A Comparison Between Measured Leakage Current And Surface Conductivity During Salt Fog Tests

Wilhelm H. Schwarzt*, Jacobus P. Holtzhausen* and Wallace L. Vosloo**

1Department of Electrical & Electronic Engineering, University of Stellenbosch, Private Bag X1, Matieland, 7602, South Africa.
**ESKOM, TSI, University of Stellenbosch, Private Bag X1, Matieland, 7602, Stellenbosch, South Africa.

Abstract This paper deals with an Insulator Pollution Monitoring Relay (IPMR), designed to measure and monitor pollution on high voltage insulators. The IPMR determines the pollution severity by measuring the surface conductivity on the test insulator. The paper reports on how the IPMR was used to measure surface conductivity on the test insulator while a salt fog test was performed on typical power line insulators. The leakage currents were measured on the test insulators and the data was captured together with the surface conductivity values. The results discuss whether the IPMR is capable of the early detection of an instantaneous pollution event. The results are also utilised to compare the relationship between measured surface conductivity and leakage current values thus predicting flashover.

Keywords Peak Leakage Current, Salt Fog Tests, Site Severity, Surface Conductivity.

I. INTRODUCTION

The performance of outdoor high-voltage insulators is adversely affected by environmental pollution in coastal and industrial regions. In some instances, solid pollution particles settle on the insulator surface and become a conductive electrolyte when the insulator surface is wetted by rain or fog. This allows leakage currents to flow over the insulator surface and lowers the electrical withstand voltage of the insulator, leading to possible flashover. This process is called a pre-deposited pollution event and is best simulated, using a pre-deposited clean fog test. A similar process takes place when a relatively clean insulator is subjected to a conductive fog or spray, a so-called instantaneous or rapid pollution event. This process is best simulated, using a salt fog test. After a rapid pollution flashover very little pollution remains on the insulator as evidence.

The Insulator Pollution Monitoring Relay (IPMR) has been developed to monitor the severity of pollution on high voltage insulators by measuring the surface conductivity on a test insulator, in the case of a pre-deposited pollution event [1]. The IPMR measurements can then be utilised to indicate whether the surrounding insulation should be cleaned.

In the present work the use of IPMR to monitor the severity of an instantaneous pollution event is investigated by measuring the surface conductivity during a salt fog test.

II TEST SET UP AND PROCEDURE

For this experiment, the IPMR is placed inside the salt fog chamber near the test insulators. The test insulators were energised from a separate high voltage source and the leakage currents were monitored for the duration of the salt fog test.

The IPMR is normally used to monitor the degree of pre-deposited pollution in the vicinity of a high voltage line or in a substation as shown in Figure 1.

Figure1: Photo showing IPMR installed at a substation.

In such cases, artificial wetting of the insulator is provided during the conductivity measurement, once or twice a day. In the case of instantaneous or rapid pollution, the artificial wetting cycle of IPMR is not required and the conductivity can be monitored continuously.

The surface conductivity is determined by applying of a $3kV_{rms}$ voltage and measuring the leakage current that
flows through the pollution layer. The voltage is only applied for 5 voltage cycles to avoid the formation of dry bands that can lead to incorrect measurements.

The salt fog chamber was built according to the specifications supplied in the IEC 60507 [2]. The chamber measures 6m (w) x 6m (w) x 3m (h). The chamber is equipped with a 9-channel leakage current monitor that uses high accuracy Hall effect current transducers. The leakage current monitor samples each channel continuously at 2 kHz. The sampled values are stored in flash memory and the highest leakage current peak occurring in each minute is stored for the duration of the test.

Various artificial testing techniques can be applied to the IPMR to simulate natural conditions. The solid layer method (clean fog method) [2] can be used to simulate effects on pollution with a pre-deposited pollution, whereas the salt fog method [2] can be used to simulate conditions during an instantaneous pollution event, as was done in the present investigation.

A number of different salt fog tests were done with different salinities, representing different pollution levels. The salt water for the fog test was prepared by mixing the required amount of NaCl with water in the storage tanks. Care was taken to ensure thorough mixing and complete solution.

The test insulator used during the IPMR surface conductivity test was one standard glass cap and pin insulator. The test insulator used during the salt fog test consisted of two standard glass cap and pin discs. Each disc has a 146mm connecting length and 280mm creepage distance. The test voltage was raised to a value such that the specific creepage distance on the test insulator was 25mm/kV. The test was started as soon as the salt water solution and air was applied to the nozzles. The IPMR and leakage current monitor were both set up to measure surface conductivity and leakage currents at 1-minute intervals.

III. DISCUSSION OF TEST RESULTS

3.1 Comparison of Measured Conductivities and Leakage Currents

The measured IPMR conductivities (µS) are plotted against the corresponding test salinities (kg/m³) in Figure 2. A linear relationship can be seen to exist for the severity range covered in these tests. The pollution classification [3] for the corresponding conductivities is also shown in the right-hand column on the graph.

The test insulator, energised at 25 mm/kV, flashed over during the 88 kg/m³ test. This value coincides roughly with the severity withstand value for this insulator energised at a specific creepage distance of 25mm/kV [4].

