Analysis of Drop Voltage in Low Voltage Network (JTR) 380/220 Volt Distribution Substation of PT PLN (Persero) ULP Tanah Jawa

M. Ricky Ardiansyah
e-mail: Rickyardi200498@gmail.com
Zuraidah Tharo
e-mail: zuraidahtharo@dosen.pancabudi.ac.id
Dino Erivianto
e-mail: dinoerivianto@dosen.pancabudi.ac.id

Universitas Pembangunan Panca Budi

Abstract

One of the reliability requirements of the electric power distribution system that must be met for service to consumers is good and stable voltage quality. Most loads have a lagging power factor and basically at peak load times, the reactive power required by the load increases and can be greater than that generated by the system. Voltage changes are basically caused by the relationship between voltage and reactive power. The voltage drop across a conductor is proportional to the reactive power flowing across the conductor. Within ± 2 years (2022-2024), the addition of a significant load to the distribution substation, especially PT PLN (Persero) Tanah Jawa, does not take into account the cross-sectional area of the conductor. This has an impact on consumers, where there is a difference between the initial voltage (220 V) and the final voltage (211 V) with a conductor length of ± 1.95 km, the voltage regulation that occurs in the house connection of this channel is 1.6%. The results of the load flow calculation using 25 mm2 and 16 mm2 AAAC cable channels, there is a voltage drop of 2.86÷3.52 Volts on all buses, the voltage regulation for all buses is above 1%. Based on (SPLN No. 56-1, 1993), the allowable voltage drop tolerance at the house connection (SR) is 1% of the nominal voltage, thus all nodes or buses have exceeded the maximum allowable tolerance limit. The results of the power flow calculation (load flow) after replacement using 35 mm2 AAAC and 25 mm2 SR channel cables, there is a voltage drop of 0.22÷0.3 Volts on all buses, the voltage regulation for all buses is below 1%.

Keywords: ***Low Voltage Network Voltage Drop, Distribution Substation***

Introduction

Electrical loads used in general are inductive and capacitive. Inductive loads require reactive power such as transformers in rectifiers, induction motors (AC) and TL lamps, while capacitive loads emit reactive power. Reactive power is useless power that cannot be converted into power and will be needed for the process of delivering electrical energy to the load. So what causes the waste of electrical energy is the amount of inductive equipment. This means that in the use of electrical energy, customers are not only burdened by active power (kW) but also reactive power (kVAR). The sum of the two powers will produce real power (VA) which is the power supplied by PLN.

One of the requirements for the reliability of the electric power distribution system that must be met for service to consumers is good and stable voltage quality. Although the continuity of electric power distribution is reliable, it is not possible to maintain a constant voltage in the distribution system, because there will be a voltage drop in all parts of the system and will change along with the load changes. Most loads have a lagging power factor and basically at peak load, the reactive power required by the load increases and can be greater than that generated by the system.

The addition of reactive power and the cross-sectional area of the line in the system allows for improvements in the system in the form of a good voltage profile and smaller power losses. Voltage changes are basically caused by the relationship between voltage and reactive power. The voltage drop across a conductor is proportional to the reactive power flowing through the conductor.

The results of temporary observations and measurements on the housing served by the PT PLN (Persero) ULP Tanah Jawa Distribution Substation network show a voltage drop, where the measured voltage is 200.15 Volts. This research is expected to provide a very constructive solution, so that losses due to resistance on the line can be reduced and the current demand decreases and the voltage returns to normal at 220 Volts

Literature Review

2.1 Distribution System

The network after leaving the GI is usually called the distribution network. After the electricity is channeled through the primary distribution, the electricity is then reduced in voltage at the distribution substation to low voltage, then channeled through the Low Voltage Network for further distribution to the homes of PLN customers (consumers) through house connections.

