# Transformer Oil Quality Monitoring Towards Degradation of Insulation Breakdown Voltage

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*Abstract*— **The transformer is one of the critical pieces of equipment for distributing electrical energy from the generator connected to the transmission to the consumer of Diesel and Gas Power Generation Service Units (ULPLTD/G). Therefore, the existence of insulation is essential due to its function as a separator among the transformer core and as a transformer cooler to minimize the heat that arises in the transformer. Hence, the objective of this research was to evaluate the transformer oil quality. The procedure was executed by observing the transformer and collecting data directly from the diesel machine of SWD 2, SWD 3, and SLZ 5. The results revealed that the breakdown voltage of transformer oil categorized as good was SLZ 5 oil with an average of 59,983, and the less good was SWD 2 oil with an average of 34.516. Furthermore, by observing the test results for new and used transformer oil, the breakdown voltage value for new transformer oil was always higher than used oil. Eventually, the transformer efficiency achieved was 95.58%.**

***Keywords—breakdown voltage, diesel machine, transformer***

## I. Introduction

The necessary for electricity every year has increased in line with the development of industry and developing technology. Therefore, quality and continuity are priorities in serving consumers. Electricity production at one of Diesel and Gas Power Generation Service Units (ULPLTD/G) in West Kalimantan is carried out through Diesel Power Plants (primary) with Marine Fuel Oil (MFO) and Gas Power Plants (secondary) with High Speed Diesel (HSD) fuel. The electricity production process starts from the engine's mechanical energy that comes from the combustion system, including the intake, compression, power, and exhaust steps carried out continuously. From this mechanical energy, it can subsequently drive a generator; hence this energy can be converted into electrical energy due to the Electromotive Force (EMF). The electrical energy generated then goes to the power transformer and is channeled through the connecting substation (GH) to the main substation (GI) for further distribution. In the distribution of electrical energy, there is an electric machine with a vital role, namely the transformer.

The transformer is one of the critical pieces of equipment for distributing electrical energy from the generator connected to the transmission to the consumer; hence, transformer maintenance is needed to operate adequately. A transformer is an electrical machine that can transform electrical energy from one electric circuit to another through a magnetic coupling based on the principle of magnetic induction. A large number of transformers of various types of voltage rating and capacity are used in distribution systems. In addition to distribution systems, these transformers are also used in power systems and electronic systems. In this case, the transformer can function as an electrical device capable of transferring and converting electrical energy from one electrical circuit to another without having to change the frequency of a system [1].

However, when operating a transformer in an electric power system, it cannot be separated from a problem that generally causes a failure, both thermal failure, and electrical failure. This thermal and electrical failure will cause the transformer's life to be not long. It will also cause damage to the transformer, which will significantly impact financial losses due to repairs that will cost quite a lot and take a long time to repair [2].

In the case that caused several Interbus Transformer (IBT) or Power Transformer to explode, after being investigated by experts, the leading cause causing this transformer to explode was the result of a huge load on the transformer which resulted in the Interbus Transformer (IBT) or Power Transformer working at its highest point for some time continuously. This phenomenon adversely affects the condition and characteristics of the transformer and its isolation. As a result of continuous use at 100% conditions, the transformer will heat the internal areas/parts of the transformer, which can be referred to as hot-spot temperatures. If this is unchecked will cause degradation of the transformer insulation, which is one of the most critical parts of a transformer, predominantly liquid insulation in the form of oil and commonly referred to as transformer oil. Transformer oil insulation conditions are also not necessarily good because the transformer oil contains a lot of contaminants and too much water content. If the transformer oil is put into the transformer and operated under these conditions, there will be insulation failure and aging of the transformer insulation caused by poor transformer oil [3].

The existence of insulation is essential because of its function as a separator among the transformer core. In addition, this insulation also acts as a transformer cooler to minimize the heat that arises in the transformer. Because the transformer oil is hot for some time, the oil will boil and produce water vapor on the ceiling of this transformer [4]. Later, the water vapors that arise will fall into the



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transformer oil and settle on the insulation between the cores and the core itself. This condition will cause the breakdown voltage of the transformer oil to decrease because the oil is no longer pure. The use of transformers in the long term can reduce the quality of transformer oil, which causes the performance of the transformer to decrease so that damage can occur, resulting in disruption of load distribution.

Therefore, the transformer's operational performance must be maintained continuously so the transformer can work effectively and optimally. Power transformers have an effective age limit, which in this case will indicate whether the transformer is still feasible and reliable to be operated in the electric power system or not possible to run. This circumstance is because the power transformer works continuously for 24 hours. According to the Institute of Electrical and Electronics Engineers (IEEE) standard [5], the lifespan of a power transformer reaches 180000 hours or equal to 20.55 years. Therefore, the continuity of the performance of the power transformer is very dependent on the quality of the isolation system. Therefore, to determine the performance of transformer oil, the research will be carried out by monitoring the condition of transformer oil towards the degradation of the insulation breakdown voltage in the company using the direct method. The data in calculating the insulation breakdown voltage can be beneficial as a factory reference in maintaining the quality of transformer oil and satisfactory transformer efficiency [6].

