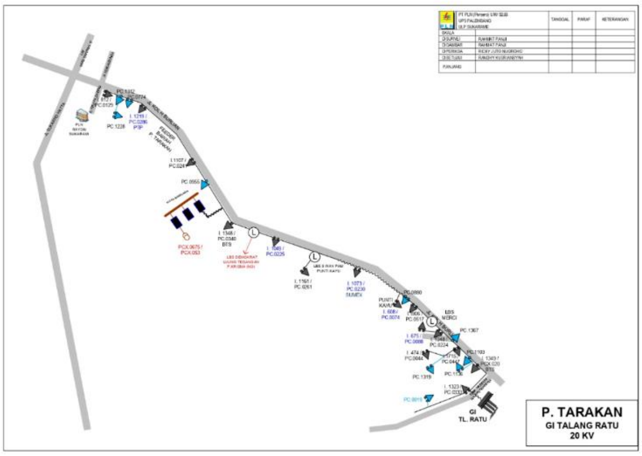


Figure 3. Tarakan Feeder

Description:

ΔP_G = Power loss due to neutral current flowing to the ground (W)

I_G = Neutral current flowing to ground (A)

R_G = Transformer neutral earthing resistance (Ω)

ΔP_G (%) = Percentage of power losses due to neutral current flowing to the ground (%)

Table 1 is a standard that has been set by PT PLN (Persero) regarding the current imbalance between phases, the amount of TR neutral current (% to transformer load current), and transformer loading (% to capacity) [10].

Table 1. Transformer Load Standard According to PLN ED Decree No. 0017.E/DIR/2014

Characteristic Group	Characteristic	Health Index			
		Good	Simply	Less	Bad
Load Reading and Profilling	Inter-phase Flow Imbalance	< 10%	10% - < 20%	20% - < 25%	≥ 25 %
	Neutral Current (% of transformer load current)	< 10%	10% - < 15%	15% - < 20%	≥ 20 %
	Transformer loading (% of capacity)	< 60%	60% - < 80%	80% - < 100%	≥ 100 %

III. RESULTS AND DISCUSSION

3.1. Distribution Transformer Load Data

In this study, only 5 (five) distribution transformers in the Tarakan Feeder were measured, namely: PC0044, PC0074, PC0088, PC0129, PC1319. Distribution transformer load measurements were carried out on 7 February 2023 with measurement time at 17.30-21.00. The results of current measurements on Distribution Transformers PC0044, PC0074, PC0088, PC0129, PC1319 can be seen in Table 2.

3.2. Results

3.2.1. Full Load Current Calculation on Transformers

1. Distribution Transformer PC0044

   The capacity of Distribution Transformer PC0044 is 315 kVA, and if the average voltage on the secondary side is 404 V, the full load current is:

   $$I_{FL} = \frac{100.000}{\sqrt{3} \times 404} = 142{,}9085\ A$$

2. Distribution Transformer PC0074

   The capacity of Distribution Transformer PC0074 is 315 kVA, and if the average voltage on the secondary side is 402 V, the full load current is:

   $$I_{FL} = \frac{315.000}{\sqrt{3} \times 402} = 452{,}7768\ A$$

3. PC0088 Distribution Transformer

   The capacity of Distribution Transformer PC0088 is 160 kVA, and if the average voltage on the secondary side is 407 V, the full load current is:

   $$I_{FL} = \frac{160.000}{\sqrt{3} \times 407} = 226{,}9682\ A$$

4. PC0129 Distribution Transformer
   The capacity of Distribution Transformer PC0129 is 200 kVA, and if the average voltage on the secondary side is 402 V, the full load current is:
   $I_{FL} = \frac{200.000}{\sqrt{3} \times 402} = 287,4773\ A$

5. PC1319 Distribution Transformer
   Distribution Transformer Capacity PC1319 is 200 kVA, and if the average voltage on the secondary side is 408 V, the full load current is:
   $I_{FL} = \frac{200.000}{\sqrt{3} \times 408} = 283,2462\ A$

3.2.2. Calculation of loading on transformer

1. Distribution Transformer PC0044
   The average current at peak load on Distribution Transformer PC0044 is:
   $I_{average} = \frac{37+125+97}{3} = 86,3333\ A$

