Analysis of Power Transformer Oil Insulation Capability Against Breakdown Voltage Due to Temperature and Loading

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ABSTRACT

The reliability of power transformers heavily depends on the performance of insulating oil, which serves as both an electrical insulation medium and a cooling agent. One of the key factors in maintaining the quality of insulating oil is its breakdown voltage, which determines the oil's ability to withstand electrical stress before insulation failure occurs. The rise in temperature during transformer operation can lead to a decrease in the oil's breakdown voltage, thus affecting the overall reliability of the transformer. This study aims to analyze the effect of temperature rise on the breakdown voltage of power transformer oil. Testing was conducted through simulations and laboratory measurements at various temperatures to identify the relationship between temperature and the oil's breakdown voltage. The results of the study indicate that an increase in temperature significantly reduces the breakdown voltage of insulating oil, thereby increasing the risk of insulation failure and reducing transformer reliability. The conclusions of this study provide essential recommendations for managing transformer operating temperatures to maintain optimal reliability and service life while avoiding potential failures caused by insulating oil degradation.

Keyword : Transformer Reliability, Breakdown Voltage, Insulating Oil, Temperature Rise.

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1. INTRODUCTION

Power transformers play a vital role in electrical systems, particularly in the regulation and distribution of electrical energy. Their primary function is to convert voltage levels from one stage to another, depending on the system's requirements. However, the performance of power transformers is heavily influenced by the condition of the insulating oil, which serves the dual purpose of electrical insulation and cooling. The quality of this insulating oil can degrade over time and usage, especially due to environmental factors such as temperature.

One critical aspect determining the reliability of insulating oil is its breakdown voltage. Breakdown voltage is the oil's ability to withstand electrical stress before insulation failure occurs. High temperature increases in transformers can lead to changes in the physical and chemical properties of the oil, which, in turn, can result in a decrease in breakdown voltage. This leads to an increased risk of insulation failure, which can have catastrophic consequences, such as fires, equipment damage, and unexpected power outages.

The growing demand for electricity across various sectors, particularly industries requiring high-voltage power supply, poses new challenges for electrical engineers, especially in handling high-voltage systems. One of the primary challenges is insulation failure, which can cause severe disruptions in the electrical system.

Insulation failure in transformers, particularly in the insulating oil, has significant impacts on the continuity of power supply within grids managed by national electricity companies like PLN. Ineffective insulation can lead to breakdown voltage issues, where the transformer oil is no longer capable of withstanding the high applied voltages. Consequently, this can damage the transformer, resulting in power outages and economic losses.

To prevent insulation failures that could lead to severe consequences, it is essential to understand the operational capabilities of transformer oil. One way to evaluate these capabilities is by conducting breakdown voltage tests on transformer oil. These tests aim to measure the insulating oil's ability to withstand high voltage and help determine safe operational conditions for transformers.

By conducting research on breakdown voltage testing for transformer oil, it is expected to provide valuable insights for managing and maintaining power transformers while improving the overall reliability of electrical systems. This knowledge will assist engineers in taking preventive measures to avoid insulation failures and ensure safe and efficient operations in electrical systems.

In the context of the ever-evolving electrical industry, understanding the relationship between temperature and the reliability of transformer insulating oil is crucial for enhancing operational effectiveness and system safety. Therefore, this research aims to analyze the impact of temperature rise on the breakdown voltage of power transformer oil. The results of this study are expected to offer deep insights into appropriate temperature management strategies to maintain the reliability and operational lifespan of transformers, while supporting sustainability and efficiency in electrical systems

2. RESEARCH STAGES

Many studies have discussed the analysis of electrical equipment reliability using the Weibull distribution method. Previous research generally shares a common goal: improving system reliability. Based on the dissertation by Olli Salmela in 2005, titled *"Reliability of Telecommunication Equipment"*, the study focuses on the reliability of communication equipment and its components. Special attention was given to establishing a strong correlation between reliability analysis conducted at different hierarchical levels. The dissertation begins by examining thermal derating.

