Identification Of Partial Discharge Phenomena In Glass Insulator Testing Using Hfct

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Abstract

Insulators are vital components in electrical power transmission systems, yet they are susceptible to degradation caused by electrical and environmental stresses. This study aims to analyze Partial Discharge (PD) characteristics in glass and porcelain insulators as an early indicator of insulation failure. Experimental testing involved a step-wise increase in AC voltage from 5 kV to 20 kV, alongside simulations of extreme conditions using exposure to a flame to trigger flashover phenomena. Discharge activity was detected using a PMDT PDetector instrument in accordance with the IEC 60270 standard. The results indicate that within the 5–15 kV range, the insulators exhibited stable performance with PD magnitudes below 20 dB. However, at 20 kV, a significant anomaly was observed in the glass insulator, characterized by a magnitude spike reaching 174 dB across the 360° phase, signaling a transition toward total failure. Phase-Resolved Partial Discharge (PRPD) pattern analysis demonstrated that thermal stress drastically lowers the air breakdown voltage threshold near the insulator surface. The study concludes that high-frequency detection methods are highly effective for the non-intrusive monitoring of insulation conditions, thereby helping to prevent catastrophic failures in electric power systems.

Keywords: *Partial Discharge, Glass Insulator, HFCT, Flashover, PMDT PDetector.*

I. INTRODUCTION

A transformer is an electromagnetic device that transforms voltage and current levels to meet specific system requirements. Operating based on Faraday's law of induction, transformers are classified in various ways depending on their operating voltage levels and specific applications within electric power systems. Generally, power generation plants are located far from end-users; consequently, transmitting power from the plant to the load requires high voltages such as 150 kVor extra-high voltages, such as 500 kV. Upon reaching the load center (the point of consumption), the voltage is stepped down to a medium voltage of 20 kV.

A High-Frequency Current Transformer (HFCT) is an electromagnetic sensor specifically designed to detect high-frequency transient current pulses triggered by partial discharge (PD) activity.

Unlike conventional current transformers, the HFCT utilizes a high-permeability ferrite core, enabling operation across a wide frequency bandwidth typically ranging from a few hundred kHz to tens of MHz. A key advantage of this technology is its non-intrusive nature; the sensor can be installed on a grounding conductor without disrupting the ongoing operation of the power system. With its ability to capture nanosecond-duration signals, the HFCT can extract critical PD parameters such as charge magnitude and discharge phase patterns making it a highly effective instrument for characterizing the insulation of high-voltage equipment, including ceramic insulators.

Glass insulators are external insulation components made of toughened glass that serve as both mechanical supports and electrical separators in power transmission systems.

Structurally, these insulators possess high dielectric strength and resistance to aging caused by ultraviolet exposure and environmental pollution. A unique characteristic of glass insulators is their transparency, which allows for the early detection of internal defects through direct visual inspection. However, under operating conditions involving high humidity or the accumulation of surface contaminants, these insulators are susceptible to surface discharge phenomena.

If allowed to persist, this partial discharge activity can trigger thermal degradation, ultimately leading to the complete failure or "self-shattering" of the insulator. High-Frequency Current Transformer (HFCT) sensors offer a superior, non-intrusive diagnostic approach. HFCTs are capable of capturing transient current pulses with very short rise times in the MHz frequency range—a key characteristic of partial discharge signals. By installing an HFCT on the grounding path, discharge activity in ceramic or glass insulators can be detected without compromising the stability of the operating system. The data obtained via the HFCT can then be used to analyze Phase-Resolved Partial Discharge (PRPD) patterns to identify the type and severity of defects in the insulator.

Partial discharge testing of suspension insulators particularly at voltage levels relevant to medium-voltage distribution systems, such as 20 kV is crucial for evaluating insulator dielectric quality both prior to installation and during maintenance. The 20 kV level is significant, as even minor insulation defects can easily trigger measurable partial discharge activity.

