On Site Partial Discharge Measurement Of Mineral Oil Distribution Transformer Using Single Phase Induced Voltage Source , An Alternative To The Use Of Three Phase Induced Voltage Source

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***Abstract*—This paper investigates the offline Partial Discharge (PD) measurement technique using single-phase Induced Voltage Partial Discharge (IVPD) testing on a 1.5MVA, 22kV/433V mineral oil distribution transformer. PD is a critical phenomenon that indicates early-stage insulation degradation and, if unaddressed, could lead to severe transformer failures resulting in costly repairs and unplanned outages.**

The study evaluates and compares single-phase and three-phase experimental setups for PD measurement, emphasizing differences in methodology, practicality, cost-effectiveness, and result accuracy. Single-phase IVPD is highlighted for its practical advantages, such as simplified test setup, reduced complexity, and suitability for field applications, particularly when access to all three phases is challenging. In contrast, three-phase setups offer benefits like a more realistic simulation of operational conditions and the ability to analyze interphase interactions.

Through a detailed analysis of both configurations, the study demonstrates that single-phase IVPD provides a practical, efficient, and accurate method for detecting PD in distribution transformers. By highlighting its practicality and cost advantages alongside its reliability, this study supports the adoption of single-phase IVPD as a viable alternative for onsite PD testing, enabling improved transformer asset management and proactive maintenance strategies.

Keywords—Partial Discharge, Induced Voltage, Single Phase, Transformers

I. INTRODUCTION

The insulation integrity of transformers plays a crucial role in ensuring the reliability and longevity of power systems. Degradation of insulation over time can lead to partial discharge (PD), a phenomenon that, if undetected, may cause insulation failure, resulting in costly repairs, unplanned outages, and potential safety hazards. PD measurement is widely used as a diagnostic tool for early-stage insulation degradation, enabling utilities and industries to take corrective actions before failures occur. While conventional testing methods, such as applied voltage withstand tests and online PD monitoring, provide useful insights into insulation condition, they may not always be sufficient in replicating real operational stresses or identifying incipient faults that can lead to long-term degradation.

To address these limitations, Induced Voltage Partial Discharge (IVPD) testing has emerged as a more effective approach for evaluating insulation health. Unlike applied voltage tests, which are conducted at line frequency and may not fully stress the insulation system, IVPD applies a controlled overvoltage at elevated frequencies, allowing for the detection of latent defects that might not be revealed under conventional test conditions. [1][3] This method is particularly useful for assessing insulation quality in both factory acceptance tests and maintenance settings, where early fault detection is critical to preventing service disruptions. This further underscores the importance of offline PD testing, reinforcing the necessity of standardized methodologies to ensure reliable and repeatable diagnostic results. [4]

This paper focuses on the accuracy, feasibility, and practicality of single-phase IVPD testing for distribution transformers as a reliable offline PD detection method. By subjecting transformers to induced voltage stress in a controlled environment, this approach allows for detailed PD analysis, helping engineers and maintenance teams evaluate insulation performance, identify potential weaknesses, and implement targeted maintenance strategies. Through experimental validation, this study demonstrates that single-phase IVPD is an effective, scalable, and accurate tool for transformer diagnostics, offering a structured approach to improving asset management and ensuring the long-term reliability of power distribution networks.

II. CONFIGURATION

A. Three Phase Configuration

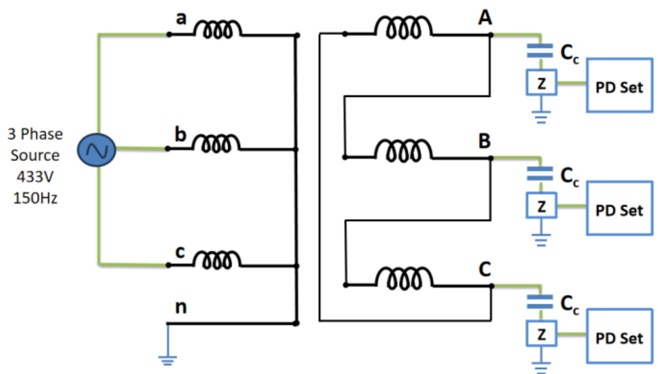

Figure 1 Three Phase Configuration, Dyn11

$$V_{ab} = V_{bc} = V_{ca} = 433V \tag{1}$$

$$V_{AB} = V_{BC} = V_{CA} = 22kV \tag{2}$$

$$V_A \text{ to ground} = V_B \text{ to ground} = V_C \text{ to ground} = 12.7kV \tag{3}$$

