Analysis of the Effect of Transformer Load Balancing on the Reduction Technical Shrinkages in Distribution Substations aAt Feeders JN 05 At PT PLN (PERSERO) ULP JANARATA

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Electricity is a vital component in supporting activities across various sectors, particularly in industry. The reliability of the power distribution system is crucial to maintaining the continuity of energy supply. However, during the distribution process, power losses (technical losses) frequently occur, primarily due to load imbalance in distribution transformers. This study aims to analyze transformer loading on the JN 05 feeder at ULP Janarata by calculating the load percentage, phase current imbalance, and power losses caused by neutral current. A quantitative approach was used, based on field measurements of 16 transformers under Peak Load Conditions (WBP) and Off-Peak Load Conditions (LWBP). Prior to load balancing, total power losses due to neutral current reached 10,190.37 kWh during LWBP and 3,733.41 kWh during WBP each month. After load balancing was performed between phases, technical losses were reduced by 13,923.77 kWh per month. These results indicate that load balancing is an effective method to reduce power losses and improve the efficiency of the distribution system.
Keywords: Transformer load imbalance, Neutral current, and Transformer losses.

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1. Introduction

Electrical energy is a primary need to support various human activities, including industrial, commercial, and residential sectors. In its distribution process, electrical energy goes through several stages, from generation to transmission to distribution. A crucial component in the power distribution system is the distribution transformer, which steps down the voltage from the primary distribution system to the voltage required by end consumers. However, in practice, distribution transformers often experience interphase load imbalances due to uneven load distribution. This imbalance causes high neutral currents, increases power losses, accelerates equipment wear, and reduces the efficiency and reliability of the overall electricity distribution system. Furthermore, load imbalances can also affect the quality of voltage received by customers and potentially cause damage to electrical equipment. PT. PLN (Persero) ULP Janarata is a unit that distributes electricity for Bener Meriah Regency and parts of Central Aceh Regency. The electrical system at ULP Janarata is supplied by the Takengon Main Substation through two substations: the Janarata Substation and the Lampahan Substation. These two substations distribute energy to the public through 14 feeders, spanning a 532.6-kilometer Medium Voltage Network (JTM). In the distribution of electrical energy at the Janarata ULP, many transformers are unbalanced, necessitating load balancing. This requires analyzing the effectiveness of transformer load balancing on neutral current reduction and power losses in the distribution system, as well as evaluating its impact on the technical performance of the distribution substations. The results of this study are expected to contribute to improving the efficiency of the electricity distribution system and support efforts to control technical losses by electricity providers.

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2. Literature Review

A distribution substation is an electrical substation consisting of Medium Voltage Distribution Equipment (PHB-TM), Distribution Transformers (TD), and Low Voltage Distribution Equipment (PHB-TR) to supply electricity to customers using both Medium Voltage (TM 20 kV) and Low Voltage (TR 220/380V) (PLN Book 4, 2010). A transformer is a static device based on electromagnetic principles, transforming alternating voltage and current between two or more windings at the same frequency and at different voltage and current values. The main structure of a transformer consists of a primary coil, a secondary coil, and a core. Voltage is applied to the primary coil, which generates a sinusoidal current. This current creates a magnetic field in the magnetic core, called flux, which also has a sinusoidal shape. The secondary coil, subjected to the flux change from the core, which is called induction, generates an Electromotive Force (EMF) that has a sinusoidal shape. The operating principle of a transformer is based on Ampere's and Faraday's laws, namely, that an electric current can produce a magnetic field, and conversely, a magnetic field can produce an electric current. If an alternating current is applied to one of the transformer coils, the number of magnetic lines of force changes, resulting in induction on the primary side. The secondary side receives a varying number of magnetic lines of force from the primary side. Induction also occurs on the secondary side, resulting in a voltage difference between the two ends. A three-phase system is a common method used to transmit electrical power. A three-phase system can use a neutral wire or a neutral wire, more commonly known as a three-phase four- wire system with a neutral wire and a three-phase three-wire system without a neutral wire. Low-voltage distribution networks in Indonesia generally use a three-phase four-wire system.