II. LITERATURE REVIEW

Glass insulators are critical components in electric power systems, manufactured from toughened glass via a thermal tempering process to achieve optimal mechanical strength and dielectric stability. Structurally, this material offers advantages over porcelain due to its homogeneous and non-porous nature, thereby minimizing the risk of premature aging caused by moisture absorption. Key technical advantages of glass insulators include their self-cleaning capability regarding pollutants and their transparency, which facilitates the identification of both internal and external damage as Fig.1.

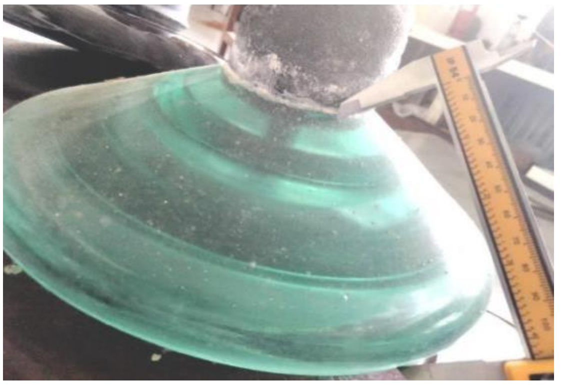

Figure 1. Glass insulator

Glass insulators are frequently exposed to pollution and moisture, which trigger the formation of a conductive layer on their surfaces. This condition gives rise to leakage currents that are periodically interrupted by localized heating—a phenomenon known as dry-band formation. This process is a primary trigger for partial discharge (PD) activity on the insulator surface (see Figure 2). Persistent PD activity subjects the glass structure to significant thermal and electrical stress, potentially leading to total insulation failure or flashover, thereby threatening the stability of the power transmission system. The conditions under which PD occurs within air gaps can be estimated using Paschen's law, which relates gas breakdown voltage to pressure and the distance between electrodes within the gas, as fig.2

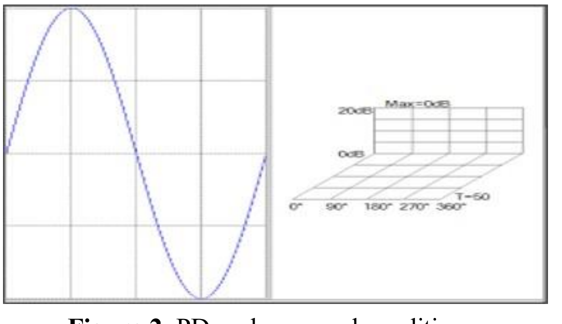

Figure 2. PD under normal conditions.

Analyzing partial discharge characteristics in glass insulators requires instruments with high frequency sensitivity, given that PD pulses have extremely short durations on the nanosecond scale.
Partial discharge charge;

$$q = Cc \cdot \Delta V \quad \text{...............(1)}$$

Energy Partial Discharge ;

$$W \approx 21q \cdot Vcacat \quad \text{..........(2)}$$

Power Partial Discharge $P \approx \sum(qi \cdot Vaplikasi \cdot f)$.(3)

III. RESEARCH METHODS

This study aims to analyze the characteristics of Partial Discharge (PD) a localized electrical discharge phenomenon bridging a small portion of the glass insulation on a conductor. This phenomenon is identified as a crucial indicator of micro-defects or dielectric weaknesses on the surface or within high-voltage insulation materials prior to total failure. In this test, the glass insulator sample is connected to a high-voltage source via an electrode system. The experimental procedure involves incrementally increasing the AC voltage to observe the PD inception threshold in the material. To simulate extreme environmental conditions and the effects of contamination that could trigger catastrophic failure, a flame source is directed at the insulator surface to represent the thermal stress that induces flashover.

Fluctuations in the magnitude of Partial Discharge (PD) values in the range of 10 dB to 20 dB at voltage levels of 5 kV to 15 kV reflect the initial phase of dielectric instability that is sensitive to changes in mechanical or thermal loads. To obtain a stable and localized indication of PD activity, the test procedure must be complemented by continuous monitoring of the Phase-Resolved Partial Discharge (PRPD) pattern. This PRPD pattern allows the separation of random environmental noise from the actual PD pulses synchronous with the AC voltage waveform. When the pulse clusters begin to concentrate consistently at a specific phase angle (usually near the peaks of the positive and negative cycles), it is a strong indicator that partial failure activity has locked on to a specific point of insulation weakness.

