Load Balancing Study Analysis Of Transformer Sya029 At PT PLN (Persero) Geudong Customer Service Unit

Irpan Efendi Daulay, Pristisal Wibowo, Dian Yulis Wulandari

Abstract

PT. PLN (Persero), as the electricity provider to customers, is expected to deliver the best possible service by maintaining the continuity and quality of electric power. However, in meeting electricity demand, uneven load distribution frequently occurs due to the connection pattern of single-phase Household Connections (SR) that does not take into account the transformer's loading condition. If left unaddressed, this leads to unbalanced transformer loading. Therefore, this research was conducted to reduce transformer load imbalance using the following method: literature review, direct field measurement, calculation of the imbalance percentage, load balancing, data analysis, and conclusion. The research produced positive results, including a decrease in the load imbalance percentage from 82.15% to 19.62%, a reduction in neutral current flowing through the neutral wire from 26.85 Amperes to 6.55 Amperes, and a decrease in power losses from 141.66 kW to 8.43 kW. In addition, this research saved undistributed energy amounting to 562.76 kWh/day and 16,882.8 kWh/month. The conclusion drawn from this research is that load balancing has a positive impact, including a reduction in neutral current, a decrease in power losses, kWh savings, and most importantly, an improvement in transformer performance optimization.

***Keywords**:* Load Imbalance, Power Losses, Load Balancing

Irpan Efendi Daulay[1]
[1] Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia
e-mail: irpan.efendi.daulay@gmail.com [1]

Pristisal Wibowo[2], Dian Yulis Wulandari[3]
[2,3] Electrical Engineering, Universitas Pembangunan Panca Budi, Indonesia
e-mail: pristisalwibowo@dosen.pancabudi.ac.id[2], dianyulis@dosen.pancabudi.ac.id[3]

Introduction

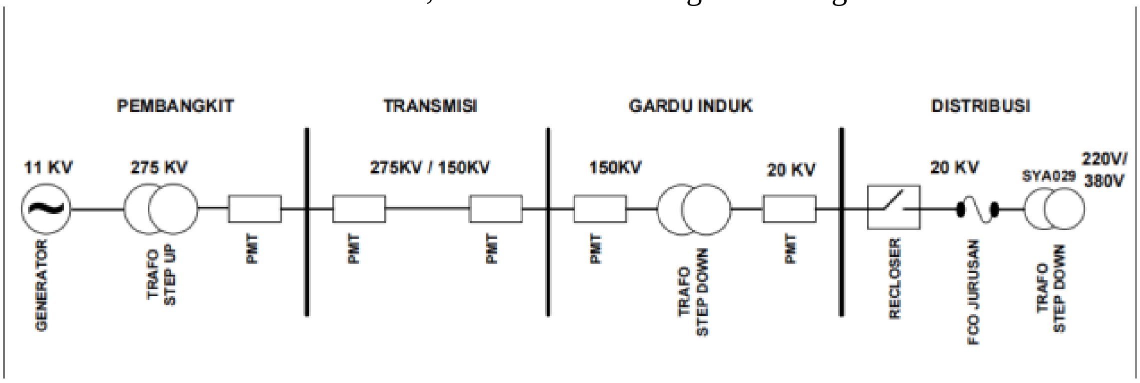
The electric power distribution system plays an important role because it is directly connected to the end users of electrical energy (customers). Continuous and stable delivery of electrical energy is a primary requirement that PLN must fulfill. In meeting electricity demand, uneven load connections across phases frequently occur. This is mainly caused by the connection pattern of single-phase Household Connections (SR) to the Low-Voltage Cable Line (SKTR), which does not take into account the loading condition of each phase when new customers are connected, resulting in an uneven distribution of load. If left unaddressed, this will cause unbalanced transformer loading.

