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Analysis of the Influence of Load Unbalance on the Neutral Current Power Loss in Substation KP10 PT. PLN (Persero) UP3 Teluk Naga

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Abstract: The research objective is to analyze the percentage value of load unbalance before and after load balancing and the effect on neutral current losses. The load imbalance that occurs at the KP10 substation is simulated through the ETAP 16.0.0 software. Based on the research results, it was found that there was an imbalance in the load of the KP10 substation in direction B, which experienced the greatest load imbalance with a percentage of 38.76% and in direction A, which experienced a load imbalance of 19.6%. Based on SPLN No. 017 of 2014, the percentage of load imbalance exceeding 25% must be repaired. So that the repair is carried out by equalizing the load by breaking the load from direction B to direction A. After the activity of equalizing the load distribution, a decrease in the percentage of load imbalance is obtained. Majoring A is 8.9% and majoring B is 12,6%. The existence of this load imbalance also causes losses due to neutral currents where before the equalization activities the neutral current losses amounted to 6.99% and after the equalization of 1.06%. A simulation was also carried out where the load imbalance simulation results were obtained with the measurement results having results that were not much different.

Keywords: Load Unbalance; Losses; ETAP 16.0.0.

INTRODUCTION

The electrical power system is a network of electrical energy installations that includes power generation, transmission, and distribution systems interconnected to meet the energy needs of humans. With the rapid development of technology and time, population growth will increase rapidly, resulting in an impact on the demand for electrical energy. Therefore, a significant supply of electrical power is expected, and in this case, electricity suppliers must pay attention to the equipment applied in the distribution system to consumers or customers, which are referred to as users. The distribution transformer is an electrical energy system device used to distribute electrical energy by reducing the voltage level from medium voltage (20 kV) to low voltage (380/220 V) [1]. These customers can be industrial or household consumer.

The presence of current in the neutral of the distribution transformer can occur in all substations. In unbalanced loads, a relatively high neutral current can appear, and even in balanced loads, there is still current in the neutral. The presence of neutral current can cause power losses, which can be detrimental to PT. PLN (Persero) company and can impact the performance of the system.

In normal conditions, balanced loads mean that linear loads are used, and there is no current in the neutral. However, if there is a neutral current in balanced loads, it indicates the presence of non-linear loads being used. Non-linear loads are frequently used in both industrial and household settings. Examples of non-linear load contributors in industrial customers include induction motors, speed controllers for electric motors, while for household customers, they include computers, air conditioners, fluorescent lamps, and many others. These non-linear loads create non-sinusoidal current waveforms that affect the measurement of secondary and primary transformer currents. Consequently, this influences the electricity measurement on the customer's kWh meter.

As the power losses increase, the performance of the system declines. Therefore, the author took the initiative to conduct research with the title "Analysis of Power Losses on Neutral Current due to Load Imbalance at KP10 Substation

In the previous research [2], the results showed that there was an influence of the causes of load imbalance on the neutral current that is directly proportional, as well as on the losses flowing to the ground. This was achieved by conducting direct measurements during both daytime and nighttime.

Based on the research conducted by the author [3], it is known that the presence of neutral current in the transformer causes load imbalance, resulting in increased power losses. In the study, load balancing was carried out to reduce load imbalance by redistributing the load to other phases. The analysis also involved simulations using ETAP 12.6.0.

In the previous study [4], it was concluded that load imbalance, influenced by population growth from 2014 to 2015, significantly affected the occurrence of load imbalance in the transformer. This load imbalance, in turn, had an impact on the current in the neutral conductor and the power losses of the transformer.

In searching for data to analyze load imbalances, direct measurements can be conducted at the distribution substation to obtain the loading data for phases R, S, T, and the neutral of the transformer. In the study [5], a comparison analysis was performed between the load measurements before load balancing and the load measurements after load balancing. Load balancing was achieved by moving some loads from phases with high load conditions to phases with low load conditions. The results of the analysis showed that the post-load balancing load loss percentage was smaller than before load balancing. Before load balancing, the percentage of neutral current in the neutral conductor of the transformer was 2.01%, and after load balancing, it reduced to 0.99%. The second percentage, the neutral current flowing to the ground, was 2.28% before load balancing and decreased to 1.06% after load balancing.