The three-phase Induced Voltage Partial Discharge (IVPD) test is a standardized method for evaluating transformer insulation under controlled overvoltage conditions. As outlined in standards, the test is conducted at an elevated frequency of 150Hz and a voltage level 1.3 to 1.8 times the rated operating voltage to effectively simulate real-world electrical stresses while minimizing core saturation effects. [2][3] As shown in Figure 1, the test setup consists of a high-frequency power supply which energizes the secondary winding of the transformer, while the primary winding is connected to measurement device. Partial discharge (PD) detection is performed using coupling capacitors (C_c), which are connected to the transformer's high-voltage terminals. These capacitors allow PD signals to be extracted. The PD signals are then processed and measured using a PD analyser compliant with IEC 60270 standards. [6] The test voltage is applied for a specific duration, during which PD activity is monitored to identify potential insulation weaknesses. However, the requirement for high-power test equipment and precise voltage control makes it more complex and resource-intensive compared to single-phase IVPD.

B. Single Phase Configurations

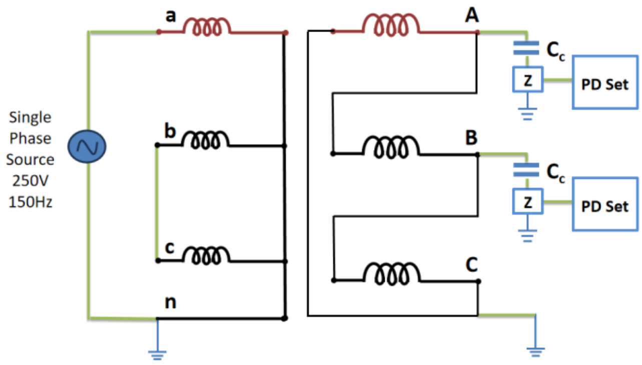

Figure 2 Single Phase Configuration with voltage at LV phase a (Dyn11 Transformer)

$$V_{an} = \frac{433V}{\sqrt{3}} = 250V \tag{4}$$

$$V_{bn} = V_{cn} = \frac{250V}{2} = 125V \tag{5}$$

$$V_{AB} = 22kV,\ V_{BC} = 11kV,\ V_{CA} = 11kV \tag{6}$$

$$V_A \text{ to ground} = 11kV,\ V_B \text{ to ground} = 11kV \tag{7}$$

$$V_C \text{ to ground} = 0V \tag{8}$$

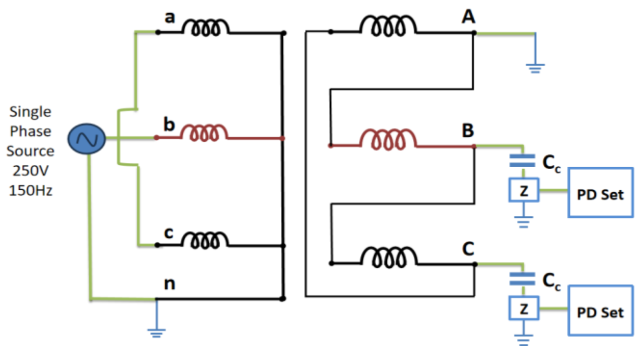

Figure 3 Single Phase Configuration with voltage at LV phase b (Dyn11 Transformer)