Load imbalance among the three phases (R, S, and T) causes current to flow through the transformer's neutral wire. If this load imbalance is continuously ignored, it will have a significant negative impact on both PLN and its customers. By carrying out load balancing, it is hoped that the current flowing through the neutral wire can be minimized and energy savings (kWh savings) can be achieved. A transformer is considered unbalanced, according to Circular Letter of the Board of Directors of PT PLN (Persero) No. 0017.E/DIR/2014, if the imbalance level exceeds 20% [14]. Meanwhile, at the Geudong Customer Service Unit, feeder LW12, transformer SYA029 has a load imbalance above 20%. Transformer SYA029, with a capacity of 50 kVA, is located in Dayah Aron Village, Syamtalira Aron Sub-district — a location where the electricity supply must remain continuous at all times, aimed at reducing customer complaints regarding power outages (zero downtime).

Literature Review

2.1. Electric Power Distribution Network

Based on voltage level, the electric power distribution network is divided into two parts: the Medium Voltage Network (JTM) at 20 kV and the Low Voltage Network (JTR) at 220/380 V. The medium-voltage distribution network starts from the outgoing cubicle of the Main Substation (Gardu Induk) and is delivered through the network to the primary side of the distribution transformer, while the low-voltage network starts from the secondary side of the transformer to the customer's home, as shown in the single-line diagram below.



2.2. Distribution Substation

A distribution substation is an electrical substation building consisting of a distribution transformer and a Low-Voltage Distribution Panel (PHB-TR), used to supply electrical power to customers at either 20 kV Medium Voltage or 220/380 V Low Voltage. A distribution substation has protection systems on both the primary and secondary sides to protect the transformer. It has four main components: the Distribution Transformer, the main equipment used to step down medium voltage to low voltage; the Lightning Arrester, which provides protection against disturbances caused by lightning strikes; the Fuse Cut Out, which provides overcurrent protection on the medium-voltage side; and the Low-Voltage Distribution Panel (PHB-TR), which regulates the distribution of electricity to consumers.

2.3. Transformer Loading

20 KV distribution transformers generally use a three-phase, four-wire system, in which the load is connected to each phase (R, S, and T) as well as the neutral. In an electric power distribution system, a transformer ideally operates under balanced load conditions; however, in practice this is difficult to achieve because single-phase customers dominate the system. Transformer load imbalance is a major problem that frequently occurs in distribution transformers and directly affects their performance. A transformer is designed to operate optimally under balanced load conditions; when load imbalance occurs, it reduces efficiency and shortens the transformer's service life. Transformer loading may come from either single-phase or three-phase customers, and uneven single-phase customer loads often cause the current in each phase to differ. Transformer loading must be monitored to prevent overload. The power on the primary side of the transformer can be calculated using the following basic formula:

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

Where:

S = Transformer power (kVA)

V = Voltage (V)

I = Current (A)

The full load current can be calculated using the formula:

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

The average current can be calculated using the formula:

$$I_{average} = \frac{Ir + Is + It}{3} \qquad (3)$$

The transformer loading percentage can be calculated using the formula:

$$\%Load = \frac{I\ average}{I\ FL} \times 100\% \qquad (4)$$

Where:

%Load = Loading percentage (%)

I_{FL} = Full load current (A)

Iaverage = Average current (A)

V = Voltage (V)

The load imbalance percentage can be calculated using the formula:

$$\%KB = \frac{Imax - Imin}{Iaverage} \times 100\% \quad (5)$$

Where:

Imax = Highet phase current (A)

Imin = Lowest phase current (A)

Iaverage = Average current (A)

2.4. Load Imbalance

Unbalanced load is a common problem frequently encountered in three-phase systems, mainly because single-phase household connections dominate over three-phase connections. When load imbalance occurs in a three-phase system, current flows through the neutral wire and the phase angle difference between phases is no longer equal to 120°. This can be illustrated more clearly using the current vector diagrams shown below.

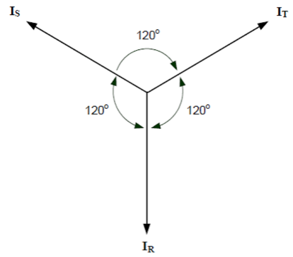


Figure 2. Balanced Current Vector Diagram

Figure 2 shows the current vector diagram under balanced conditions. It can be seen that the sum of the three current vectors (IR, IS, IT) equals zero, so no neutral current (IN) appears.