It was found that generic procedures based on handbooks might not always be very appealing, as they do not adequately consider actual lifetime requirements. An alternative approach was proposed to address this issue. Thermal cycling handbook requirements were surveyed, and based on the findings, additional measures were suggested. Furthermore, component- and product-specific approaches for developing thermal cycling requirements were recommended. When implementing this new approach, several factors can be considered: product lifetime requirements, environmental conditions, reliability test results, and statistical distribution of component populations.

In 2022, Agus Fikri, ST., MM, and Muhammad Irvan, ST., MT, conducted a study published in the scientific journal titled *"Reliability Analysis of Production Machines Using the Weibull Distribution Function"*. In production systems, all machines involved in creating added value for an object or product must operate efficiently. Machine failures can disrupt processes, or in extreme cases, halt production entirely. To ensure the continuity of production activities without prolonged interruptions, it is essential to determine and analyze the operational reliability of machines.

This study analyzed the operational time and repair time data of the Heidelberg CD-102 printing machine (2022 model) using the Weibull distribution method. The goal was to create curves representing the machine's actual condition and repair activities. Based on these curves, failure rates, failure probabilities, and, most importantly, the machine's reliability were analyzed. The results indicated that the mean time to failure (MTTF) was 1.913 hours. The reliability of the machine operating at MTTF was only 36.751%, with a high failure rate during the early stages of operation before reaching MTTF. Therefore, the study recommended that the company's existing machine maintenance practices be reviewed.

Generally, transformers consist of two main components: dielectric materials, which make up the transformer insulation system (liquid insulation such as transformer oil, askarel, and silicon; and solid insulation such as kraft paper, pressboard, wood, and other cellulose products), and magnetic materials, including windings and cores.

The electrical power generated at power plants must undergo several stages of distribution before being utilized by consumers. Power generation and distribution from power plants allow electricity to be generated in one location for use at another distant location. Due to various technical challenges, electrical power is only generated at specific locations, while electricity consumers are dispersed across different areas. Transmitting large amounts of electrical power over long distances is most efficiently achieved using high voltages. High voltage transmission reduces power losses along the transmission lines.

Substations are subsystems of the electrical power transmission system and form an integral part of the overall transmission system. Substations play a critical role in the operation of the power transmission system and cannot be separated from the system as a whole. In this discussion, the focus is on substations commonly installed in Indonesia, with a practical (applied) perspective based on their field construction.

The functions of substations include transforming electricity from extra-high voltage to high voltage (500 kV/150 kV), high voltage to lower voltage (150 kV/70 kV), or high voltage to medium voltage (150 kV/20 kV, 70 kV/20 kV), all at a fixed frequency (50 Hz in Indonesia). They also serve for measurement, operational monitoring, and power system protection, as well as managing load distribution to other substations via high voltage and to distribution substations via feeders for medium voltage. Additionally, substations provide telecommunications infrastructure (mainly for PLN's internal use) through a system known as SCADA.

In general, the purpose of an electricity company is to maintain continuity of electricity service, so that the power distributed can reach customers continuously without interruption. The electric power system starts from the generation, transmission, and distribution systems. As shown in Figure 1.

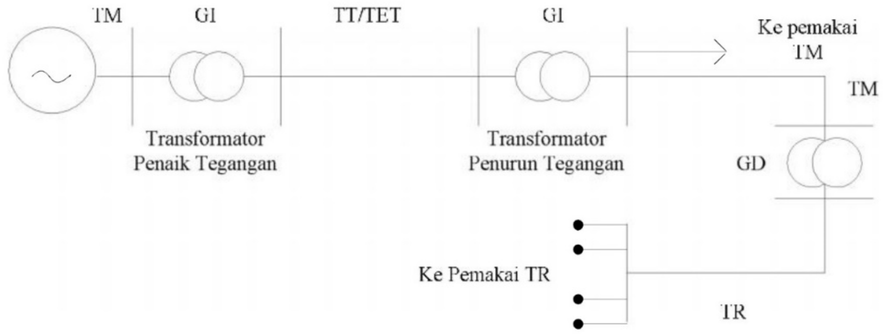

Figure 1. Single line diagram of electric power system

Image Description 1
P: Generator
TM: Medium Voltage
TT: High Voltage
TET: Extra High Voltage
GI: Main Substation
GD: Distribution Substation

However, on the one hand, the electrical equipment in the generation, transmission, and distribution systems will experience basic problems such as disturbances, maintenance, and aging which result in equipment replacement. Although maintenance has the same impact as disturbances and aging resulting in the electrical equipment stopping working, maintenance aims to improve the reliability of the electrical equipment. Therefore, well-scheduled maintenance is highly expected.

