Potential Distribution Along a 500kV Polymer Insulator in Presence of a Pollution Layer

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Abstract: The objective of this study is to assess polymeric insulators subjected to polluted environments. The study cases were conducted on polymeric insulators of 500 kV lines. All analyses were carried out with computer simulations, employing the software COMSOL Multiphysics® to calculate the voltage distribution on the surface of the insulators with deposits of pollution layer. Through the potential distribution we can estimate what is the level of pollution deposited on the insulator surface and then try to schedule a proper wash time strategy, saving resources and time. Important conclusions have been obtained, which contribute to the assessment of these events.

Key-words: polymeric insulators, finite elements method, pollution on insulators, surface discharge.

1. Introduction

The application of polymeric insulators on high voltage transmission systems has been adopted as a solution in regions with high incidences of pollution and vandalism. They are widely used, but although they present certain advantages linked to the fact that they are easy to handle and weigh relatively little, which is an attractive feature to project makers and constructers, they also carry with them a number of economic and operational concerns.

Although the price of these units has fallen over recent years, due to increased demand and more efficient manufacturing processes, operational concerns could well inhibit the demand for their use. Such concerns have been motivated by their shorter life span when compared to traditional glass and porcelain insulators, and the installations to which they are applied. These concerns become even greater when the company is faced with the possibility of having to carry out heavy, inopportune replacement works due to the short life span of the insulating units. Having to face this on-going process of degradation may overstretch maintenance teams, thus increasing the detrimental risk of being unable to provide an energy supply to its customers. Currently, this question is further aggravated as companies do not possess reliable early warning techniques, whereby insulation units may be replaced at the most appropriate moment.

Some preliminary studies have indicated insulation units where the voltage distribution on the string was nonlinear, which consequently led to an excessive concentration of voltage along localized sections. These sections, when submitted to polluted environments, characterize regions that may lead the insulators to surface electrical arcs, which may cause the gradual, premature disintegration of the units. This deterioration may develop to such a degree that the core is finally exposed, infiltration occurs and the insulator is totally damaged by electrical perforations, thus culminating in an interruption to the energy supply along the transmission line.

Figure 1. 500kV Polymer Insulator.

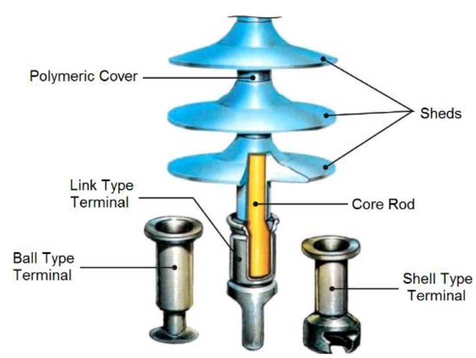

Figure 2. Polymeric Insulator's Structure.

2. Findings in Electrical Systems

Environmental pollution is one of the main problems of insulating transmission lines.

Electrical energy companies annually spend huge sums of resources on preventative maintenance, so as to minimize interruptions to the supply.

Several methods have been employed in order to measure the operational conditions of insulation, such as the visual detection of surface discharges, measuring the equivalent salt deposit density (ESDD), and current leakage and ultra-sound noises [1]. However, none of these techniques have proven totally reliable.

Currently, there is a tendency for these problems to worsen due to the accelerated rate of development and construction of new industrial parks. The use of polymeric insulation units has been favored by many enterprises in heavily polluted regions. Manufacturers however, do not even recommend any specific type of maintenance within these regions. Nonetheless, enterprises have sought to introduce monitoring techniques to prevent any untimely failures.

Also, some polymeric insulation units have presented tracking and electrical erosion when applied in these regions. Although theoretically these insulators possess improved features in order to operate in these types of regions, when compared to traditional insulators, their life expectancy is still somewhat uncertain [2].

3. Computational Methods

First, we drew the insulator's geometry using a CAD software to import to our COMSOL Model, as shown in Figure 3, and the inner structure of a polymeric insulator presented in Figure 2.

Then using the Electrostatics Physics Interface from COMSOL we obtained the voltage distribution along a clean insulator applying the service peak voltage of 407kV at the insulator's pin and grounded the top metal fitting, as shown in Figure 4.

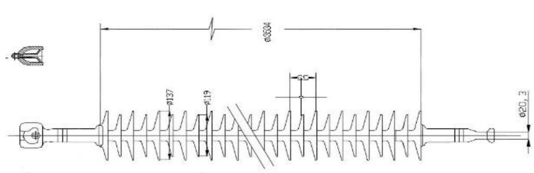

Figure 3. Insulator CAD Drawing.

Table 1 shows the materials properties used in simulation:

Material	Conductivity[S/m]	Permittivity[F/m]
Air	0	1.02
Silicon Rubber	0	3
Fiberglass	0	6.5
Metal fittings	$10.2\text{x}10^{6}$	10^{-6}

Table 1. Material Parameters used in simulation.

