Influence of Accumulated Surface Charges on Partial Discharge Activity at Micro Gap Delamination in Epoxy GIS Spacer

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Abstract: In epoxy spacers in Gas Insulated Switchgear (GIS) under operating thermal or mechanical stresses, delamination would be initiated at electrode/epoxy interface leading to partial discharge (PD) activity. In this paper, PD activity for delamination at electrode/epoxy interface in SF_6 gas is measured and analyzed to clarify the effect of accumulated charges on the epoxy surface. The delamination gap length considered in this paper is 50 µm. The moment of delamination initiation in GIS is successfully simulated by applying sudden voltage to the electrode setup. The main results show that the charge accumulation has great effect on the PD generation rate. This effect is different between negative and positive PD as a result of the difference in initial electron generation mechanism. The measurement of surface potential and the change in PD inception voltage after PD activity enable to estimate the accumulated charge polarity. Consequently, the role of charge accumulation in PD activity is proposed based on the change in local electric field inside the delamination gap.

Keywords: partial discharge, charge accumulation, electrode/epoxy interface, SF_6 gas, spacer

INTRODUCTION

Insulation defects are known to have a significant effect on the reliability of Gas Insulated Switchgear (GIS) [1]. This has made it necessary to deal with insulation condition monitoring in order to minimize the risk of failure in such equipment [2-3]. One of the most critical insulation defects that can cause failure of GIS are the defects in a GIS spacer. The development of materials and manufacturing technology of GIS spacers over the time led to reduction of defects such as voids, impurities and so on. However, under long time operation of such spacers, they are exposed to different stresses, mainly thermal and mechanical stresses. Consequently, a delamination could sometimes be initiated at the electrode/epoxy interface [4]. As a matter of fact, delamination is attributed to the loss of adhesion at the interface which usually occurs suddenly in case of the aforementioned stresses. After delamination is initiated, partial discharge (PD) activity is generated at the delamination gap under the operating voltage. Then, a spacer is degraded by PD. Finally, it breaks down. Since PD pulses for delamination defect are bounded from one side by a dielectric surface, charge accumulation plays an important role in PD activity.

From this viewpoint, the aim of this paper is to investigate and clarify the role of charge accumulation in PD activity for delamination at electrode/epoxy interface in SF_6 gas. First, PD characteristics are measured after sudden voltage application which simulates the moment of delamination initiation. Then, temporal change of PD parameters is analyzed and discussed from the viewpoint of charge accumulation effect and applied electric field strength. Moreover, after PD activity, surface potential and PD inception voltage are measured in order to clarify the charge distribution as well as charge polarity. Finally, the charge accumulation effect is explored.

EXPERIMENTAL SETUP

The electrode system setup simulating delamination at the electrode/epoxy interface in SF_6 gas is shown in Fig. 1. It is constructed of plane high voltage and grounded electrodes. The high voltage electrode was molded to avoid edge discharges. The high voltage electrode is made of SUS304 with diameter of 60 mm. The guard insulation has permittivity of 3.7 and its diameter is 90 mm. An alumina filled rectangular epoxy plate (100 mm × 100 mm × 5 mm thickness) with relative permittivity of 6.0 is sandwiched between high voltage and grounded electrodes. The epoxy plates are manufactured

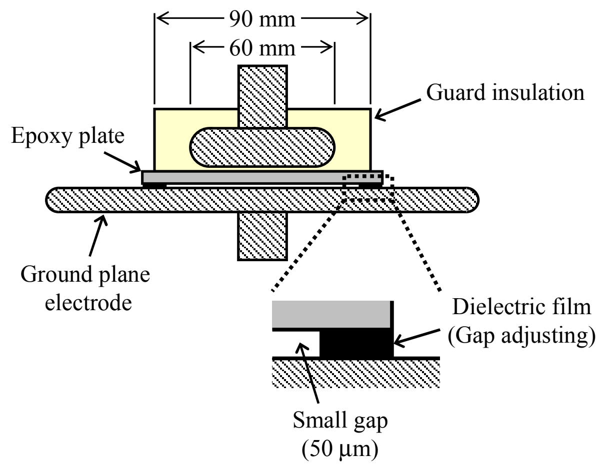

Fig. 1. Electrode setup for simulating delamination at the electrode/epoxy interface in SF_6 gas