Once a stable emission pattern is identified, the localization of high electrical stress areas can be confirmed using a combination of High-Frequency Current Transformer (HFCT) sensors in the grounding system and ultrasonic acoustic sensors along the physical equipment. By analyzing the time-of-flight differences between fast electromagnetic signals and slower acoustic signals, the geometric coordinates of electrical hotspots can be mapped with high accuracy. The stabilization of the magnitude within a certain dB range accompanied by a shrinkage of the PRPD cluster area confirms that the insulation degradation is no longer the result of a transient external phenomenon, but rather a manifestation of the intense electric field concentration in internal defects such as voids or material delamination.

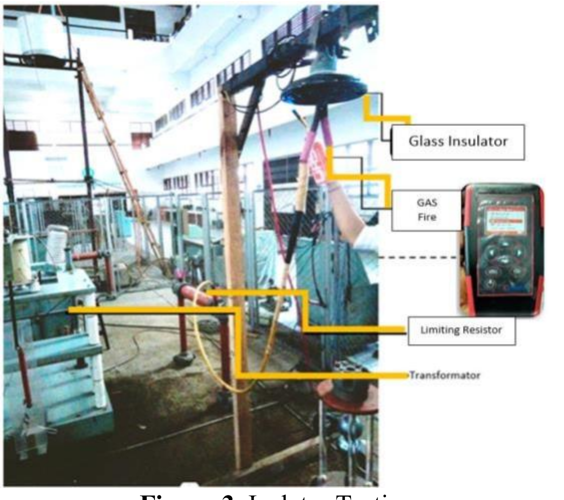

Figure 3. Isolator Testing

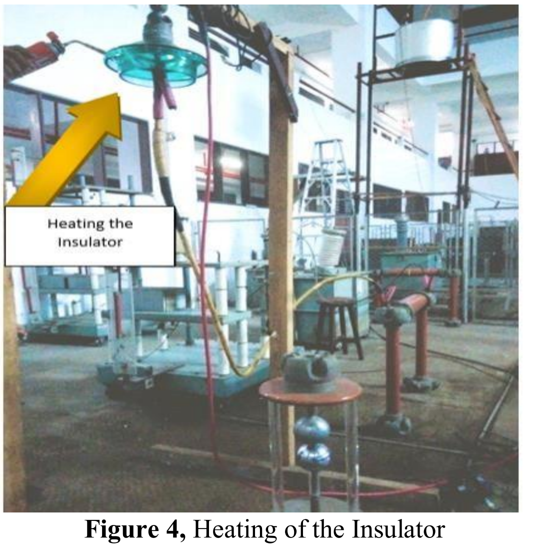

Figure 4, Heating of the Insulator

IV. RESULTS AND ANALYSIS

4.1 Data analysis

Testing in dry and clean conditions with a frequency of 50 Hz, the data shows that the Partial Discharge (PD) activity in glass insulators has a characteristic magnitude that varies with the increase in test voltage. In the voltage range of 5 kV to 15 kV, the highest magnitude recorded is at a relatively low and stable level, which is between 10 dB to 20 dB. This phenomenon indicates that at this voltage level, the charge is still localized and has not shown signs of massive insulation degradation, in accordance with the expected characteristics of glass insulators that have high dielectric strength in clean conditions.

PD activity tends to be dominant at 90° and 270° phase angles, which represent the positive and negative peaks of the sinusoidal wave.

This confirms the occurrence of surface discharge or corona phenomena in areas of highest electrical stress. However, a significant anomaly was found in the 20 kV test, where a magnitude spike of 174 dB occurred at 360°. This extreme spike indicates a very large discharge intensity, which technically indicates that the insulator is entering a critical phase leading to total insulation failure or flashover (Table 1).