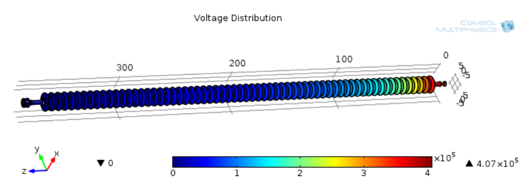

Figure 4. Potential Distribution along a clean polymer insulator.

To observe the behavior of voltage distribution along the insulator, pollution layer was modeled as a thin conductive layer of one millimeter uniformly distributed over the insulator surface, as shown in Figure 4.

Considering the conductive layer very thin, the conduction current and the displacement current densities can be considered uniform along the pollution thickness. In that case, the approximation of the layer as a conductive surface can be done [3].

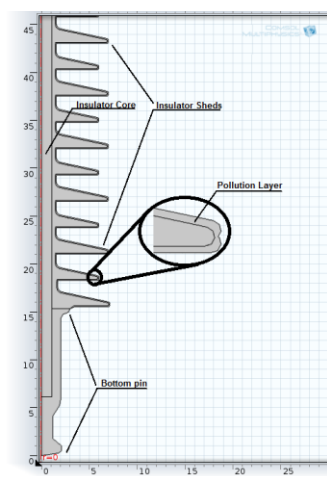

Figure 4. Pollution Modeling.

We used the interface for equation modeling, in the coefficient form, to insert our partial differential equation (PDE) of interest:

$$(\sigma_v + j\omega\varepsilon)\nabla^2 V + j\omega\rho_s = 0 \quad (1)$$

Where:
σ_v – Material Conductivity [S/m]
ε – Material Permittivity [F/m]
ρ_s – Surface Charge Density [C/m^2]
ω – Service Frequency [rad/s]
V – Electric Potential [V]

According to some researches we can consider the surface charge density along the insulator equals zero, resulting in solve a modified Laplace's Equation [4] (Asenjo):

$$(\sigma_v + j\omega\varepsilon)\nabla^2 V = 0 \quad (2)$$

Equation (2) will be used as a boundary condition in the pollution domain. We varied the values of conductivity and permittivity of pollution according to Table 2:

	Clean	**Slightly Polluted**
Permittivity[F/m]	1.02	15 and 80
Conductivity[S/m]	0	10^{-8}
	Moderately Polluted	**Highly Polluted**
Permittivity[F/m]	15 and 80	15 and 80
Conductivity[S/m]	10^{-6}	10^{-3}

Table 2. Pollution Parameter

4. Results

Varying the pollution according to Table 2, we obtains the following plots:

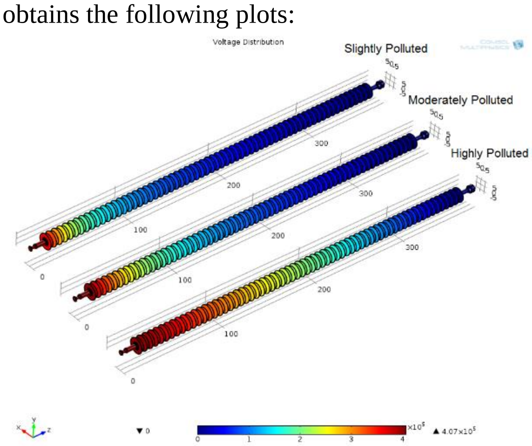

Figure 5. Potential Distribution Varying the Pollution Level - Rainbow Plot.

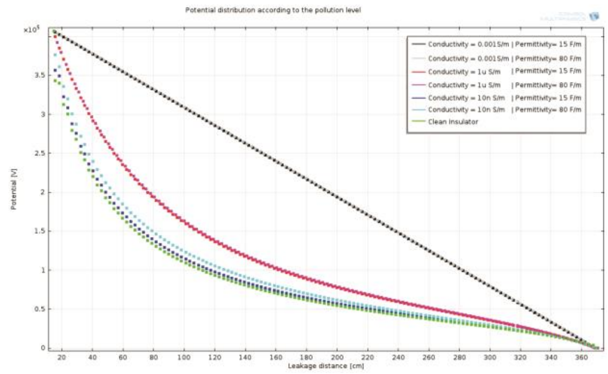

Figure 6. Potential Distribution Varying the Pollution Level - Graph Plot.