   Then the percentage of loading at peak load is:
   $I_{loading}\ (\%) = \frac{86,3333}{142,9085} \times 100\ \% = 60,4116\ \%$

2. Distribution Transformer PC0074
   The average current at peak load on Distribution Transformer PC0074 is:
   $I_{average} = \frac{128+113+108}{3} = 116,3333\ A$

   Then the percentage of loading at peak load is:
   $I_{loading}\ (\%) = \frac{116,3333}{452,7768} \times 100\ \% = 25,6933\ \%$

3. PC0088 Distribution Transformer
   The average current at peak load on Distribution Transformer PC0088 is:
   $I_{average} = \frac{82+68+66}{3} = 72,0000\ A$

   Then the percentage of loading at peak load is:
   $I_{loading}\ (\%) = \frac{72,0000}{226,9682} \times 100\ \% = 31,7225\ \%$

4. PC0129 Distribution Transformer
   The average current at peak load on Distribution Transformer PC0129 is:
   $I_{average} = \frac{105+185+136}{3} = 142,0000\ A$

   Then the percentage of loading at peak load is:
   $I_{loading}\ (\%) = \frac{142,0000}{287,4773} \times 100\ \% = 49,3952\ \%$

5. PC1319 Distribution Transformer
   The average current at peak load on Distribution Transformer PC1319 is:
   $I_{average} = \frac{271+240+280}{3} = 263,6667\ A$

   Then the percentage of loading at peak load is:
   $I_{loading}\ (\%) = \frac{263,6667}{283,2462} \times 100\ \% = 93,0874\ \%$

3.2.3. Calculation of Load Unbalance in Transformers

1. Distribution Transformer PC0044
   The coefficients a, b and c on Distribution Transformer PC0044 are:
   $a = \frac{37}{86,3333} = 0,4286$
   $b = \frac{125}{86,3333} = 1,4479$
   $c = \frac{97}{116,333} = 1,1235$

   Then the percentage of load imbalance is:
   $I_{load\ imbalance}(\%) = \frac{\{|0,4286-1| + |1,4478-1| + |1,1235-1|\}}{3} \times 100\ \% = 38,0952\ \%$

2. Distribution Transformer PC0074
   The coefficients a, b and c on Distribution Transformer PC0074 are:
   $a = \frac{128}{116,3333} = 1,1003$
   $b = \frac{113}{116,3333} = 0,9713$
   $c = \frac{108}{116,3333} = 0,9284$

   Then the percentage of load imbalance is:
   $I_{load\ imbalance}(\%) = \frac{\{|1,1003-1| + |0,9713-1| + |0,9284-1|\}}{3} \times 100\ \% = 6,6858\ \%$

3. PC0088 Distribution Transformer
   The coefficients a, b and c on Distribution Transformer PC0088 are:
   $a = \frac{82}{72,0000} = 1,1389$
   $b = \frac{68}{72,0000} = 0,9444$
   $c = \frac{66}{72,0000} = 0,9167$

   Then the percentage of load imbalance is:
   $I_{load\ imbalance}(\%) = \frac{\{|1,1389-1| + |0,9444-1| + |0,9167-1|\}}{3} \times 100\ \% = 9,2593\ \%$

4. PC0129 Distribution Transformer
   The coefficients a, b and c on Distribution Transformer PC0129 are:
   $a = \frac{105}{142,0000} = 0,7394$
   $b = \frac{185}{142,0000} = 1,3028$
   $c = \frac{136}{142,0000} = 0,9578$

   Then the percentage of load imbalance is:

$$I_{load\ imbalance}(\%) = \frac{\{|0{,}7394-1| + |1{,}3028-1| + |0{,}9578-1|\}}{3} \times 100\ \% = 20{,}1878\ \%$$

5. PC1319 Distribution Transformer
   The coefficients a, b and c on the PC1319 Distribution Transformer are:
   $$a = \frac{271}{263{,}6666} = 1{,}0278$$
   $$b = \frac{240}{263{,}6666} = 0{,}9102$$
   $$c = \frac{280}{263{,}6666} = 1{,}0619$$

   Then the percentage of load imbalance is:
   $$I_{load\ imbalance}(\%) = \frac{\{|1{,}0278-1| + |0{,}9102-1| + |1{,}0619-1|\}}{3} \times 100\ \% = 5{,}9840\ \%$$