$$V_{bn} = \frac{433V}{\sqrt{3}} = 250V \tag{9}$$

$$V_{an} = V_{cn} = \frac{250V}{2} = 125V \tag{10}$$

$$V_{AB} = 11kV,\ V_{BC} = 22kV,\ V_{CA} = 11kV \tag{11}$$

$$V_B \text{ to ground} = 11kV,\ V_C \text{ to ground} = 11kV \tag{12}$$

$$V_A \text{ to ground} = 0V \tag{13}$$

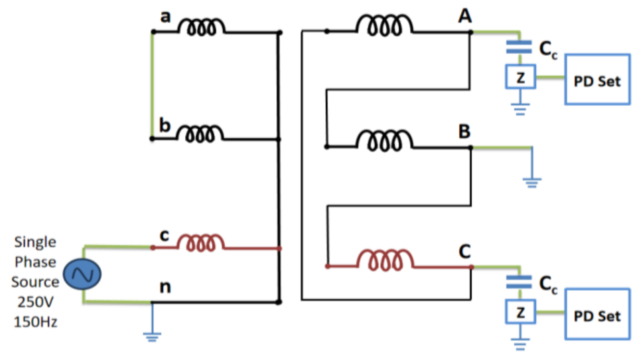

Figure 4 Single Phase Configuration with voltage at LV phase c (Dyn11 Transformer)

$$V_{cn} = \frac{433V}{\sqrt{3}} = 250V \tag{14}$$

$$V_{an} = V_{bn} = \frac{250V}{2} = 125V \tag{15}$$

$$V_{AB} = 11kV,\ V_{BC} = 11kV,\ V_{CA} = 22kV \tag{16}$$

$$V_A \text{ to ground} = 11kV,\ V_C \text{ to ground} = 11kV \tag{17}$$

$$V_B \text{ to ground} = 0V \tag{18}$$

As compared to the three-phase IVPD configuration, the single-phase test setup is significantly simpler and more straightforward, requiring only a single-phase voltage source for excitation as shown in Figure 2,3,4. In this setup, a 150Hz voltage source is applied between a line terminal and the neutral terminal of the transformer, rather than across two-line terminals as in the three-phase setup. The test voltage is determined by the rated line-to-line voltage of the low-voltage (LV) side, divided by $\sqrt{3}$ to account for the phase-to-neutral relationship. [5]

To ensure proper voltage distribution and prevent overstressing the line-to-ground insulation, one high-voltage (HV) terminal is grounded, while the two non-tested phases act as a voltage divider to ground potential. This configuration effectively maintains electrical balance, ensuring that the turn-to-turn insulation within the tested phase is fully stressed by the induced test voltage without exceeding the design limits of line-to-ground insulation. [5]

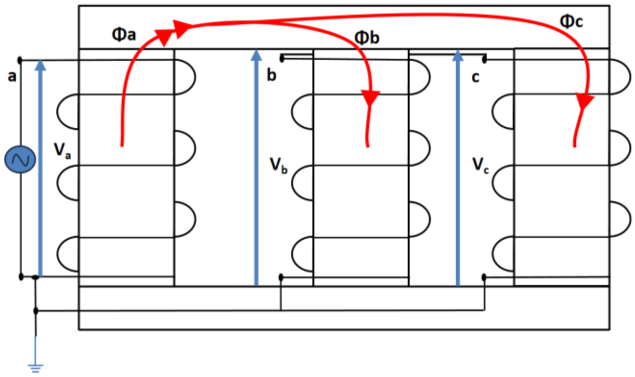

Figure 5 Flow of magnetic flux (Φ) in the iron core of transformer

$$\Phi_a = \Phi_b + \Phi_c \qquad (19)$$

$$\frac{d}{dt}(\Phi_a) = \frac{d}{dt}(\Phi_b + \Phi_c) \qquad (20)$$

$$\frac{d\Phi_a}{dt} = \frac{d\Phi_b}{dt} + \frac{d\Phi_c}{dt} \qquad (21)$$

$$N\frac{d\Phi_a}{dt} = N\frac{d\Phi_b}{dt} + N\frac{d\Phi_c}{dt} \qquad (22)$$

$$V_a = V_b + V_c \qquad (23)$$

Since b and c are shorted together, then V_b and V_c will be as follows

$$V_b = V_c \qquad (24)$$

$$V_b = \frac{V_a}{2} \qquad (25)$$

$$V_c = \frac{V_a}{2} \qquad (26)$$

The two unused line terminals on the star-connected winding of the LV side are short-circuited shown in Figure 5. This step minimizes magnetic asymmetry and ensures that the insulation is subjected to a consistent test voltage. Consequently, the voltage detected by the partial discharge (PD) measurement system, referenced to ground potential, is approximately half the total voltage applied across the tested coil.