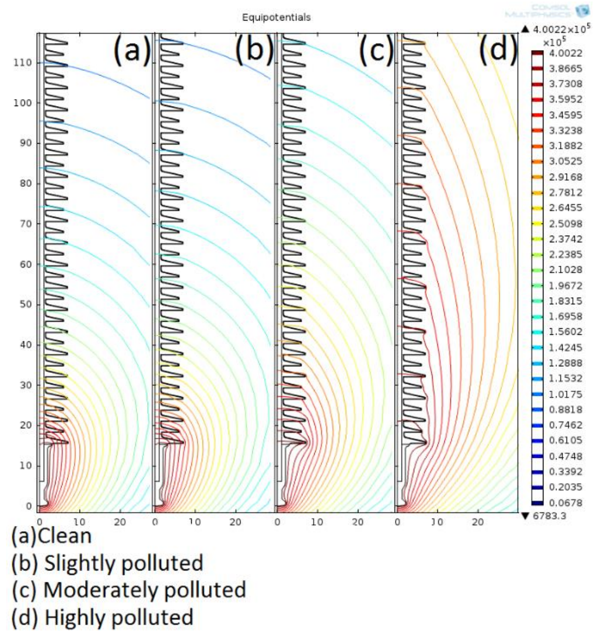

Figure 7. Potential Distribution Varying the Pollution Level - Equipotentials Plot.

As we can see according to the previous plots (Figure 5, 6 and 7) the potential distribution becomes uniform with the increase of pollution level. Clearly we observe, in Figure 5, that in slightly polluted environment the highest potential levels are concentrated in the pin. While in the heavily polluted environment, the potential distribution become uniform and the presence of higher potential values can be observed near of the insulator's middle.

Figure 6 shows that the influence of the thin layer permittivity increases as the conductivity decreases. For low conductivity, 10nS/m for instance, the potential distribution obtained is close to the potential distribution of the clean insulator, which is only governed by the capacitive regime. In this type of regime, the influence of permittivity is noticeable when we compare the cyan curve, pollution conductivity of 10nS/m and pollution permittivity of 80F/m, with the blue curve, pollution conductivity of 10nS/m and permittivity of 15F/m, these curves are slightly different.

With the increase of conductivity, the influence of the permittivity decreases and becomes neglected for a volume conductivity greater or equal to 1 μS/m. In fact, the thin layer becomes a better conductive layer entering in resistive regime making the potential distribution uniform. In this type of regime, the influence of permittivity is not noticeable as we can observe when we compare the magenta curve, pollution conductivity of 1 μS/m and pollution permittivity of 80F/m, with the red curve, pollution conductivity of 1 μS/m and permittivity of 15F/m, these curves are substantially equals.

In a highly polluted environment, the graph of the potential distribution along the leakage path of an insulator is practically linear as shown in Figure 6 represented by the gray curve, pollution conductivity of 0.001S/m and pollution permittivity of 80F/m, and the black curve, pollution conductivity of 0.001S/m and pollution permittivity of 15F/m.

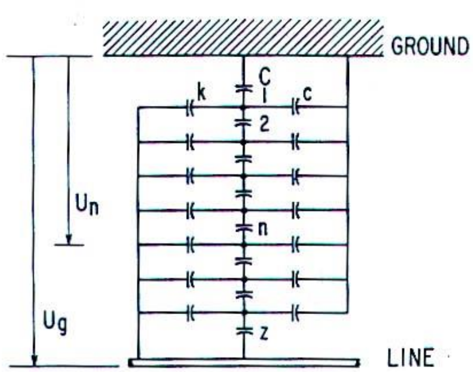

Figure 8. Equivalent Electrical Circuit for an Insulator String - Capacitive Regime

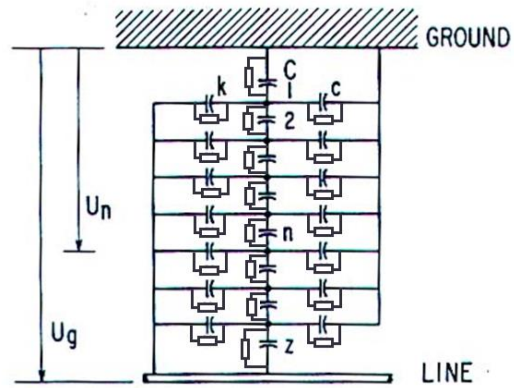

Figure 9. Equivalent Electrical Circuit for an Insulator String - Resistive Regime

5. Conclusions

The performance and functionalities of current FEM commercial software's are increasingly exploited to study the influence of pollution or ice layer of outdoor insulator electrical performance and the present article provides a significant contribution regarding the performance of polymeric insulation units in polluted environments [3].

The results obtained corroborate the practical findings observed with polymeric insulators installed on electrical systems, on which gradual degradation has been observed. Breakdowns have even been registered on sheaths nearer to the ground [5].

Although the method presented in this article was illustrated for a particular cap and pin polymeric insulator but it can be applied to insulators that have any shape and any material as any known contamination distribution within axisymmetric.

It is important to register how the efficient performance of insulators heavily depends on the level of pollution. In this respect, the use of grading rings minimized the electric stress on the most affected sheaths. However, depending on the level of pollution, some units may still be subject to intermittent discharges, causing the gradual disintegration of the dielectric.

Some improvements can be made in future studies in this area, as the development of a model considering the non-uniformity of pollution deposition on insulator surface, which is the scenario that we found in practical terms.

6. References

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7. Acknowledgements

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