Sessile Water Droplets on Insulating Surfaces Subject to High AC Stress: Effect of Contact Angle.

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Surface pollution of outdoor high-voltage insulators is an important cause of flashover. We have undertaken an experimental study of electrical breakdown at the edges of a sessile water droplet on a planar, polymeric, insulating surface when subject to AC stress, parallel to the insulator surface, up to 2MV/m. The static contact angle between droplet and surface was varied by controlling the physical properties of the droplet and by inclining the insulator plane from the horizontal. The partial discharge activity from the water droplet was investigated using a combination of high-speed video camera, operated at up to 3,000 frames per second, and an electrical partial discharge detection system. We have used this to examine the location of partial discharge at the edges of the water droplet.

1. INTRODUCTION

Outdoor high-voltage (HV) power plant, such as insulators, bushings, surge arresters and current transformers, etc. are exposed to various environmental conditions during their service life. Surface pollution is a serious problem for the design and operation of HV devices in many industrial, coastal and desert areas, for example, where the surface of insulator can become heavily polluted. Under severe environmental conditions, a pollution layer (dry or wet) may be deposited on an insulator surface and a leakage current may flow, leading to flashover [2] and compromising the reliability of the power supply [3]. The performance of an HV insulator under polluted condition is known to differ greatly from that under pollution-free conditions [4].

Discharges on the surface of a contaminated polymeric insulator are considered to be one of the ageing mechanisms responsible for the failure of the insulator and can occur between water drops on the surface of insulators, creating a number of radicals and ionized species that chemically react with the insulator surface and thus alter the original properties of the insulator material [1]. Considering the importance of pollution problems, continuous and intensive laboratory studies and field investigations have been taking place worldwide for many years. The work involves not only experimental investigations but also mathematical modeling to understand the different aspects of the contamination flashover mechanism [3].

2. EXPERIMENTAL PROCEDURE

The behaviour of a water droplet on the surface of a polymer sample was investigated using the apparatus shown schematically in Figure 1. It consisted of a polyethylene (PE) cylinder, diameter 20mm and length 30mm, with embedded electrodes. Up to 20kV, 50Hz was applied between the electrodes with one of the electrodes effectively earthed.

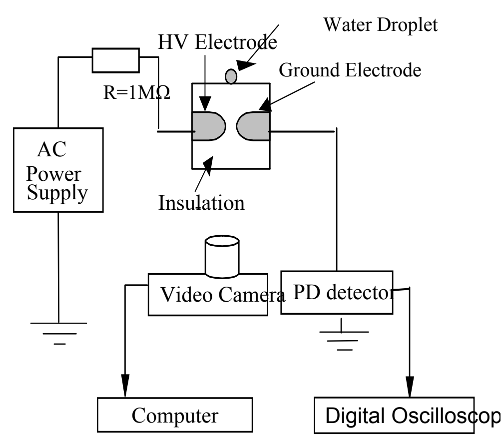

Figure 1. Schematic representation of experimental Set-up

A plane face was machined on the upper side of the cylinder and a single water droplet of volume 10µl was placed centrally on this surface. The tap water used had a resistivity of approximately $10^6\Omega m$ and a relative permittivity of approximately 80.4. The relative permittivity of the PE sample was assumed to be approximately 2.35.

The behavior of the droplet was observed using a Photron Fastcam Super 10k high-speed camera operating at 3000 frames per second. Partial discharge (PD) activity was determined by observing the electrical pulses generated across a 100-Ω resistor at the low-voltage electrode.

3. CONTACT ANGLE

Contact angle may be defined as the angle formed between the tangent to the water droplet at its point of contact and the planar surface on which it is placed. A measure of the hydrophobicity of the surface, is obtained by determining the contact angle when the contacting surface is horizontal [5]. In this study, the static contact angle was varied by tilting the insulator plane from the horizontal. This generated two separate contact angles, corresponding to the lowest and highest points of contact between the droplet and the plane surface, the lower point of contact giving the greater contact angle. The grater angle we designate angle A and the lesser angle (at the highest point) angle B.

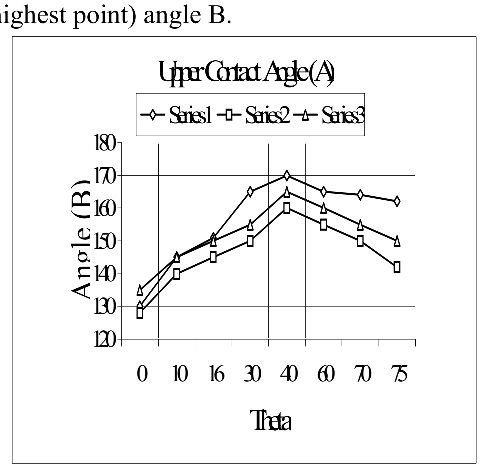

Figure 2. Upper Contact Angle A.
◊-tap water, Δ-salt water,
□-deionized water.