3.2.4. Calculation of Power Loss Due to the Existence of Neutral Current in the Transformer Neutral Conductor

1. Distribution Transformer PC0044
   The type of neutral conductor in Distribution Transformer PC0044 is BC 50 mm^2 with a resistance value is $R_N = 0{,}6842\ \Omega/km$, then the power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N = 61^2 \times 0{,}6842 = 2.545{,}9082\ W = 2{,}5459\ kW$$

   Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N\ (\%) = \frac{2{,}5459}{100 \times 0{,}91} \times 100\ \% = 2{,}6737\ \%$$

2. Distribution Transformer PC0074
   The type of neutral conductor in Distribution Transformer PC0074 is BC 50 mm^2 with resistance value is $R_N = 0{,}6842\ \Omega/km$, then the power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N = 37^2 \times 0{,}6842 = 936{,}6698\ W = 0{,}9367\ kW$$

   Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N\ (\%) = \frac{0{,}9367}{315 \times 0{,}90} \times 100\ \% = 0{,}3304\ \%$$

3. PC0088 Distribution Transformer
   The type of neutral conductor in Distribution Transformer PC0088 is BC 50 mm^2 with resistance value is $R_N = 0{,}6842\ \Omega/km$, then the power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N = 43^2 \times 0{,}6842 = 1.265{,}0858\ W = 1{,}2651\ kW$$

   Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N\ (\%) = \frac{1{,}2651}{160 \times 0{,}92} \times 100\ \% = 0{,}8594\ \%$$

4. PC0129 Distribution Transformer
   The type of neutral conductor in Distribution Transformer PC0129 is BC 50 mm^2 with resistance value is $R_N = 0{,}6842\ \Omega/km$, then the power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N = 79^2 \times 0{,}6842 = 4.270{,}0922\ W = 4{,}2701\ kW$$

   Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N\ (\%) = \frac{4{,}2701}{200 \times 0{,}91} \times 100\ \% = 2{,}6462\ \%$$

5. PC1319 Distribution Transformer
   The type of neutral conductor in Distribution Transformer PC1319 is BC 50 mm^2 with resistance value is $R_N = 0{,}6842\ \Omega/km$, then the power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N = 43^2 \times 0{,}6842 = 1.265{,}0858\ W = 1{,}2651\ kW$$
   Then the percentage of power loss due to the neutral current in the neutral conductor of the transformer is:
   $$\Delta P_N\ (\%) = \frac{1{,}2651}{200 \times 0{,}92} \times 100\ \% = 0{,}6875\ \%$$

3.2.5. Calculation of Power Loss Due to Neutral Current Flowing to Ground

1. Distribution Transformer PC0044
   The power losses due to neutral current flowing to the ground in Distribution Transformer PC0044 are:
   $$\Delta P_G = 31{,}9^2 \times 4{,}53 = 4.621{,}3801\ W = 4{,}6214\ kW$$

   Then the percentage of power loss due to neutral current flowing to the ground is:
   $$\Delta P_G\ (\%) = \frac{4{,}6214}{100 \times 0{,}91} \times 100\ \% = 5{,}0784\ \%$$

2. Distribution Transformer PC0074
   The power losses due to neutral current flowing to the ground in Distribution Transformer PC0074 are:
   $$\Delta P_G = 19{,}4^2 \times 3{,}73 = 1.399{,}9938\ W = 1{,}4000\ kW$$

   Then the percentage of power loss due to neutral current flowing to the ground is:
   $$\Delta P_G\ (\%) = \frac{1{,}4000}{315 \times 0{,}90} \times 100\ \% = 0{,}4938\ \%$$

3. PC0088 Distribution Transformer
   Power losses due to neutral current flowing to the ground in Distribution Transformer PC0088 are:
   $$\Delta P_G = 22{,}5^2 \times 4{,}96 = 2.514{,}3887\ W = 2{,}5144\ kW$$

   Then the percentage of power loss due to neutral current flowing to the ground is:
   $$\Delta P_G\ (\%) = \frac{2{,}5144}{160 \times 0{,}92} \times 100\ \% = 1{,}7081\ \%$$