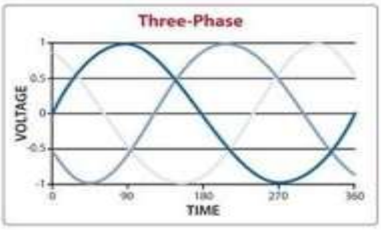

Figure 1. Normal 3-Phase System Waveform with RST Sequence

A 20 kV distribution transformer consisting of primary and secondary coils has varying voltage-to-current and voltage-to-output ratios based on the capacity of each transformer. Differences in transformer capacity will affect the primary (input) and secondary (output) current values.

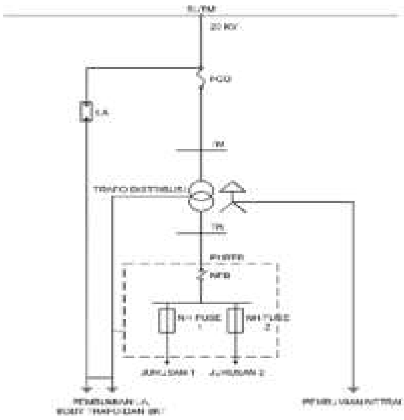

Figure 2. Single Line Diagram of a 20 kV Distribution Substation

The transformer capacity is used based on customer consumption needs, as per each consumer's power contract requirements. The transformer capacity is used based on customer consumption needs, as per each consumer's power contract requirements.

Table 1. 20 kV Distribution Transformer Capacity Data

Voltage		Capacity	Current	
Primary (V)	Secondary (V)	kVA	Primary (A)	Secondary (A)
20.000	400	25	0.72	36.08
20.000	400	50	1.44	72.17
20.000	400	100	2.89	144.33
20.000	400	160	4.62	230.93
20.000	400	200	5.77	288.67
20.000	400	250	7.22	360.83
20.000	400	315	9.09	454.65
20.000	400	400	11.5	577.33
20.000	400	500	14.3	721.67

3. Method

The object of this research is the Distribution Substation at the JN 05 (City Route) feeder of ULP Janarata PT PLN (Persero).

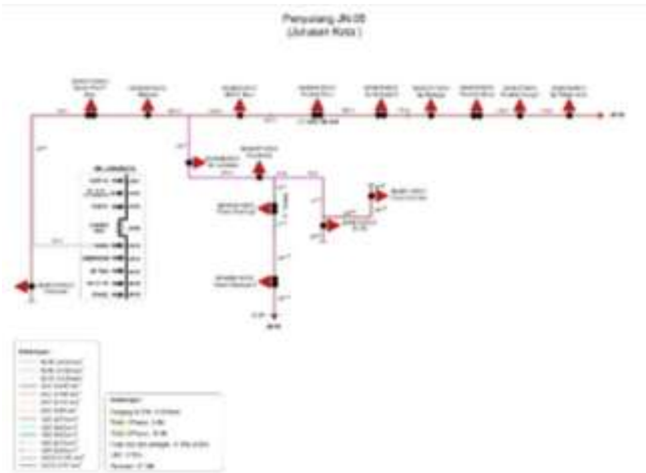

Figure 3. Single Line Diagram of the JN 05 ULP Janarata Feeder

The approach used in this research is descriptive because the data is measured and calculated directly, in the form of information expressed in numbers or numerical forms collected quantitatively. The stages begin with a literature review, which involves searching, collecting, and studying theorems that support the solution to the research problem. These theorems were obtained from scientific journals, previous research results, and reference books. Data collection was then conducted through field surveys and measurements using an ampere meter. From the collected data, mathematical calculations were performed to determine the percentage of load unbalance, the percentage of loading, the percentage of neutral current, and the neutral conductor power loss in the transformer before and after repairs.

4. Results and Discussion

Analysis Transformer.

Transformer Load Unbalance Calculation Analysis Before Repair From the results of mains current measurements (R, S, T, and N) conducted under WBP conditions (9:00 AM to 2:00 PM WIB) and LWBP conditions (2:00 PM to 9:00 AM WIB), using the formula:

%Load Unbalance={|a-1|+|b-1|+|c-1|}/3 x 100% The transformer load imbalance percentage is as follows:

Table 2. Transformer Load Unbalance Percentage under LWBP Condition

Kode Gardu	Kapasitas Trafo (kVA)	Arus Induk R (A)	Arus Induk S (A)	Arus Induk T (A)	Arus Induk N (A)	Ketidak-seimbangan Beban (%)
BAN 001	200	91	143	132	43	16.94
BAN 002	100	73	66	72	51	4.11
BAN 003	50	36	47	45	29	10.42
BAN 004	200	211	223	168	184	10.85
BAN 005	50	25	49	32	39	25.79
BAN 006	50	37	39	17	30	30.11
BAN 007	100	103	105	126	57	8.78
BAN 008	100	87	63	123	95	23.44
BAN 009	160	106	91	126	67	11.35
BAN 010	50	34	46	35	16	13.33
BAN 011	50	37	49	55	42	14.18
BAN 025	100	48	78	55	37	19.52
BAN 026	50	36	28	29	16	10.75
BAN 027	50	25	37	42	26	18.59
BAN 028	50	54	30	35	44	24.09
BAN 034	100	73	74	99	46	13.82

Table 3. Percentage of transformer load imbalance in WBP conditions

Kode Gardu	Kapasitas Trafo (kVA)	Arus Induk R (A)	Arus Induk S (A)	Arus Induk T (A)	Arus Induk N (A)	Ketidak-seimbangan Beban (%)
BAN 001	200	138	156	102	72	15.15
BAN 002	100	81	91	77	63	6.43
BAN 003	50	53	54	59	41	4.42
BAN 004	200	151	263	231	118	19.84
BAN 005	50	43	57	68	47	15.48
BAN 006	50	61	55	39	53	16.34
BAN 007	100	81	137	125	68	19.44
BAN 008	100	116	73	147	120	23.21
BAN 009	160	184	133	187	113	13.89
BAN 010	50	26	53	44	27	24.39
BAN 011	50	61	72	22	52	38.28
BAN 025	100	69	82	93	46	10.11
BAN 026	50	62	63	47	46	12.02
BAN 027	50	37	27	49	30	20.06
BAN 028	50	85	39	48	63	32.17
BAN 034	100	96	87	155	95	25.05

Based on the results of measurements carried out before load balancing, the conditions of each substation were obtained as follows when compared with SE:NO:17:14.

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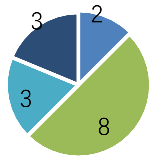

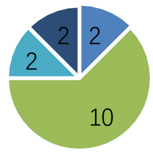

Kondisi Ketidakseimbangan Beban Gardu Distribusi Penyulang JN 05-WBP
Kondisi Ketidakseimbangan Beban Gardu Distribusi Penyulang JN 05-LWBP

Analysis of Transformer Load Unbalance Calculations after Repair

After determining the load imbalance values at each JN 05 feeder distribution substation, load balancing was performed at each unbalanced substation by moving the house line cables from the high phase to the low phase to achieve interphase balance.

Table 4. Implementation of SR Cable Transfer

Nama	Realisasi Pemindahan SR					
Gardu	R ke S (A)	R ke T (A)	S ke R (A)	S ke T (A)	T ke R (A)	T ke S (A)
BAN 001		1		4		
BAN 002				2		
BAN 003					1	
BAN 004			7		2	
BAN 005					3	
BAN 006		2		1		
BAN 007			3		2	
BAN 008						6
BAN 009	2					2
BAN 010			2		1	
BAN 011		1		4		
BAN 025					3	
BAN 026		3		1		
BAN 027						2
BAN 028	4	2				
BAN 034					2	3

The following are the load values for each phase and the percentage of unbalance between phases for each substation under both WBP and LWBP conditions.

Table 5. Percentage of Transformer Load Unbalance under LWBP Conditions

Kode Gardu	Kapasitas Trafo (kVA)	Arus Induk R (A)	Arus Induk S (A)	Arus Induk T (A)	Arus Induk N (A)	Ketidak-seimbangan Beban (%)
BAN 001	200	124	119	129	31	2.69
BAN 002	100	71	69	75	37	3.10
BAN 003	50	43	41	45	17	3.10
BAN 004	200	207	199	205	113	1.53
BAN 005	50	35	37	31	21	6.47
BAN 006	50	27	33	29	19	7.49
BAN 007	100	109	113	117	29	2.36

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BAN 008	100	89	97	93	62	2.87
BAN 009	160	109	103	101	39	2.98
BAN 010	50	36	39	41	7	4.60
BAN 011	50	45	51	43	27	6.71
BAN 025	100	65	59	58	21	4.76
BAN 026	50	29	35	30	8	7.80
BAN 027	50	31	39	36	15	8.18
BAN 028	50	41	39	35	26	5.80
BAN 034	100	83	87	81	32	2.66