The previous study [6] proposed a solution to load imbalance, which involved load balancing on one of the transformer phases. The results of the load balancing successfully reduced the load imbalance percentage by 1%, which can be considered good as it had a significant difference from the maximum load imbalance criteria, which is 10%.

METHODS

The data analysis method used in this study is quantitative, wherein the data is obtained from direct measurements and presented in the form of tables. The quantitative data taken includes the load usage data for each phase from KP10 Distribution Substation before load balancing and after load balancing, as well as data from the transformer obtained from the nameplate on the transformer.

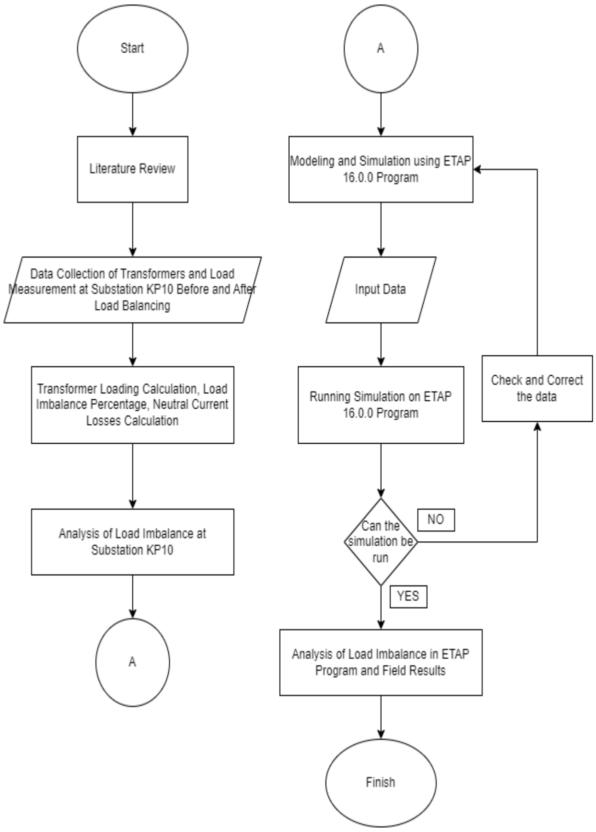

Figure 1. Research of Flowchart

Loading Analysis on Transformer

The load analysis used on the transformer is to determine the percentage of load being used by the transformer in accordance with its capacity. The calculation of transformer loading can be done by knowing the current value at full load according to the following formula.

$I_{FL} = \frac{S_{3\emptyset}}{\sqrt{3} \times V}$ Equation. 1

Information:

I_{FL} = Full Load Current (A)

$S3\emptyset$ = Power of Transformer 3 Phase (kVA)

V = Secondary Side Voltage (V)

After knowing the current at full load, the percentage of load used by the transformer per phase can be determined using the following formula:

$\%I_R = \frac{I_R}{I_{FL}}$ Equation. 2

$\%I_S = \frac{I_S}{I_{FL}}$ Equation. 3

$\%I_T = \frac{I_T}{I_{FL}}$ Equation 4

So, the total percentage of transformer loading used can be calculated using the formula:

$\%Loading = \frac{\%I_R + \%I_S + \%I_T}{3}$ Equation 5

The total power used at the peak load of the transformer can be calculated using the formula:

S = %Loading × Power Transformer Equation 6

Analysis of Load Imbalance on the Transformer

The load imbalance on the transformer can be calculated using the formula:

$I_{Rata-rata} = \frac{I_R + I_S + I_T}{3}$ Equation. 7

The value of current in a balanced condition can be used as a benchmark to find the coefficients of each phase in the unbalanced load. It is calculated using the following equation:

$a = \frac{I_R}{I_{Rata-rata}}$ Equation. 8

$b = \frac{I_S}{I_{Rata-rata}}$ Equation. 9

$c = \frac{I_T}{I_{Rata-rata}}$ Equation 10

Information:

$I_{Rata-Rata}$ = The Average Currennt In the Phase RST (A)

I_R = Current In the phase R (A)

I_S = Current in the phase S (A)

I_T = Current in the phase T (A)

A, b, c = Coefficient

From the three coefficients of the unbalanced load, the average value of the load imbalance can be determined, expressed in percentage, as follows.

