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A Study Of Electrical Equipment Life Analysis Influenced By Unbalanced Load Use

Widya Septiyani Br Ginting[1], Wahyu Desmandra[2], Syahrial Fauzi[3], Juan Daniel Siahaan[4], Solly Aryza[5]
[1,2,3,4,5]Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia

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ABSTRACT
The use of unbalanced electrical loads in power systems can significantly impact the lifespan of electrical equipment. Load imbalance often occurs in power distribution systems serving various types of consumers with diverse consumption patterns. This study aims to analyze the effect of unbalanced load usage on the lifespan of electrical equipment, such as transformers, cables, and protection devices. The methodology involves measuring electrical parameters such as current, voltage, and power factor under balanced and unbalanced load conditions. Operational data are processed to determine the level of imbalance and its effects on temperature rise, power losses, and equipment efficiency degradation. The analysis is complemented with simulation models to predict equipment lifespan reduction based on thermal and electrical standards. The results indicate that load imbalance leads to a significant increase in operating temperatures, particularly in transformers and cables, accelerating insulation degradation. Additionally, load imbalance increases power losses, reducing overall system efficiency. This study concludes that better load management to achieve balance can extend the lifespan of electrical equipment and improve the reliability of power systems.

Corresponding Author:
Widya Septiyani Br Ginting
Universitas Pembangunan Panca Budi, Medan, North Sumatera, Indonesia
sollyaryzalubis@gmail.com

INTRODUCTION

Electrical power systems are designed to deliver energy efficiently and reliably to various types of consumers. However, the increasing demand for electricity and the diverse consumption patterns often result in unbalanced loads across phases. Load imbalance occurs when the current or power consumption differs significantly between phases in a three-phase system, leading to operational inefficiencies and potentially damaging effects on electrical equipment.

Unbalanced loads can cause increased neutral currents, overheating of transformers and cables, higher power losses, and voltage imbalances. These conditions degrade the insulation of electrical components, reduce their efficiency, and shorten their operational lifespan. In critical systems, such as those in industrial and commercial facilities, load imbalance can also result in frequent outages and higher maintenance costs.

This study focuses on analyzing the effects of load imbalance on the lifespan of electrical equipment, with a particular emphasis on transformers, cables, and protective devices. The research aims to identify the primary factors contributing to equipment degradation under unbalanced load conditions and propose solutions to mitigate these impacts.

By understanding the relationship between load imbalance and equipment aging, this study seeks to provide insights into improving the reliability and efficiency of power systems. Furthermore, it highlights the importance of proactive load management and system monitoring to extend the lifespan of electrical assets and reduce operational costs.

The process of distributing electrical energy starts from generation (PLTA, PLTM, PLTMG, PLTB, PLTS) then to Transmission (SUTET, SUTT) then to Distribution (TM) and ends at Consumers (TR). This process is a stage in the process of distributing electrical energy to reach consumers. From the Medium Voltage Distribution (TM) side so that it reaches Low Voltage consumers (TR), it must go through a voltage reduction process through a 20 kV TM Distribution Transformer. The 20 kV Distribution Transformer functions to reduce the Voltage, from 20 kV to 400/231 Volts, so that it can be used according to the consumption voltage in the community. The 20 kV transformer uses a 3-phase winding system (delta - wye), for delta on the Medium Voltage side, and wye on the Low Voltage side. The distribution of TR to consumers consists of 3 phases, namely Phase R, Phase S, Phase T plus Neutral.

Low Voltage PLN Consumers are divided into 2 more groups based on their phase usage, namely 3 phase and 1 phase customers. Then, they are divided again based on different load contracts in each phase, so that the energy usage in each consumer is increasingly varied. From this problem, another problem arises, namely the imbalance in load usage which has a direct impact on the current value in each phase R, S and T which are different. Load imbalance will cause losses not only for the PLN company but also for consumers. The losses for PLN include the large amount of energy that is not distributed, the voltage service value that is not achieved, shortening the life of electrical equipment and frequent distribution disruptions.

While the losses for consumers include the poor quality of the low voltage received, so that the electrical energy used does not match the needs of the consumer's household electrical equipment. This imbalance will have a direct impact on the 20 kV Distribution Transformer, starting from the current to the load whose values are different in each phase, so that the Neutral side will have a current value. Under normal conditions, when the R, S and T phases are in a balanced state, the current in Neutral is 0 (zero).

