# EVALUATION OF THE USE OF INSULATION COVERS FOR VULTURE PROTECTION ON POWER LINES

G. Chitungo[1*], C. Nyamupangedengu[2], J. Van Coller[2]
[1]Eskom Distribution, Germiston, South Africa
[2]School of Electrical and Information Engineering, University of the Witwatersrand,
Johannesburg, South Africa
*Email: givemore.chitungo@eskom.co.za

**Abstract**: Overhead power lines are among the top contributors to vulture mortalities in South Africa due to contact electrocution. Furthermore these electrocution incidences on the endangered birds affect the power supply quality and reliability. Utilities around the world faced with the same problem have implemented various solutions such as reconfiguring the lines to bird friendly structures, retrofitting the existing structures and making use of underground cable by-passes. The choice of these preventative measures is a function of cost and reliability. This paper presents a case study on insulation covers that were retrofitted on 88 kV power line structures to mitigate vulture electrocution problems. The paper presents a theoretical evaluation of the performance of the insulation covers. Results of preliminary laboratory tests performed to evaluate the theoretical predictions are also reported in the paper. The validated model will be used in the design of similar bird electrocution prevention retrofits.

## 1 INTRODUCTION

Power lines span several thousands of kilometres across the country to deliver electricity to homes and industries. They unfortunately sometimes interfere with nature, collision and electrocution of birds such as vultures being one of the common problems. The image in Figure 1 shows an example of an electrocuted vulture on an 88 kV steel lattice structure. Utilities around the world have implemented various solutions to mitigate these adverse environmental effects [1]. Solutions such as reconfiguring the lines to bird friendly structures, retrofitting the existing structures and making use of underground cable by-passes have been utilised for purposes of electrocution prevention. These not only assist with minimising vulture electrocution but improve the power system reliability [1].

**Figure 1:** An electrocuted vulture on an 88 kV steel lattice structure (photograph courtesy of Johan van Staden)

Utilities in collaboration with conservationists have identified problem locations which include wetlands and game reserves. In these areas birds perch on power lines to rest or spot their prey. Mitigation strategies are therefore targeted on these specific areas.

An effective method to prevent the bird from contact electrocution is to cover the bare conductor of the overheard line with insulation material. This technique allows the birds to make contact with the power line but with no danger of electrocution [1].Though the technique of insulating the conductors has generally succeeded in reducing the cases of vulture electrocution, it is associated with new problems that include:

- Tracking on the insulation covers due to pollution
- Conductor corrosion on the portion of the conductors that are covered by the insulation covers

This paper evaluates the design of an insulation cover that is being used to mitigate vulture electrocution problems on power lines in a power utility.

The insulation cover accumulates pollution on its surface forming a thin partially conductive layer. The presence of a conducting or partially conducting layer of pollution on the insulator surface causes increased leakage current over the insulator surface. The leakage current eventually causes flashover [2].

The International Electrotechnical Commission (IEC) [3] specifies the pollution level on the insulators based on the severity of the pollution that will be expected to accumulate on the surface. This is quantified by the conductivity of the pollution and is specified in Table 1 below. The standard also specifies the recommended specific creepage length to prevent flashover.

**Table 1:** IEC pollution classification [3]

| IEC Pollution Classification | Surface conductivity (µS) | Recommended Specific creepage length (mm/kV)) |
|---|---|---|
| Light | 15-20 | 16 |
| Medium | 24-30 | 20 |
| Heavy | >30 | 25 |

In this study the insulation cover material is assumed unpolluted when the surface conductivity is below 15 µS.

## 2 THEORETICAL ANALYSIS

### 2.1 Electrical equivalent circuit

According to [4] the insulator can be electrically modelled to represent the clean and polluted conditions as shown in Figure 2 and Figure 3 respectively

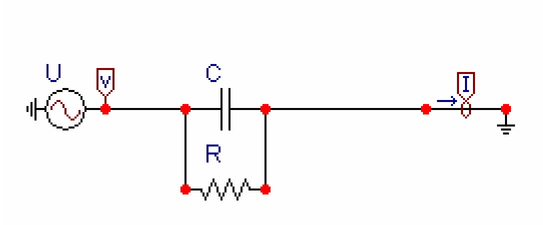

**Figure 2:** Electrical equivalent circuit of a clean insulator

The clean insulator in Figure 2 can be considered as a linear high magnitude resistor in parallel with a capacitor. The capacitance is the predominant element in the model and the current waveform is therefore dependent on the capacitance. The resultant circuit is a highly capacitive RC circuit and thus the current wave shape is expected to have some oscillations.