The test setup for IVPD testing varies depending on the vector group configuration of the distribution transformer, as different winding connections influence the voltage distribution and grounding strategy during testing. [5] While various vector groups exist, this paper focuses specifically on the Dyn11 vector group, which is one of the most used configurations for distribution transformers in Singapore. The test methodology and results presented in this study are therefore tailored to the unique electrical characteristics of Dyn11 transformers, ensuring relevance to real-world applications in the local grid infrastructure.

III. OFF-LINE MEASUREMENT

The configuration as mentioned for both the 3 phase and single phase will be implemented on a mineral oil distribution transformer Dyn11. The specification of the transformer is as listed below:

TABLE I. TRANSFORMER DETAILS

	High Voltage	**Low Voltage**
Rating	1.5MVA	
Rated Voltage (V)	22kV	433V
Rated Current (A)	39.4A	2000A
Vector Group	Dyn11	
Year	2011	

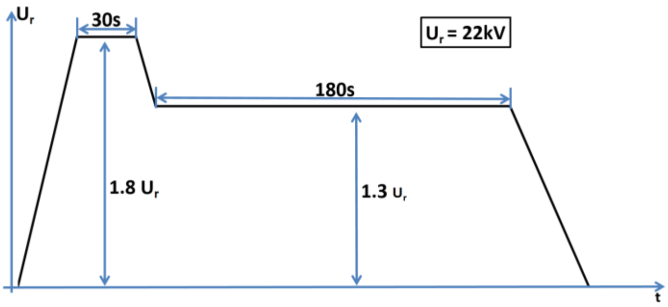

Figure 6 Voltage Application for Routine Partial Discharge Test

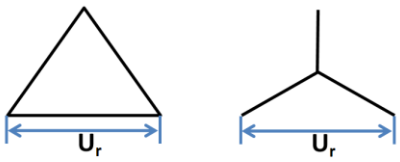

Figure 7 Voltage Application for Routine Partial Discharge Test

As the tested distribution transformer is a service-aged unit with detected partial discharge (PD) activity. The test procedure is conducted at 150Hz which consists of a pre-stress phase, where a phase-to-phase voltage of 1.8 Ur (where Ur is the rated voltage) is applied for 30 seconds. Immediately following this, without interruption, a phase-to-phase voltage of 1.3 Ur is maintained for 3 minutes, during which PD activity is monitored and recorded, as shown in Figure 6. [2][3] This approach ensures that the insulation is sufficiently stressed for defect detection while minimizing the risk of further degradation in the aged transformer. For this paper, we will focus on the 1.3Ur PD measurements results for both the 3 phase and the single-phase configurations.

IV. RESULTS

A. Three Phase Test Source at 150Hz

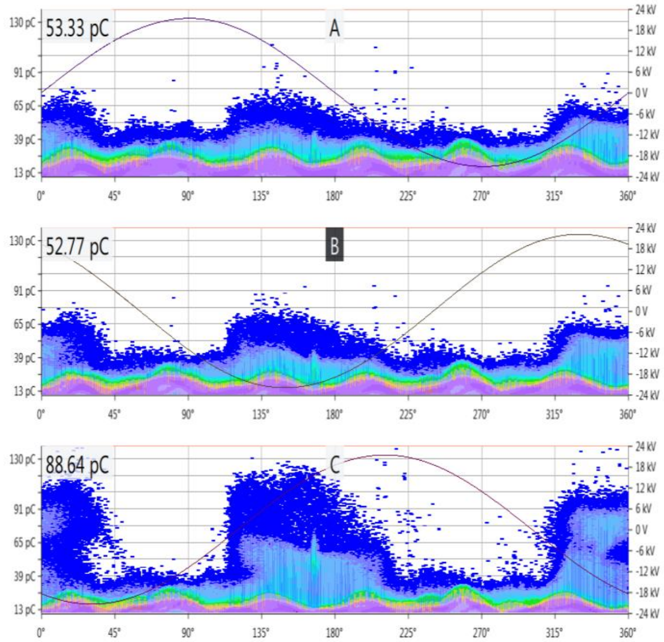

Figure 8 PD activity detected at HV Terminal A, B and C at 150Hz

The test results reveal a notable discrepancy in the activity among the three HV terminals. HV terminal C shows higher PD magnitude compared to HV terminal A and B. The PD measurements at the three HV terminal were measured synchronously, and it is concluded that the PD activity is nearer to HV terminal C. The PD activity detected at HV terminal A and B are crossed coupled from HV terminal C