$\%kb = \frac{\{|a-1|+|b-1|+|c-1|}{3} \times 100\%$ Pers. 11

Analysis of Power Losses due to Neutral Current in the Transformer

In distribution transformers, load imbalance often occurs among different phases, resulting in unbalanced neutral currents. Unbalanced neutral currents in distribution transformers can lead to significant power losses, especially in transformers with large capacity and prolonged usage. The analysis of power losses or losses due to neutral currents in distribution transformers can be conducted to calculate the magnitude of power losses caused by the unbalanced neutral currents. These power losses can be calculated based on the transformer power losses equation, which is:

$P_N = I_N{}^2 \times R_N$ Equation 12

$P_{Trafo} = S_{Trafo} \times Cos\ \varphi$ Equation 13

$\%P_N = \frac{P_N}{P_{Trafo}} \times 100\%$ Equation 14

Information:
P_N = Power losses in the transformer neutral (Watt)
I_N = The current through the neutral conductor (Amp)
R_N = Resistance in neutral conduction (Ω)
Cos φ = Cos phi (0,85)

The simulation was conducted using ETAP 16.0.0 software.

ETAP, which stands for Electric Transient Analysis Program, is a software that supports simulation of electrical power systems. In this study, an analysis of unbalanced loads was conducted using ETAP 16.0.0 software. The simulation executed was running load flow, and the results can be observed from the generated report called Unbalance Load Flow report, which shows the currents in each phase and the resulting losses. The actions performed in the simulation using ETAP 16.0.0 include:

a. Creating a Circuit in ETAP 16.0.0

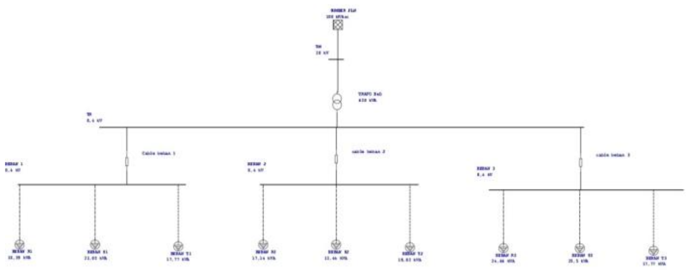

Figure 2. Figure Of Simulation Circuit ETAP 16.0.0

In ETAP 16.0.0, a simulation circuit for load imbalance in the Distribution Transformer at KP10 Substation is created. The KP10 Substation has three active directions, and each direction has three phases, namely phases R, S, and T, which are connected to the loads.

b. Performing Load Rating Input

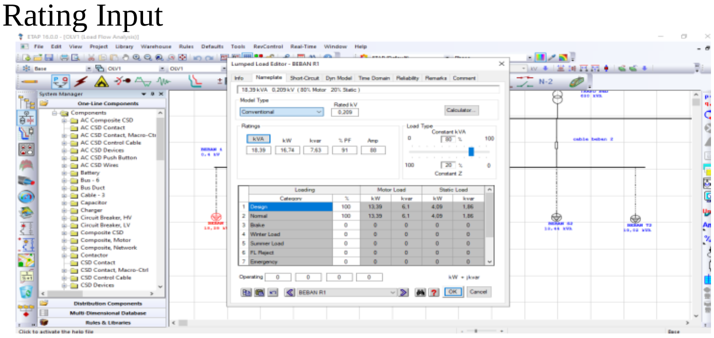

Figure 3. Charging Load Rating

Performing Load Rating Input for Each Direction. In ETAP 16.0.0, the load rating input needs to be filled for each load in each direction. The loads are set as single-phase loads because, in this simulation, we want to observe the neutral currents that occur due to the load imbalance. The ratings to be filled include phase-to-neutral voltage, power factor, and phase currents for each direction. The load rating input should be done both before load balancing and after load balancing. This will enable us to analyze the neutral currents resulting from load imbalances in different scenarios.Melakukan Running Unbalance Load Flow.

