1. Assam ZORIG [1], 2. Khaled BELHOUCHET [1], 3. Lyamine OUCHEN [2]

Department of Electrical Engineering, Faculty of Technology,Laboratory of Electrical Engineering (LGE), University of M'sila, Algeria (1)
Department of Electrical Engineering, Faculty of Technology, Ferhat Abbas University,Setif – 1, Algeria (2)
ORCID: 1. 0009-0008-0963-441X

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Performance Evaluation of cap and pin insulator under pollution conditions using Finite element method (FEM).

***Abstract**. insulators with High voltage are the key components in energy transmission systems wich may be affected by pollution. In this paper, the performance of a cap and pin insulator is investigated with the objective of predicting the propagation of an AC surface arc on contaminated insulators in the presence of a non- uniform electric field. To assess the performance of the insulator, the electric field simulation is carried out by using the finite element method. Research results show that non-uniform contamination had the worst electric field profile. This work can provide a useful tool for the design and maintenance of cap and pin insulators.*

Streszczenie.** Izolatory wysokiego napięcia są kluczowymi elementami systemów przesyłu energii, na które mogą mieć wpływ zanieczyszczenia. W tym artykule zbadano działanie izolatora kołpakowo-kołkowego w celu przewidzenia propagacji łuku powierzchniowego prądu przemiennego na zanieczyszczonych izolatorach w nierównomiernym polu elektrycznym. Aby ocenić skuteczność izolatora, przeprowadza się symulację pola elektrycznego metodą elementów skończonych. Wyniki wskazują, że zanieczyszczenie niejednorodne miało najgorszy profil pola elektrycznego. Praca ta może dostarczyć przydatnego narzędzia do projektowania i konserwacji izolatorów kołpakowych i kołkowych. (**Ocena działania izolatora kołpakowo-czopowego w warunkach zanieczyszczenia przy użyciu metody elementów skończonych (MES)).

Keywords: Insulator, Electric field, Finite element method (FEM), Comsol and Simulation.
Słowa kluczowe: Izolator, pole elektryczne, metoda elementów skończonych (FEM), Comsol i symulacja.

Introduction

Dielectric materials including glass, ceramics, and composites are used to make insulators. The ideal property of an insulator is its inability to conduct electric charge and its insensitivity to electric fields [1]. Consequently, dielectric materials with high dielectric constants and electrical resistance are employed as insulators. From the turn of the century, it began with basic glass and porcelain insulators and has expanded quickly. These insulators fall into the same category as ceramic insulators and are regarded as conventional insulators. Based on studies and fieldwork, they are dependable and reasonably priced for sizable outdoor installations [2].

As voltages rise, so does the difficulty of avoiding insulation contamination and the corresponding spike in fines resulting from equipment damage. As a result, enhancing insulators' ability to reduce pollutants needs additional focus.

The effectiveness of outdoor insulators in contaminated environments is the primary element that dictates their physical dimensions. The amount of surface leakage length that outdoor insulators need to minimize surface arcing and dry banding depends on the level of pollution and the site's moist circumstances. One of the primary issues threatening an electric power system's dependability is pollution bypass. Particularly, extremely wet and humid situations like fog, dew, or rain mixed with pollution on the insulator surface are to blame for several flashovers of insulator contamination [3].

The field of research concerning the electrical bypass of polluted insulators is very vast but the interest it arouses is felt in more and more countries affected by this problem.

Several parameters influence the proper functioning of the high voltage insulator such as the nature of the pollutant deposit [4-5], the non-uniformity of the pollution deposit [6, 7 and 8], the surface conductivity and the profile of the insulator [9], the applied voltage (direct, alternating) [10], make understanding and controlling the bypass mechanism very difficult.

Because of the complexity of this process, more laboratory and field trials under artificial or natural pollution settings are needed to fully understand the mechanism. The results of previous work have nevertheless made it possible to establish models allowing access to the characteristics of the discharges propagating on the surfaces of insulators up to the bypass.

