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Understanding the partial discharge activity generated due to particle movement in a composite insulation under AC voltages

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ABSTRACT

The UHF signals are generated due to partial discharges formed by particle movement in Gas Insulated Switchgears (GISs). It is observed that the bandwidth of UHF signals generated due to partial discharges formed by particle movement in GIS is independent of operating pressure and the applied voltage. The levitation voltage of the particle sitting on the dielectric barrier is high compared to that of it on the ground electrode. When a particle is present in between the barrier and an electrode, at certain voltage level the movement of particle will be in pseudo resonance with the applied voltage frequency. When the particle is on the barrier, on application of voltage the particle moves to the center of the electrode axis causes discharges thereby radiating UHF signals, with its dominant frequency in the range of 3–4 GHz, which is much different from that of the UHF signal generated due to partial discharges formed by particle movement. When the particle moving between the high voltage electrode and the barrier, at some time its motion get collapses and the particle settles in the low field region away from the axis of the electrode and generates UHF signals having characteristics of UHF signals generated due to corona discharge.

1. Introduction

Power transmission at higher voltages has acquired immense prominence in recent times due to its inherent advantages. It has become essential to design and develop a compact, cost effective and reliable insulation structure for enhancing the reliability of power equipment operated at higher voltages. Gas Insulated Switchgears (GISs) has been widely used in the power system network and it is essential to monitor the condition of insulation structure, during operation, for safe operation of power system. The breakdown strength of the insulating gas medium is generally increased, in a given volume, by inserting a solid insulating material in the electrode gap. This effect is called as Barrier effect [1,2]. The epoxy resin spacers used in GIS are critical component for safe operation of GIS. These spacers act as a mechanical support to the current carrying conductor and as a barrier in the electrode gap and could enhance the breakdown strength of the medium. The profile of the spacer is adjusted in such a way that the electric field in the medium is constant [3]. Thus, GIS is a multi dielectric system. Probabilistic risk assessment is one of the useful tool for system operators to carry out risk assessments for different failure conditions [4]. One of the major problems in GIS is the occurrence of partial discharge due to particle movement [5–8].

In recent times extensive research works are carried out to understand the partial discharge activities in insulation systems in order to improve power system performance and reliability [9,10]. Nafer et al., carried out studies on locating PD activity in power transformers and have concluded that neutral current measurement of the transformer winding has useful information regarding PD location [11]. Rizk et al., studied particle dynamics in SF_6 gas under direct voltage and concluded that viscous drag force can play a major role on particle velocity and charge transfer [12]. Bartnikas et al., reported that the rise and fall time of the partial discharge current signal formed in the SF_6 insulation medium are of few nanoseconds [13]. When incipient discharges initiated by partial discharge are due to particle movement, the generated current pulses involves rise and fall times of a nanosecond or less, signals in the Ultra High Frequency (UHF) range i.e., 300–3000 MHz are excited [14–16].

Having all these aspects in view, a methodical experimental study was carried out to characterize the UHF signal, generated due to particle movement, causing partial discharge, under AC voltage, in a multi dielectric system. It was performed by placing a conducting particle: (i) over the ground electrode in a sphere-plane electrode configuration with a barrier in the electrode gap and (ii) by placing the conducting particle over the barrier insulation placed in the sphere-plane electrode gap. The influence of barrier on the variations in partial discharge magnitude with time was also investigated.

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2. Experimental

The experimental setup used for the measurement of UHF signal generated by partial discharges formed due to particle movement in the SF_6 gas filled system, under AC voltages, is shown in Fig. 1. The experimental setup is sectioned into four parts such as the high voltage source, the gas filled test cell (Test Apparatus), Phase Resolved Partial Discharge (PRPD) Analysis system and the UHF sensor connected to spectrum analyzer/oscilloscope respectively.

2.1. High voltage source

The high AC voltage of power frequency is produced from a transformer rated for 5 kV A, 50 Hz, 100 kV unit. The AC voltage is measured using the capacitance voltage divider. In the present study, the AC voltage was increased at a rate of 300 V/s up to the required test voltage level.

2.2. Test cell details

The test cell used in the present work is shown in Fig. 2. It consists of two electrodes in a cylindrical container filled with SF_6 gas. The upper electrode is a spherical electrode of diameter 25 mm and the lower one was a slightly concave shape dish electrode of 50 mm diameter to contain the particle. Eventhough the bottom electrode is slightly concave, the field between the electrode gap is uniform. The gap between two electrodes is maintained at 10 mm. A circular epoxy nano-composites material of thickness 1 mm is placed at different position in the electrode gap. To understand the size of the particle on levitation voltage, different size of the particle (0.6, 1.0, 2.0, 2.5 and 3.0 mm) were used. For the purpose of understanding the particle discharge formation due to particle movement, a aluminum ball of diameter 2.5 mm was used.