Transformers are important components in the electric power system. Disturbances in power transformers result in the interruption of the power flow distributed by the power transformer, decreased reliability of the power transformer, and the most noticeable impact is economic losses to the electricity company. Power transformer disturbances are divided into 2, external disturbances and internal disturbances.

Power transformers are equipped with several protection relays that work together with the PMT (Circuit Breaker). The protection relay functions to protect the power transformer from external and internal disturbances. So the performance of the protection relay works very well, so that no damage occurs to the power transformer.

A transformer is an electrical device consisting of an iron core and a coil wrapped around the iron core. The basic principle of a transformer is based on Lorenz's law and Faraday's law. When the primary coil is given an alternating voltage, a primary current will appear in the primary coil. According to Lorenz's law, if current flows through an iron core, a magnetic field will arise around the surface of the iron core. The primary current will generate flux, flux is the number of magnetic lines that pass through an iron core. Flux changes occur because the magnetic lines of force that pass through the surface of the iron core are not always perpendicular to the surface of the iron core. According to Faraday's law, if there is a change in flux through a coil with N turns, an induced EMF will arise [1].

$$e_1 = N_1 \frac{d\emptyset}{d}$$

$$\emptyset = \emptyset m \quad s \qquad (1)$$

$$\frac{d\emptyset}{d} = \omega\ \emptyset m \quad c$$

$$e_1 = N_1\ \omega\ \emptyset m \quad c \tag{2}$$

Where :
d∅ = Change in magnetic lines of force in weber units
dt = Change in time in seconds
e1 = EMF on the primary side
N1 = Number of turns of the primary winding

Reliability refers to the probability that a device or equipment functions according to its standard within a specified time and under specific conditions. Failure analysis is part of a system or equipment assessment that identifies potential failures, possible failure modes, their effects, and failure forms in complex systems. Reliability in a distribution system measures the level of service provided by the power supply system to consumers. This reliability can be assessed by observing how frequently the system experiences outages, the duration of these outages, and how quickly the system can recover to its normal condition after an outage. The reliability level of a network can be categorized into three levels (Suhadi et al., 2008):

1. High System Reliability.
   Under normal conditions, the system can provide sufficient capacity for peak load demands with proper voltage variations. In the event of a disturbance, this system requires numerous devices and protective equipment to avoid various types of failures.
2. Medium System Reliability
   Under normal conditions, the system can provide sufficient capacity for peak load demands with proper voltage variations. In the event of a disturbance, the system can still supply power to part of the load during peak demand conditions. Therefore, the system requires a substantial number of devices to address disruptions.
3. Low System Reliability.
   Under normal conditions, the system can provide sufficient capacity for peak load demands with proper voltage variations. However, in the event of a disturbance, the system cannot supply power to any load. This means the system must first be repaired, indicating that the system's protective equipment is insufficient and relatively limited in number.
   Transformer insulating oil can be classified into three types: mineral oil, synthetic oil, and organic oil.

1. **Mineral Oil**
   Mineral oil is derived from the processing of crude oil, specifically between the diesel oil and turbine oil fractions. It has a highly complex chemical structure. The selection of the oil type depends on the environmental conditions where the transformer is used. For example, askarel is a synthetic oil that is non-flammable and resistant to oxidation, making it suitable for locations where fire hazards are significant.
2. **Synthetic Oil**
   Synthetic insulating oil is chemically processed to achieve better characteristics than mineral oil insulation. However, synthetic oil has the drawback of being hazardous to the environment.
3. **Organic Oil**
   Organic oil is obtained from the extraction of certain plants, such as castor, soybeans, and coconut.

