WATER INDUCED DISCHARGES ON TRANSMISSION VOLTAGE SILICONE RUBBER INSULATORS

By

D.A. Hoch, N. Mahatho* and F. Bologna*

School of Electrical and Electronic Engineering
University of Natal
Durban, South Africa

*South African High Voltage Engineering Centre (SAHVEC)
TSI, Eskom Enterprises
South Africa

SUMMARY

Leakage currents may be produced across the surface of a wetted hydrophobic surface at operating ac stresses. These leakage currents are in phase with the applied voltage. The onset of these leakage currents depends upon the conductivity of the water droplets introduced onto the surface of the insulator as well as the duration of the ac stressing. The leakage current flow is preceded by the observation of water droplet corona around discrete water droplets, which then develops along the length of the insulator from the energized end to the earthed end. This paper reports on the findings of an experimental investigation into this phenomenon.

INTRODUCTION

The long-term hydrophobicity of silicone rubber insulators has been identified as the main reason for the good pollution performance of silicone rubber insulators [1]. This property of hydrophobicity (water droplet contact angle>90^o) appeared to ensure that no discharges would occur even under polluted conditions, particularly if a corona ring were fitted on the live-end fitting. Research focused on the temporary loss of hydrophobicity that may occur due to corona discharges near the hydrophobic surface, either from unshielded fittings or from water droplets near a high electric field region. Such temporary loss of hydrophobicity was not seen as deleterious as the hydrophobicity would recover in a short period of time (typically 24 hours). Such research tended to focus on small scale experiments and used corona generated by metal electrodes [2]. More recently, results from large-scale aging chamber tests [3] indicated that water droplets may be causing low-level discharges to occur in the vicinity of the droplets and which produced material changes that could be determined through chemical analysis. The results from [3] indicated that these discharges, referred to as water droplet corona, would occur for electric field values ranging from 3.5kV/cm-7.5 kV/cm. More fundamental investigations into discharges associated with water droplets have been carried out in depth [4]. The application of the above results to typical 275 kV insulators as used on Eskom's Main Transmission System was then implemented [5]. Other researchers have focused on chemical changes induced by water droplet discharges [6] on temporary hydrophobicity loss and associated surface chemistry changes.

Of importance in the water droplet corona mechanism is the electric field at which this mechanism becomes observable as this may provide information on required field reductions to avoid this mechanism. Suitably designed corona rings may provide Field reductions of this magnitude. In the course of an experimental programme to investigate these water droplet corona mechanisms systematically [5], the onset of resistive current flow across the surface of the hydrophobic insulator under test was observed.

The onset of this leakage current flow (co-incident with observable low energy arcing on the surface of the insulator) depends upon the conductivity of the water droplets and the duration of exposure to ac stressing. This paper reports on an investigation to quantify this leakage current phenomena as well as the magnitude and pulse shape of the leakage currents observed.

EXPERIMENTAL INVESTIGATION

A 275 kV silicone rubber insulator was subjected to a.c. energization in the High Voltage Laboratory at the University of Natal. The unit under test was subjected to ac stressing at U_{max} under dry conditions and all corona modes recorded using a night vision image intensifier system. The unit was tested both with and without a corona ring fitted. The results are shown in Figure 1 and Figure 2 below.

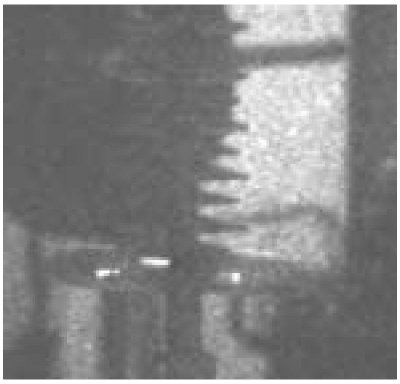

Figure 1 : Figure of dry insulator with corona ring fitted. No discernible corona activity. V=173 kV rms.