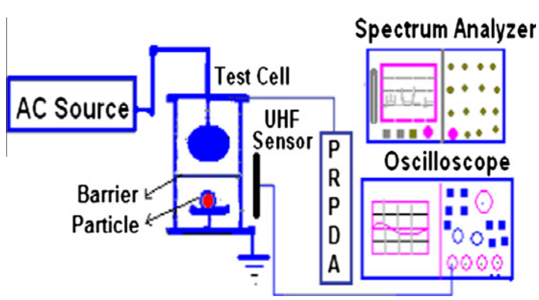

Fig. 1. Experimental setup.

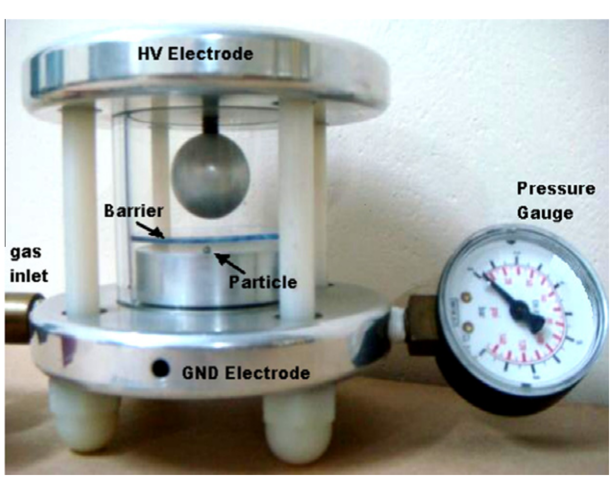

Fig. 2. Photograph of the test cell.

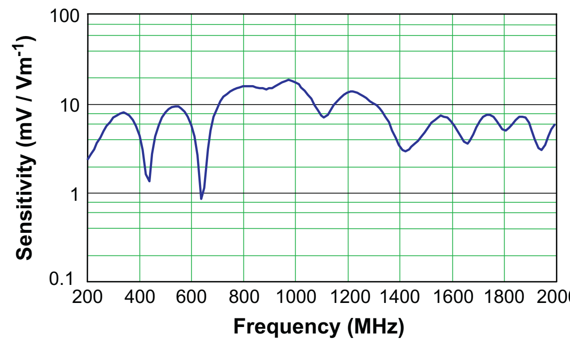

Fig. 3. Frequency response of the UHF sensor.

2.3. Partial discharge (PD) measurement system

Conventional PD measurement was carried out using Lemke partial discharge analysis system. The PD measurement system was then calibrated using a commercial PD calibrator in the range 5–5000 pC. ϕ–Q analysis (PRPDA) was carried out to understand the occurrence of discharge in the phase of applied AC voltage.

2.4. UHF sensor details

UHF sensors used for partial discharge detection must have broadband response, the reason being the frequency content of signals from a PD varies depending on its location and the signal path. The sensor used in the present study is a broadband type sensor, which is placed at a distance of 20 cm away from the test cell. Fig. 3 shows the sensor frequency response as measured using a UHF calibration system [17]. The output of the UHF sensor is connected to the spectrum analyzer/high bandwidth digital storage oscilloscope. The UHF signals were captured using a real time digital storage oscilloscope (LeCroy four channel digital real time oscilloscope, 3 GHz bandwidth, operated at 20 GSa/s) with an input impedance of 50 Ω. A spectrum analyzer (Hewlett Packard E4402B ESA-E-Series) was also used to measure signal frequency in the range 100–3 GHz with a resolution bandwidth of 3 MHz.

3. Results and discussion

3.1. Analysis of levitation voltage and particle movement

A free conducting particles at rest in the electrode gap, under high electric field, acquires certain charge and levitates once the electric force exerted by the particle exceeds the applied electric field and the combined gravitational and drag forces. Under AC voltage, the particle in the electrode gap acquires certain charge, due to which one of the several phenomena can occur. (i) The particle hovers near to the ground electrode, (ii) The particle lifts off and keeps bouncing in the electrode gap randomly (iii) Pseudo resonance can occur depending on the local electric field (iv) Reverse bouncing that may occur after the motion collapse because the electrical field gradient force drives the particle inwards of the gap. (v) Fire fly phenomena and (vi) Levitated particle moving in the electrode gap collapses and moves to the low field region. During all these process of movement, when the particle comes in contact with the electrode, charge transfer between the particle and the metal electrode occurs, generating partial discharges [18]. In the present work, the levitation voltage is defined as the voltage at which the first UHF pulse captured in the oscilloscope through