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Distribution Transformer Load Imbalance Analysis at Universitas Bangka Belitung

Deni Irwansyah[1], Welly Yandi [1*], Asmar[1], Wahri Sunanda[1] and Azriyenni Azhari Zakri[2]

[1] Department of Electrical Engineering, Faculty of Engineering, Universitas Bangka Belitung, Balunijuk, Merawang, Kepulauan Bangka Belitung 33172, Indonesia
[2] Department of Electrical Engineering, Faculty of Engineering, Universitas Riau, Jl. HR Soebrantas KM. 12.5, Simpang Baru, Binawidya, Pekanbaru 28293, Indonesia

*Corresponding Author: wellyyandi@ubb.ac.id

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Abstract

Loading between phases must always be considered in order to reduce the imbalance, which results in an increase in neutral current and loss of conductor power. Non-linear loads can cause harmonics that affect the increase in copper losses in the transformer. Harmonics can cause distortion of the voltage and current waveforms, so attention must be paid to the specified limits so as not to interfere with the performance of electrical equipment. In addition, these parameters can affect the main electrical parameters, so they must be considered at the specified limits. This study aims to analyze the condition of load imbalance, harmonic content, and the effect on power loss in distribution transformers at Universitas Bangka Belitung. Parameters were measured using a Meterel Power Meter Analyzer type MI 2592 Power Q4 for ten days with the comparative method as a data analysis method. The average current unbalanced percentage is 9.91%, with the highest value at 24.31%. Energy due to power loss in the neutral conductor is 0.46 kWh/10 days, and the total conductor loss is 18.122 kWh/10 days.

Keywords: Load Imbalance, Losses, Transformer

1. Introduction

In a 3-phase power system configuration, the loading on each phase needs to be considered as an effort to maintain electrical equipment so that the reliability of the electrical system is maintained. If the loading on each phase is not balanced, there will be a load imbalance condition that can cause the current to flow in the neutral conductor of the transformer [1]. The neutral current can certainly cause transformer losses so that it can reduce the capacity of the transformer to serve the load. Because current flows in the neutral transformer cable, the power loss that occurs in the secondary distribution network will increase [2]. This loss will have a major impact on both the consumer and PLN because it will greatly affect investment costs. In addition to supply from PLN, because the Universitas Bangka Belitung is a campus that is also actively researching the Bangka island's electricity system and renewable energy, especially solar energy, there is also electricity supply from solar panels for research purposes for lecturers and student thesis [3].

Universitas Bangka Belitung has several main buildings, namely, Rectorate, Babel I, Babel II, Tinah I, Semangat, Juang, Daya, Dharma Pendidikan, Dharma Penelitian, Dharma Pengabdian, Timah II, Babel III, and Babel IV. Universitas Bangka Belitung is currently supplied by PLN Bangka Belitung Region with a power supply of 690 kVA to meet the electrical energy needs of the campus with a total land area of 153 ha. The power requirement during the day is higher than in the afternoon. The total power (3 phases) in the morning is 194.6425 kW, while in the afternoon, it is 154.0396 kW [4].

In assessing the quality of electricity in an electrical system, the loading conditions between phases and the content of harmonics in the voltage and current waves are one of the aspects that can cause a reduction in the quality of electricity which can cause voltage distortion, current distortion, frequency distortion, overvoltage, voltage drop, current [5]. Neutral, and the most detrimental, is the increase in power loss in the transformer [6]. The fluctuations in the harmonic content need to be considered so that it remains within the allowable limits according to the standardization of electrical quality based on the Circular Letter of the Directors of PT. PLN (Persero), PLN Standards, PERMEN ESDM, IEC standards, IEEE standards, NEMA standards, and so on, as in the other reference [7].