Neutral which has a current value will certainly result in equipment damage and losses. The damage that will arise starts from damage to the 20 kV Distribution Transformer, PHB-TR Equipment (Low Voltage Distribution Equipment), Low Voltage Cable Channels (SKTR), House Channels (SR) and kWH. While the losses that will arise are the loss of electrical energy from the neutral and grounding sides and the quality of service voltage is not achieved. Efforts that can be made to balance the load in each 3 phases are through a balancing process with methods that are in accordance with the distribution conditions and consumer profiles. By

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applying the correct method, it is hoped that there will be a decrease in energy losses from the side of the 20 kV Distribution Transformer load imbalance.

This condition causes other problems, namely in terms of decreasing the life of the Transformer and the loss of energy that should have been utilized but became distribution losses in each 20 kV Distribution Transformer. causing the Transformer load imbalance to become increasingly uncontrolled. the impact of greater losses. Among the 20 kV distribution substations, there are many transformers whose balance is > 30% so that they become the target for load balancing.

METHOD

Data was obtained from several electricity customers around the researcher. The steps for data analysis are as follows:

Determination of Balancing Target

Based on Unbalanced Load, which must not be > 30% of the transformer capacity, filtering can be carried out based on the results of quarterly data (October-December) of measuring the load of 20 kV distribution substations in the working area of PT. PLN (Persero) Rayon Medan Baru.

Load Balancing Simulation

Load Based on the WBP and LWBP load measurement data, a load division simulation is first carried out in each phase, to find out how much load is transferred in each phase. For the success of the WBP and LWBP load balancing work, the work sequence needs to be arranged, so that the results can be maximized. The work sequence or Standard Operation for the WBP and LWBP load balancing methods is arranged as follows:

1. Determine the transformer to be balanced.
2. Observe the JTR (Low Voltage Network) for all directions to the end of the network.
3. Note down interesting things found such as:
   a. There is one branch whose network only consists of 2 phases
   b. Where are there JTR connections
   c. Where are there SR series
   d. Where are there 3 phase customers
   e. Where are there large 1 phase customers
   f. Where are there non-household customers
   g. Is there a PJU load
   h. Is there a load of stalls that are only open at night.
4. Mark the TR network that will be worked on.
5. Measure the load (before balancing) with an ampere clamp at night and during the day, which is appropriate/good with the following criteria:
   a. Normal/sunny weather (not cloudy/rainy)

b. The substation to be measured is not on a blackout schedule
c. The measurement is on a working day (not a holiday). Preferably between Monday and Thursday.
d. At the substation to be measured in normal conditions, there are no crowded events (open stage, world cup final, etc.).
e. During the measurement process, there should be no balancing activities in the field, such as identifying the customer's phase or ampere.

Enter the measurement data into the WBP and LWBP balancing simulation and try to simulate it even though in this simulation we cannot simulate it precisely because there is no precise data regarding:

a. How many customers are in which phase
b. From "what phase to what phase" will the customers be moved.
c. "Approximately which customers" will be moved.
d. "how many amps" will be moved.
e. Print "Customer Transfer Recommendation"
f. Give the "Customer Transfer Recommendation" Printed sheet to the officer to be executed in the field.
g. Prepare all work equipment, K2K3 equipment, balancing forms, and communication tools. Coordinate with the relevant parties if blackout activities are needed.
h. Carry out load transfer work for load balancing work.
i. Carry out re-measurements, after carrying out load balancing work at relatively the same hours as the time of measurement, compare the differences before and after carrying out load balancing work.
j. Conduct a load study, and provide an analysis of what steps will be taken by rearranging the load per phase per direction. If the results are not significant, then carry out the second stage of balancing within a period of one week.
k. Enter the measurement data from the results of the work in the field and match it with the data from the previous balancing simulation results. Evaluate and analyze.
l. Print the "Evaluation" sheet. From this evaluation sheet, you can see how good the balancing results have been.

Based on the data from the simple calculation simulation results that have been carried out, it will be easier to determine the transfer of current values that must be carried out, but it does not rule out the possibility of the transfer of current values being carried out based on field conditions. Not only customer profile factors, but there are other technical factors to consider, such as loading conditions in each direction. The balancing process is carried out based on the results of WBP measurements with consideration of the results of LWBP measurements during the balancing process in the field. Here are some balancing conditions that have been carried out based on simulations and technical factors that occur during the balancing process. Measuring the neutral grounding resistance of the transformer aims to determine how much the resistance value of the neutral phase of the transformer is so that it can be used as a calculation of the loss value due to the imbalance of the R - S - T phase on a 20 kV distribution transformer. By using the Digital Earth Tester, the grounding resistance value of each substation can be determined.

Research or analysis of the problem is seen from the frequent occurrence of damage to the electrical equipment used, this raises curiosity about what causes the damage to the equipment, after checking the electrical installation network there are no problems, then the research focuses on the 20 KV Distribution Transformer and its effect on the life of the equipment due to load imbalance. The parameters observed in this study are:

1. 20 KV Distribution Transformer
2. 3 phase load on the 20 KV Distribution Transformer
3. Electrical equipment that is damaged Data was obtained from several electricity customers around the researcher.