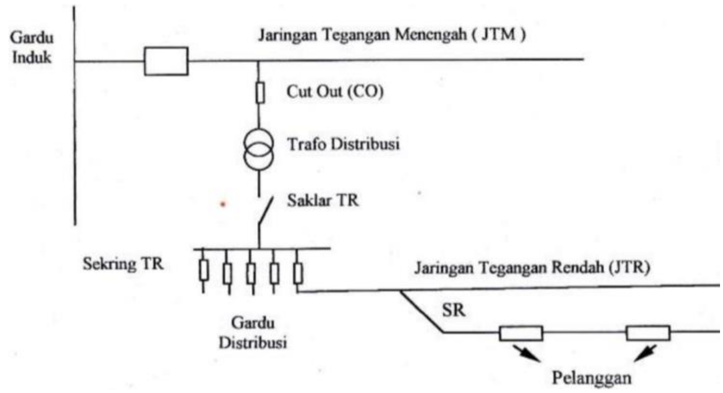

Figure 1. Medium Voltage (MV), Low Voltage (LV) and House to Customer Connection Networks

In the distribution of electricity to consumers, the voltage used varies depending on the type of consumer needed. For industrial consumers usually used medium voltage 20kV, while for household consumers used low voltage 220/380 V.

2.2 Drop Voltage

Voltage drop is caused by the current flowing through the resistance of the wire. The voltage drop V on the conductor increases if the current I on the conductor increases and if the resistance of the conductor Rℓ also increases. The voltage drop is responsible for losses in the conductor because it can reduce the voltage at the load. As a result, the voltage is below the nominal voltage required. Based on this, the permissible voltage drop for high current installations up to 1,000 V is set as a percentage of the working voltage. In accordance with the voltage standard set by PLN (SPLN), the network design is made in such a way that the voltage drop at the receiving end is 2%. Voltage drop in the network is caused by voltage losses due to electrical resistance (R) and reactance (X). The phase drop voltage Vd on a conductor that has impedance (Z) and is powered by current (I) can be explained by the following formula:

$$D_d = I.Z \quad (1)$$

In this discussion what is meant by voltage drop (ΔV) is the difference between the sending voltage (Vs) and the receiving voltage (Vr), then the voltage drop can be defined as:

$$\Delta V = (V_S) - (V_r) \quad (2)$$

Due to the resistance on the conductor, the voltage received by consumers (Vr) will be smaller than the voltage of the sender (Vs), resulting in a voltage drop (Vdrop) which is the difference between the voltage on the sending side and the voltage on the receiving side of the electric power. The relative voltage drop is called VR (voltage regulation) and is expressed by the formula:

$$V_R = \frac{V_S - V_r}{V_r} x100\% \quad (3)$$

Where:
V_R = Voltage regulation
V_s = Voltage at the base of delivery
V_r = Voltage at receiving end

To calculate the voltage drop, the reactance is taken into account, as well as the power factor that is not equal to one, the calculation method is explained. To simplify the calculation, it is assumed that the loads are balanced three-phase loads and the power factor (Cos φ) is between 0.6 and 0.85. Voltage drop can be calculated based on the following relationship approach formula:

$$\Delta V = I(R.Cos\,\varphi + X.Sin\,\varphi)\,L \quad (4)$$

Where :
I = Load current (Ampere)
R = Circuit resistance (Ohm)
X = Circuit reactance (Ohm)
L = Conductor length (m)

The amount of voltage drop is influenced by several factors, namely: Line resistance, Line current, Power factor (Cos φ) and Line length. Due to the impedance of the line and load, there is a difference between the source voltage (Vs) and the receiver voltage (Vr). Where the receiver voltage will always be smaller than the source voltage (Vs>Vr). The voltage difference is called voltage drop (ΔV). In general, the voltage drop is ΔV=Vs-Vr. The amount of load at a point (pole) is not the same in one phase with another phase, although seen from the substation, the load of each phase may be the same, which is partly due to the irregular behavior of consumer loads. The load seen from the substation is not the same for each phase, of course the load on each pole is not the same. The distribution or placement of the load on each phase is not the same.