In order to predict the propagation of AC surface arcs on contaminated insulators under non-uniform electric fields, the current work examines the performance of a cap and pin insulator. The finite element method is used to simulate the electric field and assess the insulator's performance. Commercially available simulation package, COMSOL Multiphysics, is used.

Model simulation

Understanding the electric field distribution over an insulator's surface is crucial for comprehending its flashover properties. Fig. 1 illustrates the insulator model under investigation. It was modelled as 2D geometry in Comsol Multiphysics. To evaluate the effect of contamination on E-field stress along the insulator surface, the electric field distributions for the two cases; clean and polluted insulators were shown.

The following equations govern the Comsol electric field computation [6,11].

$$E = -\nabla U$$

$$\nabla E = \frac{\rho}{\varepsilon}$$

Combination of Maxwell's, current continuity equation and Ohm's law given by the following equations:

$$\nabla J = \frac{\delta \rho}{\delta t}$$

$$J = \sigma E$$

We note: U : represent the electrical potential (V), E : represent the electrical field(V/m); ε : represents the dielectric material's permittivity; ρ: measure of charge density (C/m^3) ; J : represent the current density(A/ m^2)
σ : represents the electrical conductivity

The materials' electrical characteristics utilized in this simulation are presented in table 1.

Table 1. Material properties

material`s Types	Relative electrical permittivity ε_r	Conductivity σ(S/m)
Electrodes	1,0	1.1020
Silicone	4.2	0
Air	1,0	1,0

The electric field's distribution along an insulator surface is frequently investigated implementing the finite element technique (FEM). Triangular or quadrilateral elements define the surface of a zone-applied FEM. When it comes to calculation speed and precision, the FEM offers significant advantages. References [12,13] offer a clear explanation of how to compute the field distribution using FEM. Researchers at government laboratories and engineering firms alike have come to adopt commercial finite element analysis packages, such as COMSOL multiphysics [14].

As has been pointed out, pollution has a significant impact on figuring out the voltage distribution over the insulator. Several measurements of the polluted layer's conductivity were utilized to clarify this effect. For comparison, the scenario without pollution was also presented. The meshing of the insulator under study in clean conditions is shown in Fig. 1. Throughout the meshing process, the standard element size is chosen. In the crucial areas of the insulator, where greater precision is required, the mesh density is higher.

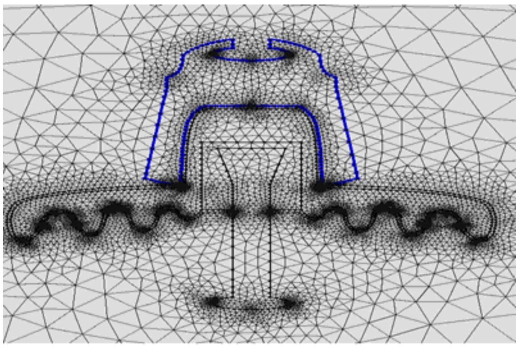


Fig.1. Mesh results from the FEM method using normal element sizes

Studies of voltage distribution under clean conditions

The material properties and boundary conditions mentioned above are assigned to a 2D FEM model. These electric parameters are integrated into the COMSOL Multiphysics software. Fig 2. shows the simulation results for the equipotential lines for a clean insulator. These findings indicate that the voltage distribution is not uniform and that the zone closest to the HT electrode has the highest levels of stress, while the voltage near the earth electrode is essentially nonexistent.

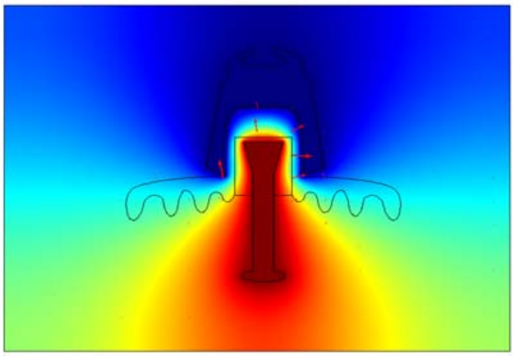


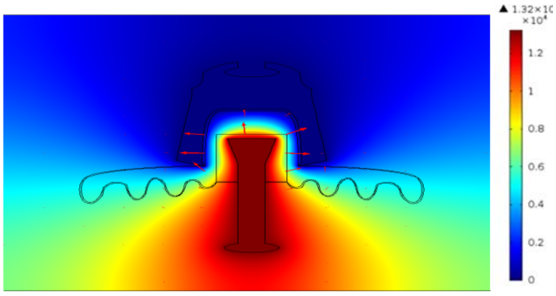
Fig.2. Equipotential lines for a clean insulator