from the same material used for a GIS spacer. A stack of thin dielectric films with each 25 µm thickness is used to adjust the delamination gap between the epoxy plate and grounded electrode. This made it possible to set a very small gap length, 50 µm, which simulate delamination lengths in GIS. The electrode setup is installed in a pressurized chamber filled with SF_6 gas at 0.1 MPa. The PD pulses at the delamination are detected by a 50 Ω resistor. The detected PD pulses are fed to a large bandwidth digital oscilloscope (40GS/s, 2.5GHz) and then are analyzed sequentially by PD-Current Pulse Waveform Analysis (PD-CPWA) developed in [5]. By PD-CPWA, the transition of PD generation rate over the time could be obtained.

In order to measure the PD inception voltage (PDIV), the target ac high voltage with frequency of 60 Hz has been increased gradually until PD occurs. However, for investigating temporal change of PD characteristics, in this paper, the target ac voltage is applied suddenly. By the voltage being suddenly applied, the generation of PD pulses during voltage increasing process and charge accumulation on the epoxy plate were prevented. In this way, the moment when delamination suddenly occurs following mechanical or thermal stresses could be simulated. Fig. 2 shows a conventional method of gradual voltage application and a sudden voltage application method with a typical waveform of applied voltage that is obtained experimentally. Different voltages are applied, starting from 1.0×PDIV to 1.5×PDIV, to change the local electric field at the delamination gap. PDIV is 14.5 kV_{rms} which is equal to theoretical values when streamer criterion is applied [6].

TIME TRANSITION OF PARTIAL DISCHARGE ACTIVITY

Fig. 3 shows sequential PD pulses just after sudden voltage application of 1.3×PDIV. Here, the voltage polarity is expressed as the bare electrode polarity at the interface. The time t = 0 defines the moment of sudden voltage application. When ac voltage was suddenly applied, negative PD pulses appeared constantly at all cycles, but positive PD did not. At about t = 0.10 sec, positive PD pulses started to appear but their generation rate and current pulse magnitude are much smaller than negative ones. Positive PD pulses increased gradually and it took more than 2 sec until it appeared at most cycles. At the other applied voltages PD activities showed similar changes, except for the case of 1.0×PDIV where positive PD pulses didn't appear at all.

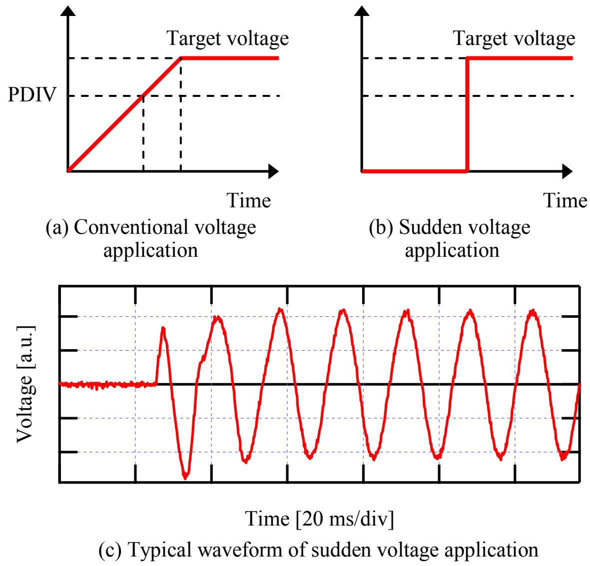

Fig. 2. Voltage application method to simulate the moment of delamination initiation