2. Materials and Methods

2.1 Full Load Current Calculation

Short Circuit Current and Percentage Loading of Transformer [8]. The transformer power, when viewed from the high voltage (primary) side of the formula ,

$$S = \sqrt{3}\,.V.I \tag{1}$$

So, to calculate the full load current and short circuit current, you can use the formula (Saadat, 1999),

$$I_{FL} = \frac{S}{\sqrt{3} \times V} \tag{2}$$

$$I_{SC} = \frac{kVA \times 100}{\%Z \times \sqrt{3} \times kV} \tag{3}$$

where S is transformer power (kVA), V is transformer primary side voltage (kV), I is line current (A), IFL is full load current (A), ISC is maximum short-circuit current (A), and %Z is the percentage per unit transformer impedance (%) [9]. Thus, calculating the percentage of transformer loading and the percentage of current loading on the conductor to the conductor's KHA are as follows [16],

$$\%\,Load\ Transformers = \frac{I_{Average}}{I_{FL}} \times 100\% \tag{4}$$

$$\%\,Load\ Line = \frac{I_{Phase}}{KHA\ Line} \times 100\% \tag{5}$$

Strength Conduct Current conductor is obtained based on the specifications of the conductor used [10].

2.2 Calculation of Percentage Unbalance, Neutral Current, and Power Loss in Conductors.

The calculation of the percentage of current unbalance can use the equation of unbalanced current with the magnitude of the phase currents can be expressed by the coefficients a, b and c,

$$I_{Average} = \frac{(I_a + I_b + I_c)}{3} \tag{6}$$

$$a = \frac{I_a}{I},\ b = \frac{I_b}{I},\ c = \frac{I_c}{I} \tag{7}$$

where the magnitude of the phase current in a balanced state is equal to the magnitude of the average current. In a balanced state, the magnitude of the coefficients a, b, and c is one [11]. Thus, the average percentage of the current unbalance is,

$$\%\,unbalanced = \frac{\{|a-1| + |b-1| + |c-1|\}}{3}\ 100\,\% \tag{8}$$

For voltage unbalance, it is also possible to use a comparison of the negative sequence component to the positive sequence component $(V_{sym\,2})$ or the zero-sequence component to the positive sequence component $(V_{sym\,0})$ [12]. This calculation is known as the Voltage Unbalance Factor (VUF) [17],

$$V_{2sym} = \frac{V_2}{V_1} = \frac{1/3\,(V_a + a^2 V_b + aV_c)}{1/3\,(V_a + aV_b + a^2 V_c)} \tag{9}$$

$$V_{0sym} = \frac{V_0}{V_1} = \frac{1/3\,(V_a + V_b + V_c)}{1/3\,(V_a + aV_b + a^2 V_c)} \tag{10}$$

Load imbalance can cause a neutral current to appear, which can cause power loss in the neutral conductor [13]. In this three-phase four-wire system, the sum of the line currents is equal to the neutral current returning through the neutral wire to,

$$I_N = (I_a + I_b + I_c) \tag{11}$$

$$I_N = 3I_0 \tag{12}$$

whereI_N is the neutral current (A), and I_0 is the zero-order component current (A). If the phase currents are balanced, then the neutral current will be zero. However, if the phase currents are not balanced, a current will appear flowing in the neutral conductor of the system, which means the neutral current is not zero [14]. Calculation of the Percentage of Neutral Current to Transformer Load Current,

$$\%\ Neutral\ Current \quad = \frac{I_{Neutal}}{I_{Highest\ Load}} \times 100\% \tag{13}$$

where the highest load current (A) used is the highest current flowing from the three phases. Current flowing in each conductor can cause power losses. In addition, a current flowing through the neutral conductor will cause power loss along the neutral conductor [15]. The number of losses in the conductor (Watts) is obtained from the equation,

$$P_{Line} = I^2 R \tag{14}$$

$$P_N = {I_N}^2\ R_N \tag{15}$$

3. Results and Discussion

3.1 Current Loading of Each Phase on Conductor CRC

Loading current that exceeds the current-carrying strength (KHA) of the conductor can cause a significant temperature increase in the conductor and cause an increase in power losses along the conductor. Based on data from KMI Wire and Cable 2009 and the type of conductor used is NYY 1×300 mm^2 0.6/1 kV, it is obtained that the KHA outlet size is 598 A. By comparing the measured current in each phase with the conductor KHA, it is obtained that the magnitude of the conductor loading (in %) according to the equation.