Table 1. Data Measurement

Glass Unit	PD Magnitude (Highest)	PD Magnitude (Lowest)	Phase °)
5 kV	20 dB	5 dB	90°
	5 dB	4 dB	180°
	20 dB	4 dB	270°
	3 dB	3 dB	360°
10 kV	10 dB	3 dB	90°
	7 dB	2 dB	180°
	17 dB	0 dB	270°
	2 dB	0 dB	360°
15 kV	10 dB	8 dB	90°
	15 dB	8 dB	180°
	17 dB	10 dB	270°
	2 dB	2 dB	360°
20 kV	15 dB	10 dB	90°
	11 dB	4 dB	180°
	13 dB	4 dB	270°
	174 dB (Anomaly)	2 dB	360°

Testing Conditions & Reference Standards:
- Environmental Status: Dry and clean
- Threshold / Temperature: >100°
- Standard Compliance: IEC 60270
- System Frequency: 50 Hz

The drastic increase in magnitude at 20 kV voltage in the final phase of the cycle (360°) is most likely triggered by the thermal stress factor from the simulated flame gas directed at the insulator surface. The high temperature of the flame causes a decrease in the air density around the glass surface, thus facilitating air ionization that leads to large discharges. These results prove that although glass insulators have good insulating properties under normal conditions, exposure to extreme thermal contamination significantly lowers their breakdown voltage threshold. These findings provide strong validation for the use of the HFCT method and the PMDT PDetector instrument in accurately identifying critical points of insulation failure based on the IEC 60270 standard. Figure 5. At the test voltage is increased to 20 kV.

At this stage, an extreme PD magnitude spike occurs, reaching 174 dB at a 360° phase angle. This value indicates a thousands-fold increase in discharge intensity compared to the previous stage.

Technically, this spike indicates that the insulator is no longer experiencing only a microscopic partial discharge but has entered a transition phase leading to total insulation failure, or flashover, which bridges the entire creepage distance, as fig,5

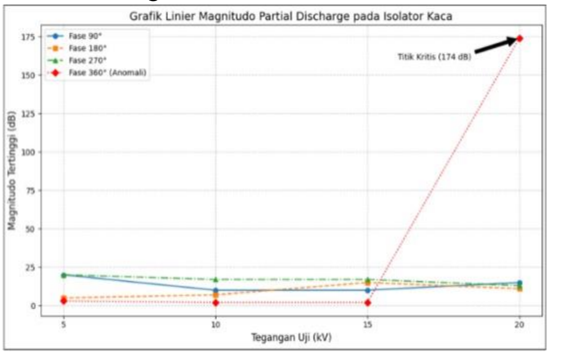

Figure 5. PD Magnitude Graph

The spike of 174 dB in the 360° phase is closely related to the simulation of extreme environmental conditions in the form of exposure to flame gas on the insulator surface. The high temperature generated by the flame source causes thermal expansion of the air around the glass surface, which directly reduces the density of air molecules. This decrease in density makes the electron ionization process easier, so that at a voltage of 20 kV, the penetrating strength of air decreases drastically and triggers a large charge release which is recorded accurately by the high frequency sensor PMDT instrument, figure 6.

PD characterization using high frequency detection method is able to map the critical threshold of a glass insulator against environmental stress. The change in magnitude from stable category (below 20 dB) to destructive category (above 100 dB) provides a very valid indication for power system operators to take preventive action. The picture strengthens the argument that HFCT-based PRPD pattern monitoring is a crucial diagnostic strategy in maintaining the reliability of distribution and transmission systems from the risk of unexpected insulation failure in insulators.