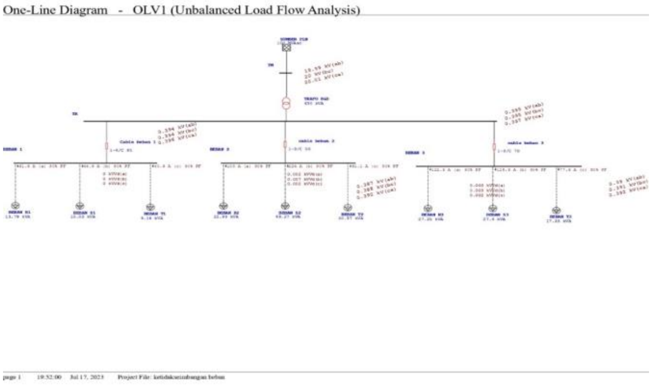

Figure 4. Running Unbalace Load Flow

Running Unbalance Load Flow is one of the icons used in ETAP 16.0.0 to analyze unbalanced loads in a three-phase system. From the results of the running, the currents used by the loads for each phase in each direction can be observed. After performing the running, a report can be generated to visualize the results of the currents in each phase and the neutral. This report provides valuable insights into the load imbalance analysis and helps to identify any issues related to the neutral currents caused by load imbalances.

RESULTS AND DISCUSSION

In this study, data was collected from KP10 Substation, which is part of the MOA Grid Interconnection in Sepatan Area under PT. PLN (Persero) UP3 Teluk Naga. KP10 Substation is connected to customers with power ranging from 900 VA to 5500 VA. The transformer used in KP10 Substation has a capacity of 630 kVA and is of the concrete substation type.

1. Load Measurement Before Load Balancing

Load measurements at KP10 Substation were conducted on September 14, 2022. The collected measurement data includes the current readings of each phase conductor and the neutral conductor, as shown in the following table:

Table 1. Load Measurement Data of Simulation ETAP 16.0.0

Load Measurment Data				
DIRECTION	R	S	T	N
A	66	46	42	24
B	105	225	97	130
D	125	128	83	80
TOTAL	296	399	222	234

A. Transformer Loading Analysis

It is known that the transformer at KP10 Substation has a capacity of 630 kVA, and using the IFL formula, the full-load current is calculated to be 909.3 A. Subsequently, after determining the peak load current of the transformer at KP10 Substation, the percentage of transformer loading on each phase R, S, T can be determined as follows:

$\%I_R = \frac{296}{909,3} \times 100\% = 32,55$ A

$\%I_S = \frac{399}{909,3} \times 100\% = 43,88$ A

$\%I_T = \frac{222}{909,3} \times 100\% = 24,41$ A

From the calculation results, the average value of the transformer loading at KP10 Substation, using equation 5, is found to be 33.613%.

B. The calculation of load imbalance:

From the data obtained, load imbalance is observed in direction B, which is relatively high. Therefore, load splitting will be conducted in direction A. Based on the transformer load data in Table 1, we can calculate the average current using equation 7 for both direction A and B as follows:

$I_{\text{rata-rata jurusan A}} = \frac{66\ A + 46\ A + 42\ A}{3} = 51,33$ A

$I_{\text{rata-rata jurusan B}} = \frac{105\ A + 225\ A + 97\ A}{3} = 142,33$ A

The average current value can be used as a benchmark to find the coefficients of each phase in the unbalanced load. It is calculated using equations 8, 9, and 10.

