Investigation of Streamer Propagation along Insulating Surfaces

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Solid insulation materials are used in high voltage gas-insulated devices for mechanical stability reasons or for the separation of different compartments of the device. While solids have generally higher breakdown strength than gases, the weakest parts are often the solid-gas interfaces of the insulation. This contribution presents first measurements of characteristics of surface flashover in a specially constructed setup. The studied samples are epoxy rods with embedded electrodes, especially designed for localized electrodeless streamer inception and discharge propagation along the surface. The capacitances of the overall system are tuned such that current measurements of the discharge can be performed. In this research we focus on the initial phase of discharge propagation – the formation and development of streamers. The main results are the streamer inception voltage and the evolution of the current shape in nitrogen at different pressures.

1. Introduction

It is known that the discharge behaviour may change in the presence of dielectric material in an insulation device like gas insulated switchgear or cable terminations [1]. Various investigations confirm that electrical discharges often prefer to propagate along the surfaces of insulators, rather than through the volume of bulk gas [2 - 5]. However, the physics of underlying processes is still poorly understood. Control and prevention of such creeping sparks for real insulation systems is often based on semi-empirical design rules, which is not satisfactory.

Therefore knowledge on the fundamental physics at gas – dielectric interfaces is highly required. The aim of this research work is to look closely at the first stages of discharge development – formation and propagation of streamers. These first stages are of major interest, since arc-formation and short circuiting can hardly be prevented after streamers have formed a conducting path.

One of the most important characteristics of a discharge process is the voltage of inception. Furthermore, it is important to have time-resolved measurements of discharge currents and evolution of the current shape with the change of experimental conditions.

2. Experimental arrangement

Experiments were performed with the configuration shown in Fig. 1. Two metal electrodes embedded in an epoxy rod were designed in such a way that the surface field leads to streamer inception without electric breakdown in the solid. In contrast to Ref. [6] here the central axis of electrodes is shifted from the central axis of epoxy cylinder in order to localize streamers on one side of the sample for the possibilities of optical investigation.

Figure 1. Configuration of experimental samples. Length: 200 mm, total diameter: 35 mm, electrode diameter: 24 mm, minimum epoxy thickness: 2 mm, electrode gap: 4 mm.

Experiments for the investigation of streamer propagation along the dielectric surface of the sample were performed in a vessel, which allows to vary parameters of the gaseous medium surrounding the area of interest. The cross-section of the experimental vessel is shown in Fig. 2(a). Figure 2(b) represents the equivalent circuit for the current in the experimental set-up, where \( C_p \) is a parasitic capacitance of the high-voltage electrode and leads to ground. While organizing the set-up the following conditions should be taken into account: 1) \( C_p \) should be much larger, than the capacitance of the sample. If this condition is not satisfied the current through the measuring resistor will be immeasurably small; 2) \( C_p \) should be positioned as close to the experimental sample as possible. Otherwise, the current loop becomes longer, which leads to higher inductance of the circuit and makes time-resolved measurements impossible. The way to satisfy these conditions is to use an electrode configuration with a sub-divided cathode [7].
Figure 2. (a) Cross-section of experimental vessel; 1 – high voltage electrode, 2 – dielectric sample with embedded electrodes, 3 – sub-divided grounded electrode. (b) Equivalent current in the experimental circuit; $V_h$ – high voltage source, $C_s$ – capacitance of the sample, $i_s$ – sample current, $R_m$ – measuring resistor, $C_p$ – “coupling” capacitance.

The shapes of electrodes were designed to satisfy the conditions mentioned above. The shape of the high voltage electrode is specified, so that the electric field along the surface of the electrode does not exceed the electric field along the surface of the sample, where the streamer activity is to be investigated.

AC 50 Hz voltage is provided to the vessel by a high voltage transformer, and is measured using the PVM-5 (1000:1) North Star voltage probe. The current is measured through the sub-divided grounded electrode, through the 50 ohm input impedance of the 104MXs-B LeCroy oscilloscope. Pressure conditions inside the vessel are set using the TCU 260D Balzers Pfeiffer vacuum pump and are monitored with Balzers TPG300 pressure controllers. Imaging of discharge processes is performed using the 4Picos-DIG ICCD camera.

3. Experimental results

An integral image of the discharge is presented in Fig. 3. It is clearly seen, that the discharge is taking place along the epoxy insulating layer, not connected to electrodes or any metallic parts. It is located in the area of 4 mm electrode gap.

Figure 3. Integral image of discharge process in Nitrogen.

During the experiments values of streamer inception voltage in $N_2$ at different pressures were measured (see Fig. 4). The inception voltage increases with the increase of the surrounding gas pressure in a nonlinear way. For 50 mbar $N_2$ inception voltage is around 4 kV, while for pressures close to atmospheric (900 mbar) critical voltage increases up to almost 30 kV. Figure 4 also represents the values of the maximum discharge current, corresponding to given voltages.

Figure 4. Inception voltage and maximum current of streamers, propagating in Nitrogen environment at different pressures.

Figure 5 (a,b) shows the evolution of the current shape of discharges in $N_2$. Streamers propagating at low pressures are relatively slow, the propagation time is around 50 ns, whereas for 900 mbar this time significantly decreases (see Fig. 5 (b)). The intensity of the streamer current increases with the pressure increase almost by the factor of four, reaching ~ 4 A for 900 mbar.

Figure 5 (a). Evolution of current shape of streamer process in Nitrogen for pressures 100 – 500 mbar.
Figure 5 (b). Evolution of current shape of streamer process in Nitrogen for pressures 600 – 900 mbar.

The increase of the maximum discharge current is correlating with the increase of breakdown voltage (see Fig. 6).

Figure 6. Current – voltage characteristic of discharge process in N₂.

4. Conclusions
A set-up was designed and built for experimental investigations on streamers, starting on and propagating along insulating surfaces away from any conducting parts. Initial experiments were performed, that showed the feasibility of chosen shapes for high voltage and grounded electrodes, and their applicability for optical and fast current measurements. First results, regarding the major properties of discharge process, such as inception voltage and current shapes, were obtained. The results allow to conclude pressure-dependent behaviour of surface streamers. The developed experimental arrangement gives the possibility for a wide range of experimental investigation of streamer ignition processes at different conditions, which can be relatively easy varied using the presented set-up.

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6. References