The pollution deposit on the insulator surface introduces a nonlinear resistance due to the moistened pollution in parallel with the model of a clean insulator as shown in Figure 3 below. Voltage and corresponding leakage current on the polluted insulator cause dry bands to form which in turn further modify the model. The dry bands can be modelled as parallel combinations of non linear resistances and capacitances in series with the conductive pollution [4].

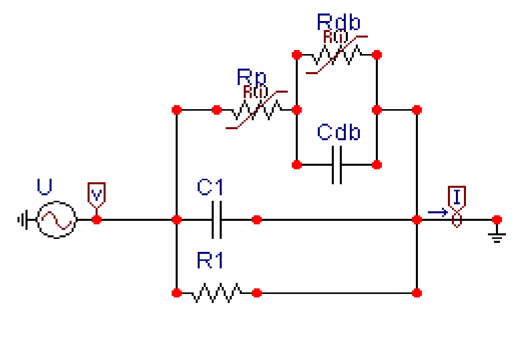

**Figure 3:** Electrical equivalent circuit of a polluted insulator with dry bands

The models in Figure 2 and Figure 3 are used as the building blocks for the complete equivalent circuit of the insulation cover as shown in Figure 4. The study uses the model to predict the leakage current on the surface of the insulator cover at the instant of a bird coming into contact with the cover at various possible positions.

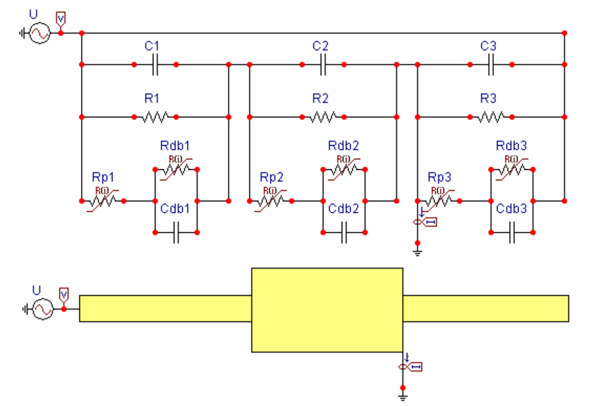

**Figure 4:** Proposed electrical equivalent circuit of a polluted insulation cover with dry bands

### 2.2 Pollution layer conductivity

According to J.P. Holtzhausen [5] the surface conductivity of an insulator is related to its shape by Equation 1 below, this assumes a uniform distribution of the pollution on the insulator surface.

$$\sigma_s = GF \qquad (1)$$

Where G = conductance [µS]

F = insulator shape form factor [unitless]

In case of the cylindrical insulator cover used for electrocution mitigation the form factor is quantified by Equation 2

$$F = \frac{L}{2\pi r} \qquad (2)$$

Where L= length of insulator [mm]

r= radius of the cylindrical insulation cover [mm]

From Equations 1 and 2, the resistance value R of the pollution layer can be quantified from the calculated value of G by Equation 3

$$R = \frac{1}{G} = \frac{F}{\sigma_s} \qquad (3)$$

### 2.3 Insulation cover capacitance

The capacitance of a hollow cylindrical insulation cover as deduced from basic electricity circuit theory is given by Equation 4

$$C = \frac{2\pi \varepsilon_r \varepsilon_o}{\ln\left(\frac{r_1}{r_o}\right)} \qquad (4)$$

Where C= capacitance of the insulation cover

$\varepsilon_r$ = relative permittivity of the insulating medium [unitless]

$\varepsilon_0$ = Absolute permittivity of free space (F/m)

$r_1$ = Outer radius of the insulating medium [mm]

$r_0$ = Inner radius of the insulating medium [mm]

The insulator R and C values for the insulation cover quantified from Equations 3 and 4 will be used as the input data into the model proposed below and were run in ATP.

### 2.4 Prediction of flashover

A very lightly polluted insulator (clean insulator) whose conductivity $\sigma_s$ approaches zero has its equivalent resistance R that approaches infinity in accordance with Equation 3. A polluted insulator has an equivalent circuit as shown in Figure 2. From basic circuit theory, a parallel combination of impedances $Z_c$ and $Z_p$ where $Z_c >> Z_p$,

$$Z_{total} \approx Z_p \qquad (5)$$

Where $Z_p$= Pollution insulator impedance [Ω]

$Z_c$= Clean insulator impedance [Ω]

$Z_{total}$ = Total insulator impedance [Ω]

Equation 5 shows that pollution dictates the leakage current magnitude. In addition to pollution severity, the insulator shape also influences surface conductance as expressed in Equation 1.