4. PC0129 Distribution Transformer
   Power losses due to neutral current flowing to the ground

in Distribution Transformer PC0129 are:

$\Delta P_G = 41{,}4^2 \times 4{,}86 = 8.315{,}8046\ W = 8{,}3158\ kW$

Then the percentage of power loss due to neutral current flowing to the ground is:

$\Delta P_G\ (\%) = \frac{8{,}3158}{200 \times 0{,}91} \times 100\ \% = 4{,}5691\ \%$

5. PC1319 Distribution Transformer
   Power losses due to neutral current flowing to the ground in Distribution Transformer PC1319 are:
   $\Delta P_G = 22{,}5^2 \times 4{,}74 = 2.402{,}8634\ W = 2{,}4029\ kW$

   Then the percentage of power loss due to neutral current flowing to the ground is:
   $\Delta P_G\ (\%) = \frac{2{,}4029}{200 \times 0{,}92} \times 100\ \% = 1{,}3059\ \%$

3.3. Discussion

The results of the calculation of the percentage of transformer loading, the percentage of load imbalance, power loss on the neutral conductor of the transformer, and power loss due to neutral current flowing to the ground for Distribution Transformers PC0044, PC0074, PC0088, PC0129, PC1319 Tarakan Feeder can be seen in Table 3.

Table 3. Calculation Results

Distribution Transformer	Transformer Loading (%)	Load Imbalance (%)	I_N (A)	I_G (A)	ΔP_N (W)	ΔP_N (%)	ΔP_G (W)	ΔP_G (%)
PC0044	60,4116	38,0952	61	31,9	2,5459	2,6737	4,6214	5,0784
PC0074	25,6933	6,6858	37	19,4	0,9367	0,3304	1,4000	0,4938
PC0088	31,7225	9,2593	43	22,5	1,2651	0,8594	2,5144	1,7081
PC0129	49,3952	20,1878	79	41,4	4,2701	2,3462	8,3158	4,5691
PC1319	93,0874	5,9840	43	22,5	1,2651	0,6875	2,4029	1,3059

3.3.1. Transformer Loading

Table 2 shows the percentage of loading during peak load:

1. Distribution Transformer PC0044 is 60.4116%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the transformer loading (% of capacity) is included in the sufficient category because the transformer loading is between 60% - < 80%.
2. Distribution Transformer PC0074 is 25.6933%. Based on PLN ED Decree No. 0017.E/DIR/2014, the transformer loading (% of capacity) is in the good category because the transformer loading is < 60%.
3. Distribution Transformer PC0088 is 31.7225%. Based on PLN ED Decree No. 0017.E/DIR/2014, the transformer loading (% of capacity) is in the good category because the transformer loading is < 60%.
4. PC0129 Distribution Transformer is 49.3952%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the transformer loading (% of capacity) is in the good category because the transformer loading is < 60%.
5. Distribution Transformer PC1319 is 93.0874%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the transformer loading (% of capacity) is included in the sufficient category because the transformer loading is between 80% - < 100%.

The percentage of loading at peak load is greatest for Distribution Transformer PC1319. The magnitude of the percentage of loading on the transformer is influenced by the average current at peak load. Where if the average current at peak load is getting bigger, the percentage of loading on the transformer will be even greater.

3.3.2. Load Unbalance in Transformers

Table 2 shows the percentage of load imbalance at:

1. Distribution Transformer PC0044 is 38.0952%. Based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the bad category because the load imbalance is ≥ 25%.
2. Distribution Transformer PC0074 is 6.6858%. Based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the good category because the load imbalance is <10%.
3. Distribution Transformer PC0088 is 9.2593%. Based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the good category because the load imbalance is <10%.
4. Distribution Transformer PC0129 is 20.1878%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the current imbalance between phases is included in the less category because the load imbalance is between 20% - < 25%.
5. PC1319 Distribution Transformer is 5.9840 %. Based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the goodcategory because the load imbalance is <10%.

The largest percentage of load imbalance occurs in Distribution Transformer PC0044. The magnitude of the percentage of load imbalance in the transformer is influenced by the current imbalance between phases in the distribution transformer. Where if the current imbalance between phases at peak load is getting bigger, the percentage of load imbalance in the transformer will be even greater.