RESULT

Result Field Balancing.

Based on the measurement data that has been carried out after the balancing process, a difference in the decrease in the neutral phase current value was obtained in the WBP conditions at night and LWBP during the day. So it can be interpreted that the load balancing process of the 20 kV distribution transformer has improved even though the neutral phase current value is still far close to zero. The following data shows the improvement in the neutral phase current value before and after balancing was carried out.

Table 1. Data Of Balancing

NO GARDU	BEBAN INDUK (SEBELUM)								BEBAN INDUK (SETELAH)							
	SIANG (LWBP)				MALAM (WBP)				SIANG (LWBP)				MALAM (WBP)			
	R	S	T	N	R	S	T	N	R	S	T	N	R	S	T	N
BS 070	63	45	76	30	95	52	123	64	59	60	59	15	102	89	92	35
BS 074	133	202	155	69	183	191	110	67	175	176	157	41	184	188	149	40
BS 115	56	39	44	20	114	29	41	53	47	62	64	15	47	62	64	15
BS 008	81	147	79	107	87	123	84	93	132	125	128	36	111	127	142	49
BS 006	69	110	121	50	58	100	147	57	105	85	79	23	122	111	88	35
BS 151	47	81	67	37	44	119	45	65	83	70	90	25	83	95	51	37
BS 150	32	6	22	22	44	8	22	32	16	22	22	10	28	15	22	16
BS 160	43	66	67	23	53	81	92	35	55	64	57	19	68	75	80	26
BS 073	75	104	60	43	97	110	58	45	77	90	80	22	95	79	88	23
BS 099	19	54	37	35	82	58	104	53	38	31	36	15	82	78	83	30
BS 111	80	61	103	52	112	82	134	70	79	71	94	21	105	125	128	52
BS 140	38	45	53	18	49	85	95	37	45	44	43	16	68	73	88	23
BS 174	27	12	14	13	43	26	32	19	19	18	14	11	33	36	32	13
BS 053	104	128	176	58	76	89	117	38	107	116	163	48	93	89	96	19
BS 110	23	26	41	17	48	41	74	21	22	23	33	12	54	52	60	18
BS 125	57	69	49	31	100	142	80	56	55	55	62	21	100	111	110	23
BS 142	64	64	42	32	97	82	64	46	62	67	54	22	83	82	75	25

Based on the measurement data after the balancing process, the author performed calculations to find the current value flowing in the neutral phase so that later the kWh saving value can be compared between the real in the field and based on the calculation results. Here are the data:

Table 2. Neutral Phase Calculation Data

NO	NO GARDU	PENGUKURAN								PERHITUNGAN							
		SIANG				MALAM				SIANG				MALAM			
		R	S	T	N	R	S	T	N	R	S	T	N	R	S	T	N
1	BS 070	59	60	59	15	102	89	92	35	59	60	59	1	102	89	92	12
2	BS 074	175	176	157	41	184	188	149	40	175	176	157	18	184	188	149	37
3	BS 115	47	62	64	15	47	62	64	15	47	62	64	16	47	62	64	16
4	BS 008	132	125	128	36	111	127	142	49	132	125	128	6	111	127	142	27
5	BS 006	105	85	79	23	122	111	88	35	105	85	79	24	122	111	88	30
6	BS 151	83	70	90	25	83	95	51	37	83	70	90	18	83	95	51	39
7	BS 150	16	22	22	10	28	15	22	16	16	22	22	6	28	15	22	11
8	BS 160	55	64	57	19	68	75	80	26	55	64	57	8	68	75	80	10
9	BS 073	77	90	80	22	95	79	88	23	77	90	80	12	95	79	88	14
10	BS 099	38	31	36	15	82	78	83	30	38	31	36	6	82	78	83	5
11	BS 111	79	71	94	21	105	125	128	52	79	71	94	20	105	125	128	27
12	BS 140	45	44	43	16	68	73	88	23	45	44	43	2	68	73	88	18
13	BS 174	19	18	14	11	33	36	32	13	19	18	14	5	33	36	32	7
14	BS 053	107	116	163	48	93	89	96	19	107	116	163	52	93	89	96	6
15	BS 110	22	23	33	12	54	52	60	18	22	23	33	10	54	52	60	7
16	BS 125	55	55	62	21	100	111	110	23	55	55	62	5	100	111	110	10
17	BS 142	62	67	54	22	83	82	75	25	62	67	54	11	83	82	75	7

Energy Loss Analysis

Based on the data of the difference in current values obtained before and after the 20 kV distribution transformer load balancing process, the loss values can also be calculated based on the measurement results (in the field) and based on the calculation results, the loss values that are the cause of the losses that have been saved are obtained, here is the data: For active transformer power (P): P = S.cos phi = 100. 0.85 = 85 kW Losses due to neutral current flowing to the ground can be calculated as follows: PG = IG 2. RG = 152. 7 = 1575 watts = 1.575 kW (LWBP) PG = IG 2. RG = 292. 7 = 5887 watts = 5.887 kW (WBP).

