Analysis of Neutral Conductor Power Loss of PLN ULP Aek Nabara Distribution Transformer Distribution Substation An.02 and An.92

Gian Prayogo, Rahmaniar, Adisastra

Abstract

In the distribution of electrical energy to consumers, energy loss or energy loss occurs. Energy loss or energy loss occurs. In an electrical system, energy losses inevitably occur. This is because there is a barrier in the conductor which is a natural property of the issue. The process of calculating energy losses involves many calculations on the problem due to the extensive distribution network. Therefore, we need a way to calculate losses, by measuring distribution substations, calculating voltage drops, and calculating line resistance to calculate peak and average power losses using the ETAP application. The aim of this research is to determine the power lost due to unbalanced loads and this affecting the conductor. Next, calculate the power lost due to the transformer's limp loading and the current flowing to the neutral. The results obtained are that the losses in the transformer distributed in a limping condition are greater than in a balanced load because the transformer works in conditions that are not optimal and the conductors are damaged more quickly due to the unevenly distributed load.

***Keywords**:* Unbalanced Load, Current of Neutral, Energy loss.

Gian Prayogo[1]
[1]Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia
e-mail: gianyogo@gmail.com

Rahmaniar[2], Adisastra[3]
[2,3]Lecture of Electrical Engineering Faculty, Universitas Pancabudi Medan, Indonesia.
e-mail: rahmaniar@dosen.pancabudi.ac.id, adisastra.tarigan@gmail.com

Introduction

The national electricity system faces various challenges, both technical and non-technical, which can occur from generation, transmission, to the distribution of electrical energy [1]. One of the main issues at the distribution stage is the high electrical energy loss. Energy loss is the difference between the energy generated and the energy recorded on the customer side [2], which directly impacts system efficiency and the potential revenue of the company.

Energy loss in distribution is divided into two types: technical loss and non-technical loss [3]. Technical loss is caused by natural factors such as conductor resistance, network length, conductor cross-sectional area, and transformer load imbalance [4]. Non-technical loss is generally related to inaccurate meter readings, electricity theft, or administrative errors [5].

Handling energy losses, particularly technical losses, is an important focus to improve the operational efficiency of the distribution system [6]. Therefore, technical improvements such as load balancing are necessary. Uneven transformer loads and small conductor cross-sections cause a loss of revenue per kWh, making corrective measures essential to save lost kWh.

Imbalanced transformer loads can be corrected by transferring load from heavily loaded phases to lightly loaded phases so that the three-phase vector remains close to 120°, which helps reduce the current flowing through a transformer's neutral wire.

Additionally, power losses can also be caused by small and long conductors, which prevent proper energy distribution to the public and result in energy losses. Technical losses due to long feeders are unavoidable, but various measures can be taken to reduce the magnitude of these losses. For example, increasing the conductor cross-sectional area at the output can help minimize technical losses caused by heat on the conductors.

Literatur Review

2.1 Distribution Transformer

A transformer is a component/device consisting of two or more windings connected through a mutual magnetic field. When one of these windings, the primary, is connected to an alternating voltage source, it generates an alternating flux whose amplitude depends on the primary voltage and the number of turns. This mutual flux links to the other winding, the secondary, inducing a voltage whose value depends on the number of secondary turns [1].

2.2 Transformer Load Imbalance

A distribution transformer functions to deliver electrical energy from the medium-voltage system to the low-voltage system for consumer use [1]. In a three-phase power system, load balance refers to the condition where the power or current in each phase (R, S, and T) is distributed evenly [2].

In ideal conditions, the current in each phase has the same value, so the current flowing through the neutral conductor approaches zero [3]. Load balance is very important to maintain voltage quality, minimize power losses, and sustain the operational efficiency of the transformer as well as the lifespan of electrical equipment [8].