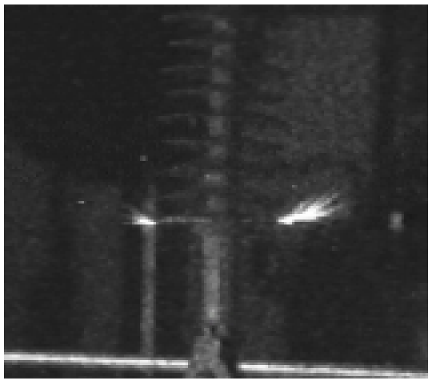

Figure 2 : Figure of dry insulator witout corona ring fitted. Corona activity is discernible. V=173 kV rms.

The insulator was then wetted with a hand-held spray gun with water of a specified conductivity. The insulator was then energized and subjected to a.c. stressing for a period of time whilst observation of corona activity (night vision device) and leakage current activity were made.

At low conductivities, water droplet activity was observed only in the vicinity of the live end. As the conductivity of the water was increased through the addition of salt, the corona activity still initiated near the live end but then progressed up the length of the insulator as a function of the duration of the stressing.

The observed corona activity for low conductivity water (light pollution) both with and without a corona ring fitted are shown in Figures 3 and 4 below.

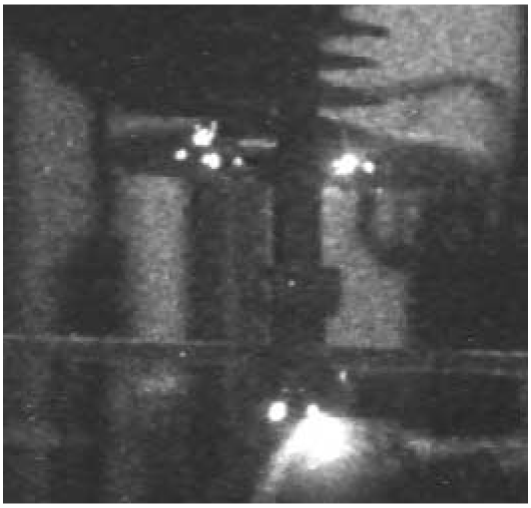

Figure 3 : Insulator wetted with low conductivity water (10 microSiemens/cm) : corona ring fitted. V=173 kV rms.

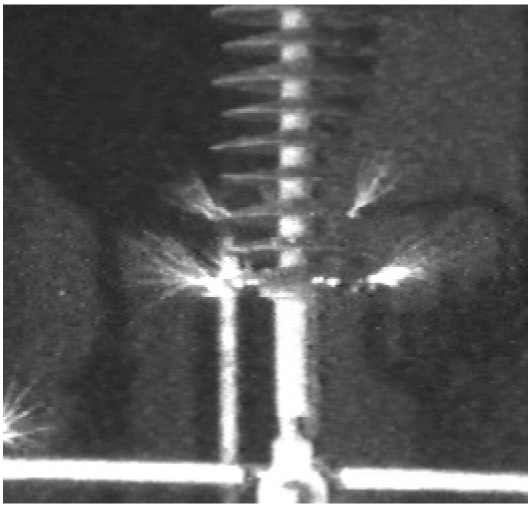

Figure 4 : Insulator wetted with low conductivity water (10 microSiemens/cm) : no corona ring fitted. V=173 kV rms.

Water droplet corona is clearly visible in Figure 4 whereas Figure 3 indicates that a correctly fitted corona ring will suppress these water droplet discharges near the live end.

At higher conductivities, the water droplet discharges developed over time into more energetic activity and also occurred at points along the length of the insulator moving as a function of time from the vicinity of the live end towards the dead end of the insulator. In certain cases, discharges were observed on the sheath of insulator nearest the grounded end. This is shown in Figures 5 and 6 below.

Figure 5 : Figure showing discharges along the length of the insulator for water droplets of conductivity 42 mS/cm. V=173 kV rms.