According to the State Electricity Company Standard (SPLN) No. 56-1 of 1993, the allowable voltage drop in each type of connection, namely the voltage drop in the medium voltage network (JTM) is allowed 2% of the working voltage as mentioned in paragraph 22 for systems that do not utilize STB (i.e. Spindle and Cluster systems). 5% of the working voltage for systems that utilize STBs, i.e. above-ground radial systems and node systems. Voltage drop at distribution transformers is allowed 3% of the working voltage. Voltage drop at low voltage connections (STRs) is allowed up to 4% of the working voltage depending on the load density. Voltage drop at the house connection (SR) is allowed 1% of the nominal voltage.

2.3 Transformer Full Load Current Calculation

Transformer power when viewed from the high voltage side (primary) can be calculated by the formula

$$S = \sqrt{3}.V.I\,(VA) \qquad (5)$$

Where:

S = Transformer power (kVA)
V = Transformer primary side voltage (kV)
I = Mesh Current (A)

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

$$I_{FL} = \frac{S}{\sqrt{3}.V}\,Ampere \qquad (6)$$

Where

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

Research Methodology

3.1 Type of Research Data

The types of data needed to analyze the calculations are

a. Primary Data
   Data obtained from the measurement of PT PLN (Persero) ULP Tanah Jawa distribution substation transformer data, current and voltage data at the distribution substation
b. Secondary Data
   Data obtained from references (books, journals, and PLN), transformer specification data and standard data on types and sizes of lines/cables

Table 1 Variable Analysis

No	Variable	Symbol	Unit
1	Transformer load imbalance		%
2	Losses due to current in the neutral conductor of the transformer	P_N	Watt
3	Losses due to neutral current flowing to ground	P_G	Watt

Analysis of load imbalance calculations in this study, focused on

a. Transformer full load current.
b. Average transformer current during the day and night.

c. Presentation of transformer loading during the day and night.
d. Transformer load imbalance during the day and night.
e. Losses due to current in the neutral conductor of the transformer for a cross-sectional area of 50 mm2 during the day and night.
f. Losses due to current in the neutral conductor of the transformer for a neutral conductor cross-sectional area of 70 mm2 during the day and at night.
g. Losses due to current in the neutral conductor of the transformer for a neutral conductor cross-sectional area of 95 mm2 during the day and at night.
h. Losses due to neutral current flowing to the ground during the day and night.
i. Conclusion

Results and Conclussion

The research results were obtained from the data source of PT (Persero) PLN Tanah Jawa, measurements at the end of the conductor. Results and data obtained in September 2023.

Factory-made	: Starlite
Type	: Outdoor
Power	: 100 kVA
Working voltage	: 20 kV / 400 V
current	: 5 – 250 A
Relationship	: Dyn5
impedance	: 4%
Number of transformers	: 1 x 3 phasa

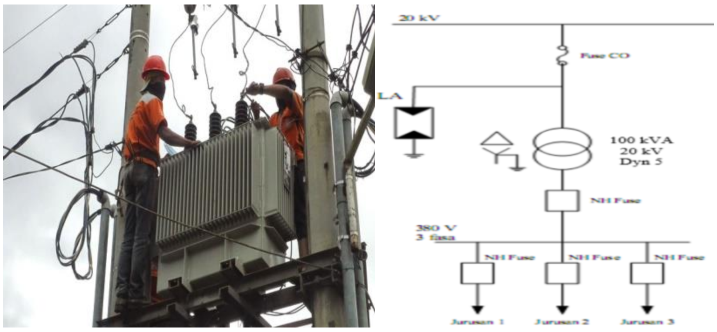

Figure 2. Distribution transformer and 100 kVA single line

The measurement data can be seen in the table below:

Table 1. Measurement Results of 100 kVA Distribution Transformer During the Day

Phase	S (kVA)	Vp	I (Ampere)	Cosφ
R	29,25	213	137,60	0,82
S	25,66	215	119,50	0,84
T	18,57	220	84,54	0,85
I_N	98,05 A			
I_G	49,75 A			
R_G	0,3420 Ω			

