Characteristics of Negative Corona on RTV SIR Coated Insulating Surface under Ramp High Voltages

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Abstract: **Negative corona discharges along glass insulating surfaces coated by Room Temperature Vulcanized Silicone Rubber (RTV SIR), are experimentally investigated in a non-uniform electric field electrode arrangement under ramp high voltages. The insulating surfaces were bridging a short needle-plane gap, which was stressed by applying voltages just sufficient for corona inception up to values causing flashover; the case of air alone was considered as a reference. The salient corona discharge characteristics, namely inception voltage and current as well as the energy dissipated were obtained. Results are discussed based on different modes of corona growth as affected by applied voltage and presence of an insulating surface. Corona growth along an insulating surface is suppressed, thus flashover occurs at a higher applied voltage.**

I. Introduction

The use of polymeric coatings, usually made of silicone rubber compositions, is a common practice of power utilities for improving the ceramic insulators performance under pollution conditions [1], [2]. However, the polymeric coatings in service can be significantly degraded under several uncontrolled ageing stresses acting interactively, depending on environmental and operational conditions [3], [4]. Among ageing stresses, partial discharge activity is of major importance, affecting coating performance and life time [5-7]. An insulator surface may degrade due to surface corona under the action of electron and ion bombardment being also exposed to ozone and UV irradiation.

Ageing of polymeric materials under long term exposure in corona discharges has been widely investigated [6], [8-11]. Recent research [12-16] is mainly focused on changes in structure and hydrophobicity of the surface material. Special interest has been given on evaluating AC corona effects on polymeric materials due to their wide application in high voltage insulation technology. Thus, several test methods, including the method proposed by IEC Std. 60343 [17], have been developed for evaluating corona resistance of polymers.

Although significant research work has been conducted on the effects of partial discharge activity on the performance of polymeric coatings, the physical processes involved in interactions between polymeric coated insulators and partial discharges are not yet fully understood. In this study, a continuation of previous work [18], the basic characteristics of surface corona growth on insulating surfaces are experimentally investigated under negative ramp DC high voltages. The insulating surfaces, made of pure glass and RTV SIR (silicone rubber) coated glass, were bridging a needle-plane gap; air alone was considered as a reference. The corona current as well as the associated rise of temperature on the surface of insulating specimens were continuously measured. Thus, current-voltage characteristics were attained; the power and energy dissipated by the discharge were estimated. Surface corona growth is suppressed; thus, flashover occurs at a higher applied voltage as compared with the case of air alone.

II. Experimental Arrangement

A needle-plane electrode arrangement (Fig. 1), as detailed in a previous study [18], was used to investigate negative surface corona under ramp DC high voltages. Two glass specimens (100x50x5 mm), one in pure form (ε_r = 6.3) and the other coated by a thin film (0.5 mm in thickness) of Room Temperature Vulcanized Silicone Rubber (RTV SIR) with ε_r = 3.5, were tested; they were bridging the gap (16 mm in length), gently placed in contact with the electrodes; air-alone was considered as reference.

The ramp DC high voltages of negative polarity were generated by controlling a Glassman FC30R4 power supply (120 W, 30 kV) with the aid of a National Instrument system, which was also used (set at 50 kS/s per input channel), for continuous monitoring and recording the applied voltage and discharge current. Also, the use of an infrared camera (OPTRIS PI400) enabled monitoring the rise of temperature on the surface of the insulating specimens due to corona activity.

Three successive tests per insulating specimen (time interval 5 min) were conducted to investigate corona discharge, by applying voltages from threshold values, sufficient for corona onset, up to values resulting in flashover. The atmospheric conditions were rather constant during tests: Pressure: 787 mmHg, Temperature: 20°C and Relative Humidity: 30%.

Figure 1. Electrode set-up; RTV SIR coated glass surface.

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III. Experimental Results and Discussion

A. *Regimes of development of electrical discharges*

The present experimental arrangement has the advantage of observing discerned regimes of discharge development depending on the applied voltage [18]; these regimes can be identified based on discharge current measurements. Corona discharge always initiates at the energized needle tip, where the electric field in the gap is maximum, and develops towards the grounded plane. The discharge inception and development characteristics are significantly affected when an insulating surface bridges the gap (Fig. 2).

In the case of air alone, negative corona initiates as high frequency current pulses (Trichel pulses) of small amplitude (~1 μA) (Fig. 2a). With increasing applied voltage, both the repetition rate and amplitude of the Trichel pulses increase up to the establishment of a continuous current related to a stable glow (Fig. 2a). At applied voltages higher than a critical value the transition from glow to streamer regime occurs (Fig. 2b); in the latter regime the corona current augments abruptly as the applied voltage increases to values up to ~ 200 μA, eventually causing breakdown (Fig. 2b).