Table 6. Percentage of transformer load imbalance in WBP conditions

Kode Gardu	Kapasitas Trafo (kVA)	Arus Induk R (A)	Arus Induk S (A)	Arus Induk T (A)	Arus Induk N (A)	Ketidak-seimbangan Beban (%)
BAN 001	200	133	128	139	47	2.83
BAN 002	100	87	76	82	42	4.63
BAN 003	50	57	54	59	27	3.14
BAN 004	200	221	235	231	63	2.33
BAN 005	50	49	57	53	36	5.03
BAN 006	50	47	49	55	43	6.18
BAN 007	100	119	109	113	33	3.13
BAN 008	100	105	114	109	84	2.85
BAN 009	160	159	169	164	79	2.03
BAN 010	50	39	43	47	14	6.20
BAN 011	50	55	53	48	28	5.13
BAN 025	100	87	82	79	25	3.49
BAN 026	50	58	53	53	31	4.07
BAN 027	50	38	37	41	16	4.02
BAN 028	50	63	55	59	32	4.52
BAN 034	100	107	112	103	64	2.90

Analysis of Transformer Load Unbalance Percentage Before & After Repairs

The load balancing activities carried out have had a positive impact on reducing the percentage of transformer load imbalance in the JN 05 feeder.

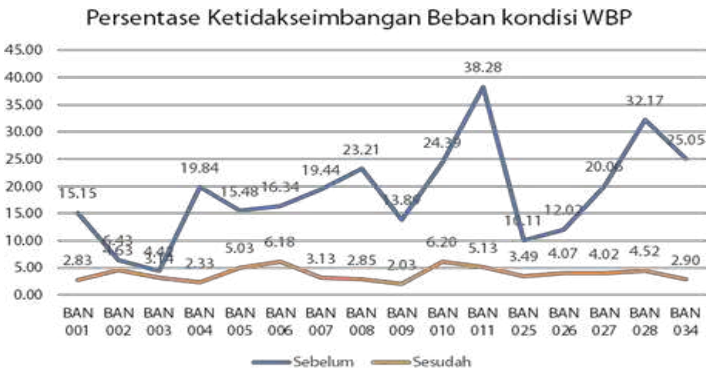

Figure 4. Percentage of Transformer Load Unbalance in WBP condition before and after repair

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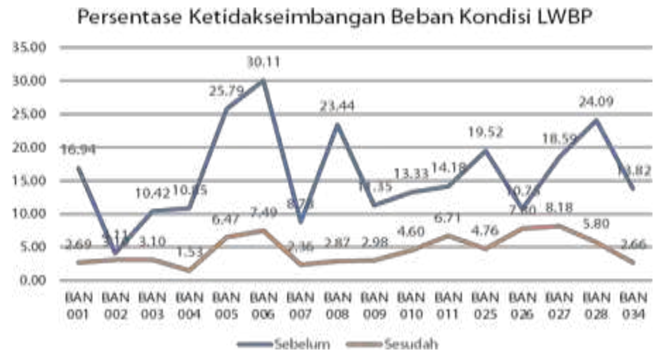

Figure 5. Percentage of Transformer Load Unbalance in LWBP condition before and after repair

Analysis of the Effect of Transformer Load Balancing on Neutral Current

The reduction in load imbalance on the JN 05 feeder transformer also resulted in a decrease in the neutral current in the neutral conductor. The magnitude of the neutral current reduction can be seen in the following graph.

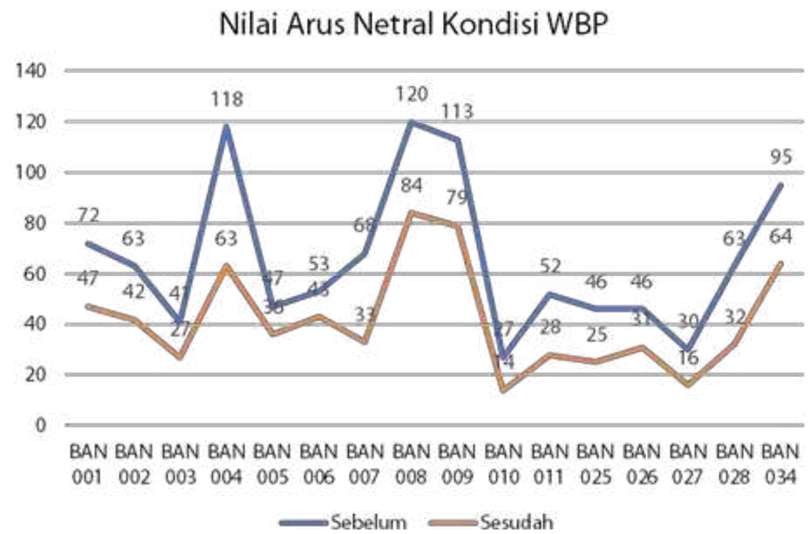

Figure 6. The value of the neutral current in the WBP condition before and after repairs