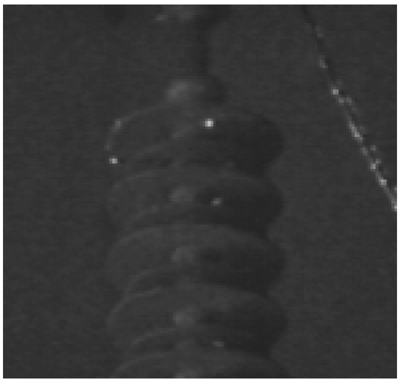

Figure 6 : Heavily wetted insulator with saturated water showing corona at the dead-end. V=173 kV rms.

After some period of stressing (typically 20-30 minutes), a more intensive discharge mode was observed and which had the appearance of dry band activity observed under polluted conditions on glass cap-and-pin insulators. Such discharges are shown in Figure 7 and 8 below.

Figure 7 : Onset of discharge activity at dead end after ~30 minutes stressing. V=173kV rms.

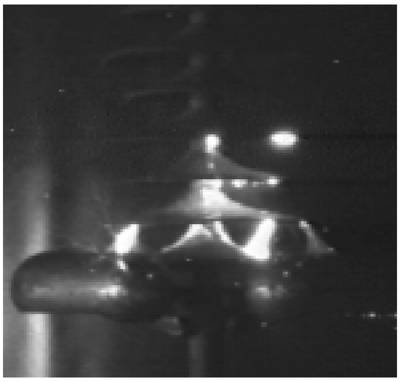

Figure 8 : Corresponding activity at live end. V=173 kV rms.

Of note is the absence of a clear conducting path to earth. Further, after de-energizing the test set-up, discrete droplets were observed on the surface and no water filming (as for ceramic insulators) could be seen except in localized regions (eg. on the sheath nearest the live end-fitting). Insertion of a measurement resistor and monitoring of the currents to earth simultaneously with voltage measurement enabled the phase relationship between voltage and current to be determined. A typical trace under the reported conditions is shown in Figure 9 below.

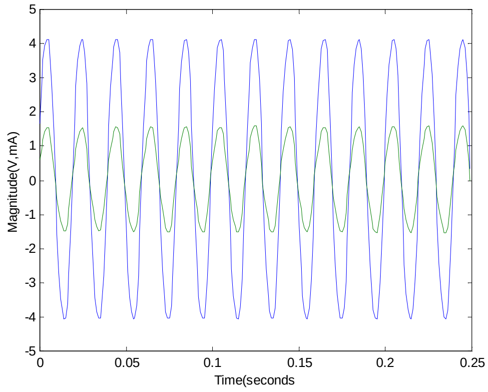

Figure 9 : Figure showing phase relationship between voltage and current for onset of discharge modes as indicated in Figures 7 and 8 above. The components are in phase i.e. there is resistive current flow. Peak value of leakage current ~1.5mA. Voltage is scaled : applied V=173 kV rms

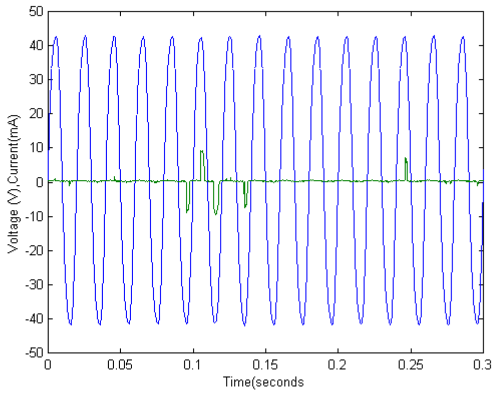

Figure 10 : Figure of leakage currents during activity shown in Figures 8 and 9. Pulses are of short duration but are in phase with the voltage and hence indicate resistive current flow. Peak of current pulses = 10mA. Voltage is scaled : applied V=173 kV rms.

