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Analysis Method of Testing the Time Period of Partial Discharge Symptoms on Automotive Engine Lubricant Insulation with Needle Plate Electrodes

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ABSTRACT

Good insulation function in transformers is a major concern in the reliability of electrical energy distribution systems. Transformers serve as key components requiring effective insulation systems. This study analysis the time period of partial discharge (PD) phenomena in automotive engine oil using needle-plate electrodes with two detection components: HFCT and loop antenna. Testing was conducted 10 times with parameters including BGN on/off, positive/negative PDIV, PDIV × 1.25, and PDIV × 2. Results show automotive engine oil PDIV (2.0 kV) is lower than transformer oil (2.35 kV). PD time period in automotive oil was 6-6.4 µs, while transformer oil was 6.8 µs. Positive PDIV frequency in automotive oil (166.7 Hz) was higher than negative PDIV (156.250 Hz), while transformer oil had equal frequencies (147.1 Hz). The study concludes that PD in automotive engine oil insulation is more severe compared to transformer oil, with transformer oil demonstrating superior insulation strength. Keywords: insulation, PD, frequency, needle-plate electrode.

Keywords: Isolation, Partial Discharge, Frequency, Needle-Plate Electrode, Time Period.

INTRODUCTION

Reliability in the distribution of electrical energy from the power source to consumers through transmission and distribution lines is one of the main concerns in the electric power system (Hani, 2014). An electric power system is a series of electrical components or devices, such as generators, transformers, transmission lines, distribution lines, and loads, which are interconnected to form a system (Pandjaitan 2012). Transformers as a crucial element in the distribution system require an isolation system capable of protecting the distribution of electrical energy from disturbances. Isolation is a layer or insulating material used to separate one live part from another live part to prevent failures and disturbances that affect the reliability of electric power (Ariyanto 2019).

Isolation has a maximum voltage limit that can be handled, and insulation failure can result in disruptions in the distribution of electrical energy (Oktarini 2020). Isolation failure is a common problem in the process of electrical energy distribution (Harinata, Ilham, and Yusuf 2019). The initial symptom of insulation failure is the phenomenon of partial discharge (PD), which is the process of releasing some of the electrical energy in the insulation that connects conductors with different voltages (Academy, Of, and Czech 2009).

PD can occur as a result of imperfections, defects, or excessive electrical voltage in the insulation system (Ardiansyah and Pramudita 2020). This phenomenon can gradually damage the insulation and reduce the efficiency of the electric power system. Several previous studies have examined partial discharge in various insulating materials. (Pompili et al. 2023) conducted partial discharge inception voltage measurements in dielectric fluids. (Korobeynikov et al. 2020) studied partial discharge in various fluids. (Chandrasekar and Montanari 2014) studied the Analysis of partial discharge characteristics of natural esters as dielectric fluid for electric power apparatus applications, while (Ardiansyah and Pramudita 2020)focused on partial discharge on the insulation surface. However, no study has specifically examined the time period of partial discharge waves in automotive engine lubricants and compared them with transformer oil using needle-plate electrodes. This study aims to: (1) determine the characteristics of PD in automotive engine lubricants and transformer oil detected by HFCT sensors and loop antennas, (2) analyze the time period and frequency of PD in both insulating materials, and (3) compare the severity of PD symptoms between automotive engine lubricants and transformer oil..

RESEARCH METHODS

The equipment and materials needed for this research have been prepared in the laboratory, as explained further. The research was conducted in the High Voltage Laboratory of the Faculty of Technology, University of Indonesia (FPTK UPI) using standard PD testing equipment. The HV 9103 Control Desk was used to regulate the voltage to laboratory standard specifications. An HV 9105 step-up transformer with a maximum capacity of 100 kV served as the high voltage source; the testing device system is shown in Figure 1.
Liquid Insulation Main Switch