In the case of load imbalance, the sum of the three current vectors (IS, IR, and IT) is not equal to zero (0), resulting in a neutral current (IN) whose magnitude depends on the degree of imbalance. To determine the extent of the load imbalance, the first step is to calculate the average current (Irata-rata) using the following formula:

$$I_{Average} = \frac{I_R + I_s + I_T}{3} \qquad (1)$$

$$I_R = a \times I_{\text{Average}} \text{where} a = \frac{I_R}{I_{\text{Average}}} \qquad (2)$$

$$I_S = b \times I_{\text{Average}} \text{where} b = \frac{I_S}{I_{\text{Average}}} \qquad (3)$$

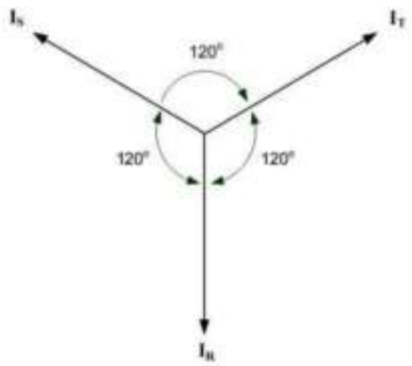
$$I_T = c \times I_{\text{Average}} \text{where} c = \frac{I_T}{I_{\text{Average}}} \qquad (4)$$

Thus, the load imbalance percentage is calculated using the formula :

$$Imbalance(\%) = \frac{(|a-1|+|b-1|+|c-1|)}{3} \qquad (5)$$

Description ;

I_R = current flowing in phase R (A)
I_S = current flowing in phase S (A)
I_T = current flowing in phase T (A)



Gambar 1. Diagram Beban Seimbang [1]

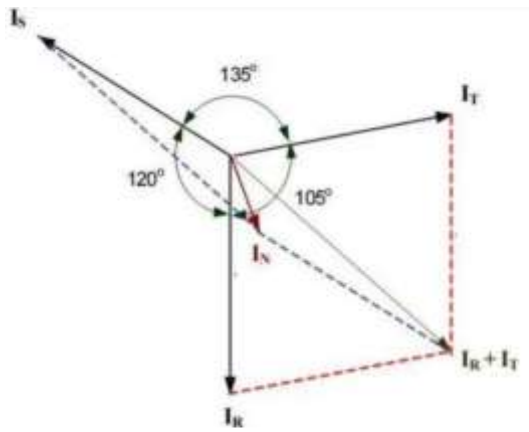


Figure 2. Unbalanced Load Diagram [1]

2.3 *Losses* (Power Losses) Due to Neutral Current

Load imbalances result in neutral currents in the neutral conductor of distribution transformers [4]. These currents cause additional power losses in the form of resistive losses (I^2R Losses) in the neutral conductor [5]. The greater the neutral current, the greater the energy lost as heat.

The amount of power loss due to neutral current can be calculated as follows:

$$P_N = I_N^2 \times R_N \quad (6)$$

Description :
P_N = power loss in the neutral conductor (A)
I_N = current flowing in the neutral conductor (A)
R_N = resistance in the neutral conductor (Ohms)

These power losses will contribute to increasing total distribution power losses and reducing system efficiency.

2.4 Calculating Wasted Energy

The losses referred to are material losses caused by power losses in the transformer. The method for calculating PLN's losses is as follows:

$$W_L = P_L \times t \quad (7)$$

Keterangan :
W_L = Total energy (kWh)
P_L = Power loss due to losses (kW)
t = Time (hours)

To determine how much energy is wasted due to neutral current, calculate the power loss due to neutral current and multiply it by the number of hours of operation.

Once the amount of energy lost due to neutral current is known, multiply the lost energy by the rupiah value per kWh to determine the amount of PLN's material losses due to neutral current.

Methode

In the data collection process used in the preparation of this final project, the researcher employed several methods:

3.1 Observation Method

The observation method is a data collection method that utilizes direct observation of the research object. The data used for observation is Transformer AN.02 and AN.92 at the RR.03 Bendi Feeder.

3.2 Interview Method

The interview method is a method for finding and collecting data, obtaining materials, or eliciting statements and questions and answers through interviews with parties with expertise in their fields. This can also include discussions with competent representatives from PT. PLN (Persero), specifically regarding the questions posed in this final project.

