THE PREDICTION OF INSULATOR LEAKAGE CURRENTS FROM ENVIRONMENTAL DATA

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ABSTRACT
The leakage currents of various insulators were monitored together with environmental data at a coastal test site. In addition the daily maximum surface conductivity was measured. In this paper it is shown how, using multiple regression, the leakage current can be predicted from the measured weather and environmental parameters.

1. INTRODUCTION
Koeberg Insulator Pollution Test Station (KIPTS) is situated along the Cape West Coast, 50 m from the sea. The site is generally accepted as a severe coastal test station for the pollution and ageing performance of outdoor insulators. Various types of energised insulators are exposed to the environment, while the leakage current flow over the insulator surface is monitored. In a specific experiment a number of new 22 kV insulators having the same shapes but made of different materials were energised at the site. Leakage currents were monitored continuously and the highest value of each 10 minute period was stored. Meteorological data were logged simultaneously.

Post-processing software facilitate analysis of the leakage current data. The equivalent surface conductivity, based on the peak leakage waveform and a the form factor was also derived for each day. Leakage currents were monitored continuously and the highest value of each 10 minute period was stored. Meteorological data were logged simultaneously.

During this outage on day 5 the following measurements were done:
• The six-weekly average directional dust deposit gauge (DDG) pollution measurements were exceptionally high (1336 µS/cm). The highest pollution emanated from the west (2178 µS/cm) and north (1707 µS/cm) and the lowest from the east (567 µS/cm). Note that the sea is situated on the western side of KIPTS and the land on the eastern side.
• The six-weekly ESDD pollution on a porcelain longrod was measured as heavy (0.16 mg/cm²).
• The six-weekly NSDD pollution on a porcelain longrod was measured as very light (0.044 mg/cm²).

The 10-minute climatic measurements (precipitation, relative humidity, UV-B solar radiation and ambient temperature) recorded in week 24 are plotted in Figure 2 while the wind data is given in Figure 3.

The following are aspects should be pointed out in connection with this data:
• It rained 2.0 mm on day 5, 5.7 mm on day 6 and 1.1 mm on day 7.
• The week was cool to moderate, with daily average humidity levels above 85%.
• The UV-B solar radiation had increased significantly since week 18, indicating the change in season from winter to summer.
• There was a strong north-westerly and westerly breeze on days 5 and 6.

3. REGRESSION ANALYSIS
Analysis of the leakage current and the weather data indicated a strong correlation of leakage current with
some of the climatic parameters. The question which comes to mind is whether the insulator leakage current can possibly be determined from the environmental and climatic conditions monitored. In this section, multiple regression techniques are used to try and resolve this question [2,3].

The measured peak wave surface conductivity values for the week were compared with the measured ESDD values and both methods agreed on a heavy pollution level. It was therefore decided to use the daily peak waveform surface conductivity as the pollution level parameter. The 10-minute climatic parameters measured (humidity, rainfall, UV-B solar radiation, temperature, and directional wind speed) are used as independent variables along with the daily peak wave conductivity (representing the environmental pollution level). These independent variables are used to determine the dependent variables (the peak leakage current levels), using linear and non-linear regression techniques [3].

In the linear multiple regression method the dependent variable is expressed as linear equation of the independent variables, i.e.

$$y = c_1 x_1 + c_2 x_2 + c_3 x_3 + \ldots$$  \hspace{1cm} (1)

In this equation $c_1$, $c_2$, $c_3$... are the regression coefficients to be determined to obtain the best data fit.

Likewise, in the non-linear regression method, the following equation is obtained for the best fit:

$$\log(y) = c_1 \log(x_1) + c_2 \log(x_2) + c_3 \log(x_3) + \ldots$$  \hspace{1cm} (2)

Once the coefficients are obtained, the independent variable in eq. (2) can be written as:

$$y = x_1^{c_1} x_2^{c_2} x_3^{c_3} \ldots$$  \hspace{1cm} (3)

The leakage current was chosen as the dependent variable and the independent chosen variables are indicated in Table 1:

| $x_1$, $c_1$ | Peak wave conductivity |
| $x_2$, $c_2$ | Humidity |
| $x_3$, $c_3$ | Rainfall |
| $x_4$, $c_4$ | UV-B |
| $x_5$, $c_5$ | Temperature |
| $x_6$, $c_6$ | Wind speed |
| $x_7$, $c_7$ | North |
| $x_8$, $c_8$ | East |
| $x_9$, $c_9$ | South |
| $x_{10}$, $c_{10}$ | West |

The regression constants calculated for insulator 3P for...
Figure 2: Precipitation, relative humidity, UV-B solar radiation and ambient temperature measurements during week 24
Figure 3: Wind speed measurements recorded in week 24
Table 2: Table of Regression constants of \((c_1\) to \(c_9\)) for each day of week 24 for Insulator 3P

<table>
<thead>
<tr>
<th>Peak Wave Conductivity</th>
<th>Peak Wave Conductivity</th>
<th>Linear</th>
<th>Non-Linear</th>
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<tbody>
<tr>
<td>Humidity</td>
<td>Humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall</td>
<td>Rainfall</td>
<td></td>
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<tr>
<td>UV-B</td>
<td>UV-B</td>
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<tr>
<td>Temperature</td>
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<tr>
<td>340 (North)</td>
<td>340 (North)</td>
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<td>70 (East)</td>
<td>70 (East)</td>
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<tr>
<td>160 (South)</td>
<td>160 (South)</td>
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<tr>
<td>250 (West)</td>
<td>250 (West)</td>
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</table>

<table>
<thead>
<tr>
<th>Regression constants for Insulator 3P during week 24 ((c_1 - c_9))</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
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<tbody>
<tr>
<td>Predicted</td>
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<tr>
<td>Measured</td>
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</table>

**Figure 4:** Predicted and measured leakage currents, using linear and non-linear multiple regression
week 24, using these techniques, are given in Table 2.

The coefficient of determination $R^2$, representing the “strength” or “magnitude” of the relationship, is also given (0 = poor, and 1 = excellent).

With the regression constants known for the respective independent variables, the predicted current can be "reconstructed", using either equation (1) or (3) for a linear or non-linear regression respectively.

The results of such predictions are shown in Figure 4.

The present analysis is only valid for porcelain insulators, but similar analyses were done for other insulator materials with similar results. All these insulators were hydrophilic.

4. DISCUSSION

From Table 2 it is clear that the coefficient of determination ranges between 0.43 and 0.95, with high values on most of the days. The non-linear regression method clearly is more accurate than the linear method.

All variables were sampled at 10 minute intervals with the exception of the peak wave conductivity that represented the daily maximum value. This value would not reflect rapid changes in pollution on the insulator, e.g. due to rain washing or salt storms. An improvement would be to monitor the surface conductivity at 10-minute intervals on a separate pollution monitoring device.

Despite these limitations the leakage current values calculated, using the measured independent variables show a remarkable agreement with the measured leakage current data.

Further work could concentrate on incorporating continuous surface conductivity measurements and using methods such as artificial neural networks [4,5].

5. CONCLUSION

The non-linear multiple regression method has been shown to be able to be able to determine the leakage current with a reasonable accuracy. Further work is required to refine the method.

6. REFERENCES:


7. AUTHORS:

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Wallace Vosloo holds a PhD degree in Electrical Engineering from the University of Stellenbosch. At present he is Chief Consultant (Insulators) for Eskom, TSI.

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Presenter:
The paper is presented by Wallace Vosloo.