Table 2. Nighttime 100 kVA Distribution Transformer Measurement Results

Phase	S(Kva)	Vp	I (Ampere)	Cosφ
R	37,44	209	179,21	0,82
S	35,92	211	170,33	0,84
T	19,15	218	87,90	0,85

Phase	S(Kva)	Vp	I (Ampere)	Cosφ
I_N	102,17 A			
I_G	58,41 A			

Ukuran kawat kabel netral transformator sebesar 50 mm2 (AAAC) dengan R = 0,6452 Ω/km, While the cable wire for the phase has a diameter of 70 mm2 (AAAC) with R = 0.4608 Ω / km, the phase cable wire fund also has a cable size diameter of 95 mm2 (AAAC) with R = 0.3096 Ω / km. As for the transformer grounding cable size has a diameter of 70 mm2 (XLPE) with R = 0.3420 Ω/km. The current flow scheme on the secondary side during the day and night is shown in the figure below:

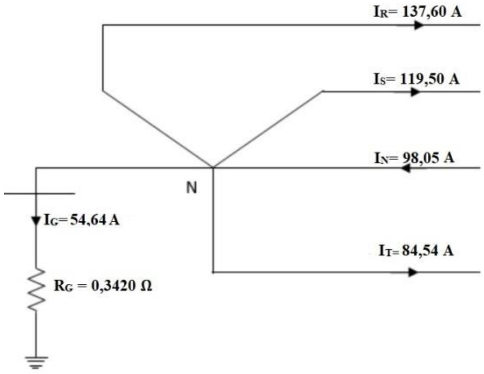

Figure 3. Schematic of Current Flow on the Secondary Side of the Transformer during the Da

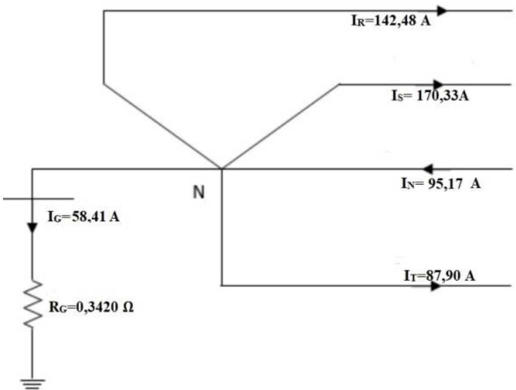

Figure 4. Schematic of Current Flow on the Secondary Side of the Transformer at Night

4.1 Transformer Loading Calculation

Transformer Full Load Current

Calculate the full load current (full load) on the distribution transformer, using the equation belowi:

$$S = 100\,kVA$$

$$V = 0{,}38\,kV$$

$$I_{FL} = \frac{S}{\sqrt{3}.V}$$

$$= \frac{100000}{\sqrt{3}.980} = 152{,}11A$$

Average current of the transformer

Daytime

I_R = 137,60 A

I_S = 119,50 A

I_T = 84,54 A

$$I_{Average} = \frac{I_R + I_S + I_T}{3}$$
$$= \frac{137{,}60 + 119{,}50 + 84{,}54}{3} = 133{,}88\,A$$

Nighttime

I_R = 179,21 A
I_S = 170,33 A
I_T = 87,90 A

$$I_{Average} = \frac{I_R + I_S + I_T}{3}$$
$$= \frac{179{,}21 + 170{,}33 + 89{,}70}{3} = 145{,}81\,A$$

Percentage of Transformer Loading
Daytime

$$\%_{TL} = \frac{I_{Average}}{I_{FL}} x100\% = \frac{133{,}88}{152{,}11} x100\%$$
$$= 88{,}01\%$$

Nighttime

$$\%_{TL} = \frac{I_{Average}}{I_{FL}} x100\% = \frac{145{,}81}{152{,}11} x100\%$$
$$= 95{,}85\%$$

From the above calculation, it can be seen that at night (WBP = Peak Load Time) the percentage of loading is quite high, reaching 95.85%.