3.3 Literature Research Method

The literature research method is a method used to obtain supporting theories and references containing formulas useful in calculations related to the problem being studied. These references can be taken from PLN books, SPLN, and journals.

Results and Discussion

4.1 Transformer Nameplate Data

Table 1. Nameplate Trafo AN.02

No.	Description	Specification
1	Transformer Number	AN.02
2	Location	AEK NABARA
3	Feeder	RR.03
4	Substation	GIRAP
5	Brand	SINTRA
6	Standard	SPLN.D3.002-1:2020
7	Serial Number	211311119
8	Rated Power	100 kVA
9	Type	100-AA-Yzn5
10	Frequency	50 Hz
11	Rated Voltage	
	A. Primary	20,000 V
	B. Secondary	400 V
12	Rated Current	
	A. Primary	2.886 A
	B. Secondary	144.3 A
13	Short-Circuit Voltage	4.0 %
14	Losses	
	No Load	145 W
	Full Load	1,420 W
15	Oil Type	Mineral Paraffinic
16	Oil Brand	APAR
17	Cooling Method	ONAN
18	Oil Volume	150 Liters
19	Total Weight	690 kg

Table 2. Nameplate Trafo AN.92

No.	Description	Specification
1	Transformer Number	AN.92
2	Location	AEK NABARA
3	Feeder	RR.03
4	Substation	GIRAP
5	Brand	SINTRA
6	Standard	SPLN.D3.002-1:2020
7	Serial Number	230290627
8	Rated Power	50 kVA
9	Type	50-AA-Yzn5
10	Frequency	50 Hz
11	Rated Voltage	
	A. Primary	20,000 V
	B. Secondary	400 V
12	Rated Current	

	A. Primary	1.443 A
	B. Secondary	72.17 A
13	Short-Circuit Voltage	4.0 %
14	Losses	
	No Load	90 W
	Full Load	800 W
15	Oil Type	Mineral Paraffinic
16	Oil Brand	APAR
17	Cooling Method	ONAN
18	Oil Volume	130 Liters
19	Total Weight	480

4.2 Load Measurement

Table 3. Load Before AN.02

No.	Load	Phase	Result
1	R	52,4	
2	S	53,4	
3	T	33,3	
4	N	22,3	

Table 4. Load After AN.02

No.	Load	Phase	Result
1	R	45,6	
2	S	47,8	
3	T	38,6	
4	N	17,5	

Table 5. Load Before AN.92

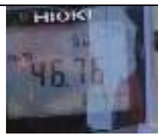
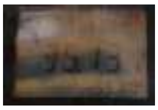
No.	Load	Phase	Result
1	R	46,76	
2	S	38,42	
3	T	24,47	
4	N	22,40	

Table 6. Load After AN.92

No.	Load	Phase	Result
1	R	39,04	
2	S	35,13	
3	T	30,57	
4	N	8,83	

4.3 Balanced Load ETAP Analysis

The ETAP analysis model design uses the Rantauprapat Substation, located in Labuhan Batu Regency. The ETAP simulation uses a 60 MVA power transformer. The Rantauprapat Substation has a primary voltage of 150 kV and a secondary voltage of 20 kV.

The power transformer at the Rantauprapat Substation steps down the voltage from 150 kV to 20 kV, which is then distributed to the public through a distribution transformer. The distribution transformer uses sample data from AN.02 and AN.92 load measurements.

Table 7. Pre-load Measurement Data

No.	Trafo Code	Capacity	Load (Ampere)			
			R	S	T	N
1	AN.02	100 kVA	52,4	53,4	33,3	22,3
2	AN.92	50 kVA	46,76	38,42	24,47	22,4

Table 8. Load Measurement Data After

No.	Trafo Code	Capacity	Load (Ampere)			
			R	S	T	N
1	AN.02	100 kVA	45,6	47,8	38,6	17,5
2	AN.92	50 kVA	39,04	35,13	30,57	8,83

Based on the analysis of the ETAP application, the Neutral Current value obtained is different from the results of direct measurements in the field with the values obtained in the following table.