Studies of voltage distribution under polluted conditions

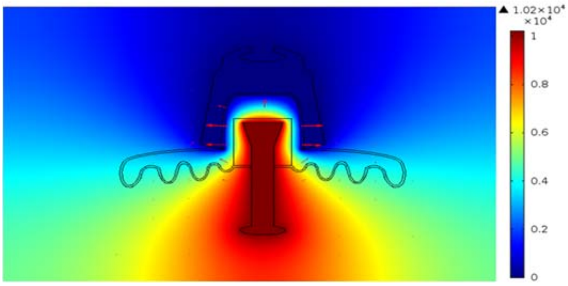
In this part of the work, the study of the distribution of the voltage and the electric field in the presence of a layer of pollution on the surface of the insulator was made. Its objectives is to see the effect of the different conductivities and the nature of the pollution on voltage distribution. To this end, different scenarios were carry out and presented separately in the following paragraphs. The case without pollution is introduced for comparison.

Uniform pollution

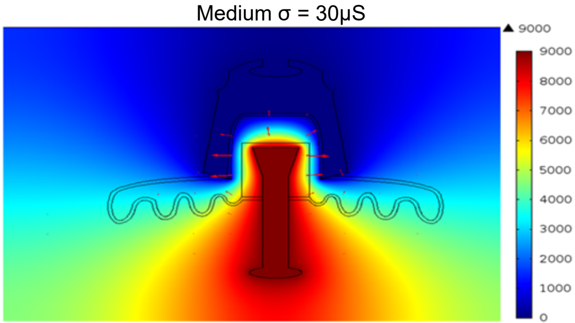
The surfaces of high voltage insulators are subjected to various forms of pollutants and the atmosphere in outdoor applications. As a result, outdoor insulators' surfaces could become partly or uniformly contaminated. When an insulator is pure, the voltage distributions and electric field surrounding it are very different from when there is uniform or partial surface contamination. Therefore, it's critical to understand how surface pollution of various types and intensities affects the electric field and voltage distributions surrounding an outdoor insulator. Among the most important issues with power transmission is the pollutant flashover, which is seen on insulators used in transmission at high voltage. It's an extremely complicated topic because of a number of things, including the modeling challenges [15,16].



(a) light σ = 10μS



Medium σ = 30μS



Heavy σ = 50μS

Fig. 3. Distribution of equipotential lines for different values of conductivity.

In this first test, a uniform layer of pollution having conductivities equal to 10μS, 30 μS and 50μS is applied to the surface of the insulator. The results are shown in Figs. 3, 4 and 5. In fig. 3 that represent the distribution of equipotential lines for different values of conductivity . The voltage is seen to gradually decrease from the insulator pin to the insulator cap. Figs. 4 and 5. represent the voltage and electric field distribution for different values of conductivity respectively. We note that there is confusion in the potential graphs and It is evident that variations in the conductivity of the contaminated layer have no effect on the potential along the insulator. When comparing the potential obtained for a cleaned and a contaminated insulator, no differences were found.

