INFRARED IMAGING OF DRY-BAND FAILURE OF SILICONE-RUBBER INSULATORS

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ABSTRACT

Composite insulators using silicone rubber (SiR) formulations have become commonly employed to reduce dry-band formation,because these can offer hydrophobicity transfer to control wetting of the layer. However, new fog-chamber tests on 11 kV SiR insulators manufactured in-house show that a salt/kaolin layer on the insulator can stillcause a substantial fall of the flashover voltage [1]. Bright, mobile partial arcs are initiated at voltages well below flashover [2]. In the present paper, additional infrared (IR) recording reveals the formation and development of heated bands in the pollution layer which are found always to precede the arc initiation.

Close-up visual photography shows that current continuity is maintained in the pollution layer by small streamer/spark discharges bridging the dry bands. The current associated with these discharges is limited by the low conductance of the pollution layer in series with the bands; the local surface temperature is raised to 5-10°C above ambient, which is sufficient to prevent re-wetting of the dry band. A higher voltage enables short, incipient spark channels to develop from the dry-band discharges, and sometimes to link separate dry bands. These can grow into the longer partial-arc channels that normally precede flashover.

1.INTRODUCTION

Recent papers [1] have described successful new laboratory procedures which are aimed to provide a contribution to the development of standard testing of non-ceramic composite insulators. These embrace a new method of applying a saline layer to a hydrophobic surface, the use of a series of linear-ramp voltages which obviates the difficulty of up-and-down strategies, and the measurement of insulator leakage current throughout the pre-flashover period. In addition to the results already reported, measurements of insulator heating were made using an IR camera. This has enabled an assessment of the prevalence and properties of dry bands on polluted SiRinsulators, the results of which are now presented. Synchronous visual photography shows that small streamer/spark discharges bridging these dry bands result in a surface temperature of 5 to 10°C above ambient which is sufficient to maintain the dry band. A higher voltage enables short, incipient spark channels (partial arcs) to develop from the dry-band discharges, and sometimes to link separate dry bands.

2. TEST RESOURCES

(a) Test insulators. The profile employed in the tests is based upon a commercial four-shed 11kV design, and was manufactured in-house (Figure 1).

Figure 1 Test insulator

The insulator dimensions (mm) arecreepage length L (375), trunk diameter (28), shed diameter (90)and axial length (175).The form factor Fis calculated from integration along the surface creepage path 0≤x≤L where the variation of insulator diameter D(x) defines the profile:

$$F = \int_0^L \frac{dx}{\pi D(x)} = 2.76 \qquad (1)$$

(b) Pollution procedure. Because the hydrophobic surface of theSiR insulator resists wetting by the saline solution which is used as artificial pollution, a wetting agent is incorporated, in the manner specified by IEC 60587 in the different context of inclined-plane tests [3].

(c) Fog chamber. This is 2m square and height 3m and has a windowless aperture in the access door forobservation and visual and infrared recording of the test insulator.

(d) Test voltage source. The Hipotronics 150kVA, 50Hz transformermaximum output voltage is 75kV. A motorized variable input autotransformer produces a high-voltage ramp output at a rate of rise of 4kV/minute.

(e)Infrared and video recording. A FLIR A325 camera is employed to map the surface temperature change over the insulator surface during the fog chamber test. This has a spectral range from 7.5 to 13µm with an infrared resolution of 320x240 pixels.A Sony Handycam enables partial-arc activity to be correlated with the dry-bands as revealed by the infrared recordings. Additionally, a Nikon D700 digital camera with 200mm focal length is used with long exposure time to detect low-luminosity discharges.

(f) Voltage and current measurement. To enable stored electrical data from tests to be analysed together with the associated IR and visual images, the necessary temporal correlationis achieved by clock synchronisation or by reverse measurement from a flashover event. The DAQ system digitizes and stores voltage and current signals at a sampling rate of 200 samples per cycle of 50Hz for subsequent data processing.

3. INFRARED IMAGES

Figure 2 shows a typical development of dry-bands on the insulator trunk sections during a ramp voltage test under conditions of high pollution and light fog. A heated ring (dry band) is formed on the middle trunk at low voltage (2kV). This brightens with increasing voltage, until at 14.6kV a second dry band forms adjacent to the first, with the third band forming on the upper trunk. At 27.1 kV five bands can be seen, although in this instance noneforms on the third trunk section before flashover occurs atjust above 27.5kV.

The temperature rise associated with dry-band formation is modest. The insulator in Figure 3 isin a fog environment at 17°C, yet most of its surface is at 22°C and the dry bands reach 26-27°C.