Table 9. Unbalanced Load Flow Report (ETAP)

No.	Trafo Code	Capacity	Load (Ampere)			
			R	S	T	N
1	AN.02	BEFORE	52,8	53,8	33,5	19,9
2	AN.92	BEFORE	47,4	38,8	24,6	19,9
3	AN.02	AFTER	45,9	48,1	38,8	18,8
4	AN.92	AFTER	39,5	35,5	30,8	7,5

It was found that 3 neutral current values in the ETAP analysis were smaller than the direct measurement values, namely in AN.02 before being balanced at 19.9 A, AN.92 before being balanced at 19.9 A and AN.92 after being balanced at 7.5 A and there was 1 neutral current value that was greater than the direct measurement results in the field, namely in the AN.02 measurement after being balanced at 18.8 A..

4.4 Transformer Loss Analysis

Based on equations (1) and (6) regarding the analysis of transformer load and unbalance, the results of the systematic loss calculation are shown in the following table:

Table 10. Average Transformer Current

No.	Code	$I_{Average}$ Unbalanced	$I_{Average}$ Balanced
1	AN.02	46,36 A	44,00 A
2	AN.92	36,55 A	34,91 A

The difference in average current in unbalanced and balanced loads is caused by fluctuating loads, therefore there is a slight difference in the results of the transformer load.

Table 11. Percentage of Load Balance Before

No	Code	Presentasion
1	AN.02	18,8 %
2	AN.92	22 %

Table 12. Percentage of Load Balance After

No	Code	Presentasion
1	AN.02	8,2 %
2	AN.92	8,3 %

Losses due to neutral current (Unbalanced Load)

- AN.02 with SKUTR 70 mm^2 (R=0,443 Ω/km)

$$P_N = I_N^2 \times R_N \quad (8)$$

$$P_N = 22{,}3^2 \times 0{,}443 \quad (9)$$

$$P_N = 220{,}3 \text{ W}/0{,}220 \text{ kW} \quad (10)$$

- AN.92 with SKUTR 35 mm^2 (R=0,867 Ω/km)