B. Single Phase Test Source at 150Hz

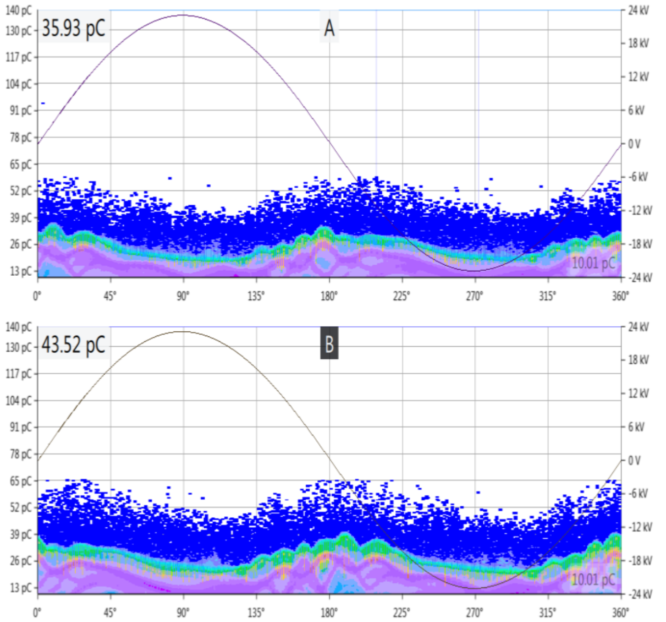

Figure 9 No PD activity detected at HV Terminal A, B of Figure 2 at 150Hz

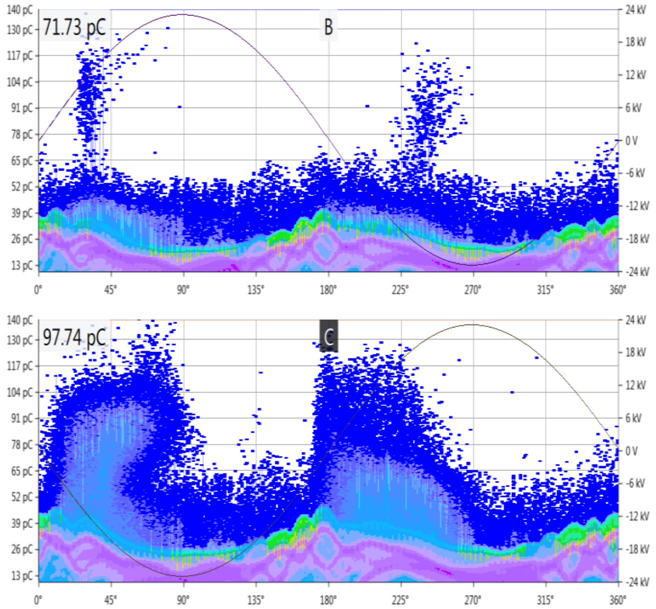

Figure 10 PD activity detected at HV Terminal B, C of Figure 3 at 150Hz

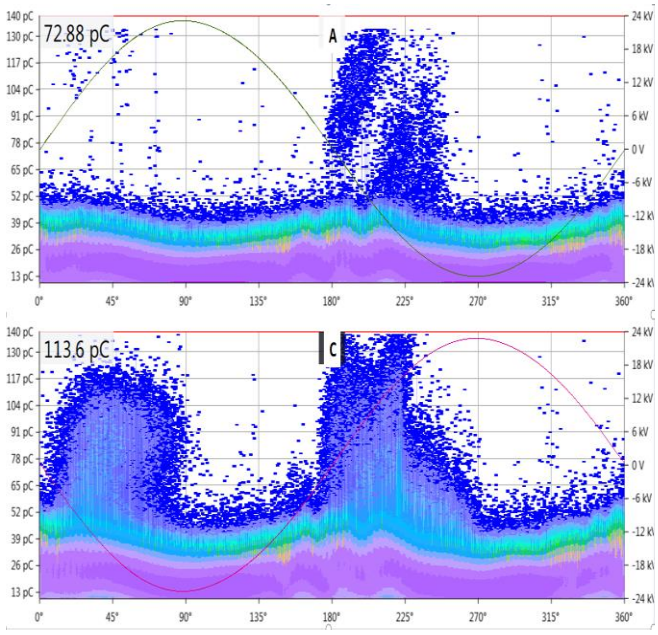

Figure 11 PD activity detected at HV Terminal A, C of Figure 4 at 150Hz

Using single phase IVPD 150Hz source, PD was detected at HV terminal C, as shown in Figure 10 and 11. This is consistent with PD activity detected at HV terminal C using three phase IVPD source as shown in Figure 8. At Figure 9 for single phase IVPD source, there is no PD detected at HV terminal A and B. This support the conclusion of the 3 phase IVPD test, that there is cross coupling of PD at HV terminal A and B.

Subsequently, the test configuration illustrated in Figure 4 was employed to investigate the influence of varying test frequencies on the Phase-Resolved Partial Discharge (PRPD) patterns observed at Terminals A and C of the transformer. This setup enabled a controlled analysis of how different excitation frequencies impact the characteristics, magnitude, and phase positioning of PD activity, providing deeper insights into the insulation behavior under different stress conditions. By capturing the PRPD patterns across a range of frequencies, this approach allowed for a comparative evaluation of the sensitivity and consistency of PD detection in response to frequency variation, contributing to a more comprehensive understanding of insulation condition diagnostics.