When an insulating surface bridges the short gap, negative surface corona initiates in the form of "Trichel" pulses (~0.2 μA), increasing both in repetition rate and amplitude with applied voltage, as can be seen in Fig. 2a. For applied voltages higher than a threshold value an unstable glow is established comprising of repetitive current pulses, associated with surface streamers, superimposed on a discontinuous current component (Fig. 2b). At even higher voltages the glow discharge becomes stable (continuous current) and then a stable streamer discharge forms, associated with an abrupt increase in current with applied voltage, eventually causing flashover (Fig. 2b).

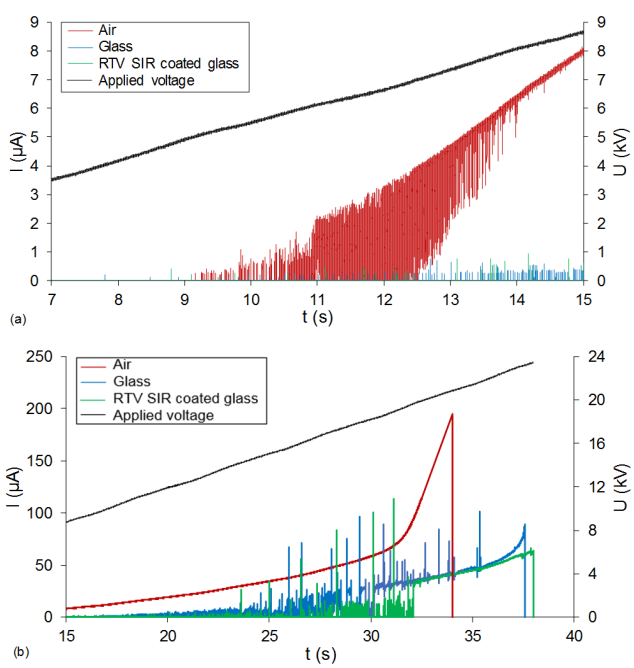

Figure 2. Negative ramp DC high voltage (0.6 kV/s) and discharge current; (a) corona onset, (b) streamer inception and flashover.

From Fig. 2a it is evident that at corona onset the Trichel pulses initiate at a higher applied voltage and are higher both in amplitude and repetition rate for air alone than when an insulator bridges the gap. Also, their characteristics vary a little between the two insulating surfaces; Trichel pulses initiate at slightly higher applied voltage and are higher in amplitude but of reduced repetition rate for the coated than the pure glass specimen (Fig. 2a). These results are reasonably associated with the electric field enhancement near the needle tip due to the insulating surface, especially as the electrical permittivity of the insulating material increases.

At applied voltages higher than the corona onset voltage, the discharge current is highest in the pure air gap; this is not the case when surface streamers start to develop in a repetitive mode along the insulating surfaces (Fig. 2b). It must be noted that during this phase of unstable glow, the current of the repetitive surface streamers is greater in amplitude and of reduced repetition frequency for the coated surface than pure glass specimen. As the applied voltage increases further, a stable streamer discharge forms (Fig. 2b); this phase starts at a lower voltage but with higher current for air alone. It also initiates with a slightly higher applied voltage and lower current for the coated than pure glass specimen. Consequently, flashover voltage is higher in the case of an insulating surface bridging the gap, and slightly higher for the coated than pure glass specimen (Fig. 2b).

Table I summarizes average values of the pre-discharge and flashover characteristics for the three tests on the specimens.

TABLE I
Corona and Flashover Characteristics

	Corona onset		Streamer Inception		Flashover	
	Voltage, kV	Current, μA	Voltage, kV	Current, μA	Voltage, kV	Current, μA
Air	5.20 (12.01%)	0.97 (66.44%)	17.69 (2.09%)	54.05 (7.23%)	20.60 (0.93%)	183.59 (9.74%)
Glass	3.84 (1.62%)	0.22 (6.43%)	18.47 (1.00%)	29.61 (5.54%)	22.94 (0.39%)	77.69 (14.57%)
RTV SIR coated glass	4.16 (15.59%)	0.33 (28.03%)	18.56 (10.59%)	27.22 (34.58%)	23.75 (0.92%)	100.65 (3.48%)

Values in parenthesis show standard deviation.

B. *Current-Voltage (I-U) characteristics*

The mean I-U characteristics obtained for all successive tests on each specimen are shown in Fig. 3. In air alone, the corona current increases continuously as the applied voltage increases, with a rate of rise markedly higher in the streamer than glow regime. In the presence of insulating surfaces, the current of surface corona is discontinuous and rather negligible in mean values up to voltages causing stable streamer inception. Then, with further increase of the applied voltage, the current rate of rise augments significantly, causing eventually flashover. It must be noted that the discharge development phase of repetitive current pulses, associated with surface streamers, superimposed on a discontinuous current component is more obvious in the case of the pure glass specimen than the coated glass surface.