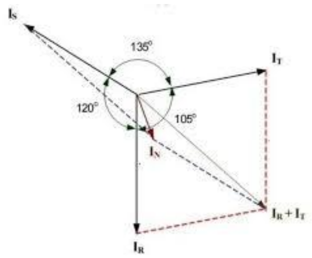


Figure 3. Unbalanced Current Vector Diagram

Figure 3 shows the current vector diagram under unbalanced conditions. It can be seen that the sum of the three current vectors does not equal zero, so a quantity known as the neutral current appears as a result of the imbalance.

Table 1. Transformer loading standard according to Circular Letter of the Board of Directors of PT PLN (Persero) No. 17 of 2014

Characteristic	Health Index			
	Good	**Fair**	**Poor**	**Bad**
Current imbalance between phases	<10%	10%-<20%	20%-<25%	≥ 25%
Neutral current magnitude, LV (% of transformer load current)	<10%	10%-<20%	15%-<20%	≥ 20%

Transformer loading (% of capacity)	<60%	60%-<80%	80%-<100%	≥ 100%

2.5. Neutral Current Magnitude and Power Losses

According to the State Electricity Company Standard (SPLN) SE 17:2014, the tolerable percentage of load imbalance at a distribution substation is below 20%; if the load imbalance percentage at a distribution substation exceeds 20%, transformer maintenance in the form of load balancing must be carried out (SPLN D3.002-1, 2007) [14]. Unbalanced load conditions can cause various problems, such as increased neutral current, higher power losses, reduced voltage quality, and a shortened transformer service life. The magnitude of the neutral current flowing can be calculated using the following formula:

$$IN = \sqrt{(I^2R + I^2S + I^2T) - (IR \,.\, IS + IS \,.\, IT + IT \,.\, IR)} \quad (6)$$

Meanwhile, the power loss in the neutral wire can be calculated using the following formula:

$$P_N = I_N^2 \,.\, R_N \quad (7)$$

Where:

$$R_N = \frac{\rho \,.\, L}{A}$$

With:

P_N = Power loss occurring in the neutral wire (watt)

I_N = Current flowing through the neutral wire (A)

R_N = Resistance of the neutral wire (Ohm)

ρ = Resistivity of copper conductor (0.0172 $\Omega.mm^2/m$)

L = Conductor length, 800 m

A = Conductor cross-sectional area, 70 mm^2

Thus:

$$R_N = \frac{\rho \,.\, L}{A} = \frac{0{,}0172 \,.\, 800}{70} = \frac{13{,}76}{70} = 0{,}1965\ \Omega$$

2.6. kWh Savings After Load Balancing

The kWh savings obtained after load balancing can be calculated using the following formula:

$$\Delta E = \frac{(\text{PLoss before} - \text{PLoss after}) \,.\, V \,.\, t \,.\, \phi}{1000} \quad (8)$$

Where :

ΔE = kWh savings (kWh)

$P_{Loss\ before}$ = Power loss before (kW)

V = Voltage (v)

$P_{Loss\ after}$ = Power loss after (kW)

$\phi = 0.8$

t = Time (hours)

Research Methodology

3.1 Research Location and Time

This research was carried out at PT. PLN (Persero) Geudong Customer Service Unit, at transformer SYA029, feeder LW12, located in Dayah Aron Village, Syamtalira Aron Sub-district. The research period, covering data collection, data processing, and analysis of the research results, ran from 10 May 2026 to 10 July 2026.

3.2 Literature Study

The literature study is a series of processes used as a reference for collecting data through journals, web pages, and field notes or documents related to this final project.