$$P_N = I_N^2 \times R_N \quad (11)$$

$$P_N = 22{,}4^2 \times 0{,}867 \quad (12)$$

$$P_N = 435 \text{ W}/0{,}43 \text{ kW} \quad (13)$$

Losses due to Unbalanced Load based on ETAP analysis

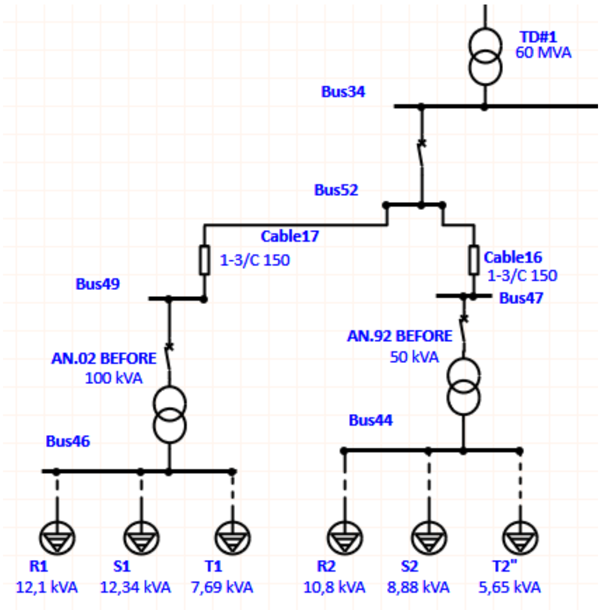


Figure 3. Unbalanced load SLD

CKT / Branch		From-To Bus Flow		To-From Bus Flow		Losses	
ID	Phase	MW	Mvar	MW	Mvar	kW	kvar
Cable16	A	0.008	0.001	-0.008	-0.001	0.0	0.0
	B	0.009	0.004	-0.009	-0.004	0.0	0.0
	C	0.007	0.003	-0.007	-0.003	0.0	0.0
Cable17	A	0.010	0.002	-0.010	-0.002	0.0	0.0
	B	0.012	0.004	-0.012	-0.004	0.0	0.0
	C	0.009	0.005	-0.009	-0.005	0.0	0.0
AN.02 BEFORE	A	0.010	0.002	-0.011	-0.004	-1.6	-1.8
	B	0.012	0.004	-0.012	-0.004	0.0	0.1
	C	0.009	0.005	-0.007	-0.002	1.8	2.1
AN.92 BEFORE	A	0.008	0.001	-0.010	-0.003	-1.8	-2.1
	B	0.009	0.004	-0.008	-0.003	0.8	1.0
	C	0.007	0.003	-0.005	-0.002	1.3	1.5
TD#1	A	0.018	0.003	-0.018	-0.003	0.0	0.0
	B	0.021	0.008	-0.021	-0.008	0.0	0.0
	C	0.016	0.008	-0.016	-0.008	0.0	0.0
						0.6	0.8

Figure 4. Results of Unbalanced Shrinkage Calculation (ETAP)

The transformer loss due to unbalanced load at ETAP is 0.6 kW and the power loss is 0.8 kvar. For the calculation of both transformers outside the cross-section used:

Losses due to neutral current (Balanced Load)

- AN.02 with SKUTR 70 mm² (R=0,443 Ω/km)

$$P_N = I_N^2 \times R_N \quad (14)$$

$$P_N = 17{,}5^2 \times 0{,}443 \quad (15)$$

$$P_N = 135{,}67 \text{ W}/0{,}136 \text{ kW} \quad (16)$$

- AN.92 with SKUTR 35 mm² (R=0,867 Ω/km)

$$P_N = I_N^2 \times R_N \quad (17)$$

$$P_N = 8{,}83^2 \times 0{,}867 \quad (18)$$

$$P_N = 67{,}6 \text{ W}/0{,}068 \text{ kW} \quad (19)$$

Losses due to Unbalanced Load based on ETAP analysis

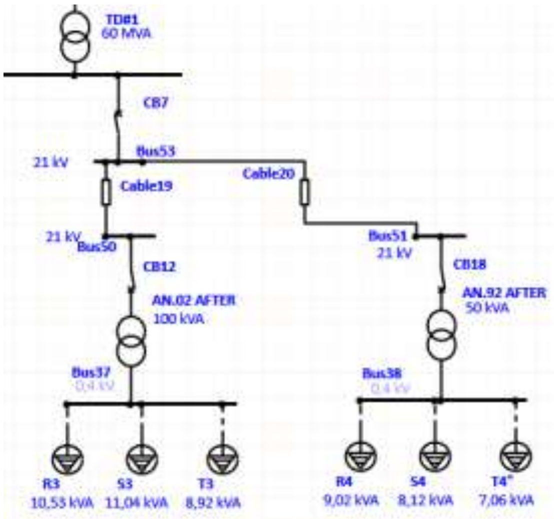


Figure 5. Balanced Load SLD

CKT / Branch		From-To Bus Flow		To-From Bus Flow		Losses	
ID	Phase	MW	Mvar	MW	Mvar	kW	kvar
Cable19	A	0.010	0.004	-0.010	-0.004	0.0	0.0
	B	0.009	0.004	-0.009	-0.004	0.0	0.0
	C	0.009	0.004	-0.009	-0.004	0.0	0.0
Cable20	A	0.008	0.002	-0.008	-0.002	0.0	0.0
	B	0.008	0.003	-0.008	-0.003	0.0	0.0
	C	0.007	0.003	-0.007	-0.003	0.0	0.0
AN.02 AFTER	A	0.010	0.004	-0.009	-0.006	0.6	-1.4
	B	0.009	0.004	-0.010	-0.003	-1.3	0.7
	C	0.009	0.004	-0.008	-0.003	0.9	1.0
AN.92 AFTER	A	0.008	0.002	-0.009	-0.003	-0.6	-0.7
	B	0.008	0.003	-0.008	-0.003	0.4	0.5
	C	0.007	0.003	-0.007	-0.002	0.5	0.6
TD#1	A	0.017	0.006	-0.017	-0.006	0.0	0.0
	B	0.017	0.007	-0.017	-0.007	0.0	0.0
	C	0.016	0.007	-0.016	-0.007	0.0	0.0
						0.5	0.7

Figure 6. Results of the balanced shrinkage calculation (ETAP)

The transformer loss after load balancing at the ETAP is 0.5 kW, and the power loss is 0.7 kvar. For the calculation of both transformers, the outside cross-section is used.