## II. METHODS

This research was implemented at the State Electricity Company (PT. PLN Persero) at the Diesel and Gas Power Generation Service Unit (ULPLTD/G) in West Kalimantan. The research procedure was executed by exploring literature and transformer observation by collecting data directly and systematically to determine the oil quality in the machine.

### A. *Equipment*

The information from each diesel engine unit PLTD can be regarded in Table 1 below:

TABLE 1 DIESEL ENGINE INFORMATION

| Merk | Operated Year | Type | Installed Power (KW) | Capacity (KW) | Status |
|---|---|---|---|---|---|
| SWD 2 | 1977 | 9 TM 410 | 4000 | 3200 | operated |
| SWD 3 | 1977 | 9 TM 410 | 4000 | 3200 | operated |
| SWD 4 | 1986 | 18 TM 410 | 10400 | 7000 | operated |
| SLZ 5 | 1985 | 12 ZV 40/48 | 6300 | 5000 | operated |
| SLZ 6 | 1985 | 12 ZV 40/48 | 6300 | - | semi overhaul |
| CAT 7 | 2007 | 16 CM 32 C | 7648 | - | maintenance required |
| CAT 8 | 2007 | 16 CM 32 C | 7648 | 3500 | stand by emergency |
| | | Total | 46296 | 21900 | |

A transformer is an electrical device that transfers power or energy from one circuit to another through a magnetic coupling without changing its frequency. The essential thing in calculating the efficiency of a transformer is to calculate the number of power losses as core power losses, both hysteresis losses and eddy current losses, and primary and secondary copper winding power losses. The data specifications of the PLTD transformer are as follows.

TABLE 2 TRANSFORMER SPECIFICATION

| Specification | Details |
|---|---|
| Type | Outdoor |
| Capacity | 315Kva |
| Working Voltage | 22,21,20,19,18kV// 400/231 V |
| Current | 9,25 - 454,84 A |
| Vector Group | DyN5 |
| Impedance | 4,06 % |
| Wire | 1×3 Phase |
| Cos φ | 95,6 % |

### B. *Breakdown Voltage Test*

The breakdown voltage test was conducted after the oil sample was obtained from the transformer using a measuring instrument based on the IEC 60156 standard. The breakdown voltage test was carried out in PT. PLN Persero at the Diesel and Gas Power Generation Service Unit (ULPLTD/G) in West Kalimantan uses the Megger OTS80PB tool. IEC standard 60156 with two mushroom electrodes spaced 2.5 ± 0.05. Filling in the breakdown voltage measuring instrument container, the transformer insulating oil test sample must fill the test container and cover all electrode parts.


**Fig 1**. Breakdown voltage measuring instrument

The stages before testing the breakdown voltage using the Megger OTS80PB tool were:

a. cleaned the oil sample container from dirt by washing it
b. the tested oil sample was collected by not touching and exposing it to the outside air for too long because this oil is susceptible.
c. the distance between the two electrodes was up to 2.5 mm by turning the spacer back and forth between the electrodes.
d. oil sample was placed on the test equipment
e. turned on the test equipment
f. pressed the start button and the counter thus the dielectric ability of the oil would be recorded automatically. After the counter stopped and the reset button was on, the reset button was pressed to return to its original position.
g. the results of the breakdown voltage test were acquired on average 6 (six) times with an interval of 5 minutes and 2 minutes.
h.



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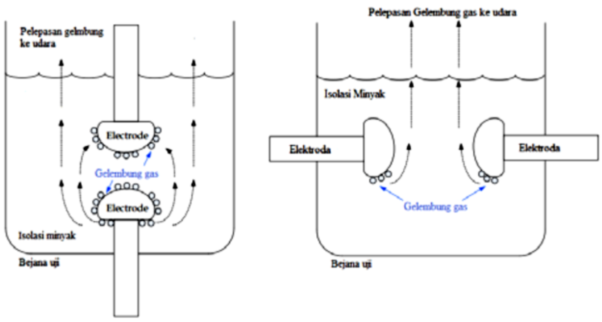


(a) (b)

**Fig 2**. (a) The process of the direction of the gas bubble at the vertical electrode position, (b) The process of the direction of the gas bubble at the horizontal electrode position

In this case, the position of the electrode must be installed horizontally. Because if the electrode were installed vertically as performed in Fig 2(a), the gas bubbles formed after the breakdown voltage would try to escape and float into the air and be trapped in the oil insulation because of the vertical position of the electrode blocks them. However, if the electrode were installed horizontally, as shown in Fig 2(b), the gas bubbles formed would quickly be released and float into the air without any obstacles.