Dry-band lifetimes are many minutes before eventual rewetting occurs. This persistence of dry-band heating indicates that current continuity is maintained in the band despite the loss of conductance of the pollution layer. Figure 4(a) provides the explanation for this: a close-up visual image on a trunk section is compared with the corresponding IR image. The visual image is rich in UV, typical of streamer discharges bridging the dry-band even though no partial arcs are present.

The power dissipation in these small discharges is sufficient to sustain the dry-band heating and to enable evaporation to prevent rewetting. It is also sufficient to promote the inception of the partial-arc discharges (Figure 4(b)) that eventually lead to insulator flashover. These channels are brighter than the streamers, and their yellow colour suggests the presence of sodium from the pollution layer.

4. ELECTRICAL CHARACTERISTICS

(a) Before dry-band formation. At low voltage (≈ 100V), the polluted insulator exhibits an in-phase sinusoidal leakage current and the corresponding maximum pollution-layer conductance (assuming uniform pollution) is about 2.8µS.

(b) Onset of dry bands. Figure 5(a) shows a voltage of 2kV r.m.s. applied in four steps to a fully wetted insulator, together with the associatedleakage current (Figure 5(b)).For the first two voltage steps, the leakage conductance is maintained constant at about 1µS.

However, the next step to 1.6kV soon leads to areduction to about 0.1µS. A further voltagestep to 2kV produces a short-lived leakage conductance of 0.4 µS which falls within 2s to 0.05 µS or less. The reduction of leakagecurrent indicates the formation of a dry band in the moist pollution layer as observed in Figure 2.The subsequent small transient current perturbations accompany bridging corona discharges of the kind seen in Figure 4.

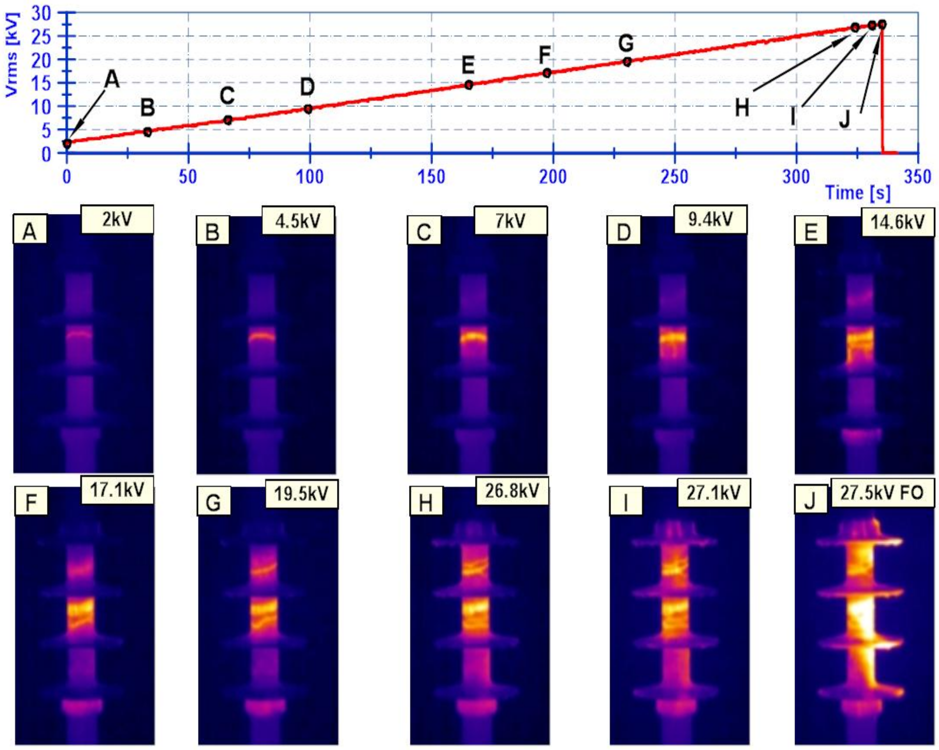

Figure 2. Formation and development of dry-bands during a ramp voltage test (11.2 S/m and 3 l/h).pollution (11.2 S/m) and low fog (3 litres/hour).*The number and width of the dry-bands increase with the test voltage.*