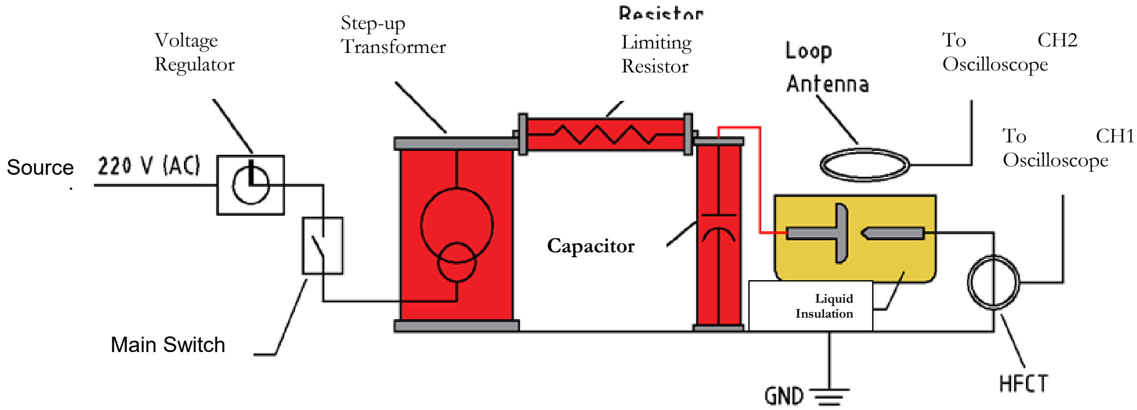

Figure 1. Schematic of PD test circuit using needle-plate electrodes

The placement of the needle-plate in testing liquid insulating materials according to previous research is set at a distance of 2.5 mm, as seen in the image below.

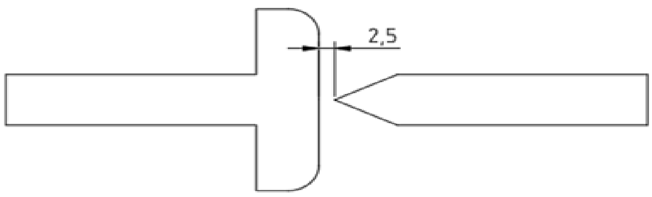

Figure 2. Needle-plate electrode with an electrode spacing of 2.5 mm used in the test.

The needle-plate isolation detection system uses two main components: a High Frequency Current Transformer (HFCT) sensor and a loop antenna connected to an oscilloscope via a coaxial cable with a BNC connector. The use of this dual detector aims to improve measurement accuracy and serve as a backup system(Junaidi 2021). The needle-plate electrode was chosen because of its characteristic of creating a non-homogeneous electric field, thus facilitating partial discharge for research purposes (Mulyana, E., & Anggio 2023; Patel, N. J., Dudani, K. K. 2012)

The insulating materials used were Shell Helix HX6 10W-40 API SN oil as a representative of automotive engine lubricant and Shell Diala B transformer oil. The selection of these two materials refers to previous research which showed almost equivalent dielectric strength (Islam Sazzad et al. 2024)

Testing Procedures

Testing was conducted according to the (Academy et al. 2009) standard 10 times for each parameter to ensure data accuracy and repeatability. Prior to testing, the grounding resistance was checked using a clamp grounding tester, which showed a value of 0.21 Ω, meeting the PUIL 2000 standard, which requires a grounding resistance of less than 1 Ω.

The testing procedure consists of three main stages:

1. Background Noise (BGN) Check: BGN off (equipment off) and BGN on (equipment on at 0 kV) to calibrate the system and ensure there is no interference with the equipment (Syakur and Facta 2005).
2. PDIV (PD Inception Voltage) Test: Search for the minimum voltage at which PD occur using positive and negative triggers. The voltage is increased in 0.1 kV increments at 1-minute intervals until stable PD symptoms are detected (Prihatnolo, Syakur, and Facta 2011).
3. Increment Test: PDIV × 1.25 and PDIV × 2 (positive and negative) to validate and analyze the increase in PD intensity.

The data captured includes the Vmax, Vmin, and Vpp values displayed by the oscilloscope, as well as wave capture for manual analysis of the time period with a time/div setting of 2.00 ms.