## III. Results And Discussion

The breakdown voltage test method will produce an average voltage to penetrate the transformer oil insulation. If the breakdown voltage value is low, the transformer oil insulation is facilely penetrated by electrical voltage. This condition can generate an electric spark in the transformer and easily cause degradation of the transformer oil. Information observed on transformer oil at Diesel Power Company in West Kalimantan was as follows:

- Electrode type: electrode fungus/mushroom
- Gap distance: 2.5 mm

From the tests carried out, the data attained are presented in the following table.

TABLE 3 SWD 2 OIL BREAKDOWN VOLTAGE TEST RESULTS

| Test | Breakdown Voltage/ 2,5 mm (kV) | Time (minute) | Oil Color |
|---|---|---|---|
| 1 | 40.1 | 5 | Yellow |
| 2 | 34.8 | 5 | |
| 3 | 37.1 | 2 | |
| 4 | 41.3 | 2 | |
| 5 | 29.6 | 2 | |
| 6 | 24.2 | 2 | |
| Average | 34.51666667 | | |

TABLE 4 SWD 3 OIL BREAKDOWN VOLTAGE TEST RESULTS

| Test | Breakdown Voltage/ 2,5 mm (kV) | Time (minute) | Oil Color |
|---|---|---|---|
| 1 | 58.8 | 5 | |
| 2 | 60 | 5 | Slightly Clear |
| 3 | 55.7 | 2 | |
| 4 | 60.1 | 2 | |
| 5 | 59.6 | 2 | |
| 6 | 50.3 | 2 | |
| Average | 57.41666667 | | |

TABLE 5 SLZ 5 OIL BREAKDOWN VOLTAGE TEST RESULTS

| Test | Breakdown Voltage/ 2,5 mm (kV) | Time (minute) | Oil Color |
|---|---|---|---|
| 1 | 60 | 5 | Clear |
| 2 | 60 | 5 | |
| 3 | 60 | 2 | |
| 4 | 60 | 2 | |
| 5 | 60 | 2 | |
| 6 | 59.9 | 2 | |
| Average | 59.98333333 | | |

If we combine the three previous variables with being analyzed simultaneously, we will get the following graph.

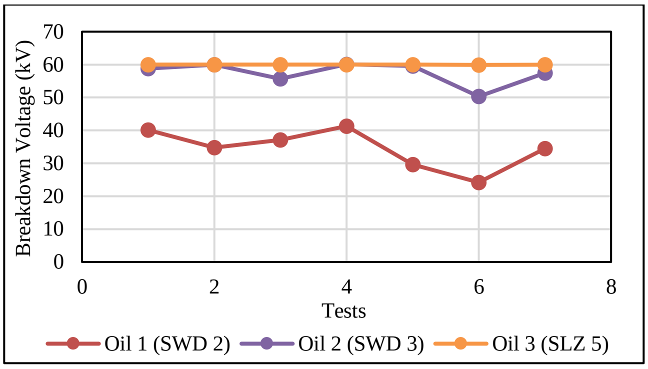


**Fig 3**. Breakdown voltage tests

- Transformer Power Loss Calculation

  The number of losses that occur at the PLTD substation can be calculated using the equation:

  $P_N = I_N^2 \times R_N$

  $R_N$ = Resistance of conductor (per kilometer) × length of conductor

  $I_N$ = Neutral current

  $$R_N = 0{,}093 \times \frac{8\ \text{m}}{1000\ \text{m}} = 0{,}000744\ \Omega$$

  $$P_N = 212{,}8985^2 \times 0{,}000744$$

  $= 33{,}7223$ Watt

  The percentage of losses due to the current flowing in the neutral conductor can be calculated by this equation:

  $$(\cos\theta) = \frac{P\ (\text{Watt})}{S\ (\text{VA})}$$

  $P = S \cos \varphi$

  $= 315 \times 95{,}6\ \% = 301{,}14$ kVA

  $= 301.140$ VA

- The transformer efficiency can be calculated by employing the following equation:

  $$\eta = \frac{P_s}{P_p} \times 100\%$$



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$P_s$ : transformer secondary side power (output)
$P_p$: transformer primary side power (output)

$$\eta = \frac{P - P_N}{P_p} \times 100\%$$
$$= \frac{301.140 - 33,7223}{315.000} \times 100\%$$
$$= 95,58\ \%$$

Transformer oil is a complex mixture of hydrocarbon molecules. The breaking of some bonds between C-H and C-C elements as a result of thermal or electrical failure will produce ionic fragments such as H, $CH_3$, $CH_2$, CH, or C, which will recombine and produce gas molecules such as hydrogen (H-H), methane ($CH_3$-H), ethane ($CH_3$-$CH_3$), ethylene ($CH_2$=$CH_2$) or acetylene (CH≡CH). These gases are known as fault gases [7].