For Direction A:

$a = \frac{I_R}{I_{Rata-rata}} = \frac{66\ A}{51,33\ A} = 1,285797779$ A

$b = \frac{I_S}{I_{Rata-rata}} = \frac{46\ A}{51,33\ A} = 0,896103896$ A

$c = \frac{I_T}{I_{Rata-rata}} = \frac{42\ A}{51,33\ A} = 0,818181818$ A

For Direction B:

$a = \frac{I_R}{I_{Rata-rata}} = \frac{105\ A}{142,3\ A} = 0,737722195$ A

$b = \frac{I_S}{I_{Rata-rata}} = \frac{225\ A}{142,3\ A} = 1,580796253$ A

$c = \frac{I_T}{I_{Rata-rata}} = \frac{97\ A}{142,3\ A} = 0,681514790$ A

From the calculation results of the load imbalance, expressed as a percentage of load, we have the following:

% Load Imbalance in direction A:

$= \frac{\{|a-1|+|b-1|+|c-1|}{3} \times 100\% = \frac{\{|1,285-1|+|0,896-1|+|0,818-1|}{3} \times 100\%$

= 19,06 %

% kb direction B

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

$= \frac{\{|0,737-1|+|1,581-1|+|0,681-1|}{3} \times 100\%$

= 38,76%

Based on SPLN Regulation No. 17 of 2014, a load imbalance value greater than 25% falls into the "poor" category, necessitating corrective actions or replacement. Therefore, load balancing is required from direction B to direction A, as the latter can still accommodate additional load. Direction A has a lower total current compared to the other directions.

C. Analysis of Power Losses or Losses Due to the Presence of Neutral Currents in the Transformer

Power losses or losses can result in power not reaching the receiver from the sender.

P_N $= I_N^2 \times RN$
$= (234\ A)^2 \times 0{,}6842\ \Omega/km$
$= 37{,}4640552\ kW$

The power losses generated are 37.4640552 kW. We can calculate the percentage of losses due to the neutral current in the KP10 Substation transformer as follows:

P_{Trafo} $= S_{Trafo} \times Cos\ \varphi$
$= 630\ kVA \times 0{,}85$
$= 535{,}5\ kW$

P_N $= \frac{P_N}{P_{Trafo}} \times 100\%$

$= \frac{37{,}4640552}{535{,}5} \times 100\%$

$= 6{,}99\ \%$

D. ETAP 16.0.0 Simulation

The simulation using ETAP was conducted to compare and observe the differences between the obtained results and the actual field data. Based on the Single Line Diagram, KP10 Substation consists of three active directions delivering electricity to customers, namely Load 1, Load 2, and Load 3. Each direction comprises three phases: phase R, phase S, and phase T, as shown in Figure 5 below:

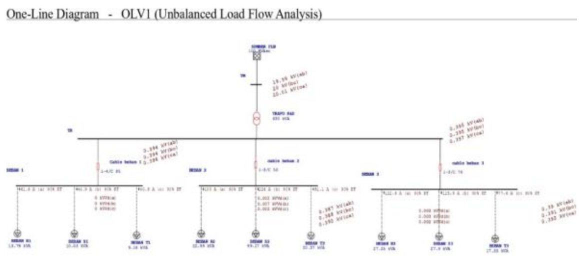

Figure 5. Single Line Diagram Trafo Gardu KP10

Based on the simulated circuit, the results of the running Unbalance Load Flow provide the following load data:

Table 2. Load Measurement Data of Simulation ETAP 16.0.0

LOAD MEASURMANT DATA				
DIRECTION	R	S	T	N
A	61,6	44,9	40,8	18,9
B	103,0	224,0	91,1	127,1
D	122,6	125,9	77,6	46,3

Based on the field calculation, the average transformer loading is 33.613%. From the simulation results in ETAP, the transformer loading is obtained as follows: direction A: 31.3%, direction B: 42.8%, direction C: 22.9%. To find the average transformer loading from the ETAP simulation results, we sum up the percentages of all directions and divide by the total number of directions:

Loading $= \frac{\%I_R + \%I_S + \%I_T}{3}$

$$= \frac{31,3+42,8+22,9}{3}$$

$$= 32,3\%$$

From the results, we can compare them with the field data, and the difference is 1.313%, which means they are relatively close.