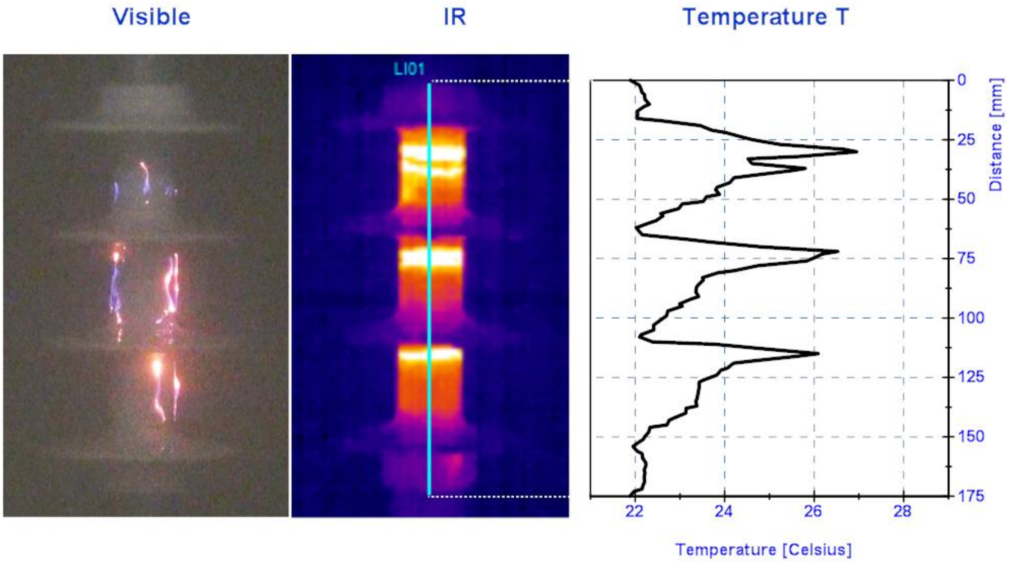

Figure 3. Visible image, infrared record and temperature profile on insulator at 30 kV.

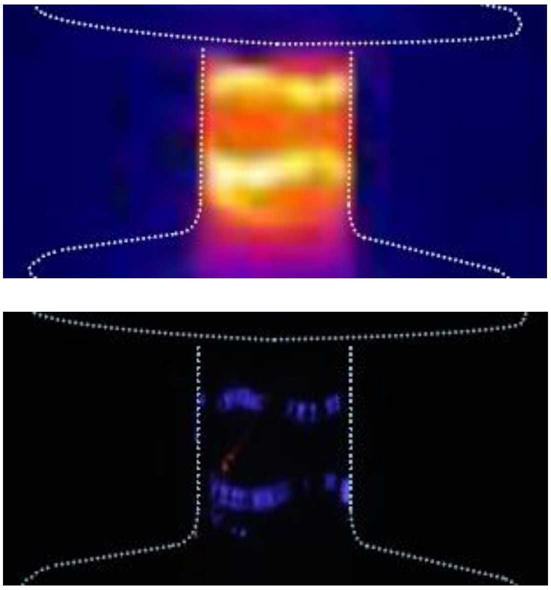

Figure 4(a). IR and visible close-ups of dry-band heating and corona discharges on the top trunk section.

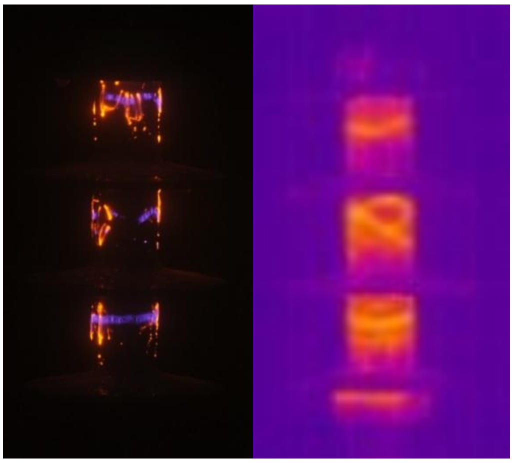

Figure 4(b). Dry-band streamers, incipient partial arcs and IR record.

a)

b)

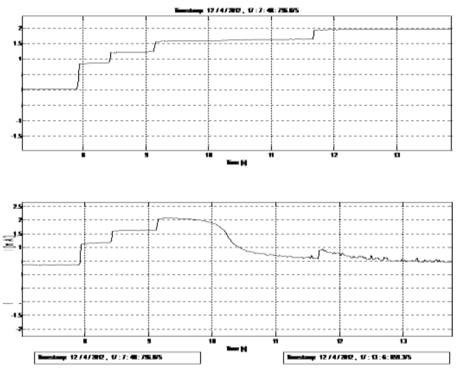

Figure 5. Dry band inception on insulator (a) Stepped applied voltage (b) Leakage current.

5. CONCLUSIONS

1. IR surveys of overhead line insulators are sometimes used for the detection of abnormal heating associated with physical deterioration or damage. In the present work, infra-red imaging has been shown to reveal the detailed development of dry bands which are normally invisible to observation.

2. The current continuity and heating of the dry bands are maintained by small-scale streamer spark discharges.

3. Comparison of visible and infrared emissions indicates that dry-band discharges may initiate more extended, higher-current surface discharges (partial arcs). These frequently link discrete dry-band regions.

4. Ongoing work is applying the spatial and electrical data from these tests to existing and alternative models of flashover of polluted insulators.

REFERENCES

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