To clarify in more details the changes in PD activity, the time transition of PD generation rate, expressed in pulses per second (pps), over 10 minutes is obtained when different voltages was applied to the electrode setup as illustrated in Fig. 4. In these figures, PD generation rate is calculated using a sample data with fixed time duration. For PD generation rate at 1.0×PDIV

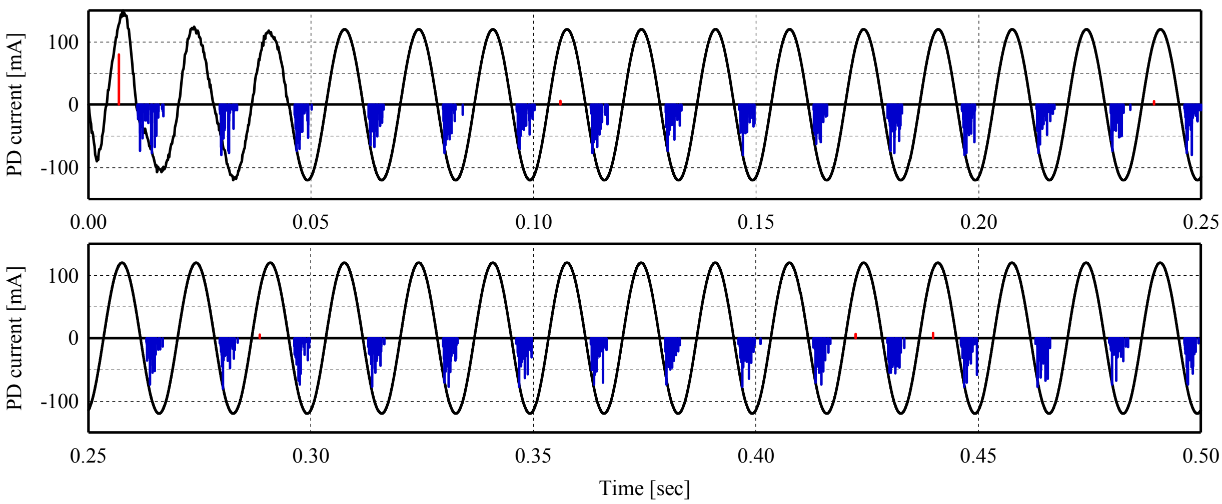

Fig. 3. Sequential PD pulses just after voltage application for 50 µm delamination gap (V_a = 1.3×PDIV)

shown in Fig. 4(a), the generation rate of negative PD pulses increased just after voltage application. Then it reduced to a very few number of PD pulses after about 5 minutes. Finally, at the end of 10 minutes, negative PD pulses approximately stopped. The positive PD pulses at 1.0×PDIV didn't appear at all. For the cases of 1.3×PDIV and 1.5×PDIV shown in Fig. 4(b) and Fig. 4(c) respectively, negative and positive PD pulses appeared. For the temporal change of PD generation rate it was found that the number of negative PD pulses reduces and the number of positive PD pulses increases at the first few minutes after voltage application. After about 5 minutes of voltage application, the PD generation rates of both PD polarities reached a steady state values.

As evident from these figures, the PD generation rate changes greatly at the first few minutes after the voltage application. Also it is clear that the time transition of PD generation rate exhibits different tendencies for negative and positive PD pulses. The reason of different tendencies is considered to be attributed to accumulated charges on the epoxy surface.