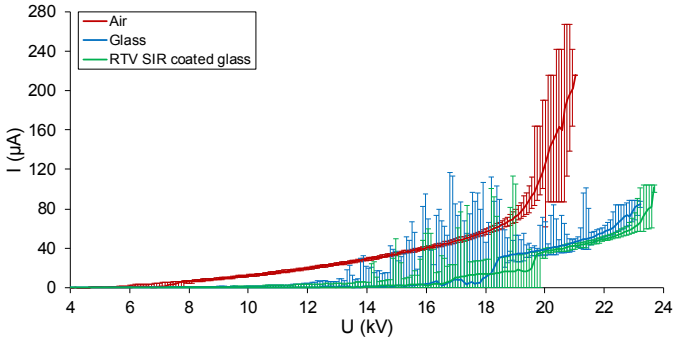

Figure 3. I-U characteristics under negative ramp DC high voltage (0.6 kV/s). Mean values for all three consecutive tests, bars denote min and max current values.

Fig. 4 shows the cumulative energy dissipated by the discharge from onset up to flashover. This energy is highest in the case of air alone, largely owing to glow discharge losses. When an insulating surface bridges the gap, almost all of the energy required for flashover is dissipated during the stable streamer propagation phase. It is noted that this energy is slightly higher for the coated surface than the pure glass specimen.

C. Temperature rise

A high frequency infrared camera was employed to continuously monitor the rise of temperature on the surface of the insulators during the tests. Typical thermal images referring to the RTV SIR coated surface are shown in Fig. 5.

At applied voltages sustaining streamer inception in repetitive mode only a concentrated discontinuous hot spot area in the vicinity needle tip could be detected. When a stable surface streamer is formed, the temperature rises, continuously and almost linearly with current, along a restricted linear area covering the shortest distance between electrodes (Fig. 5a-5c). This area is narrow close to the tip of needle and slightly widens as the discharge propagates over the insulating surface towards the plane electrode. The temperature on the insulating surface is not uniformly distributed, due to the non-uniformity of current distribution. Actually, the surface temperature rise is highest close to the needle tip, reduces in mid-gap and then increases a little close to the plane electrode. At flashover voltage, a spark channel is observed associated with an abrupt increase in temperature rise (Fig. 5d).

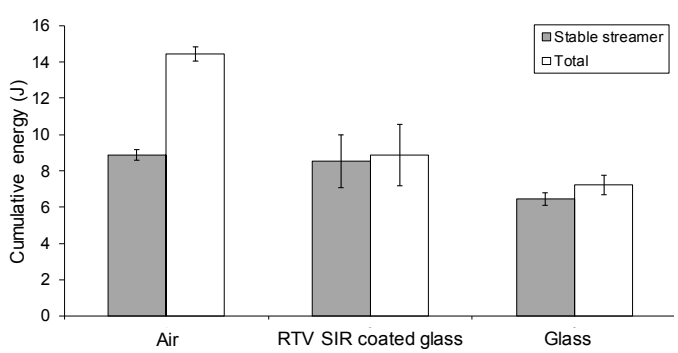

Figure 4. Energy required for flashover; the vertical bars denote 2σ.

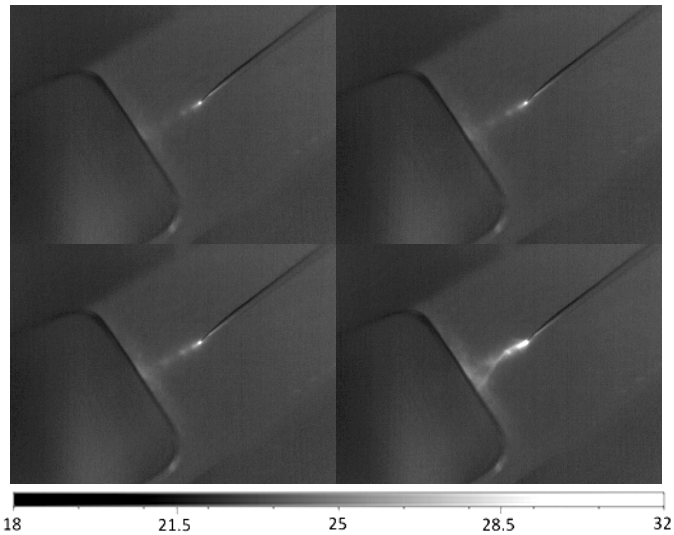

Figure 5. Thermal images under negative ramp DC high voltage (0.6 kV/s); RTV SIR coated glass surface; flashover voltage $U_f = 23.5$ kV. (i) $0.92 \cdot U_f$, (ii) $0.95 \cdot U_f$, (iii) $0.97 \cdot U_f$ and (iv) U_f.