Good transformer insulation oil should possess the following physical characteristics:

1. **Clarity**
   The clarity of the oil is evaluated based on its appearance. High-quality oil is clear, clean, and free of sediment. During transformer operation, the oil may dissolve particles or sediment. The more dissolved sediment in the oil, the darker its color becomes.
2. **Viscosity**
   Viscosity is crucial as it determines the oil’s ability to circulate effectively, ensuring proper cooling of the transformer core and windings. High-quality transformer oil should have low viscosity, with a standard value of ≤18 cSt for new oil. The viscosity test for new oil follows the ISO 3104 standard.
3. **Density**
   Transformer oil should have low density to allow particles within the oil to settle quickly. Density is

the ratio of the mass of a liquid volume at 15.56°C to the mass of an equal volume of water. The density of transformer oil must be lighter than that of water.

4. **Flash Point**
   The flash point of new transformer oil must not be lower than 135°C, while used oil should not be less than 130°C. The flash point is a safety consideration and is determined using the Pensky-Martens closed-cup method as per IEC standards. A low flash point indicates the presence of volatile combustible components, which can cause the oil to evaporate and reduce its volume, leading to higher viscosity.
5. **Pour Point**
   The pour point helps identify the type of equipment that can use the insulating oil. It is the temperature at which the oil stops flowing when cooled below normal temperatures. A lower pour point indicates better performance of transformer oil insulation.

3, RESULTS AND DISCUSSION

This research employs an experimental and quantitative approach to analyze the insulation capability of transformer oil in terms of breakdown voltage due to temperature and loading conditions. The research methodology involves the following steps:

1. Initial Research Phase

This phase involves a literature review to understand the theories and prior studies related to:

- Characteristics of power transformer insulation oil.
- Breakdown voltage of insulation oil.
- The impact of temperature and loading on electrical insulation performance in transformers.

The literature includes books, scientific journals, industry standards such as IEEE, IEC, or SNI, and relevant studies on power transformers and insulation oil.

2. Sampling of Insulation Oil

Insulation oil samples will be taken from several power transformers operating under field conditions. Sampling considers variations in loading levels and operating temperatures. Factors to be considered include:

- Oil Age Variations: Fresh oil and used oil.
- Transformer Operating Environment: Transformers operating in high- and low-temperature environments.
- Transformer Loading Levels: Transformers under high, medium, and low loads.

3. Experimental Testing Design And Breakdown Voltage Testing.

Testing aims to determine the effect of temperature and loading on the ability of insulation oil to withstand breakdown voltage. The experimental design involves:

Testing follows IEC 60156 or ASTM D877 standards to measure the breakdown voltage of insulation oil. Procedures include:

1. Insulation oil is placed in a breakdown voltage testing apparatus.
2. AC voltage is gradually applied until insulation failure or breakdown occurs.

4. Temperature Variation Testing and loading Condition Testing

Insulation oil will be tested at different temperature levels, such as 40°C, 60°C, 80°C, and 100°C, to observe how increasing temperature affects insulation capability.

Transformer loading (percentage of full capacity) will be simulated in the laboratory to examine its impact on insulation oil performance. Low, medium, and high load levels (e.g., 50%, 75%, and 100% capacity) will be tested to evaluate the effect of load on oil condition.

The test data for breakdown voltage under various temperature and loading conditions will be processed quantitatively using statistical methods. Parameters analyzed include:

- Breakdown Voltage: Voltage level at which oil insulation fails.
- Temperature Effects: Analysis of how temperature changes affect breakdown voltage.
- Loading Effects: Analysis of how transformer loading impacts the oil's insulation performance.

Data analysis will use linear regression or ANOVA to identify relationships between temperature, loading, and insulation oil capability. This analysis aims to determine:

- Whether there is a significant relationship between increasing temperature and the reduction in insulation oil capability.
- Whether increasing transformer load accelerates oil degradation, thereby affecting breakdown voltage.

Based on the data analysis, conclusions will be drawn regarding:

- The impact of operational temperature on transformer oil breakdown voltage.

- The effect of transformer loading levels on insulation oil performance.
- The extent to which temperature and loading factors contribute to the degradation of insulation oil quality, along with maintenance recommendations to ensure insulation performance.

This research will provide technical recommendations on maximum safe operating temperatures and loading levels for power transformers, as well as the frequency of insulation oil testing to ensure electrical system reliability. These recommendations are expected to help electric utility companies extend transformer life and prevent failures due to insulation breakdown.