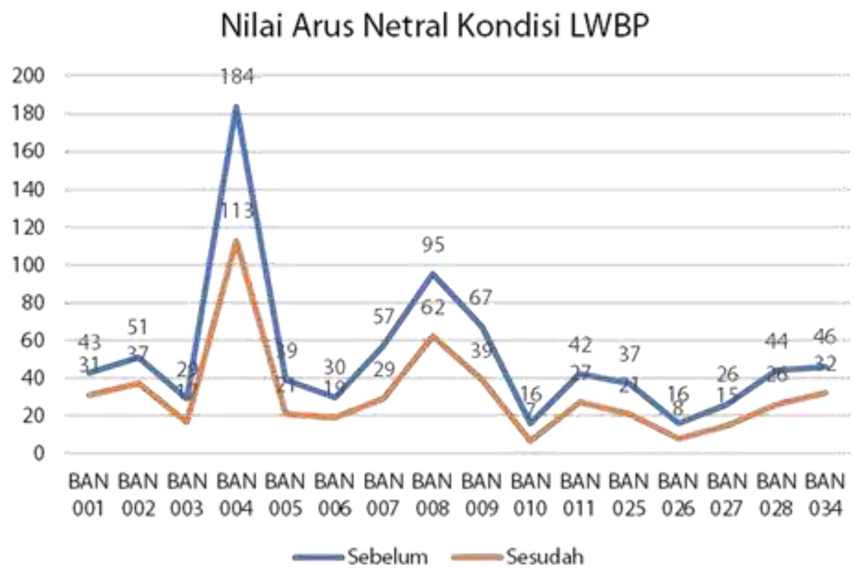

Figure 7. The value of the neutral current in LWBP conditions before and after repairs

Analysis of Losses in Neutral Conductors Caused by the Emergence of Neutral Current before and after repairs

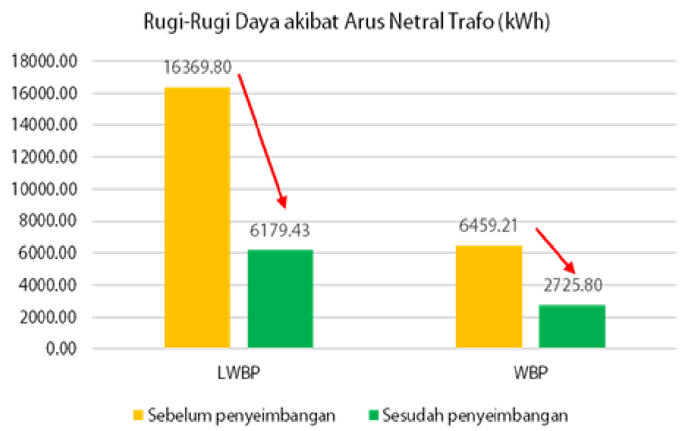

Figure 8. Power loss due to neutral current before and after load balancing

From the load balancing activity, the reduction in neutral current also had a significant impact on reducing losses or saving kWh by 13,923.77 kWh. Converted to Rupiah using the average kWh tariff of the Janarata ULP, it is:

Savings = 13,923.77 kWh x Rp 628.11/kWh
= Rp 8,745,662.00/month

5. Conclusion

Based on the previously analyzed data, it can be concluded that:

1. The power losses caused by the current flowing in the neutral conductor of the JN 05 feeder transformer on the LWBP before balancing were 16,369.8 kWh, while on the WBP it was 6,459.21 kWh.
2. The power losses caused by the current flowing in the neutral conductor of the JN 05 feeder transformer on the LWBP after balancing were 6,179.43 kWh, while on the WBP it was 2,725.80 kWh.
3. From these improvement activities, the total kWh savings achieved were 13,923.77 kWh/month, or Rp 8,745,662.00/month.

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