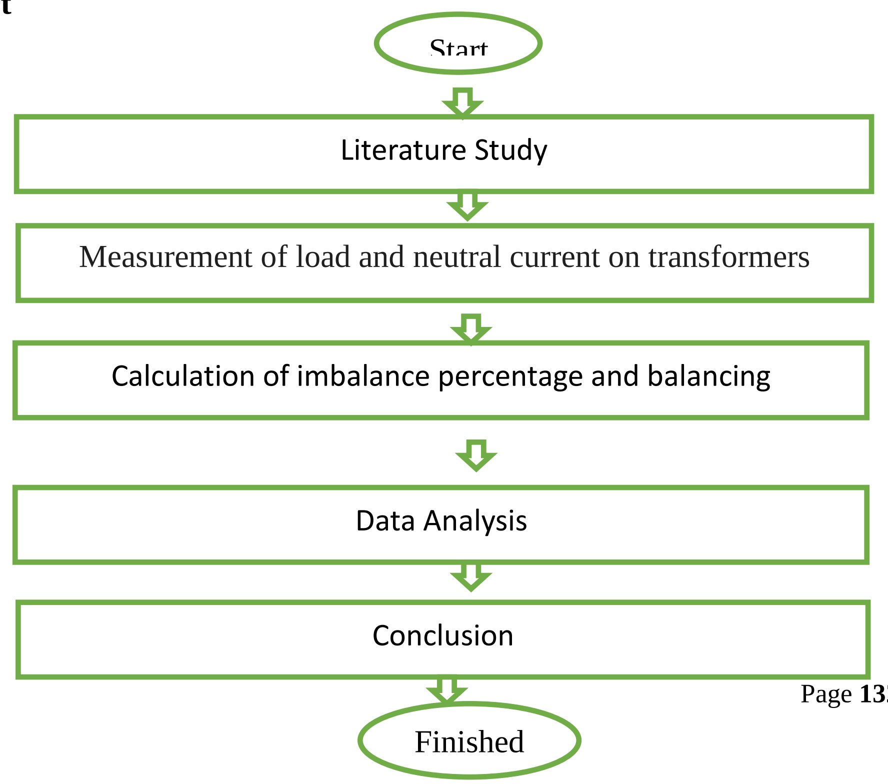
3.3 Observational Study

Technical data collection was carried out through direct field observation, namely by measuring the substation load at night during Peak Load Time (WBP). Measurements were taken on the low-voltage side of the transformer using a clamp ammeter, and the measurement results were recorded for data analysis.

3.4 Data Analysis Technique

Data analysis was carried out once the data collection was complete, followed by calculation and analysis. The calculations were performed to determine the full load current, the average current, the transformer loading percentage, the transformer load imbalance percentage, the magnitude of the neutral current flowing, and the kWh savings obtained after transformer load balancing.

3.5 Flow Chart



Results

4.1. Measurement Results Before Load Balancing

Transformer SYA029 has a capacity of 50 kVA and is located in Ds. Dayah Aron, feeder LW12, supplied from the Bayu Main Substation (GI Bayu). Measurements were taken during Peak Load Time (WBP), once a month for three months from May 2026 to July 2026, and the resulting average load values are shown in Table 2 below.

Table 2. Measurement Results Before Balancing (WBP)

CURRENT (AMPERE)				
PHASE	**R**	**S**	**T**	**N**
Main load (incoming)	53	24	29	35
Branch A	38.6	15.8	18.7	26.7
Branch B	13.4	7.2	10.3	5.3
VOLTAGE (VOLT)				
Phase–Phase	**RS**	**RT**	**ST**	
	412	409	408	
Phase–Neutral	**RN**	**SN**	**TN**	
	234	237	234	

4.2. Calculation Description Before Load Balancing

4.2.1 Calculating the full load current, using equation (2):

$$I_{FL} = \frac{S}{\sqrt{3} \times V} = \frac{50.000}{1,732 \times 410} = \frac{50.000}{697}$$