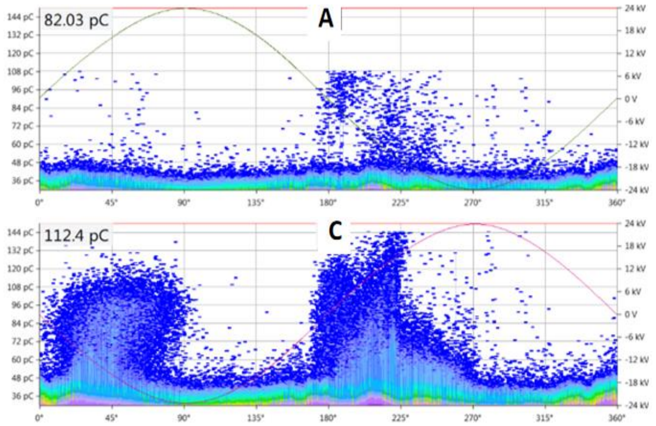

Figure 12 PD activity detected at HV Terminal A, C of Figure 4 at 100Hz

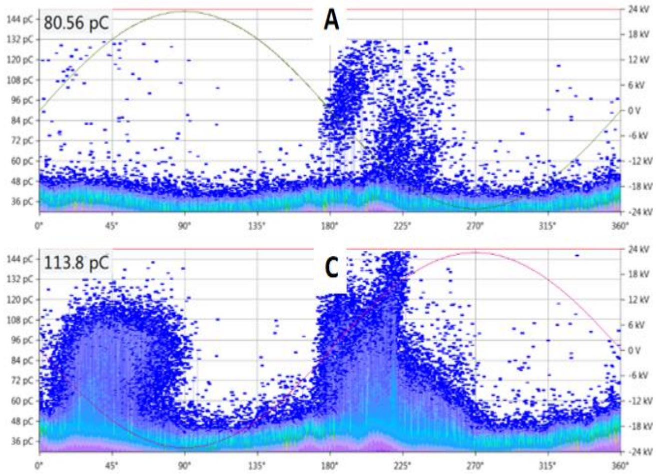

Figure 13 PD activity detected at HV Terminal A, C of Figure 4 at 125Hz

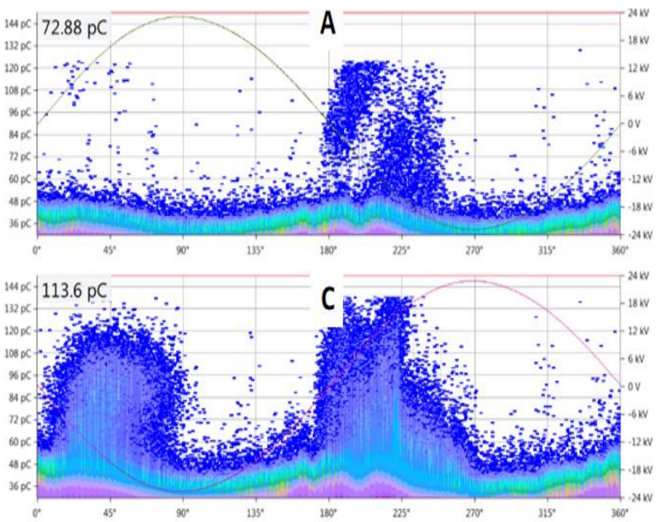

Figure 14 PD activity detected at HV Terminal A, C of Figure 4 at 150Hz

TABLE I. SUMMARY OF VARIED FREQUENCY

Frequency (Hz)	HV Terminal A (pC)	HV Terminal C (pC)
100 Hz	82.03	112.4
125 Hz	80.56	113.8
150 Hz	72.88	113.6

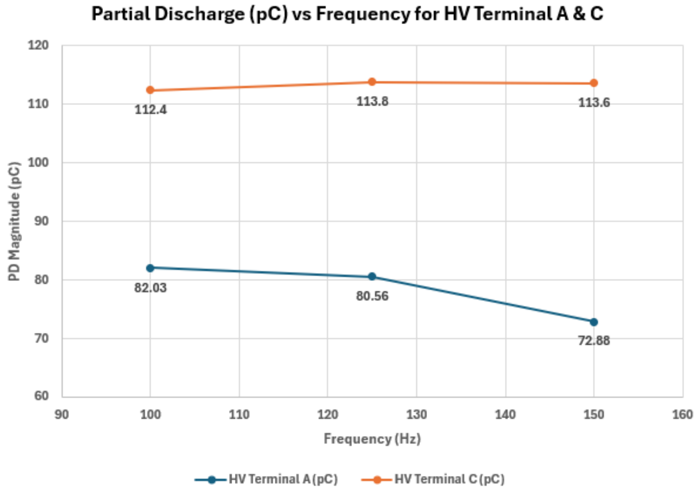

Figure 15 Partial Discharge vs Frequency at HV Terminal A & C

The test results show minimal variation in both the PRPD pattern and discharge magnitude across the range of test frequencies applied for 100 Hz, 125 Hz and 150Hz as seen in Figure 12, 13 and 14. This consistency suggests that the frequency within this range has limited influence on the overall discharge behaviour as seen in Table I and Figure 15, reinforcing the reliability of IVPD testing under standard conditions. It is noteworthy that 150 Hz is commonly used by transformer OEMs during factory acceptance tests.

The 22 kV transformer under test features delta-connected windings, meaning each winding is associated with two high-voltage terminals. Due to this configuration, it is not possible to isolate PD activity to a single-phase winding with certainty. As a result, while PD was clearly detected at specific terminals, no definitive conclusion can be drawn regarding which individual phase winding is the source of the discharge.

V. CONCLUSION