To enhance the research on "Analysis of Transformer Oil Insulation Capability against Breakdown Voltage Due to Temperature and Loading," the following elaborates each stage with additional variables, more complex testing procedures, and deeper analytical approaches:

Comprehensive collection of scientific and technical information focusing on:

- **Physical and Chemical Characteristics of Insulation Oil**: Including chemical composition, viscosity, dielectric strength, boiling point, and thermal stability.
- **Insulation Oil Degradation**: Examining phenomena such as degradation due to overloading, contamination, moisture, and high temperatures, which may result in dissolved gas formation and changes in dielectric properties.
- **Temperature and Loading on Electrical Systems**: Studying how these factors influence the lifespan and performance of insulation oil in power transformers.
- **International and National Standards**: Referring to standards such as IEC 60156 (for breakdown voltage testing), IEEE C57.106 (for insulation oil), and relevant SNI standards for transformer usage in Indonesia.

Sampling considers natural and artificial degradation factors to improve data relevance:

- Sampling from transformers with various operational ages: fresh oil (≤1 year), mid-aged oil (3–5 years), and aged oil (≥10 years).
- Oil with different contamination levels, including moisture and dissolved gases.
- Transformers operating under low (≤50%), medium (50–75%), and high (≥75%) loads.

Experiments simulate detailed field conditions, including additional variables:

- Breakdown Voltage Testing: Oil is tested at temperatures of 20°C, 40°C, 60°C, 80°C, and 100°C to measure changes in dielectric properties with temperature.
- Moisture Content Testing: Using Karl Fischer titration to quantify water contamination before breakdown voltage testing.
- Dissolved Gas Analysis (DGA): Identifying the effect of gases (e.g., hydrogen, carbon monoxide, acetylene) on breakdown voltage.

Data is processed using multivariate statistical methods:

- **Linear Regression Analysis**: To assess the relationship between temperature or loading and breakdown voltage.
- **ANOVA and t-tests**: To evaluate the significance of the effects of temperature, loading, and degradation on breakdown voltage.
- **Multivariate Analysis**: To determine combined effects of multiple factors (e.g., high temperature and full load) on oil performance.

The research will result in precise technical guidelines, including:

- Optimal operational conditions (temperature and load) for maintaining insulation oil performance.
- Thresholds for moisture and dissolved gases to prevent insulation failures.
- Maintenance strategies, such as regular testing intervals and transformer cooling system improvements, to enhance oil reliability.

This comprehensive approach ensures deeper insights into the effects of temperature and loading on transformer oil performance, providing precise technical recommendations for practical application.

3.1 RESULT.

In table 1 below are the test results which are then compared with the breakdown voltage standard based on IEC 60422, namely SPLN. Table 1 explains that 5 tests have met the SPLN NO 50: 1991 value standard with a maximum value of 35kV and the lowest value of 32kV. In other words, from the 5 breakdown voltage tests, it can be said to be quite reliable. The highest test value is in the 4th test with a value of 35kV, while to touch the good category it must reach a value of 40 and above. While the lowest value is in the 2nd test with a value of 32kV which means it has not touched the bad category. So the test results can be said that transformer oil is still quite reliable because it does not touch the bad category value.

Table 1. Comparison of breakdown voltage results according to SPLN standards

Results Testing	Voltage Translucent (kV/2.5 mm)	Breakdown Voltage Standard Based on IEC 60422 (kV/2.5mm)		
		Good	Enough	Bad
		> 40	30– 40	< 30
1	32.4 kV	-	√	-
2	32 kV	-	√	-
3	33.2 kV	-	√	-
4	35 kV	-	√	-
5	32.4 kV	-	√	-

In the calculation of the interface voltage test results, it has been obtained that the test results of the STARLITE 400kV Transformer oil located in the Jatirangon Substation of PT. PLN (Persero) UP3 Pondok Gede are still classified as good because from the 5 tests the results are still below the permitted good limits.