In the present work contact angles were measured for water droplets produced using tap water and, for comparison, nominally de-ionised water and tap water containing 1% saturated sodium chloride solution. These were chosen to represent three different water conductivities. All three conductivities show similarities in behaviour

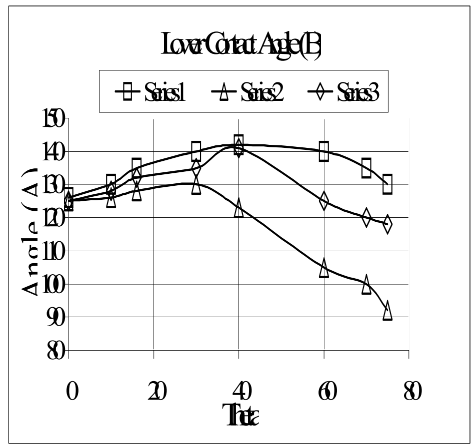

Figure 3. Lower Contact Angle B
□-tap water, ◊-salt water,
Δ-deionised water.

With increasing angle of inclination, θ, the angles A and B pass through a maximum as seen in Figures 2 and 3. When θ is zero the measured contact angles A and B show a small dependency on the conductivity but for a particular conductivity A and B are approximately the same. For larger values of θ the values of contact angle A are greater than the angle B, as might be expected. Tap water shows the largest measured contact angles although its conductivity lies between that of deionised water and water containing NaCl. However, it may be that the more complex nature of the dissolved content in the tap water droplets makes it difficult to compare the contact angle results directly with those for the other types of droplet.

4. PARTIAL DISCHARGE ACTIVITY

PD patterns were obtained for a 10µl droplet deposited in the middle of the flat portion of the sample. As described above, the PD activity was detected in two ways: electrically and visually by high-speed video camera.

4.1 Electrically detected partial discharges.

Figure 4 shows the PD activity generated by the system when no water droplet was present on the surface of the sample. The inception voltage was 8.25kV and discharges were observed on both half cycles close to the peak of the applied voltage waveform. The magnitude of these discharges does not appear to damage the sample and does not lead to breakdown if allowed to continue for a period of time.

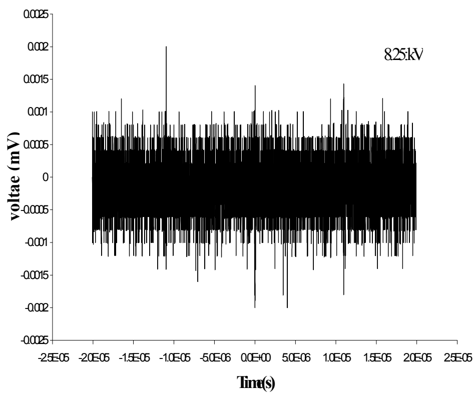

Figure 4. Partial discharge activity with no water droplet present.

When a water droplet was placed midway between the two electrodes on the flat horizontal polymer it was observed that surface partial discharge activity at the edges of the droplet was initiated when the applied voltage was raised to 11.7kV. Figure 5 shows the typical PD record obtained under these conditions.

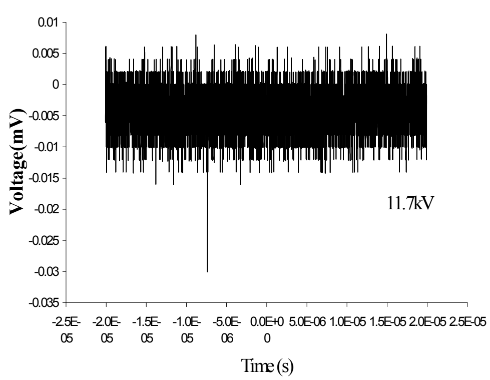

Figure 5. Partial discharge activity at the edges of a water droplet in the absence of droplet vibration.

The PDs in the negative half cycle appear to be larger than those in the positive half cycle. The magnitude of this negative PD is some 15 times greater than that observed without the presence of the droplet. Optical observation showed that the droplet was sessile and did not vibrate.

