DISCHARGE PHENOMENA AT PARTIALLY DAMAGED DIELECTRIC ELECTRODE COATINGS IN SF6-INSULATED SYSTEMS AT AC AND DC STRESS

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ABSTRACT

Dielectric coated electrodes in gas insulated switchgear (GIS) components were studied in presence of metallic particles. In the context of microscopic surface degradations, various unexpected phenomena were observed. A simplified test set-up was used to perform fundamental investigations. Low frequency behaviour was examined at DC and 50 Hz AC voltage in pressurized SF_6 gas.

1. INTRODUCTION

The dielectric strength of GIS can be reduced by conductive particles significantly. Loose, metallic particles can move freely in the gas gap between the electrodes. Without particle traps there is no preferential particle position. Thus a particle can move almost everywhere within a GIS compartment. AC and DC stress manifests itself differently regarding particle behaviour, electric field distribution and discharge development. Lift-off and gas gap crossings of a particle are more likely to happen in DC case compared with AC case [1]. Contrary to bare electrodes, dielectric coated electrodes are known to impede the initial particle lift-off effectively. Furthermore, the intensity of spark discharges can be reduced in case of tentative electrode tangency [2]. For electrode arrangements without particle contamination, even thin dielectric conductor coatings may yield to an increase of breakdown field strength [3].

2. EXPERIMENTAL INVESTIGATIONS

Initially, loose conductive particles were studied in a horizontal SF_6 insulated duct. GIS housing and inner conductor featured both bare and insulate-lacquered surfaces. Placed on bare electrode areas, particles started to move continuously under applied high DC voltage. During the ongoing motion process, particles got from bare areas into lacquered electrode areas.

Temporary presence of moving particles in lacquered areas could be detected by external measurements: at DC, load current of the test pole was abnormally high, the test voltage was dropping (test voltage was not stabilized), GIS enclosure got warm, SF_6 decomposition products were generated and conventional partial discharge (PD) measurement readings reached the range of nanocoulomb. Simultaneous video recordings were showing visible, transient flashing discharge figures in particle presence. Without particle presence, the effects described above could not be detected. During experiments of short duration (30 min), faultless lacquered electrode surfaces were heavily damaged by particle impact (**Fig. 1**).

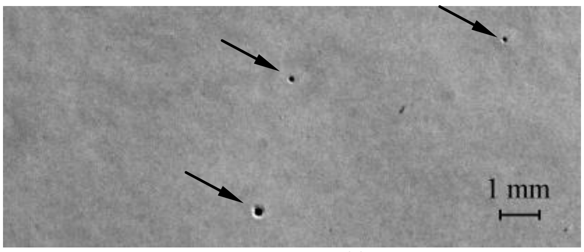

Fig. 1: Partially damaged coating of field grading electrode

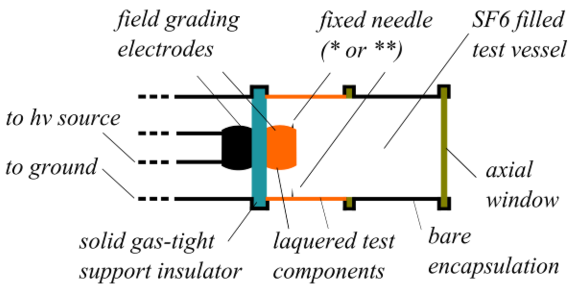

Fig. 2: Phantom view of coaxial test vessel

A simplified test set-up (**Fig. 2**) consisting of partially damaged, lacquered electrodes and an ion source (fixed needle on system electrode) was capable to reproduce similar discharge figures. Using this set-up, several observations were made. The investigated voltage waveforms were DC and 50 Hz AC. Electrode distance was approximately 65 mm.

At first, the discharge phenomena were investigated under DC voltage stress with fixed needles, placed on high voltage (HV) and ground electrode. Visible discharge figures were observed at the high voltage electrode for both polarities. It can be seen, that there is a strong polarity dependence, as discharge figures at positive polarity appear brighter and bigger. **Fig. 3** shows the comparison of positive and negative polarity for the case of a 2 cm needle on the ground electrode at 2 bar absolute pressure in radial view.

If the needle is placed on the HV electrode, discharge figures constitute brighter and bigger. **Fig. 4** gives the comparison of 2 cm needles mounted on HV and ground electrode at comparable negative DC voltages and 2 bar absolute pressure in radial view.

Brightness and size of the discharge figures depend also on gas pressure. A brightness maximum was identified at an absolute pressure of 2.5 to 3.0 bar. Raising the pressure to higher values under constant voltage, the visible intensity decreases (**Fig. 5**).

Based on the fact that discharge figures arise at positive DC voltage more intensively, DC positive and AC were compared: the intensity presents itself higher in DC positive case for similar voltage amplitudes. **Fig. 6** gives the comparison between DC positive and AC for a 2 cm needle fixed on HV electrode at 2 bar absolute pressure in axial view.