Literature shows that when the leakage current increases and reaches a threshold value ($I_{max}$) given by Equation 6 [6], flashover is bound to happen. The equivalent critical flashover voltage according to Rizk [6] is given in Equation 7.

$$I_{\max} = \left[\frac{SCD}{15.32}\right]^2 \qquad (6)$$

Where: SCD is the specific creepage distance as defined in IEC 60815.

$$V_c = k_1 \times 10^{-3} \left[\frac{F \times 10^6}{\sigma_s L}\right]^{k_2} \times L \qquad (7)$$

Where $V_c$ =critical flashover voltage [kV]

$\sigma_s$ =surface conductivity [µS]

F= insulator form factor [unitless]

L= creepage distance [mm]

$k_1$= 7.6

$K_2$=0.35

A vulture can come into contact with the insulation cover and bridge the gap with the nearest earthed part of the structure. Depending on the insulator pollution severity and point of contact (either position 1, 2 or 3 in Figure 3, the resultant leakage current can reach the flashover threshold value. For insulation on a 88 kV line, according to IEC recommendations (as shown in Table 1), the SCD is 16mm/kV and this gives a threshold leakage current of 1mA.

A laboratory experiment as presented in the next section was set up to investigate how the leakage current and flashover voltage on an insulator cover varied as a function of pollution severity and contact position (creepage distance).

## 3 EXPERIMENTAL WORK

### 3.1 Experimental setup and procedure

The tests were performed in the high voltage laboratory at the University of the Witwatersrand, Johannesburg. A sample bus connector insulation cover (BCIC) with dimensions (r= 95.1mm and L=480mm) and medium voltage line cover (MVLC) with dimensions (r= 23.2mm and L=300mm) were used in the experimental test. The test set up was as shown in Figure 5 below.

Voltages ranging from 10 kV to 55 kV which gives a voltage within the expected phase to ground voltage were applied on the insulation cover. To simulate bird contact, a wire connected to earth through a 100 Ω resistor was attached to the insulation cover at either position 1, 2 or 3 as shown in Figure 5. At each contact position the voltage was varied from 0 kV to 55 kV. At suitable voltage steps the leakage current was noted. The procedure was repeated for clean and polluted conditions. Pollution was introduced by uniformly spraying a pollutant prepared by mixing NaCl and Kaolin in proportions given in Table 2.

**Table 2:** An extract of conductivity measurement of different kaolin pollutant solution from [7]

| Pollutant concentration (gr/ltr) | Solution conductivity (μS) |
|---|---|
| 20 | 16.64 |
| 40 | 17.07 |
| 80 | 21 |
| 100 | 22.7 |
| 120 | 25.3 |

For this research, a pollutant concentration of 20gr/ltr of NaCl and 40g of Kaolin was used to simulate the light pollution

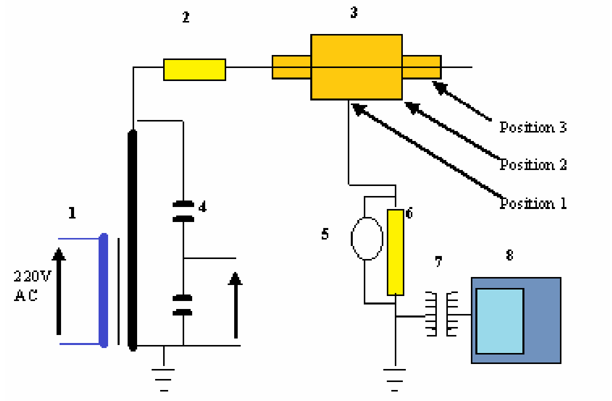

**Figure 5**: (1) Supply voltage (2) Protective resistor (3) insulation cover (4) Voltage divider (5) Voltmeter (6) Series resistor (7) Current transformer (8) Oscilloscope

### 3.2 Experimental results

Variations of the leakage current as a function of pollution at contact position 1 are shown in Figure 6. The leakage current increased with pollution as anticipated.