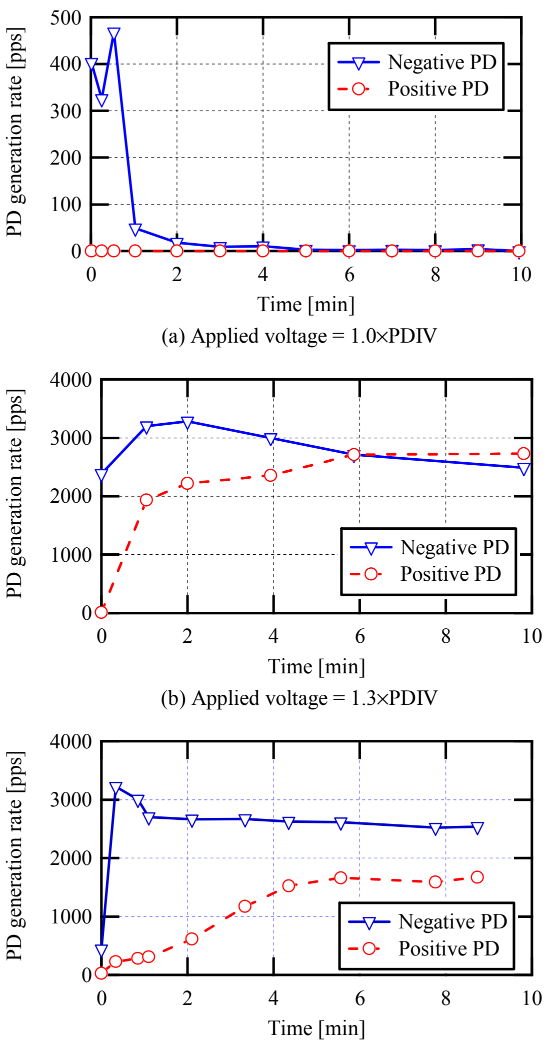

Fig. 4. Time transition of PD generation rate for 50 µm delamination gap

CHARGE ACCUMULATION PROCESS

PD activity is triggered by the electric field in the delamination gap which is affected largely by accumulated charges on the epoxy surface. Hence, it is important to clarify the role of surface charge accumulation in PD activity. To do that, it is important to obtain the distribution of accumulated surface charges as well as their polarity. For obtaining surface charge distribution, surface potential measurements are carried out using an electrostatic voltmeter after the epoxy surfaces were exposed to PD activity for 10 minutes as shown in Fig. 5. It is evident that the charge distribution is uniform around the surface under high voltage electrode. This implies that PD occurs all over the epoxy surface exposed to electric field.

Following that PDIV measurements were carried out before and after PD activity. It is found that PDIV increased after 10 minutes of exposure to PD activity, with PD inception occurred at the negative polarity of grounded electrode. The accumulated charge density is estimated from change in PDIV measurements using the equations of uniform electric field distribution and the equations of boundary conditions at guard insulation / epoxy boundary and epoxy / gas boundary. It is found that accumulated charge density is in the range −10 µC/m^2 ~ −20 µC/m^2. Negative charge density indicates that the local electric field weakened and strengthened for negative and positive polarity respectively.

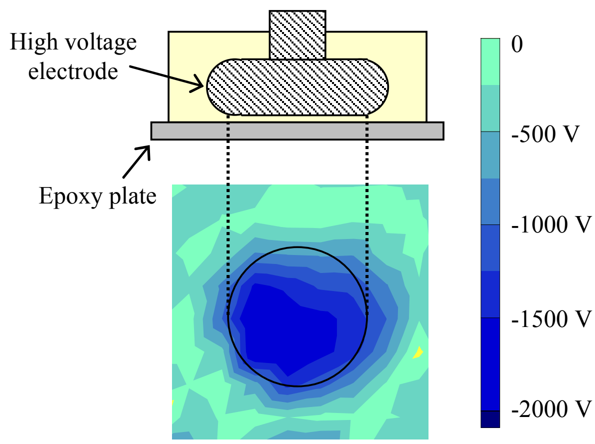

Fig. 5. Surface potential measurements on the epoxy plate after exposing to PD activity at 1.3×PDIV

DISCUSSIONS

Based on the conducted experiments and the obtained results, it was proved that PD parameters change greatly with time after voltage application. First of all, it must be pointed out that the resultant electric field E_g in the gap is composed of two components. The first component E_a is generated by the externally applied voltage. The second component E_q is a local dc electric field produced by the accumulated surface charges after several minutes of PD activity. Here, the second component E_q is the responsible for changes in resultant electric field and PD activity. At the first few minutes after sudden voltage application, charges were accumulated on the epoxy surface causing remarkable change in PD generation rate. However, when the ac voltage was applied for a long time and surface charging occurred, PD characteristics became stable in Fig. 4. The charging effect on negative and positive PD generation rate is different based on the different mechanisms of PD polarity. This is explained by considering the charge accumulation effect together with the initial electron generation mechanism for both PD polarities as shown in Fig. 6.