Data Analysis

The time period is calculated using the standard oscilloscope waveform formula (Nugroho, Sudjadi, and Christyono 2019):

$T = \text{horizontal div} \times t/\text{div}$

Frequency is calculated using the fundamental formula:

$f = 1/T$

Numerical data were processed using Microsoft Excel 2013 to calculate the mean and standard deviation. Data validity was determined based on the standard deviation value, which must be below the mean to indicate high measurement accuracy ((Kartono, Harlanu, and Suryanto 2012).

RESULT AND DISCUSSION

PD Characteristics

The test results showed standard deviation values below the average for all parameters, indicating high measurement accuracy in accordance with experimental research validity standards (Mika, Patras, and Lisi 2019). Figure 1 shows the results of the grounding resistance check which showed a value of 0.21 Ω, meeting work safety standards for high voltage testing.

Figure 3. The results of checking the grounding resistance of the testing equipment show a value of 0.21 Ω.

The PDIV for automotive oil was found at 2.0 kV (positive and negative), while for transformer oil at 2.35 kV. These results are consistent with research by (Mulyana, E., & Anggio 2023), who found the PDIV for engine oil was 2.03 kV and for transformer oil 2.25 kV. This difference indicates better insulating strength for transformer oil than automotive oil, in line with the findings of (Ardiansyah and Pramudita 2020), who reported the PDIV for transformer oil was 2.07-2.19 kV. Figure 4 below shows the waveform visualization during background noise off (BGN off) testing for both types of insulation materials. No interference or PD waves were detected, confirming that the test system was functioning normally.

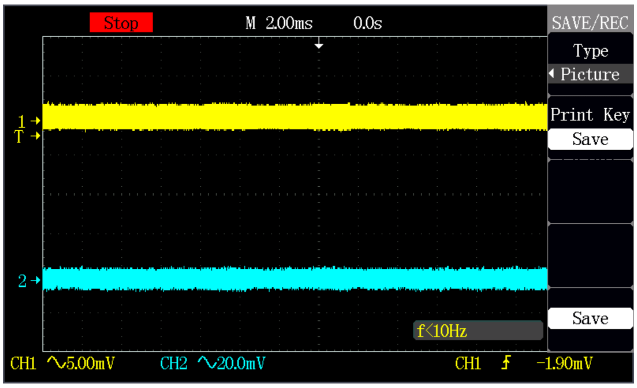

Figure 4. Waveform visualization when background noise is off in automotive oil and transformer oil.

A significant peak-to-peak increase in V value was detected when PDIV was reached, confirming the occurrence of partial discharge activity. This phenomenon is consistent with the theory that PD produces electromagnetic pulses that can be detected by the HFCT sensor and loop antenna (Herawan 2020). Figures 5 and 6 show visualizations of positive PDIV waveforms for automotive oil and transformer oil.

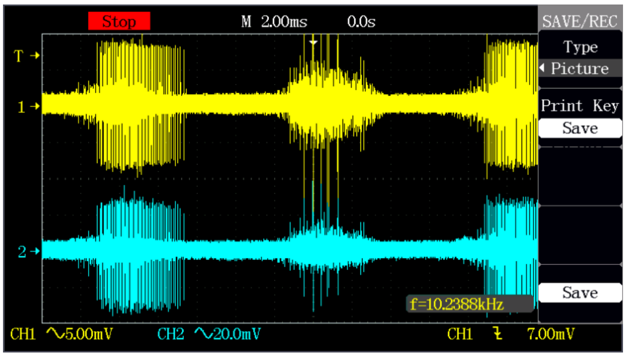

Figure 5. Visualization of the positive PDIV wave of automotive oil at a voltage of 2.0 kV shows wave instability which indicates the occurrence of PD.