3.3.3. Power loss due to the presence of neutral current in the transformer neutral conductor

Table 2 shows the percentage of power losses due to the presence of neutral current in the neutral conductor of the transformer:

1. Distribution Transformer PC0044 is 2.6737%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the amount of neutral current TR (% of transformer load current) is included in the good category because the power loss due to the neutral current in the neutral conductor of the transformer <10%.
2. Distribution Transformer PC0074 is 0.3304%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the amount of neutral current TR (% of transformer load current) is included in the good category because the power loss due to the neutral current in the neutral conductor of the transformer <10%.
3. Distribution Transformer PC0088 is 0.8594%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the amount of neutral current TR (% of transformer load current) is included in the good category because the power loss due to the neutral current in the neutral conductor of the transformer <10%.
4. Distribution Transformer PC0129 is 2.3462%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the amount of neutral current TR (% of transformer load current) is included in the good category because the power loss due to the neutral current in the neutral conductor of the transformer <10%.
5. Distribution Transformer PC1319 is 0.6875%. Based on PLN ED Decree No. 0017.E / DIR / 2014, the amount of neutral current TR (% of transformer load current) is included in the good category because the power loss due to the neutral current in the neutral conductor of the transformer <10%.

The percentage of power loss due to the neutral current in the neutral conductor of the transformer is greatest in Distribution Transformer PC0044. The magnitude of the percentage of power loss on the neutral conductor of the transformer is influenced by the neutral current in the distribution transformer. Where if the neutral current in the neutral conductor of the transformer is getting bigger, the percentage of power loss due to the neutral current in the neutral conductor of the transformer will be even greater.

3.3.4. Power Loss Due to Neutral Current Flowing to Ground

Table 2 shows the percentage of power losses due to neutral current flowing to the ground in Distribution Transformer PC0044 is 5.0784%, Distribution Transformer PC0074 is 0.4938%, Distribution Transformer PC0088 is 1.7081%, Distribution Transformer PC0129 is 4.5691%, Distribution Transformer PC1319 is 1.3059%.

The percentage of power loss due to neutral current flowing to the ground is greatest in Distribution Transformer PC0044. The magnitude of the percentage of power loss due to neutral current flowing to the ground in the transformer is influenced by the neutral current flowing to the ground in the distribution transformer. Where if the neutral current flowing to the ground transformer is getting bigger, the percentage of power loss due to the neutral current flowing to the ground in the transformer will be even greater.

IV. CONCLUSIONS

1. The percentage of loading during the largest peak load occurs in Distribution Transformer PC1319 which is 93.0874%. Based on PLN ED Decree No. 0017.E/DIR/2014, the transformer loading (% of capacity) is included in the sufficient category because the transformer loading is between 80% - <100%. The percentage of loading is influenced by the average current during peak load on the distribution transformer. If the average current during peak load is greater, the percentage of load on the transformer will also be greater.
2. The largest percentage of load imbalance occurs in Distribution Transformer PC0044 which is 38.0952%. Based on PLN ED Decree No. 0017.E/DIR/2014, the current imbalance between phases is included in the bad category because the load imbalance is ≥ 25%. The percentage of load imbalance is influenced by the current imbalance between phases in the distribution transformer. If the current imbalance between phases at peak load is getting bigger, the percentage of load imbalance in the transformer will also be bigger.
3. The percentage of power loss due to the neutral current in the neutral conductor of the largest transformer occurs in Distribution Transformer PC0044 which is 2.6737%. Based on PLN ED Decree No. 0017.E/DIR/2014, the amount of TR neutral current (% of transformer load current) is included in the good category because the power loss due to the neutral current on the neutral conductor of the transformer is <10%. The percentage of power loss in the neutral conductor is influenced by the neutral current in the distribution transformer. If the neutral current in the neutral conductor is getting bigger, the percentage of power loss caused by the neutral current in the neutral conductor of the transformer will also be bigger.
4. The percentage of power losses due to neutral current flowing to the ground is greatest in Distribution Transformer PC0044 which is 5.0784%. The percentage of power loss caused by neutral current flowing to the ground is influenced by the amount of neutral current flowing to the ground in the distribution transformer. If the neutral current flowing to the ground is getting bigger, then the percentage of power loss due to neutral current flowing to the ground in the transformer will also be bigger.

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