KP10 Substation is a substation that supplies low-voltage customers with power ranging from 900 VA to 5,500 VA. In the simulation, a single-phase load was connected to observe the neutral current resulting from load imbalances. This simulation was conducted to understand the impact of load imbalances on each phase and compare the results with direct field measurements. The simulation revealed that the current values flowing through each phase and the neutral were smaller compared to the field measurement results. This difference is attributed to the fact that ETAP 16.0.0 assumes all equipment conditions to be ideal without considering losses in other equipment. As a result, the simulation might not fully capture real-world conditions and losses that occur in practical scenarios.

2. Measurment Of Load After Righting

Load measurements after load balancing at KP10 Substation were conducted on December 5, 2022. Similar to the data collection before load balancing, the measurement data was obtained by measuring the load on each phase conductor and the neutral conductor, as shown in the following table:

Table 3. Load of Transformer Data After Righting

LOAD MEASURMENT DATA				
DIRECTION	R	S	T	N
A	88	105	85	21
B	82	64	91	28
D	118	122	85	40
TOTAL	288	291	261	89

The load balancing activity was performed by transferring a portion of the load from direction B to direction.

A. Transformer Loading Analysis

Based on equations 2, 3, and 4, the percentage of transformer loading after load balancing can be determined as follows:

$$\%I_R = \frac{288}{909,3} \times 100\% = 31,67\ \%$$

$$\%I_S = \frac{291}{909,3} \times 100\% = 32\ \%$$

$$\%I_T = \frac{261}{909,3} \times 100\% = 28,70\ A$$

B. Calculation Of Load Unbalanced

After load balancing by transferring a portion of the load from direction A to B, the average current values using equation 7 for direction A and B are obtained as follows:

$$I_{\text{rata-rata jurusan A}} = \frac{I_R + I_S + I_T}{3}$$

$$= \frac{88\ A + 105\ A + 85\ A}{3} = 92,67\ A$$

$$I_{\text{rata-rata jurusan B}} = \frac{I_R + I_S + I_T}{3}$$

$$= \frac{82\ A + 64\ A + 91\ A}{3} = 79\ A$$

The average current value can be used as a reference to find the coefficients for each phase in the unbalanced load. It is calculated using equations 8, 9, and 10.

At Direction A

$$a = \frac{I_R}{I_{Rata-rata}} = \frac{88\ A}{92{,}67\ A} = 0{,}949640287\ A$$

$$b = \frac{I_S}{I_{Rata-rata}} = \frac{105\ A}{92{,}67\ A} = 1{,}133093525\ A$$

$$c = \frac{I_T}{I_{Rata-rata}} = \frac{85\ A}{92{,}67\ A} = 0{,}917266187\ A$$

In direction B

$$a = \frac{I_R}{I_{Rata-rata}} = \frac{82\ A}{79\ A} = 1{,}037974684\ A$$

$$b = \frac{I_S}{I_{Rata-rata}} = \frac{64\ A}{79\ A} = 0{,}810126582\ A$$

$$c = \frac{I_T}{I_{Rata-rata}} = \frac{91\ A}{79\ A} = 1{,}151898734\ A$$

xFrom the results of the load imbalance calculations, the percentage of load imbalances for each phase is as follows:

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

$$= \frac{\{|0{,}949 - 1| + |1{,}133 - 1| + |0{,}917 - 1|}{3} \times 100\%$$

= 8,9 %

% kb direction B

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

$$= \frac{\{|1{,}038 - 1| + |0{,}810 - 1| + |1{,}152 - 1|}{3} \times 100\%$$

= 12,6 %

From the obtained results after redistributing the load from direction B to A, the percentage of load imbalance in direction B decreased to 12.6%, which falls under the "Good" category according to the SPLN No.17 of 2014 regulations. The load redistribution in direction A also resulted in a decrease in load imbalance because the current values between phases did not have a significant difference, which helped reduce the load imbalance to 8.9% in that direction.