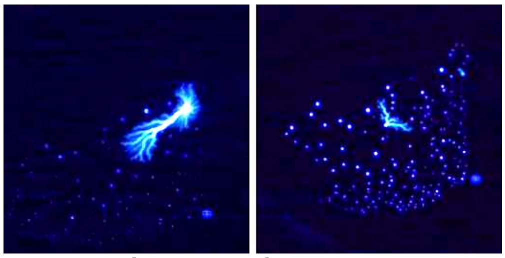
Fig.3: Dependence on DC polarity: positive vs. negative

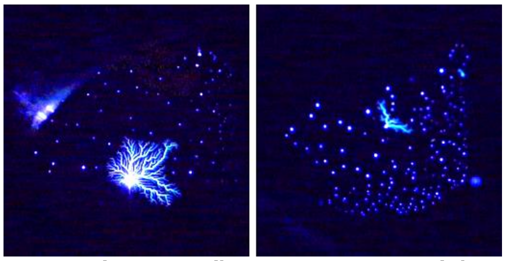
Fig. 4: Dependence on needle position: HV vs. ground electrode

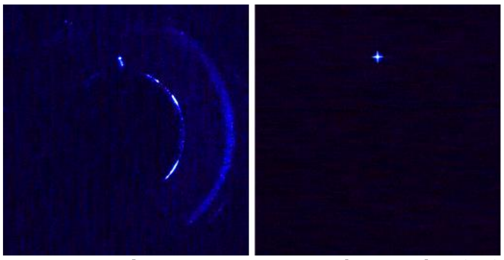
Fig. 5: Dependence on gas pressure: 2 bar vs. 4 bar (AC)

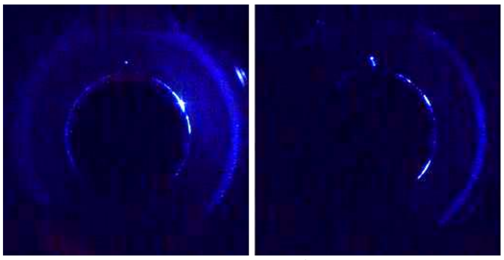
Fig.6: Dependence on voltage waveform: DC positive vs. AC

AC is more likely comparable to negative DC behaviour, but the phenomenon exists for both voltage waveforms.

The observations presented above are based on step-motion analysis of moving image captures, shutter speed was 0.5 seconds. For time domain characterization, the discharge figures were analyzed with a widely focused photomultiplier tube (Hamamatsu H10721P-110) and a digital storage oscilloscope. Typical intervals between bright light pulses were in the range of milliseconds to seconds. **Fig. 7** shows a typical pulse sequence of optical events in the millisecond range. **Fig. 8** gives a short-time analysis of a single high-intensity flashing discharge figure. Pulse width was fluctuating between a few nanoseconds and a few 100 nanoseconds.

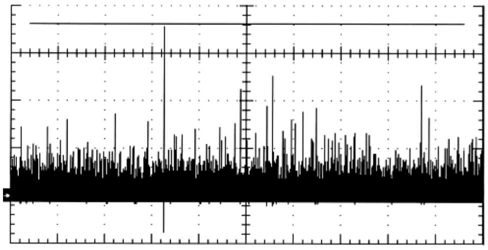

Fig. 7: Sequence of emitted light pulses, timebase: 4 ms / div.

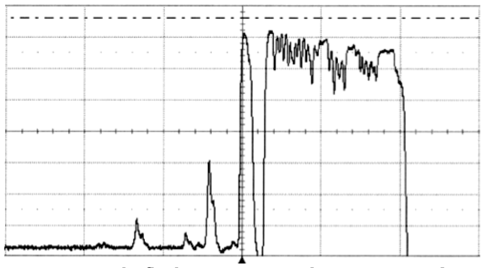

Fig. 8: Bright flashing event, timebase: 100 ns / div.

Due to limited bandwidth of the measuring system, actual rise times are supposed to be shorter than they appear in measurements. Maximum system sensitivity (horizontal bars in **Fig. 7, 8**) was adopted to fit bright flashing pulses. Events of visible inception reached approximately 10 % of the maximum. Noise in the acquired optical signal can be neglected. Spikes within the rectangular pulse may arise from superposition of sequenced, narrow pulses (**Fig. 8**).

Discharge figures arise only at punctured areas of the coating. **Fig. 9** illustrates this circumstance: dark shades indicate SF_6 decomposition products where discharge figures developed before. Light spots indicate former punctures. Areas of uniform, plain tonality represent faultless lacquered surfaces.