When the applied voltage was increased to 14.25 kV, the water droplet was observed to vibrate but without spreading. With the voltage raised to 16.8 kV, the droplet was observed to vibrate vigorously and then spread over the surface of the insulator http://www.mecheng.strath.ac.uk/news.asp. The measured PD activity at 16.8 kV is shown in figure 6. The peak magnitude was typically 25 times above the level observed without a water droplet. As before, PD activity is more pronounced during the negative half cycle. Under these conditions, the motion of the water droplet along the surface of the supporting insulator eventually lead to total breakdown along its surface

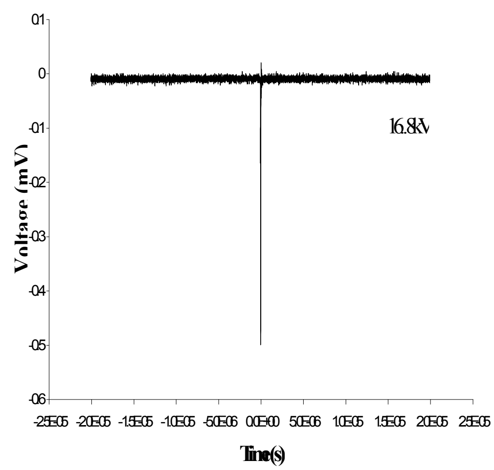

Figure 6. Partial discharge activity as the droplet spread over the surface.

4.2 Visual observation

Figure 7 shows a discharge at the edge of a droplet deposited on a level PE surface. The applied voltage was 16.8 kV and the water droplet had started to vibrate and expand. In the complete video sequence, the droplet is observed to vibrate and eventually spread over the whole sample as a wave-like vibration mode developed before complete electrical breakdown took place.

Figure 7. Discharge at the edge of a droplet spreading over the insulator surface..

5. ELECTRIC FIELD AROUND A DROPLET

When a droplet vibrates the contact angle varies considerably. As part of our study of this, we recorded a tap-water droplet on a PE surface inclined at 60^o and computed the field around the resultant shape. Figure 8 shows the droplet profile and the computed equipotentials. From this computation, we have determined the variation in field along the surface of the PE between location s A and B shown on figure 10 for an average applied field of 2MV/m between the embedded electrodes

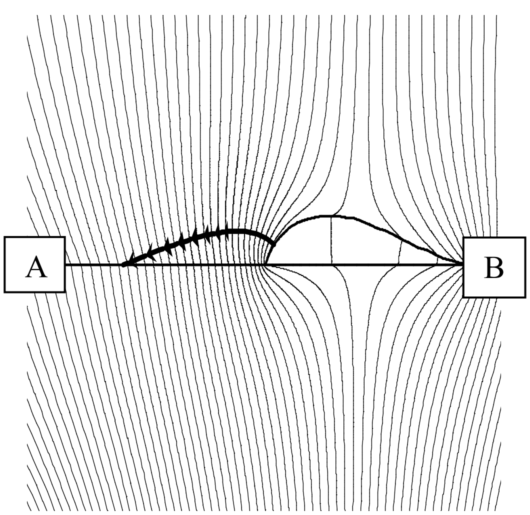

Figure 8. Equipotentials around a droplet on a PE plane inclined at 60^o.

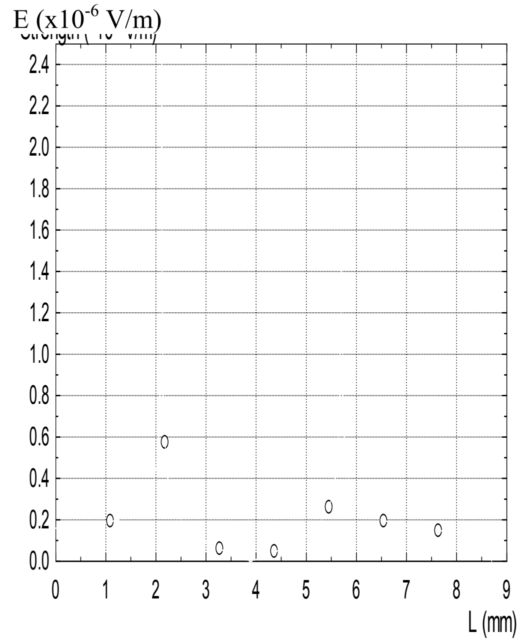

Figure 9. The electric field (E) between the locations A and B of figure 8.

. The results are presented in figure 9, which shows that, for the conditions studied, increasing the contact angle increases the field at the triple junction. It is reasonable to suggest that a similar increase can be expected when the droplet vibrates under an applied AC field. This effect is likely to contribute to the development of partial discharges around a vibrating droplet and to promote eventual full breakdown. It is intended to examine this point in more detail.

6. CONCLUSIONS

As an applied AC field is raised above a threshold level, a water droplet initially vibrates in a fixed position. As the field is raised, the droplet vibrates increasingly vigorously, spreads out and eventually extends over the surface. This process is associated with partial discharge activity at the edge of the droplet. The vibration of the droplet promotes partial discharges by altering the contact angle and so increasing the field near the triple point.

7. ACKNOWLEDGEMENTS

One of us (H.A.G.) wishes to acknowledge support from the Ministry of Defence, Armament Authority, Cairo, Egypt. We also acknowledge support from EPSRC for provision of the high-speed camera system.

8. REFERENCES

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