C. Power Loss Analysis or Consequence Losses

After load balancing, the neutral current in the transformer decreased, resulting in a reduction in losses. The losses can be calculated using equations 12, 13, and 14 as follows: [Please provide the equations and the relevant data, and I'll help translate them into English.]P_N $= I_N^2 \times RN$

$= (89\ A)^2 \times 0{,}6842\ \Omega/km$
$= 5{,}4195482\ kW$

The losses generated amount to 5.4195482 kW, so we can calculate the percentage of losses due to neutral current in the KP10 Substation transformer as follows:

$P_{Trafo} = S_{Trafo} \times \text{Cos}\ \varphi$
$= 630\ kVA \times 0{,}85$
$= 535{,}5\ kW$

$P_N = \frac{P_N}{P_{Trafo}} \times 100\%$

$= \frac{5{,}4195482}{535{,}5} \times 100\%$
$= 1{,}01\ \%$

D. ETAP 16.0.0 Simulation

In this study, simulation of load imbalance after load balancing was also conducted using the same circuit, but with varying current magnitudes in each direction.

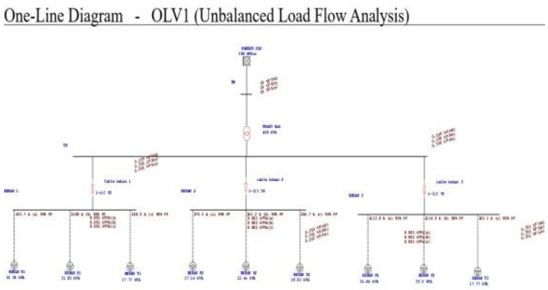

Figure 6. Single Line Diagram Trafo Gardu KP10

From the results of the Unbalance Load Flow running, the load data obtained is as follows:

Table 4. Load Measurement Data of Simulation ETAP 16.0.0

LOAD MEASURMENT DATA

DIRECTON	R	S	T	N
A	83,7	100	80	17,9
B	78,2	61,2	86,7	22,4
D	112,9	116,8	81,1	33,8

From the field calculation results, the transformer loading for phase R is 31.67%, phase S is 32%, phase T is 28.70%, and the average transformer loading is 30.79%. From the simulation results, the transformer loading for phase R is 29.9%, phase S is 30.2%, and phase T is 27.1%. The average transformer loading from the ETAP simulation is:

$$\text{Loading} = \frac{\%I_R + \%I_S + \%I_T}{3}$$

$$= \frac{29{,}9 + 30{,}2 + 27{,}1}{3}$$

$$= 29{,}06\%$$

From the comparison of the field data with the simulation results, the difference is approximately 1.73%, which means it is not too far apart. Similarly, as observed before load balancing, the simulation results show that the current values for each phase and neutral are smaller compared to the field measurements. This is because the ETAP 16.0.0 program assumes ideal equipment conditions without considering other losses in the equipment.

CONCLUSION

Substation KP10 experiences an imbalance in one of its phases, requiring load balancing to other phases. The most significant impact of the imbalance is on phase B, with a percentage of 38.76%, while phase A has an imbalance percentage of 19.6%. Therefore, load balancing is performed by transferring some of the load from phase B to phase A.

From the load balancing activity by redistributing the load between phases A and B, a reduction in the percentage of load imbalance was achieved. Phase A's imbalance decreased to 8.9%, which is considered good according to SPLN No.017 of 2014, as the percentage is below 10%. Meanwhile, phase B's imbalance reduced to 12.6%, which is considered sufficient as it falls within the range of more than 10% and less than or equal to 20%.

The losses due to neutral current represent the power that is not absorbed by the load but wasted. Before load balancing activity, the losses due to neutral current were 6.99%, and after load balancing, it reduced to 1.01%. There was a significant decrease in the percentage of losses after load balancing activity.

In this study, simulations were also conducted in the ETAP program for load imbalance before and after, in order to compare the field results with the simulations. From the simulation results, a discrepancy was found compared to the field measurements. This is because the ETAP 16.0.0 simulation measures the equipment's condition ideally and does not account for losses in other equipment.

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