$$I_{FL} = 71,7 \text{ Amperes}$$

4.2.2 Calculating the average load current, using equation (3):

$$I_{average} = \frac{Ir+Is+It}{3} = \frac{53+24+29}{3}$$

$$I_{average} = 35,3 \text{ Amperes}$$

4.2.3 Calculating the transformer loading percentage, using equation (4):

$$\%Load = \frac{I\ average}{IFL} \times 100\%$$

$$\%Load = \frac{35,3}{71,7} \times 100\%$$

$$\%Load = 49,23\%$$

4.2.4 Calculating the load imbalance percentage, using equation (5):

$$\%KB = \frac{Imax - Imin}{Iaverage} \times 100\%$$

$$\%KB = \frac{53 - 24}{35,3} \times 100\%$$

$$\%KB = \frac{29}{35,3} \times 100\%$$

$$\%KB = 82,15\%$$

4.2.5 Calculating the magnitude of the neutral current flowing, using equation (6):

$$IN = \sqrt{(I^2R + I^2S + I^2T) - (IR.IS + IS\,IT + IT.IR)}$$

$$IN = \sqrt{(53^2 + 24^2 + 29^2) - (1272 + 696 + 1537)}$$

$$IN = \sqrt{(2809 + 576 + 841) - (1272 + 696 + 1537)}$$

$$IN = \sqrt{4226 - 3505}$$

$$IN = \sqrt{721}$$

IN = 26,85 Ampere

4.2.6 Calculating the power loss in the neutral wire (where RN = 0.1965 Ω), using equation (7):

$$P_{Loss} = In^2 . Rn$$

$$P_{Loss} = 26,85^2 . 0,1965$$

$$P_{Loss} = 720,92 . 0,1965$$

$$P_{Loss} = 141,66 \text{ kW}$$

4.3. Measurement Results After Load Balancing

Once it was known that the load imbalance percentage exceeded PLN's tolerance standard of >20%, transformer load balancing was carried out in the field during daytime hours. The method used was to redistribute the Household Connection (SR) cables on the Low Voltage Network (JTR) evenly — that is, moving the larger phase load to the smaller phase load to achieve balance between phases. The results of the load balancing, measured during Peak Load Time (WBP), are shown in Table 3 below.

Table 3. Measurement Results After Balancing (WBP)

CURRENT (AMPERE)				
PHASE	**R**	**S**	**T**	**N**
Main load (incoming)	40	33.0	34	19
Branch A	25.3	23.0	26.1	13.0
Branch B	14.8	11.0	8.5	9.0

VOLTAGE (VOLT)				
Phase–Phase	**RS**	**RT**	**ST**	
	411	412	410	
Phase–Neutral	**RN**	**SN**	**TN**	
	235	233	234	

4.4. Calculation Description After Load Balancing

4.4.1 Calculating the full load current, using equation (2):

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

$$I_{FL} = \frac{50.000}{1,732 \times 412}$$

$$I_{FL} = \frac{50.000}{700,4}$$

I_{FL} =71,3 Amperes

4.4.2 Calculating the average load current, using equation (3):

$$I_{average} = \frac{Ir+Is+It}{3}$$

$$I_{average} = \frac{40+33+34}{3}$$

$I_{average}$ = 35,67 Amperes

4.4.3 Calculating the transformer loading percentage, using equation (4):

$$\%Load = \frac{I\ average}{I\ FL} \times 100\%$$

$$\%Load = \frac{35,67}{71,3} \times 100\%$$

%Load = 50,02%

4.4.4 Calculating the load imbalance percentage, using equation (5):

$$\%KB = \frac{Imax - Imin}{Irata - rata} \times 100\%$$

$$\%KB = \frac{40 - 33}{35,67} \times 100\%$$

$$\%KB = \frac{7}{35,67} \times 100\%$$

%KB = 19,62%

4.4.5 Calculating the magnitude of the neutral current flowing, using equation (6):

$$IN = \sqrt{(I^2R + I^2S + I^2T) - (IR\ .IS + IS\ .IT + IT\ .\ IR)}$$

$$IN = \sqrt{(40^2 + 33^2 + 34^2) - (1320 + 1122 + 1360)}$$

$$IN = \sqrt{(1600 + 1089 + 1156) - (1320 + 1122 + 1360)}$$

$$IN = \sqrt{3845 - 3802}$$

$$IN = \sqrt{43}$$

IN = 6,55 Amperes

4.4.6 Calculating the power loss in the neutral wire (where RN = 0.1965 Ω), using equation (7):

$$P_{Loss} = In^2 \,.\, Rn$$

$$P_{Loss} = 6{,}55^2 \,.\, 0{,}1965$$

$$P_{Loss} = 42{,}9025 \,.\, 0{,}1965$$

$$P_{Loss} = 8{,}43 \text{ kW}$$

4.4.7 kWh savings, using equation (8):

$$\Delta E = \frac{(\text{PLoss before} - \text{PLoss after}) \,.\, V \,.\, t \,.\, \phi}{1000}$$