Table 3. Data Saving Losses of Balanced Transformers

NO	NO GARDU	DAYA (kVA)	DAYA AKTIF (kW)	SEBELUM		SESUDAH		GROUND (Ohm)	SELISIH NETRAL LWBP (A)	SELISIH NETRAL WBP (A)	RUGI RUGI LWBP (kW)	RUGI RUGI WBP (kW)
				LWBP	WBP	LWBP	WBP					
				N	N	N	N					
1	BS 070	100	85	30	64	15	35	7.0	15	29	1.58	5.89
2	BS 074	200	170	69	67	41	40	5.0	28	27	3.92	5.65
3	BS 115	50	43	20	53	15	15	10.1	5	38	0.25	14.58
4	BS 008	200	170	107	93	36	49	8.4	71	44	42.34	16.26
5	BS 006	160	136	50	57	23	35	7.3	27	22	5.47	3.65
6	BS 151	100	85	37	65	25	37	6.0	12	28	0.86	4.70
7	BS 150	50	43	22	32	10	16	3.6	12	5	0.52	0.09
8	BS 160	100	85	23	35	19	26	12.4	4	9	0.20	1.00
9	BS 073	100	85	43	45	22	23	3.4	21	22	1.30	1.65
10	BS 099	100	85	35	53	15	30	5.1	20	23	2.04	2.70
11	BS 111	100	85	52	70	21	52	4.2	31	18	4.04	1.36
12	BS 140	100	85	18	37	16	23	13.1	2	14	0.05	2.57
13	BS 174	50	43	13	19	11	13	14.1	2	6	0.06	0.51
14	BS 053	160	136	58	38	48	19	9.3	10	19	0.93	3.36
15	BS 110	100	85	17	21	12	18	11.4	5	3	0.29	0.10
16	BS 125	100	85	31	56	21	23	6.7	10	33	0.67	7.30
17	BS 142	100	85	32	46	22	25	7.2	10	21	0.72	3.18
TOTAL SAVING RUGI - RUGI (kW)											68.43	72.82

Balancing Analysis

Based on Simulation vs. Field Conditions There are several points of difference between balancing based on simulation of measured load results and adjusting load balancing based on field conditions, including:

1. Balancing based on load measurement data with the method of equalizing the current value in each phase until it reaches an average value is not an absolute benchmark to be used as a balancing determination in the field, but rather a reference for how much load value will be transferred or taken in each phase that needs it. Because if it is absolutely based on the load transfer value based on simulation, it will be very difficult to obtain this value because the load usage value in each customer varies up and down. But it must be based on the habit of susceptible load usage in each phase in each substation direction.
2. There are also where balancing conditions are only carried out by transferring a full load to a load that is still empty in the substation direction because balance is indeed needed more for the balance of the main phase load of the transformer only. The results of the LWBP and WBP measurement data simulation will be a good reference in load balancing in the field because we can see how much load will be diverted during the day so that at night, the diverted load is also in accordance with the WBP balancing needs.

CONCLUSION

This study demonstrates that unbalanced load usage in power systems significantly impacts the lifespan of electrical equipment, such as transformers, cables, and protective devices. Load imbalance leads to increased operating temperatures, power losses, and voltage imbalances, accelerating insulation degradation and shortening equipment lifespan. Unbalanced loading on a 20 kV distribution transformer causes current to flow in the neutral conductor. This current becomes a loss that must be borne by PT PLN because there is resistance along the neutral conductor. Load equalization is carried out by rewiring the customer's house connection from the heavy phase to the lightly loaded phase. With the load equalization program on the 20 kV Distribution Transformer, the results of suppressing losses in the neutral conductor were 65.68 kW (LWBP condition) and 72.72 kW (WBP condition) based on the measurement results. Based on the measurement results, the results of suppressing losses were 41.79 kW (LWBP condition) and 44.82 kW (WBP condition). The difference between the data results based on measurements and calculations is caused by several factors, including: Transformer age, transformer oil content, transformer coil condition, conductor contact loss, neutral grounding resistance value, and measuring instrument precision. Load Balancing on Transformers can extend the life of electrical equipment.

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