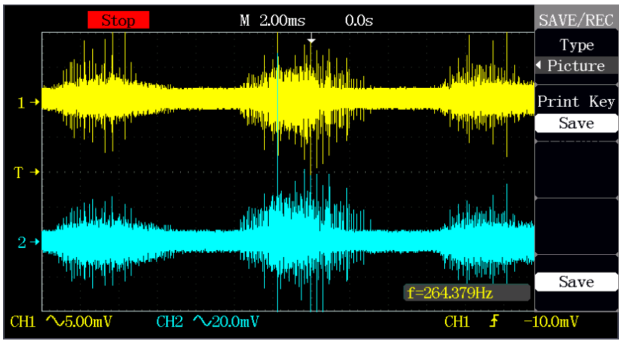

Figure 6. Visualization of positive PDIV wave of transformer oil at a voltage of 2.35 kV

Table 1 shows a comparison of test data between automotive oil and transformer oil for various parameters measured.

Table 1. Comparison of PDIV Data for Automotive Oil and Transformer Oil

Parameter	**Oli Otomotif**	**Transformer Oil**	**Unit**
PDIV Positif	2,0	2,35	kV
PDIV Negatif	2,0	2,35	kV

Vpp PDIV Positif (HFCT)	14,8 ± 0,42	12,4 ±0,52	mV
Vpp PDIV Negatif (HFCT)	13,6 ±0,38	11,8 ±0,48	mV

Time Period Analysis

Manual analysis of the oscilloscope graph with a time/div setting of 2 μs yielded different time period data between the two types of insulating materials. Figure 7-10 shows the PD waveform under PDIV conditions for the time period analysis..

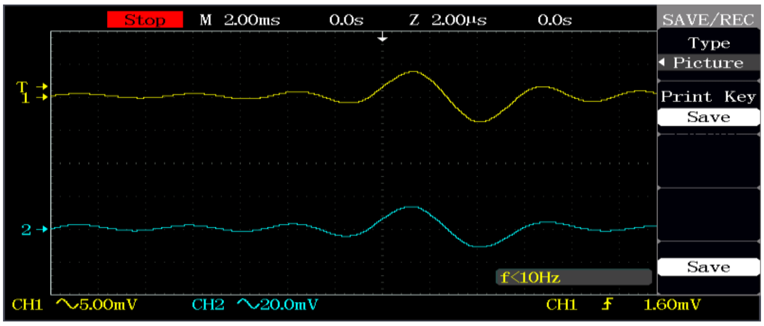

Figure 7. Positive PDIV waveform of automotive oil for time period analysis (T = 3 × 2 μs = 6 μs)

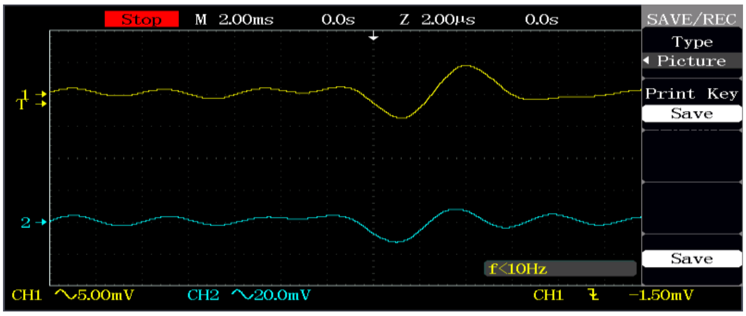

Figure 8. Negative PDIV waveform of automotive oil for time period analysis (T = 3.2 × 2 μs = 6.4 μs)

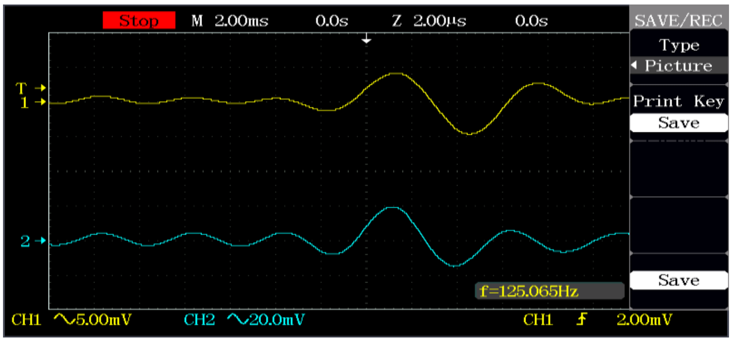

Figure 9. Positive PDIV wave of transformer oil for time period analysis (T = 3.4 × 2 μs = 6.8 μs)