Load Imbalance
Daytime

By using the equation formula above, the coefficients a, b, and c can be known in magnitude, where the magnitude of the phase current in a balanced state (I) = the magnitude of the average current (Average)

$$I_R = a.I_{Average}\; Maka\, a = \frac{I_R}{I_{Average}} = \frac{137.60}{133.88} = 1{,}027$$
$$I_R = b.I_{Average}\; Maka\, b = \frac{I_S}{I_{Average}} = \frac{119{,}50}{133.88} = 0{,}892$$
$$I_R = c.I_{Average}\; Maka\, c = \frac{I_T}{I_{Average}} = \frac{84{,}54}{133.88} = 0{,}631$$

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

$$= \frac{\{|a-1| + |b-1| + |c-1|\}}{3}$$
$$= \frac{\{|1{,}027-1| + |0{,}892-1| + |0{,}631-1|\}}{3} = 1{,}68\%$$

Nighttime

By using the equation formula above, the coefficients a, b, and c can be known in magnitude, where the magnitude of the phase current in a balanced state (I) = the magnitude of the average current (Average)

$$I_R = a.I_{Average}\ Maka\ a = \frac{I_R}{I_{Average}} = \frac{179{,}21}{145{,}81} = 1{,}229$$

$$I_R = b.I_{Average}\ Maka\ b = \frac{I_S}{I_{Average}} = \frac{170{,}33}{145{,}81} = 1{,}168$$

$$I_R = c.I_{Average}\ Maka\ c = \frac{I_T}{I_{Average}} = \frac{84{,}54}{145{,}81} = 0{,}579$$

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

$$= \frac{\{|a-1| + |b-1| + |c-1|\}}{3}$$

$$= \frac{\{|1{,}229-1| + |1{,}168-1| + |0{,}579-1|\}}{3} = 2{,}72\%$$

From the above calculations, it can be seen that both during the day and at night, the load imbalance is still within the tolerance of the maximum limit of load imbalance value assumed by PLN, which is 20

4.2 Calculation of Losses Due to the Current in the Transformer Neutral Cross-Sectional Area of Neutral Conduit 50 mm^2

Daytime

From the measurement table and with the above, it can be calculated using the loss equation due to the current in the neutral conductor of the transformer can be calculated as follows:

I_N = 98,05 A
R_N = 0,6452 Ω
$PN = I_N^2 x R_N$
= $98{,}05^2$ x 0,6452 = 6202.825 Watt ≈ 6.202 kW

Where the active power of the transformer (P):

P = S x Cos φ,

Where cos φ used is 0.85 and transformer apparent power (S) = 100 Kva

P = 100 x 0,85 = 85 kW

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

$$\%_{PN} = \frac{P_N}{P} x100\% = \frac{6.202}{85} x100\%$$

$$= 7{,}29\%$$

Nighttime

From the measurement table and with the above, it can be calculated using the loss equation due to the current in the neutral conductor of the transformer can be calculated as follows:

I_N = 102,17 A
R_N = 0,6452 Ω
$PN = I_N^2 x R_N$
= $102{,}17^2$ x 0,6452 = 6735.054 Watt ≈ 6.735 kW

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

$$\%_{PN} = \frac{P_N}{P} x100\% = \frac{6.735}{85} x100\%$$

$$= 7.92\%$$

Neutral Conduit Cross-Sectional Area 70 mm²

To minimize losses due to the current in the neutral conductor of the transformer, a calculation is made using a neutral conductor cross-sectional area of 70 mm²

Daytime

I_N = 98,05 A
R_N = 0,4608 Ω
PN = $I_N^2 x R_N$
= $98{,}05^2$ x 0,4608 = 4430.040 Watt ≈ 4.430 kW

Where the active power of the transformer (P):

P = S x Cos φ,

Where cos φ used is 0.85 and transformer apparent power (S) = 100 Kva

P = 100 x 0,85 = 85 kW

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

$$\%_{PN} = \frac{P_N}{P} x100\% = \frac{4.430}{85} x100\%$$

$$= 5.21\%$$

Nighttime

I_N = 102,17 A
R_N = 0,4608 Ω
PN = $I_N^2 x R_N$
= $102{,}17^2$ x 0,4608 = 4810.157 Watt ≈ 4.810 kW