Table 2. Comparison of interfacial tension test results according to IEC 60422 SPLN standard

Results Testing	Inter-voltage face (mN/m)	Standard Interfacial Tension Based on IEC 60422		
		Good	Enough	Bad
		> 28	22–28	< 22
1	28	√	-	-
2	26	√	-	-
3	26	√	-	-
4	24	√	-	-
5	25	√	-	-

Table 2 above shows the results of the comparison of the results of the interfacial tension test. From these results, the value of the overall test is categorized as good for use, which means that there is little contamination of the insulating oil with other substances that do not have much effect on the breakdown voltage. From the overall water content test, the results obtained were that the oil tested had good water content, the less water content there is in the transformer, the less it will affect the breakdown voltage of the insulating oil.

Table 3. Results of water content testing in oil

Results Testing	Water Content (ppm)	Water Content Standard Based on IEC 60422 (ppm)		
		Good	Enough	Bad
		<20	20-30	>30
1	15.6	√	-	-
2	16	√	-	-
3	15.2	√	-	-
4	15.6	√	-	-
5	14.2	√	-	-

In table 3 of the overall test value, it gets a good category for use, which means it has a small amount of water in the insulating oil that comes from two things, namely oil decomposition or due to oil being exposed to outside air. Excessive water content can reduce the breakdown voltage of the oil and reduce the life of the transformer oil. From the overall acidity test, the results obtained are quite reliable for transformers based on SPLN standards. Transformers are indeed dominated by metal materials. If the transformer oil already has a high acid content, the oil needs to be cleaned or replaced with new transformer oil. In table 5, the overall test value has a sufficient acid content value for use, and also from the results of the acid breakdown voltage, the acid content also affects the insulating oil, this is caused by oxidation that produces acid and causes (corrosion) in parts of the transformer that are dominated by metal materials.

Table 4. Comparison of acid content test results in oil

Results Testing	Acid Level	Standard Based on IEC 60422 (mg KOH/gr)		
		Good	Enough	Bad
		< 0.1	0.1 – 0.2	> 0.3
1	0.251	-	√	-
2	0.246	-	√	-
3	0.244	-	√	-
4	0.220	-	√	-
5	0.250	-	√	-

The transformer works at optimum condition continuously, causing the oil temperature of the transformer to increase. This high oil temperature will cause the molecules in the oil to break so that the dielectric leakage factor will be higher. The color of the transformer oil which is still yellow in new condition will change to brown and even dark. Over time, oxygen from the air, humidity from the transformer, and other chemical substances such as acid and carbon can cause the quality of the transformer oil to worsen because most of the oil will undergo a chemical reaction that can cause the chemical composition of the transformer oil to decompose. In addition, the older the age of the transformer oil, the more dirt there will be so that the oil will be increasingly contaminated and cause the breakdown voltage of the transformer to be lower.

4. CONCLUSION

Based on the study of the insulating capability of transformer oil against breakdown voltage due to temperature and loading, the following conclusions can be drawn:

1. Effect of Temperature on Breakdown Voltage
   - Increased temperature significantly reduces the insulating capability of transformer oil.
   - Higher temperatures lead to lower breakdown voltage due to increased ionic mobility in the oil and reduced viscosity, accelerating the discharge process.
   - The decline in breakdown voltage becomes notable at temperatures above 60°C, with critical conditions reached at temperatures near or exceeding 100°C.
2. Effect of Loading on Breakdown Voltage
   - High loads (≥75% capacity) accelerate the degradation of transformer oil, as evidenced by a faster decline in breakdown voltage compared to medium or low loads.
   - Full or near-capacity loading leads to an increase in operational oil temperature, accelerating oxidation and thermal degradation of the oil.
3. Impact of Moisture and Dissolved Gases
   - Transformer oil with high moisture content exhibits significantly lower breakdown voltage compared to oil with low moisture levels. This is because moisture acts as a conductive medium.
   - Dissolved gases such as hydrogen, carbon monoxide, and acetylene produced from oil degradation also contribute to the reduction of insulating capability.
4. Interaction Between Temperature and Loading
   - The combination of high temperature and heavy loading has a synergistic effect in lowering the breakdown voltage of transformer oil.
   - Transformers operating under high load conditions in hot environments require special attention to prevent failures caused by insulation breakdown.
5. Technical Recommendations
   - Operational Temperature: It is recommended to maintain oil temperatures below 60°C to preserve optimal insulation performance. Cooling systems must be enhanced if temperatures frequently exceed this threshold.
   - Oil Testing Frequency: Transformer oil in high-load or high-temperature environments should be tested regularly (every six months) to monitor moisture content, dissolved gases, and breakdown voltage.
   - Oil Replacement: Oil exhibiting a significant reduction in breakdown voltage (below IEC 60156 standards) should be replaced immediately to prevent system failures.
6. System Safety and Reliability
   - This study emphasizes the importance of monitoring transformer oil conditions as a proactive measure to prevent system failures.
   - By maintaining the quality of transformer oil through regular maintenance and testing, the service life of transformers can be extended, reducing failure risks and repair costs.