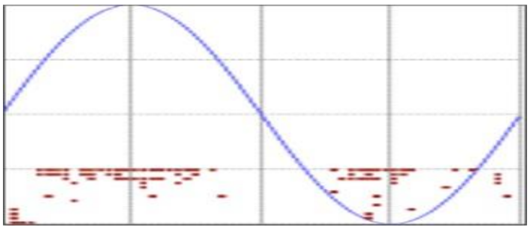

Figure 6a. PD magnitude conditions

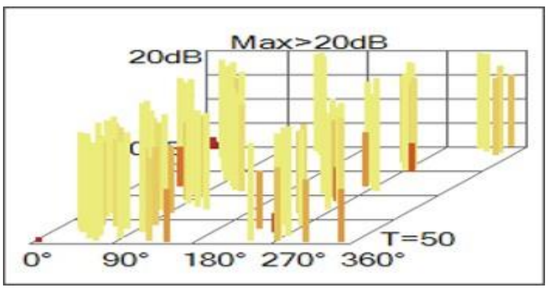

Figure 6b. Surge conditions at 10 KV

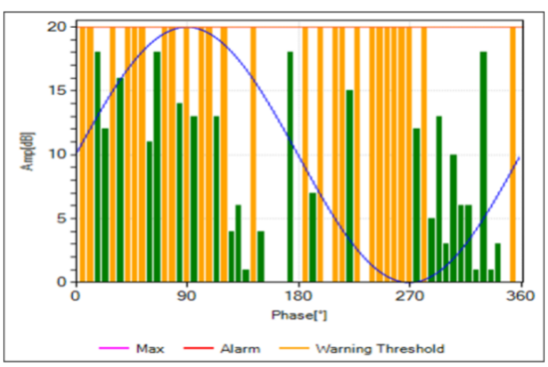

Figure 6c. 10 KV Surge Condition Graph

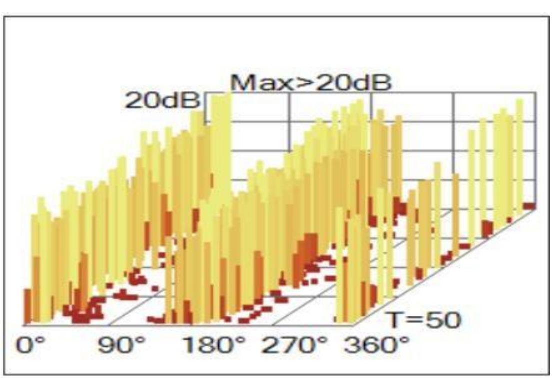

Figure 6d. Surge conditions at 20 KV

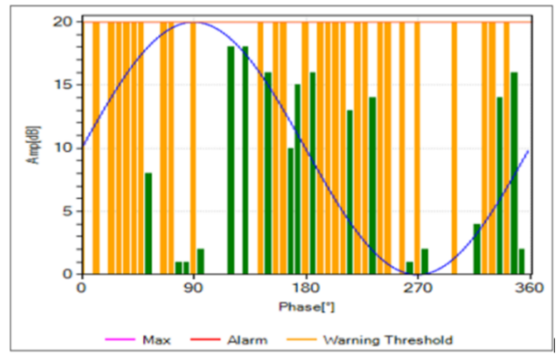

Figure 6d. 20 KV Surge Condition Graph

V. CONCLUSION

5.1 Conclusion

Partial Discharge (PD) characteristics of glass insulators have a significant dependence on the test voltage level and extreme environmental conditions. In the voltage range of 5 kV to 15 kV, the insulator shows stable dielectric integrity with the discharge magnitude remaining below the 20 dB threshold, indicating that the discharge activity is still localized on the surface. However, a very extreme magnitude spike reaching 174 dB at a voltage of 20 kV at a phase angle of 360° occurs, indicating the transition from partial discharge to flashover phenomenon, which is triggered by a decrease in air density due to thermal stress from the simulated flame gas. The use of the PMDT PDetector instrument based on the IEC 60270 standard for tools as a non-intrusive diagnostic method in mapping insulation health in real-time. The high-frequency sensor's ability to capture phase pattern anomalies (Phase Resolved Partial Discharge) provides accurate parameters to identify critical points of failure before permanent damage or self-shattering phenomena occur in glass materials.

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