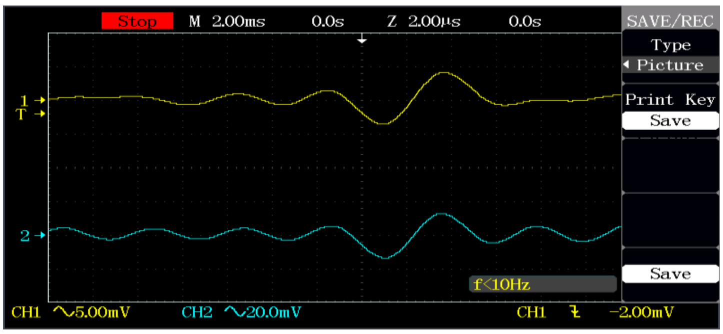

Figure 10. Negative PDIV waveform of transformer oil for time period analysis (T = 3.4 × 2 μs = 6.8 μs)

The results of the time period calculation show:

- Oli otomotif PDIV positif: 6 µs
- Oli otomotif PDIV negatif: 6,4 µs
- Minyak trafo PDIV positif: 6,8 µs
- Minyak trafo PDIV negative: 6,8 µs

The variation in the time period in automotive oil (6.0-6.4 µs) indicates instability in the insulation characteristics, while the transformer oil shows consistency with the same time period (6.8 µs) for both positive and negative polarities.

Figures 11-12 show a comparison of PD intensities at higher voltages (PDIV × 2), where a significant increase in waveform instability is observed.

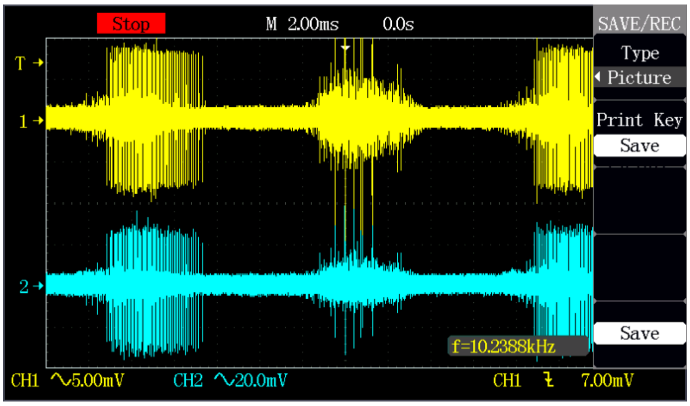

Figure 11. Visualization of positive PDIV × 2 waveform of automotive oil shows high instability.

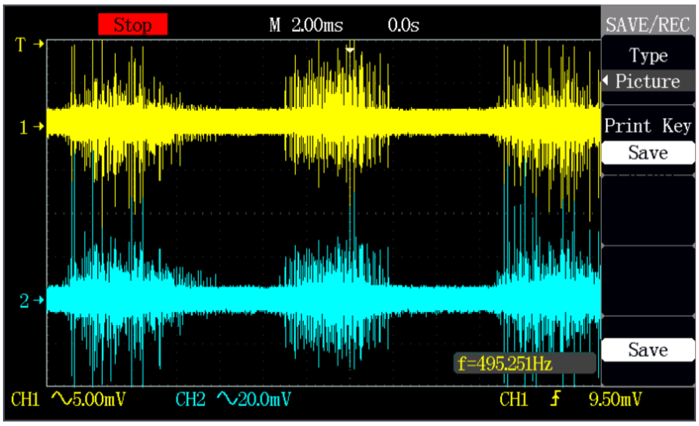

Figure 12. Visualization of positive PDIV × 2 waveform of transformer oil

Frequency Analysis

Based on the time period obtained, the PD frequency is calculated using the formula f = 1/T (Nugroho et al. 2019). Table 2 shows the results of the frequency calculation and comparison of PD characteristics.