This study has demonstrated that single-phase Induced Voltage Partial Discharge (IVPD) testing is an effective and practical method for detecting partial discharge (PD) activity in the 1.5MVA, 22kV/433V mineral oil distribution transformer. As discussed in the introduction, ensuring insulation integrity is critical for maintaining the reliability of power systems, and while traditional insulation assessment methods provide valuable insights, they may not always replicate real-world operating stresses. IVPD addresses these limitations by applying controlled overvoltage conditions, enabling more accurate defect detection. [2][3]

Through experimental validation, the results obtained on-site confirm that single-phase IVPD can effectively identify

PD activity using a smaller, more portable test setup compared to conventional three phase testing configurations. The simplified test arrangement reduces complexity while maintaining high sensitivity and diagnostic accuracy, making it an ideal solution for field applications where access to all three phases may be challenging. Furthermore, the offline nature of IVPD allows for comprehensive insulation assessments without the need for prolonged service interruptions, aligning with the best practices for transformer maintenance and diagnostics. [4]

By proving that single-phase IVPD testing can reliably detect PD with minimal equipment, this study highlights its feasibility, efficiency, and practicality for both routine maintenance and condition-based monitoring of distribution transformers. The findings reinforce IVPD's role as a valuable tool for proactive asset management, ensuring early fault detection, improved transformer reliability, and reduced risk of unexpected failures in power distribution networks. Future work could further refine the methodology by exploring its application across a wider range of transformer designs and operating conditions, optimizing its effectiveness as a standard diagnostic approach.

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