$$\Delta E = \frac{(141{,}66 - 8{,}43) \,.\, 220 \,.\, 24 \,.\, 0{,}8}{1000}$$

$$\Delta E = \frac{133{,}23 \,.\, 220 \,.\, 24 \,.\, 0{,}8}{1000}$$

ΔE = 562,76 kWh/day

ΔE = 16882,8 kWh/month

4.5 Data Analysis

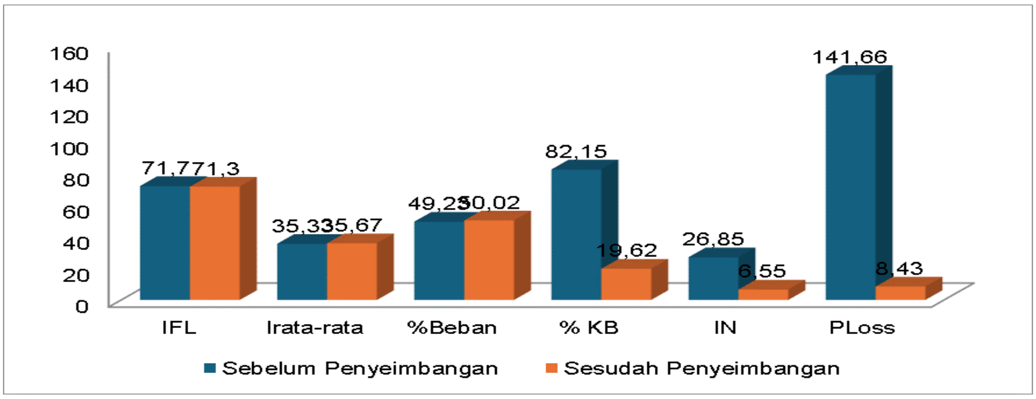
Table 4. Comparison of Calculation Results

DESCRIPTION	IFL	Iaverage	%Load	%KB	IN	PLoss	ΔE
Before	71,7A	35,33A	49,23%	82,15%	26,85A	141,66 kW	0
After	71,3A	35,67A	50,02%	19,62%	6,55A	8,43 kW	16882,8 kWh/month

Based on the data in Table 4, a comparison can be seen between the conditions before and after load balancing. With a transformer loading current of around 71 Amperes and an average loading current of around 35 Amperes, the load imbalance percentage decreased from 82.15% to 19.62%, the neutral current flowing through the neutral wire decreased from

26.85 Amperes to 6.55 Amperes, and the power losses also decreased from 141.66 kW to 8.43 kW. This shows that after balancing, the imbalance percentage between phases improved to a fairly good condition (<20%) according to the transformer loading standard.

Graph 1. Comparison of Calculation Results



Conclusion

By carrying out transformer load balancing, the load imbalance percentage decreased from 82.15% to 19.62%, the neutral current flowing through the neutral wire also decreased from 26.85 Amperes to 6.55 Amperes, and the power losses decreased from 141.66 kW to 8.43 kW.

Load balancing has a positive impact, including a reduction in neutral current, a decrease in power losses, the saving of energy/kWh that would otherwise not be delivered to customers, and, most importantly, an improvement in transformer performance optimization.

References

[1] Anisah, Siti, Zuraidah Tharo, and Suhardi Suhardi. "Analisis perbaikan tegangan ujung pada jaringan tegangan menengah 20 kV dengan simulasi E-TAP (studi kasus PT. PLN (Persero) rayon Kuala." *Seminar Nasional Teknik (SEMNASTEK) UISU*. 2019.

[2] Anonim. Buku 4 Standar Konstruksi Gardu Distribusi dan Gardu Hubung Tenaga Listrik. Jakarta Selatan: PT PLN (PERSERO). 2010:21-25.

[3] D. Ardhianto, B. Utama, dan M. Arsyad, "Penyeimbangan Beban Trafo Distribusi 3 Fasa pada Jaringan Tegangan Rendah (Studi Kasus PT. PLN (Persero) ULP Purwokerto Kota)," *JMTE*, vol. 1, no. 1, pp. 31–43, Sep. 2020.