The initial electron for negative PD pulses is generated from the grounded electrode. Therefore, at the few seconds following sudden voltage application, the number of negative PD pulses was large. On the other side, the very small number of the initial electrons for positive PD is generated in the short gas gap, and the very small number of positive PD pulses appears. The high generation rate of negative PD pulses caused negative charge to accumulate on the epoxy surface. Then, the dc electric field caused by accumulated charge weakens the electric field for negative polarity PD pulses and strengthens the electric field for positive polarity PD pulses. Consequently, the generation rate of negative PD pulses decreased and the generation rate of positive PD pulses increased until steady state conditions have been reached after several minutes.

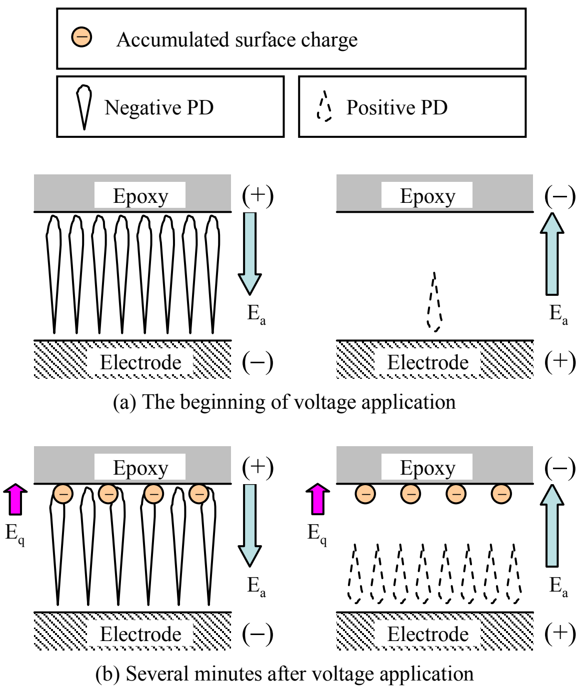

Fig. 6. The role of accumulated charges on the epoxy surface in PD activity for delamination defect

When applied voltage was set at 1.0×PDIV, generation rate of negative PD pulses reduced to a very small value and positive PD pulses didn't appear at all. As a result, PD activity approximately stopped. This indicates that charge accumulation might limit PD detection for delamination defect.

CONCLUSIONS

The role of surface accumulated charge in partial discharge activity for electrode/epoxy delamination in GIS spacer has been clarified in this paper. The moment of delamination initiation is simulated using sudden voltage application method. The gap considered is 50 μm simulating delamination gap in actual GIS spacer. The time transition of PD characteristics was obtained after sudden voltage application and discussed from the viewpoint of charge accumulation effect. As a result the following findings were concluded:

(1) PD activity changes greatly at the first few minutes following sudden voltage application due to the effect of charge accumulation on the epoxy surface. After several minutes, PD characteristics became stable when surface charging occurred.

(2) The accumulated surface charges were uniform around the area where PD activity is generated. Their polarity was negative.

(3) The tendency in the generation rate of positive PD pulses was different from that of negative PD pulses where negative accumulated charges weakened the electric field for negative PD pulses and strengthened the electric field for positive PD pulses.

(4) As a result of fast changes in PD characteristics due to accumulated charges, it is considered that PD monitoring after delamination occurrence would be useful to detect and identify such defect type in GIS spacer.

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