3.2 Critical Flashover Voltage, derived from the measured surface conductivity:

Theoretical models to predict insulator flashover have been developed and applied by Rizk [5], Holtzhausen [6] and Vosloo [7]. According to these models the critical flashover voltage of an insulator depends on the surface conductivity of the insulator surface and the shape (form factor) of the insulator.

This critical flashover voltage is given by the following semi-empirical formula [5, 6]:

$$V_c = k_1.10^{-3} \left[ \frac{FF.10^6}{\sigma_s L} \right]^{k_2} L$$

where:

- $V_c$: critical insulator flashover voltage (kV)
- $FF$: form factor of the insulator
- $\sigma_s$: surface conductance (µS)
- $L$: creepage length of the insulator (mm)
- $k_1$ = 7.6
- $k_2$ = 0.35

**Figure 2: IPMR Surface Conductivity (µS) vs. Salinity (kg/m³).**
As the relationship between the surface conductivity and salt fog salinity is known from Figure 2, the critical voltage \((V_c)\) was calculated and plotted against the test salinity in Figure 3. The dotted horizontal line represents the applied voltage and the solid-line curve the calculated critical voltage. It can clearly be seen that flashover probability is increased when the critical flashover voltage approaches the applied voltage. This increased flashover probability coincides with a salinity between 50 and 60 kg/m\(^3\). The severity withstand levels for salt fog tests are given in Table 1.

### Table 1: Salinity withstand values and recommended specific creepage lengths.

<table>
<thead>
<tr>
<th>Degree of Pollution</th>
<th>Salinity range (kg/m(^3)) ([2])</th>
<th>Recommended specific creepage length ([3])</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>5 - 14</td>
<td>16</td>
</tr>
<tr>
<td>Medium</td>
<td>14 - 40</td>
<td>20</td>
</tr>
<tr>
<td>Heavy</td>
<td>40 - 112</td>
<td>25</td>
</tr>
<tr>
<td>Very Heavy</td>
<td>&gt; 160</td>
<td>31</td>
</tr>
</tbody>
</table>

It is interesting to note that the above range falls in the "Heavy" pollution range. The specific creepage length of the insulators (25 mm /kV) is also suitable for heavily polluted areas. It is interesting to note that one flashover did occur 88 kg/m\(^3\).

It must be borne in mind that the IPMR surface conductivity values were measured on a “cold” (non-energised) insulator surface whereas the peak leakage currents were measured on a “hot” (full-time energised) insulator surface. The actual surface conductivity of the insulator was thus appreciably higher at the 88 kg/m\(^3\) test – it could be as high as double the value \([6]\).

### 3.3 Critical leakage current \((I_{\text{max}})\)

Theoretical and empirical investigations indicate that there exists a critical value of leakage current that presents a threshold above which the flashover probability increases sharply. \([6]\), \([8]\), and \([9]\).

Verma \([8]\) defined this current as the maximum peak leakage current that flows the half cycle before flashover as \(I_{\text{max}}\).

\[
I_{\text{max}} = \left( \frac{SCD}{15.32} \right)^2
\]

where:

- \(SCD\) : Specific Creepage Distance (mm/kV)

Holtzhausen \([9, 10]\) proposed that, to minimise flashovers, the maximum permissible peak leakage current must remain below 25% as that of \(I_{\text{max}}\).

The peak leakage current, measured in each test, was plotted against the test severity in Figure 3. Similarly to Figure 2, the flashovers can be experienced when the peak leakage currents exceed the maximum permissible peak leakage current.

It will be noted that this point again coincides with salinity between 50 and 60 kg/m\(^3\). These tests were done at a fixed specific creepage length for the specific test insulators.
IV. CONCLUSIONS

It appears that IPMR can be used to evaluate the severity of an instantaneous pollution event as simulated by the salt fog tests. The results obtained show that the occurrence of pollution flashovers were observed in all cases when the measured values and calculated parameters approached the critical insulator performance limits (surface conductivity, critical flashover voltage and $0.25 \cdot I_{\text{max}}$).

The inclusion of a real time leakage current measuring sensor and weather monitoring facilities in the IPMR measuring options will improve the IPMR measurement capability.

Further work is required to investigate the effect of variation in specific creepage distance and the effect of different insulator shapes.

V. REFERENCES


VI. AUTHORS

Principal Author: Wilhelm H Schwardt received his Post Graduate Diploma in Engineering (PDE) from the University of Stellenbosch in 2001. He is currently working towards his M.Sc (Eng.Sci) at the same institute.

Co-Author: Jacobus P Holtzhausen holds a PhD degree in Electrical Engineering from the University of Stellenbosch. He is a retired Senior Lecturer from the University of Stellenbosch and is presently employed under contract to do research in High Voltage Engineering at the same University.

Co-Author: Wallace L Vosloo holds a PhD degree in Electrical Engineering from the University of Stellenbosch. He is at present a Chief Consultant (Insulators) for ESKOM, TSI.