The preferred voltage range, in which the described discharge figures are starting spontaneously, depends mostly on voltage waveform and gas pressure. For test voltages below this band, no discharge figure appears at all. In the case, test voltage was risen quickly to a value above the band, no discharge figure started or breakdown occurred. In case discharge figures were visible and the test voltage was risen considerably, the phenomenon stopped immediately and/ or breakdown occurred. During voltage application for one hour, the visible intensity decreased. Main reason seems to be increased lacquer conductivity as a result of generated decomposition products. Renewal of the gas was helpful for a successful restart.

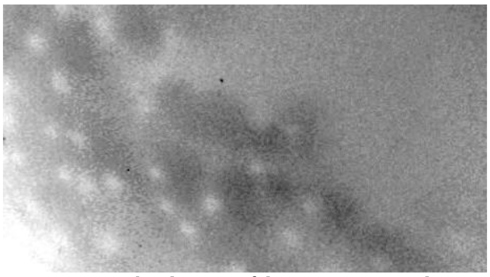

Fig. 9: Localised traces of decomposition products

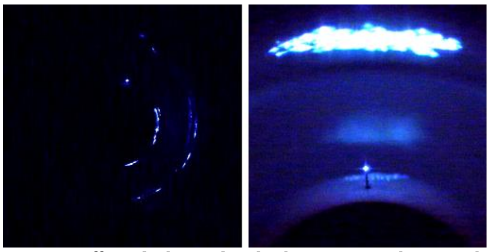

Fig. 10: Affected Electrodes: both vs. encapsulation only

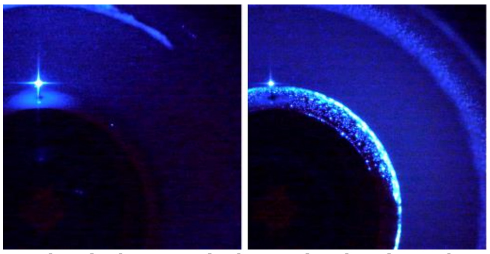

Fig. 11: Glow discharge vs. discharges distributed over the surface

The speed of stepping-up the test voltage seems to have influence on the development of discharge figures. Practically a rise from zero to inception voltage within a few minutes was beneficial to incept discharge figures. The spread of glow discharges on the punctured surface needed several minutes. The preferred voltage band described above can be considered as a band of electrical field strength. The following fact shall prove this statement: under slow voltage rise, the following sequence can be observed in axial perspective. Firstly discharge figures incept at the inner electrode. Secondly discharge figures incept additionally at the outer electrode. Phenomena exist on both electrodes (**Fig. 10**, left image). If the test voltage is still being risen, discharge figures can extinct at the inner electrode. Nevertheless, discharge figures at the outer electrode can keep active (**Fig. 10**, right image).

In case the conditions for occurrence of flashing discharge figures are not fulfilled, glow discharges solely at the needle tip or surface discharges of other shapes appear (**Fig. 11**). Particle punctures mostly appear as continuous glow discharges after a while.

3. DISCUSSION

Due to free moving particles in a gas insulated system, lacquered electrodes have been damaged partially. These punctures of the insulating coating are a necessary requirement to start the observed surface discharges, as the tests show.

The second condition required, is an adequate amount of charge carriers. As soon as the applied voltage exceeds the inception voltage of the fixed needle on the high voltage or ground electrode, positive or negative charge carriers will be generated.

Due to the applied voltage, the generated charge carriers will move in the electrical field. These space charges will be shifted to the electrode of opposite polarity. In DC case, the direction of the electrical field is not alternating. Therefore the visible intensity probably constitutes higher than in AC case.

The dielectric electrode coating impedes charge carrier neutralisation. Hence, ionic layers will build up on the lacquer and increase the electrical field stress of the coating. Generally, its dielectric strength is sufficient. In case of surface degradations, the resulting high field strength possibly leads to first discharges in the punctures, because of the gas having a lower dielectric strength. This can be noticed as a visible glowing of the punctures.

In dependence of the electrode polarity, two different ways of electron allocation are possible:

- positive ionic layer on negative electrode: electron emission out of the cathode due to high field strength
- negative ionic layer on positive electrode: electron detachment [4] from negative SF_6 ions [5] due to high field strength

The glowing discharges are producing charge carriers (ions) of both polarities in big quantities [6]. Hence, the ionic layers will be strengthen, due to the direction of the ion-drift, i.e. the electric field. The visible appearance of the resulting discharges is, amongst others, depending on the polarity and the type of the applied voltage, the source of charge carriers and the gas pressure.

4. CONCLUSION

In general, it can be stated, that the accumulated surface charges on the lacquered electrodes can generate bright flashing discharge figures, if the dielectric coating is partially damaged. Several conditions (gas pressure, voltage polarity, duration of voltage stress, etc.) determine the exact appearance. With respect to the huge variety of influencing parameters, additional investigations are necessary, in order to present a comprehensive and more detailed description of the observed discharge phenomena.

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