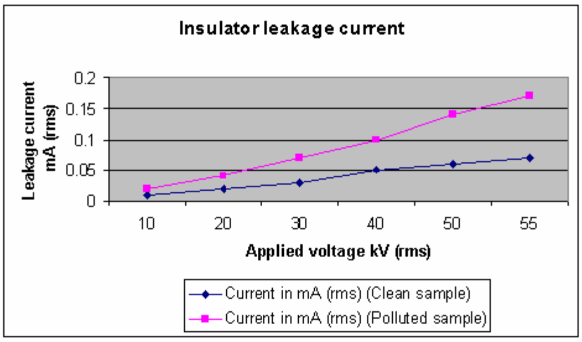

**Figure 6:** Leakage current on clean and polluted insulator cover

For the same pollution level, the leakage current increased as the contact position was varied from positions 1 to 3. Moreover as the position of the contact to earth was moved towards the live conductor the withstand voltage stress reduced as shown in Table 3.

**Table 3:** Variations of the leakage current as a function of contact position on the insulator

| Applied Voltage in kV(rms) | Current in mA(rms) (Polluted sample) Position 1 | Current in mA(rms) (Polluted sample) Position 2 | Current in mA(rms) (Polluted sample) Position 3 |
|---|---|---|---|
| 10 | 0.02 | 0.02 | 0.25 |
| 20 | 0.04 | 0.04 | 0.59 |
| 30 | 0.07 | 0.07 | flashover |
| 40 | 0.10 | 0.10 | |
| 50 | 0.14 | 0.14 | |
| 55 | 0.17 | flashover | |

## 4 DISCUSSION OF EXPERIMENTAL RESULTS

The experimental results show that the leakage current for both the clean and polluted insulation covers increases with increasing voltage. This is in agreement with similar findings [7]. The results also show that the leakage current on polluted insulation covers is larger than on clean insulation covers and this applies for both dry and wet conditions. The experimental results confirm the theoretical predictions.

Changing the contact positions along the insulator cover gets to a point where flashover occurs. The position closest to the conductor gave the lowest flashover voltage. This is attributed to the reduced creepage distance along the insulator at that position and is in agreement with predictions by Rizk [6].Under the same conditions there exists a point along the insulator length where the leakage current reaches a critical flashover value, developing a critical flashover voltage which subsequently leads to flashover.

In the case of vultures on power lines, the bird can make contact with the insulation cover at a position that gives the critical flashover voltage. This voltage can be increased by increasing the creepage distance (see Equation 7). This can be achieved through various possibilities such as redesign and re-dimensioning of the insulation cover. Another more attractive possibility is the coating of the insulation cover with a silicone rubber layer. The latter is hydrophobic and more immune to pollution. Future work on this project will therefore entail repeating the tests presented in this work but with a silicone rubber coating.

## 5 CONCLUSION

The investigation shows that the problems of insulation covers are associated with leakage current. Possible solutions are to increase the creepage distance on the insulation cover or to coat the insulation cover with a silicone rubber layer.

## 6 ACKNOWLEDGMENTS

The authors would like to acknowledge with gratitude Eskom for their support of the High Voltage Engineering Research Group of the University of the Witwatersrand, Johannesburg through TESP. They would also like to express gratitude to the Department of Trade and Industry (DTI) for THRIP funding and to thank the National Research Foundation (NRF) for direct funding of the research group.

## 7 REFERENCES

[1] IEEE Task Force, “Preventative measures to reduce bird related power outages-part I: Electrocution and collision”, IEEE Transaction on Power Delivery. Vol 19 No. 4. pp 1843-1847, October 2004.

[2] Cigre Task Force 33.13.01 “Polluted Insulators: a review of current knowledge”, Cigre Task force, June 2000.

[3] IEC 815. "Guide for the Selection of Insulators in Respect Of Polluted Conditions". IEC Recommendations. Publication. 815, 1986.

[4] Waluyo, P.M. Pakpahan, Suwarno,”Study on the electrical equivalent circuit model on polluted outdoor insulators”,8th International Conference on Dielectrics, pp 546 -549, 2006

[5] J.P. Holtzhausen Personal communication

[6] F. A. M. Rizk, “Mathematical models for pollution flashover”, Electra, Vol. 78, pp 71-103, 1978.

[7] S. Manjang, I. Abduh,: “Leakage current pattern on artificially polluted Porcelain and Polymer insulators”, 8th International Conference on Dielectrics , pp 443-446, 2006.