DISCUSSION

The observed discharge modes of Figures 5,6,7 and 8 on the surface of the silicone rubber insulators clearly differ considerably to what is commonly referred to as water droplet corona. Of note is that the discharges may occur anywhere along the length of the insulator if the wetted insulator is subjected to ac stressing for a sufficiently long time. The appearance of corona near the dead end is a very suprising result as typical onset electric field values reported on in the literature for water droplet corona are 3.5kV/cm-7.5 kV/cm [3]. The values of the electric field near the dead-end may be as low as 0.6 kV/cm. A typical electric field plot for the insulator tested and indicating electric field values of these magnitudes at the dead-end are shown in Figure 11 below.

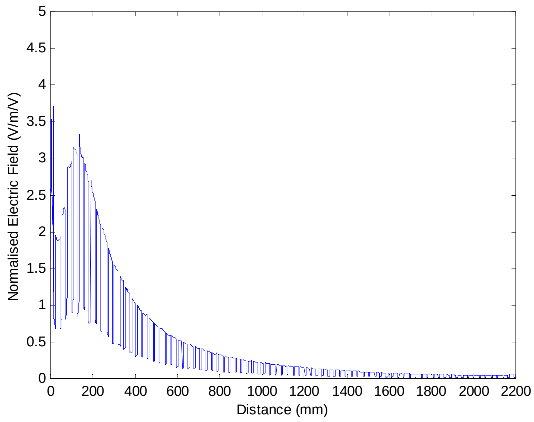

Figure 11 : Electric field plot for insulator with corona ring fitted. The vertical axis represents normalized electric field values in units of V/m per applied volt.

The above evidence would appear to support the hyphothesis that the electric field along the length of a silicone rubber insulator may be significantly distorted by the introductiuon of water droplets of medium conductivity onto the hydrophobic surface. Some evidence to support this field distortion theory is supplied in Figure 6 where corona off the measurement cable (terminated onto the measurement resistor at the dead-end) is visible. Such corona was not visible prior to the introduction of the water drolets. Electric field measurements have also indicated that such field distoritons are produced by the water droplets.

CONCLUSIONS

Water droplet discharges may occur on transmission level insulators under service stressing. Correctly fitted corona rings will suppress such discharges where the water droplets on the surface of the insulator are of low conductivity (rain water). Where the droplets have slightly higher conductivities corresponding to light to medium pollution levels (12-42 mS/cm), the nature of the discharge is no longer that of water droplet corona in that it appears to be more intensive than for low conductivity water droplets. These water induced discharges are not confined to the high stress region of the insulator as determined for electric field plots of a dry insulator but may occur anywhere along the length of the insulator, including near the dead-end fitting. These water induced discharges may develop over time until resistive current flow may be observed across the surface of the hydrophobic insulator. This then results in a form of dry-band discharging along the length of the insulator. Electric field measurements not reported in depth here have indicated that the electric field along the length of the insulator does become highly distorted under wet and polluted conditions compared to the field distribution of the dry case.

REFERENCES

[1] J Kindesberger and M Kuhl, "Effect of Hydrophobicity on Insulator Performance", 6th International Symposium on High Voltage Engineering, New Orleans, USA, August 1989.

[2] DA Swift, "AC Flashover Mechanism for Water Droplets on an Hydrophobic Insulator", 8th International Symposium on High Voltage Engineering, Yokohama, Japan, August 1993.

[3] AJ Philips, DJ Childs and HM Schneider, "Water Droplet Corona Effects on a Full Scale 500kV Non-Ceramic Insulator, IEEE Transactions on Power Delivery, Vol. 14, No. 1, January 1999.

[4] D Windmar, "Water droplet initiated discharges in air", PhD Thesis, Uppsala University Press, 1994.

[5] F Bologna and DA Hoch, "Water induced discharges on silicone rubber insulators", Eskom Research Report, TRR/E/99/EL082, Johannesburg, 1999.

[6] SM Reynders, JP Reynders and IR Jandrell, "The impact of corona ageing on the surface and subsurface layers of silicone rubber insulation", 7th Southern African Universities Power Engineering Conference, Stellenbosch, South Africa, January 1998.