REFERENCES

Aryza, S., Wibowo, P., & Saputra, D. (2022, July). Rancang Bangun Alat Pengontrolan Proses Pemanasan Produksi Biodisel Dari Minyak Jelantah Berbasis Arduino Mega. In Prosiding Seminar Nasional Sosial, Humaniora, dan Teknologi (pp. 121-127).

Arismunandar, Artono, "Teknik Tegangan Tinggi Suplemen", Jakarta: Ghalia Indonesia, 1983.

Arigayota, Abdul Rahman, "Memantau Kualitas Minyak Trafo". Teknologi dan Energi Vol.2 No.4: Halaman 392, Oktober 2012.

Azizah, N. N. (2024). Cloud Computing Adoption Trends: A Systematic Literature Review of Organizational Perspectives. *Journal of Computer Science, Information Technology and Telecommunication Engineering*, *5*(1), 481-487.

Febrina, Dewi Cahya, Tugas Akhir, "Pengaruh Temperatur Terhadap Tegangan Tembus dan Usia Kerja Berbagai Jenis Minyak Transformator di PT.PLN (Persero) P3B JB APP - Surabaya", Bidang Studi Teknik Sistem Tenaga Jurusan Elektro, ITS, 2016.

Chapman, Stephen. J., "Electric Machinary Fundamentals: Fourth Edition", McGraw-Hill Education, New York, Ch. 2, 2005.

Dedy, A. P., Zambak, M. F., Ahmad, A. A., & Suwarno, S. (2020). PLC Implementation as a Flow Computer for Calculation of Saturated Steam Mass Meetings with the Linear Divided Regression Method (Application: PT. XYZ-Kuala Tanjung). *Journal of Computer Science, Information Technology and Telecommunication Engineering*, *1*(1), 8-16.

olikhudin, M., “Studi Gangguan Interbus Transformer (IBT-1) 500/150 kV di Gitet 500 kV Kembangan – Jakarta Barat”, Thesis, Fakultas Teknik Program Pasca Sarjana Departemen Teknik Elektro, UI, Bab 2, 2010.

F. Husnayain, M. Latif, O, dan I. Garniwa, “Transformer Oil Lifetime Prediction Using the Arrhenius Law based on Physical and Electrical Characteristics”, IEEE 2015 International Conference on Quality in Research, pp. 115 – 120, Aug, 2015.

Yuliastuti, Endah, Morshuis, P.H.F, and Chen, X, “Analysis of Dielectric Properties Comparison between Mineral Oil and Synthetic Ester Oil”, Master Thesis, Delft University of Technology, Oktober 2010.

International Electrotechnical Commission. “Mineral insulating oils in electrical equipment – Supervision and maintenance guidance”, IEC 60422 Ed.4 2013-01, Jan 2013.

Institute of Electrical and Electronics Engineers. “IEEE Guide for the Statistical Analysis of Thermal Life Test Data”, ANSI/IEEE Std. 101-1987. New York, Des 2010.

S. Anisah dkk (2022) Comparison of Lighting Efficiency (Led-CFL) based on Environmentally FriendlyTechnology. Journal of Applied Engineering and Technological Science (JAETS), 4(1), 568-577.

Z. THARO (2022) PENGARUH PENGGUNAAN BEBAN YANG TIDAK SETUJU PADA ALAT LISTRIK. Jurnal Elektro dan Telkomunikasi, 8(01), 13-18.