Table 2. Comparison of PD Frequency and Time Period

	Automotive Oil		**Transformer Oil**	
	Positive	**Negative**	**Positive**	**Negative**
Time Period	6 µs	6,4 µs	6,8 µs	6,8 µs
Frequency	166,66 Hz	156250 Hz	147,058 Hz	147,058 Hz
Frequency Difference (%)	-	-6,67	-	0

A comparison of positive and negative PD characteristics in automotive oil shows a shorter time period and a higher PD frequency compared to transformer oil.

A higher PD frequency in automotive oil indicates a greater PD severity compared to transformer oil. The difference in positive and negative PDIV frequencies in automotive oil indicates non-uniform insulation characteristics, while transformer oil exhibits good consistency. This is consistent with research by (Ravichandran and Jayalakshmi 2019; Sun, Huang, and Huang 2012) which states that PD frequency correlates with the degree of insulation degradation.

Figure 13. shows a schematic graph comparing the PD frequency between automotive oil and transformer oil.

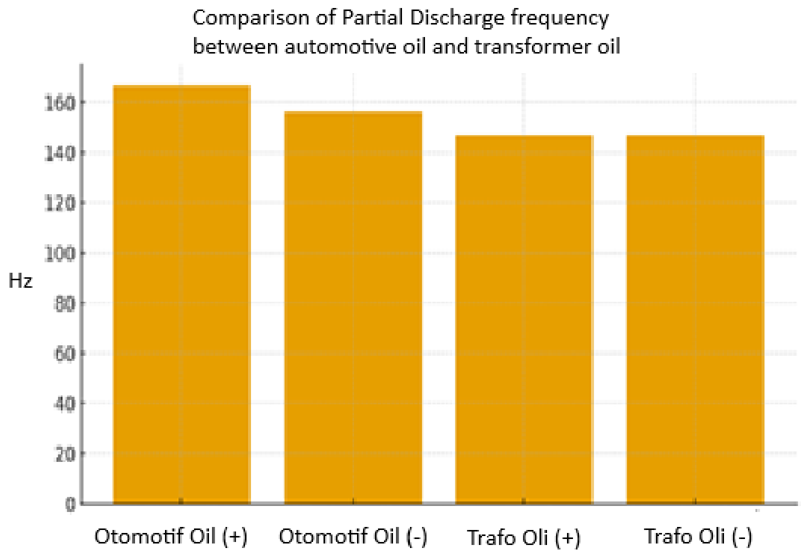

Figure 13. Comparison of PD frequencies of automotive oil and transformer oil at positive and negative PDIV

Comparison of Severity Levels Comparative analysis shows that PD in automotive oil has worse characteristics than transformer oil. Comparison parameters include:

a) PDIV: Automotive oil (2.0 kV) vs. transformer oil (2.35 kV), indicating weaker insulation strength (Feri, Jamaaluddin, and Ayuni 2025; Ravichandran and Jayalakshmi 2019)
b) Frequency: Automotive oil exhibits a 6.3-13.4% higher partial discharge frequency than transformer oil, indicating more intensive discharge activity.
c) Variability of characteristics: The difference in positive and negative PDIV frequencies in automotive oil (6.67%) compared to transformer oil (0%), indicates insulation instability.

The needle-plate electrodes used in this study were chosen because they can create a non-homogeneous electric field to facilitate partial discharge. This finding is consistent with research by (Korobeynikov et al. 2020), which states that the frequency of PD is positively correlated with the degree of degradation of the insulating material. Transformer oil has more stable and consistent insulating characteristics, in accordance with its function as a special insulator for electrical applications (Akbar 2018).

CONCLUSION

This study concludes that: (1) The PDIV of automotive oil (2.0 kV) is lower than that of transformer oil (2.35 kV), indicating the superior insulating strength of transformer oil; (2) The PD time period of automotive oil (6-6.4 μs) is shorter than that of transformer oil (6.8 μs); (3) The frequency of PD of automotive oil is higher and varies, while that of transformer oil is consistent; (4) PD in automotive oil insulation is greater than that of transformer oil; (5) Automotive oil has properties as a liquid insulating material. The conclusion of this research provides an understanding of the insulating characteristics of both materials and can be a reference for the application of electrical insulation systems for liquid insulating materials.

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