Table 1. Summary of calculation results for every phase of current loading for ten days

Phase	Minimum (%)	Average (%)	Maximum (%)
R	10.97	28.72	76.72
S	12.76	28.46	55.82
T	14.13	32.47	74.31

Based on table 1 of the Tier-1 Online Assessment Matrix, the standard specifies a good condition if the percentage of phase loading is below 60% and a sufficient condition if it is between 60%-80%. From the calculation results, the average current loading on the conductor is still in the good category. Meanwhile, the highest values in the R and T phases reached sufficient conditions.

3.2 Transformer Loading and Current Unbalance

One of the calculations for the percentage of transformer loading and the percentage of current unbalance on Tuesday, February 23, 2021, at 09.00 AM is as follows:

The average current calculation,

$$|I_R| \;=\; 251{,}4\ A;\ |I_S| \;=\; 238{,}6\ A;\ |I_T| \;=\; 313{,}6\ A$$

Calculation of transformer full load current,

$$I_{FL} = \frac{1.250.000}{\sqrt{3}\ \times\ 400} \;=\; 1804.22\ A$$

The average current calculation,

$$I_{Average} \;=\; \frac{251{,}4\ +\ 238{,}6\ +\ 313{,}6}{3} \;=\; 267{,}87\ A$$

Transformer loading percentage,

$$\%\ Load\ Transformer \;=\; \frac{267{,}87}{1804{,}22} \times 100\% \;=\; 14{,}85\ \%$$

Coefficients a, b, and c,

$$a = \frac{251{,}4}{267{,}87} = \ 0{,}94$$

$$b \;=\frac{238{,}6}{267{,}87} = 0{,}89$$

$$c \;=\frac{313{,}6}{267{,}87} = 1{,}17$$

Current unbalance percentage,

$$\%Unbalanced = \frac{\{|0{,}94 - 1| + |\ 0{,}89 - 1| + |1{,}17 - 1|\}}{3}\ 100\ \%$$

$$= \ 11{,}33\ \%$$

The percentage of current imbalance between phases is 11.33% and is included in the health index enough. The following are the results of the calculation of the percentage of transformer loading and the percentage of current unbalance.