From the graph, it can be demonstrated that the older the transformer oil, the lower the breakdown voltage of the transformer oil. In addition, the chart above can also represent the breakdown voltage comparison between the tested oils. This is caused by the increasing amount of dirt that settles or mud in the oil and adheres to the paper insulation rather than the transformer itself. The presence of this dirt demands to be anticipated to avoid the impact of continuing damage to the transformer because the transformer oil is no longer working as an insulator it should.

By analyzing the test results of new and used transformer oil, the breakdown voltage value for new transformer oil is always higher than the used one. This is because the electrons in the material's molecular structure in the former transformer oil are tightly bound to the molecules that are pressurized due to high voltage. The voltage that passes through the transformer oil will drive the transfer of electrons from one molecule to another; thus, conduction currents or leakage currents will arise. The reduced dielectric strength value in used transformer oil is caused by impurities, including particles, water, and bubbles [8]. The electric field will cause the water droplets to be trapped in the oil, which extends in the direction of the area, and at a critical field, the droplets become unstable. The failure channel will propagate from the tip of the elongated droplet resulting in a total failure [9].

Based on the previous test results, the low dielectric leakage factor is an expected characteristic of transformer oil as in Oil 3 (SLZ 5). Transformer oil is a liquid insulating material that is used as insulation as well as a coolant in transformers. As an insulating material, the oil must have the ability to withstand breakdown voltages. In contrast, as a cooling transformer, the oil must be able to reduce the heat generated; hence with these two capabilities, transformer oil is expected to be able to protect the transformer from interference [10]. The new transformer oil installed in the transformer will work as insulation from the transformer. The transformer works at its optimum condition continuously, causing the oil temperature of the transformer to rise. This high oil temperature will cause heating of the transformer, which in turn will cause heating of the transformer oil. Heating this transformer oil will cause the molecules in the oil to break; thus, the dielectric leakage factor will be higher [11].

The color of the transformer oil, which in its new condition is still clear, will turn yellow (as in Oil 1 SWD 2) and even darker. Over time, oxygen from the air, humidity from the transformer, and the content of other chemicals such as acid and carbon can cause the quality of the transformer oil to get worse because most of the oil will undergo chemical reactions that can cause the chemical composition of the transformer oil to degrade [12]. The thermal aging of the insulation system of the power transformer is connected to the chemical reactions generated in the oil, caused by oxidation and accelerated by temperature, oxygen, and humidity. Temperature favors the development of hydrocarbon oxidation reactions of the oil by forming free radicals and hydroperoxides and, eventually, oxides, acids, and other oxidation products [13]. Oxidation consists of three steps:

| | |
|---|---|
| Initiation | : $RH + O_2 \rightarrow RO_2\bullet$ |
| Propagation | : $RO_2\bullet + RH \rightarrow ROOH + R\bullet$ |
| | $R\bullet + O_2 \rightarrow RO_2\bullet$ |
| Breaking | : $RO_2\bullet + R\bullet \rightarrow ROOR$ |

The oxidation rate and the concentration of the transient product depend on the chemical structure of the oil and the oxidation conditions, temperature, pressure, and ambient air contact, respectively. In addition, the older the transformer oil is, the more dirt will be; thus, the oil will be more contaminated and cause the breakdown voltage of the transformer to be lower [14].

From the data collected, the amount of current flowing in the transformer is 212.8985 A. The value of the current flowing in the transformer conductor confirms that the magnitude of the measured power losses is 33.7223 Watt. The heat generated by the transformer when operating is noted as transformer losses.

Losses in the transformer are affected by two components of power loss, namely load loss or copper loss (PCu) and no-load loss consisting of eddy current loss (Pe) and hysteresis loss (Ph). Copper losses are losses due to an excessive current flowing through the resistance value, which can cause heating of the copper wire of each coil. Eddy current losses are losses that occur in the iron core due to eddy currents, while hysteresis losses are losses in the iron core due to alternating flux [15]. Based on the results of the analysis of losses, the calculation of the efficiency of the transformer is 95.58%.

## IV. CONCLUSION

The breakdown voltage of transformer oil categorized as good was SLZ 5 oil with an average of 59,983, and the less good was SWD 2 oil with an average of 34.516. Furthermore, by evaluating the test results for new and used transformer oil, the breakdown voltage value for new transformer oil was always higher than used oil. Eventually, the transformer efficiency achieved is 95.58%.

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