Comparison of Mathematical Values and ETAP

Table 12. ETAP Loss Calculation

No	Code	Unbalanced	Balanced
1	AN.02	0,242 kW	0,211 kW
2	AN.92	0,310 kW	0,268 kW

Table 13. Mathematical Loss Calculation

No	Code	Unbalanced	Balanced
1	AN.02	0,220 kW	0,136 kW
2	AN.92	0,43 kW	0,07 kW

4.5 Analysis of Wasted Energy Consequences

Using the results of the power loss calculations due to neutral current and transformer losses in the ETAP simulation, we can find the wasted energy using equation (7) as follows:

Transformator AN.02 Before Balancing

$$W_L = (0{,}220 + 0{,}242) \times 12 \quad (20)$$

$$W_L = 5{,}544\, kWh \quad (21)$$

$$LossPLN = 5{,}544 kWh \times Rp1444{,}70 \quad (22)$$
$$= Rp\, 8.009{,}416$$

Transformator AN.92 Before Balancing

$$W_L = (0{,}430 + 0{,}310) \times 12 \quad (23)$$

$$W_L = 8{,}880\, kWh \quad (24)$$

$$LossPLN = 8{,}880 kWh \times Rp1444{,}70 \quad (25)$$
$$= Rp\, 12.828{,}936$$

AN.02 Transformer After balancing

$$W_L = (0{,}136 + 0{,}211) \times 12 \quad (26)$$

$$W_L = 4{,}164\, kWh \quad (27)$$

$$LossPLN = 4{,}164 kWh \times Rp1444{,}70 \quad (28)$$
$$= Rp\, 6.015{,}7308$$

AN.92 Transformer After balancing

$$W_L = (0{,}068 + 0{,}268) \times 12 \quad (29)$$

$$W_L = 4{,}032\, kWh \quad (30)$$

$$LossPLN = 4{,}032 kWh \times Rp1444{,}70 \quad (31)$$
$$= Rp\, 5.825{,}0304$$

Conclussion

Based on direct field measurements and analysis using the ETAP application on AN.02 (100 kVA) and AN.92 (50 kVA) distribution transformers, it can be concluded that: Load imbalance in distribution transformers causes significant neutral currents, thereby increasing power losses in the conductors and reducing distribution system efficiency.

Unbalanced load conditions result in greater power losses than balanced loads. This is evident from measurement and simulation results, where load balancing reduced the AN.02 load imbalance percentage from 18.8% to 8.2% and the AN.92 load imbalance from 22% to 8.3%, which is very good (ideal) according to SPLN No. 17 of 2014 [12], which is below 10%. It also reduced neutral conductor power losses in the AN.02 transformer from 0.220 kW to 0.136 kW and in the AN.92 transformer from 0.43 kW to 0.07 kW. Based on ETAP analysis, transformer balancing significantly reduced transformer losses from 0.6 kW with a power loss of 0.8 kvar to 0.5 kW with a power loss of 0.7 kvar.

Interphase load balancing provides significant benefits, including reducing neutral currents, reducing conductor heat, extending equipment life, and saving lost energy (kWh), thus positively impacting PLN's cost reduction.

Suggestion

1. PLN should regularly monitor transformer loads to detect and correct load imbalances early.
2. A periodic customer load realignment strategy is necessary, especially in areas with rapid load growth, to ensure even current distribution between phases.
3. The use of conductors with appropriate cross-sections and low resistance can help reduce technical losses in the distribution network.

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