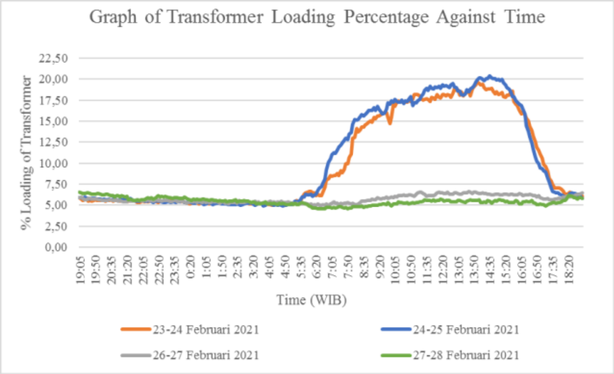


Figure 1. ~~T~~ransformer loading percentage

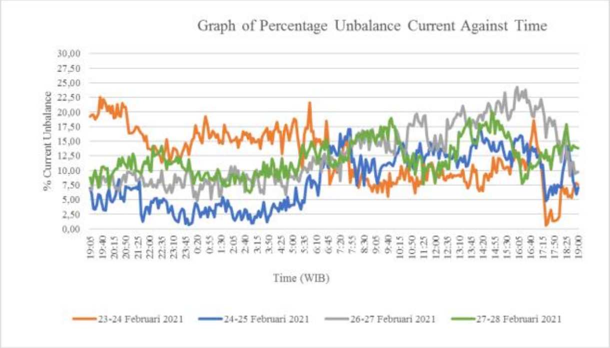


Figure 2. ~~C~~urrent unbalance percentage

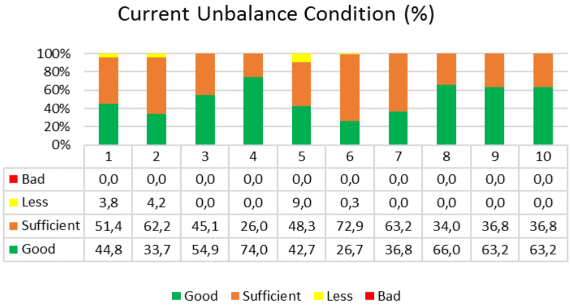
Table 2. Summary of calculation of transformer loading percentage for ten days

Statistical Results	Value
Average (%)	9.58
Highest score (%)	21.45
The lowest value (%)	4.54

Table 3. Summary of calculation of unbalance currents for ten days

Statistical Results	Value
Average (%)	9.91
Highest score (%)	24.31
The lowest value (%)	0.07

The graph of transformer loading shows that the highest transformer loading occurs during working hours in the period from 10.00 WIB to 15.00 WIB. Meanwhile, on holidays, transformer loading tends to remain below 7%. The average measurement for ten days is 9.58%, with the highest value of 21.45% and the lowest value of 4.54%. So that the transformer loading conditions can be categorized as 100% good health index.



	1	2	3	4	5	6	7	8	9	10
🟥 Bad	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
🟨 Less	3,8	4,2	0,0	0,0	9,0	0,3	0,0	0,0	0,0	0,0
🟧 Sufficient	51,4	62,2	45,1	26,0	48,3	72,9	63,2	34,0	36,8	36,8
🟩 Good	44,8	33,7	54,9	74,0	42,7	26,7	36,8	66,0	63,2	63,2

Figure 3. Distribution of current unbalance condition data

The current unbalanced percentage graph shows a value that fluctuates over time. The average value of the current unbalance for ten days is 9.91%, with the highest value reaching 24.31%. The percentage of the highest score is close to the bad health index category, which is 25%. Although there is no distribution of bad health index data, the large distribution of health index data does not indicate that it is necessary to pay attention to the condition of loading current between phases. Based on this analysis, it is recommended to pay attention to the distribution of the loading of each phase at critical times when the current changes significantly. To anticipate the occurrence of a bad current unbalance's percentage, load transfer can be carried out, especially in the phase that has a larger load, based on the identification of the use of the load for each phase over a long period of time.

3.3 Voltage Unbalance

The results of measuring the voltage imbalance from the results of the recording data of the measuring instrument are as follows,

Table 4. summary of measurement results for the percentage of voltage unbalanced for ten days

Imbalance	Lowest	Average	Highest
Vsym2 **(%)**	0,29	0,60	0,88
Vsym0 **(%)**	0,07	0,17	0,34

The magnitude of the voltage imbalance is still below the specified standard, which is 2%, with an average voltage imbalance of 0.60%. The highest measurement value is 0.88%, so during the measurement time, the measurement results show a number below 2% in the range of 100% of the measurement time. For this reason, the condition of the voltage imbalance is still in the good category, and no corrective action is needed.

4. Conclusion

The results of the analysis show that the average transformer loading percentage is still quite good based on the standard. The increase in transformer loading is dominated by weekdays during working hours at 07.00-17.00 WIB. The percentage of current unbalance shows an average of 9.91%, while the highest value reaches 24.31%. The average condition is still classified as good, while the highest condition is classified as less based on the standard. The average percentage of voltage imbalance is 0.6%, with the highest value of 0.88%, so it is still classified as good because it is below the standard limit. The highest increase in neutral current is 167.67 A.

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