Where the active power of the transformer (P):

P = S x Cos φ,

Where cos φ used is 0.85 and transformer apparent power (S) = 100 Kva

P = 100 x 0,85 = 85 kW

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

$$\%_{PN} = \frac{P_N}{P} x100\% = \frac{4.810}{85} x100\%$$

$$= 5.65\%$$

Neutral Conduit Cross-Sectional Area 95 mm²

Daytime

From the measurement table and with the above, it can be calculated using the loss equation due to the current in the neutral conductor of the transformer can be calculated as follows:

I_N = 98,05 A
R_N = 0,3096 Ω

$PN = I_N^2 x R_N$
$= 98{,}05^2$ x 0,3096 = 2976.433 Watt ≈ 2.976 kW

Where the active power of the transformer (P):

P = S x Cos φ,

Where cos φ used is 0.85 and transformer apparent power (S) = 100 Kva

P = 100 x 0,85 = 85 kW

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

$$\%_{PN} = \frac{P_N}{P} x 100\% = \frac{2.976}{85} x 100\%$$

$$= 3{,}50\%$$

Nighttime

I_N = 102,17 A
R_N = 0,3096 Ω
$PN = I_N^2 x R_N$
$= 102{,}17^2$ x 0,3096 = 3231.824 Watt ≈ 3.231 kW

Where the active power of the transformer (P):

P = S x Cos φ,

Where cos φ used is 0.85 and transformer apparent power (S) = 100 Kva

P = 100 x 0,85 = 85 kW

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

$$\%_{PN} = \frac{P_N}{P} x 100\% = \frac{3.231}{85} x 100\%$$

$$= 3.80\%$$

4.3 Calculation of Losses Due to Neutral Current Flowing to Ground

Losses due to neutral currents flowing to the ground during the day can be calculated using the following equation:

Daytime

$$P_G = I_G^2 \, x \, R_G, Where I_G = 49{,}75 A \, and \, R_G = 0{,}3420 \Omega$$

$$= 49{,}75^2 \, x \, 0{,}3420 = 0.846 \, Watt \approx 0.846 kW$$

Thus the percentage of losses is:

$$\%_{PG} = \frac{P_G}{P} x 100\% = \frac{0.846}{85} x 100\%$$

$$= 0{,}99\%$$

Nighttime

$$P_G = I_G^2 \, x \, R_G, Where I_G = 58{,}41 A \, and \, R_G = 0{,}3420 \Omega$$

$$= 58{,}41^2 \, x \, 0{,}3420 = 1012.473 \, Watt \approx 10.12 kW$$

Thus the percentage of losses is:

$$\%_{PG} = \frac{P_G}{P} x 100\% = \frac{1{,}012}{85} x 100\%$$

$$= 1.19\%$$

The greater the neutral current flowing in the neutral conductor of the transformer (IN), the greater the loss in the neutral conductor of the transformer (PN). Vice versa, if the greater the neutral current flowing to the ground (IG), the greater the losses due to the neutral current flowing to the ground (PG). With the increasing neutral current and losses in the transformer, the transformer efficiency will decrease. If the size of the neutral conductor wire is made the same as the phase conductor wire (70 mm2), the neutral current losses will decrease.

Conclusion

Based on the data analysis that has been carried out, it can be seen that the effect of load imbalance on neutral current and power losses in the transformer of PT PLN (Persero) Tanah Jawa Distribution substation can be concluded as follows:

a. Losses (loss) of power due to the current in the neutral conductor (P_N)
b. During the day, power losses due to the current in the neutral conductor (PN) amounted to 7.2.
c. At night the power losses due to the current in the neutral conductor (PN) amounted to 7.92%.
d. Power losses due to neutral current flowing to the ground (PG)
e. During the day the power losses due to neutral current flowing to the ground (PG) amounted to 0.99%.
f. At night, power losses due to neutral current flowing to the ground (PG) amounted to 1.19%

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