Fig. 6 shows the variations of corona current and related maximum temperature rise on the surface of the specimens with applied voltage. The rise of temperature is markedly lower for the pure glass than coated insulating surface. Differences in temperature rise between insulating materials could be associated with their thermal conductivity, ~1 W/mHK for the pure glass and ~0.2 W/mHK for the RTV SIR coating. It is well known that the thermal energy is dissipated more easily for materials with higher thermal conductivity, thus in the present case for the pure glass specimen than RTV SIR coated glass surface. However, the discharge path with respect to the insulating surface (adhering

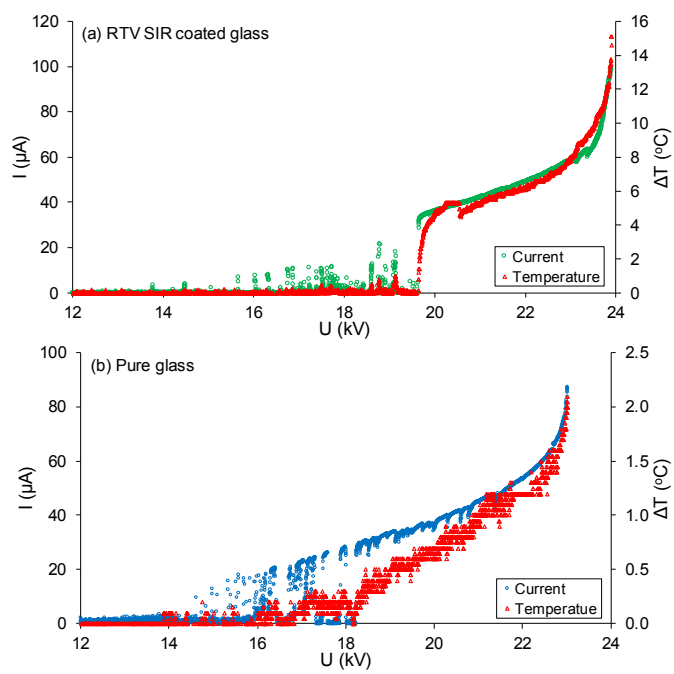

Figure 6. Current, *I*, and maximum temperature rise, ΔT, variation with applied DC ramp voltage (0.6 kV/s).

to the surface or partly away from the latter) may also affect the rise of temperature on the surface of the insulators. It is important that the surface temperature rise of a few degrees of Celsius on the RTV SIR coated specimen due to discharge activity is not expected to thermally deteriorate the material. Other ageing factors primarily associated to chemical changes of the material due to interactions between corona products and surface material are acknowledged [3, 5, 7, 9, 13, 15].

The dielectric strength of nonuniform air gaps stressed by negative impulse voltages when bridged by insulating surfaces is reduced, due to the favored growth of streamer corona [19-20]. This does not apply to the present experimental results (Fig. 3); under slowly rising applied voltages corona growth along an insulating surface is suppressed and a higher applied voltage is required for flashover to occur. These effects can be attributed to negative surface charging due pre-discharge activity [21]. As polymers are known for their affinity to surface charging, as compared to ceramic materials, [22], the surface corona current is lower and the flashover voltage is higher in the case of coated surface than in the case of pure glass specimen (Fig. 3). It is noteworthy that the extent of discharge development along the insulating surface and partly in air alone may also affect the corona current, thus also flashover.

IV. Conclusions

Corona discharges in air-alone and along pure glass and RTV SIR coated glass surfaces bridging a short needle-plane gap stressed by negative ramp DC high voltages have been investigated. The salient characteristics of corona discharges are discussed based on current and surface temperature rise measurements, conducted by applying voltages with values corresponding to corona onset up to values causing flashover.

With reference to air alone, along an insulating surface the onset corona voltage and current are lower, but the glow discharge is greatly suppressed and the formation of streamers, thus also flashover, is hindered. A stable streamer discharge is established at a slightly higher voltage but lower current for the RTV SIR coated than the pure glass specimen; this results in higher flashover voltage. These are attributed to negative surface charging due predischarge activity, especially for the RTV SIR coated glass insulating surface.

When a stable surface streamer is formed, the temperature rises, continuously and almost linearly with current, along a restricted linear area covering the shortest distance between electrodes. The rise of temperature on the insulator surface caused by corona activity is higher for the coated than pure glass surface. This could be reasonably attributed to the lower material thermal conductivity of the RTV SIR coating; however, the extent of discharge development in air alone and along the insulator surface may also play a important role to this effect. The maximum temperature rise on the surface of the insulator observed due to corona activity (up to ~15 ^{o}C) is rather low to be considered as crucial for thermal degradation of the investigated materials.

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