[4] F. Muhammad, P. Siagian, dan M. Fahreza, "Penyeimbangan Beban Transformator Distribusi PCC-007 untuk Mengurangi Rugi-Rugi Jaringan pada Tegangan Menengah 20 kV," Power Elektronik: Jurnal Orang Elektro, vol. 13, no. 2, pp. 284–287, 2024.

[5] I. Bursa, R. L., dan N. A. Noor, "Analisis Rugi-Rugi Daya Akibat Ketidakseimbangan Beban pada Jaringan Distribusi Sekunder di PT. PLN (Persero) ULP Watang Sawitto," dalam *Prosiding Seminar Nasional Teknik Elektro dan Informatika (SNTEI) 2021*, Makassar, Indonesia, 21 September 2021.

[6] I. Ismail, D. Erivianto, dan Z. Tharo, "Analisis Perbaikan Jatuh Tegangan dan Reduksi Rugi Daya Melalui Uprating Konduktor serta Penyeimbangan Beban pada Sistem Distribusi di PT. PLN ULP Tebing Tinggi," Jurnal Nasional Teknologi Komputer, vol. 6, no. 2, pp. 586–597, Apr. 2026.

[7] W. Sudiartha, I. P. Sutawinaya, I. Ketut, TA., dan A. Firman, “Manajemen Trafo Distribusi 20 kV Antar Gardu BL031 dan BL033 Penyulang Liligundi dengan Menggunakan Simulasi Program ETAP,” Jurnal Logic, vol. 16, no. 3, pp. 166–172, Nov. 2016.

[8] M. Muliadi, S. Syukri, T. M. Asyadi, dan A. Salim, "Analisa Pengaruh Ketidakseimbangan Beban Pada Trafo Distribusi Penyulang Mibo Rayon Merduati," *Aceh Journal of Electrical Engineering and Technology*, vol. 2, no. 2, pp. 7–13, Des. 2022.

[9] M. Muslimin, A. Trihasto, D. Pravitasari, dan A. A. Kurniawan, “Analisis Ketidakseimbangan Beban terhadap Kerugian Daya pada Transformator Distribusi 20 kV Menggunakan Software ETAP,” Jurnal Teknik Elektro dan Komputasi (ELKOM), vol. 8, no. 1, pp. 19–34, Mar. 2026.

[10] M. Siddik, Hamdani, dan B. Satria, "Sistem Ketidak Seimbangan Beban Pada Jaringan Tegangan Rendah Menggunakan Alat PHB–SR (Peralatan Hubung Bagi Sambungan Rumah) di PT. PLN Persero ULP Binjai Timur," Power Elektronik: Jurnal Orang Elektro, vol. 13, no. 2, pp. 212–218, 2024.

[11] P. Wibowo and S. Aryza, "A Quality Distribution Networks with Unbalanced Load Management Distribution Transformator," *Peer-Reviewed, Ref. Index. J. with IC*, vol. 4, no. 10, 2018.

[12] PT PLN (Persero) ULP Geudong, "Data timbang beban trafo USD07," Laporan bulanan. 2026.

[13] R. S. Siregar dan R. Harahap, "Perhitungan Arus Netral, Rugi-Rugi, dan Efisiensi Transformator Distribusi 3 Fasa 20 KV/400V di PT. PLN (Persero) Rayon Medan Timur Akibat Ketidakseimbangan Beban," Journal of Electrical Technology, vol. 2, no. 3, pp. 79–86, Okt. 2017.

[14] S. Anisah, R. Rahmaniar, and A. Khaizairani, "Analisis Perbaikan Tegangan Ujung Pada Jaringan Tegangan Menengah 20 KV Express Trienggadeng Daerah Kerja PT PLN (Persero) Area Sigli Rayon Meureudu Dengan Simulasi E-Tap," in *Prosiding SEMNASTEK UISU 2018*, Medan, Indonesia, 2018.

[15] S. Pranoto, Sofyan, dan N. N. Rusli, “Penyeimbangan Beban pada Trafo Distribusi Penyulang Akkarena di Unit Layanan Pelanggan Mattoanging PT PLN (Persero),” dalam Prosiding Seminar Nasional Teknik Elektro dan Informatika (SNTEI) 2020, Makassar, Indonesia, 7 Okt. 2020.