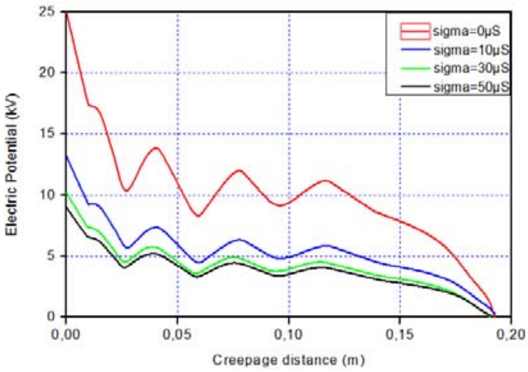


Fig. 4. Voltage distribution for various values of σ (uniform)

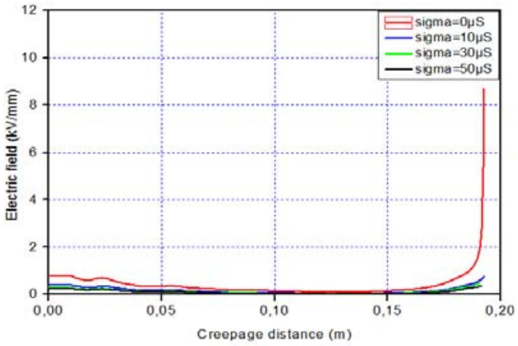


Fig.5. Electric field for various values of σ (uniform)

Non-uniform pollution

Non-uniformity of pollution has been investigated on the bottom and upper surface along with the insulator leakage distance. The flashover voltage on the studied insulator surface is in relation with non-uniform contamination at the bottom and top side.

It is well known that E-field intensity varies with the position of the pollution. The pollution layer closest to the powered end was found to have the most electric field stress.

Along the insulator length, the non-unifomity may occur between the upper and bottom surfaces. This can be examined by taking into account the different zones' levels of contamination.

The degree of pollution and the degree of non-uniform contamination distribution on the upper and bottom surfaces of the insulator are connected to the pollution flashover voltage. Because of the cleaning effects of wind and rain, the top surface is typically less contaminated than the bottom surface [17, 18].

The field distribution along the creep age path is significantly altered by the existence of a pollution layer on the insulator's upper surface. The live-fitting-end (pin) area of the unit experiences the most stress when a homogenous pollution layer (uniform polluted state) is deposited on it, yet the electric field's amplitude is comparable to that in a clean situation.

Considering the results of the simulation; it was observed that electric field is dependent on pollution layer position. In comparison with uniformly polluted insulators, the pollution withstand voltage of porcelain insulators ranges from 30% to 50%, despite the fact that their top to bottom surface pollution ratio varies from 1/5 to 1/10 [14]. It is true that higher withstand voltage is a result of more non-uniform pollution.

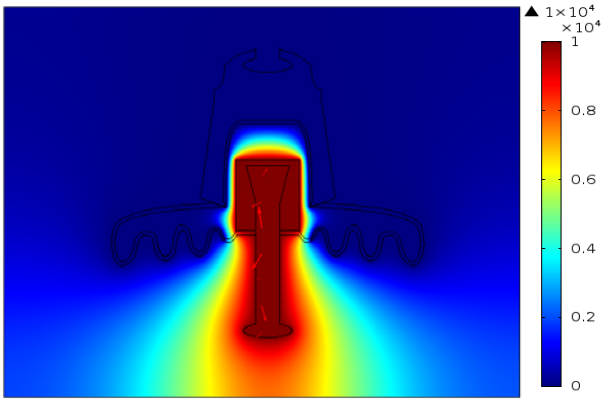


Fig.6. Equipotential distribution Non-uniform pollution

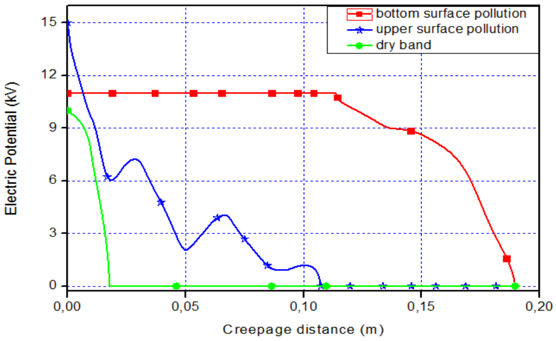


Fig.7. Voltage distribution as a function of creepage distance

Furthermore we notice, as was expected, that the maximum values of the potentials are near the high voltage electrode and begin to decrease until their cancellation when we get closer to the ground electrode. For the cases of the pollution layer, the axial distribution of potential and electric field are shown in Fig. 8.

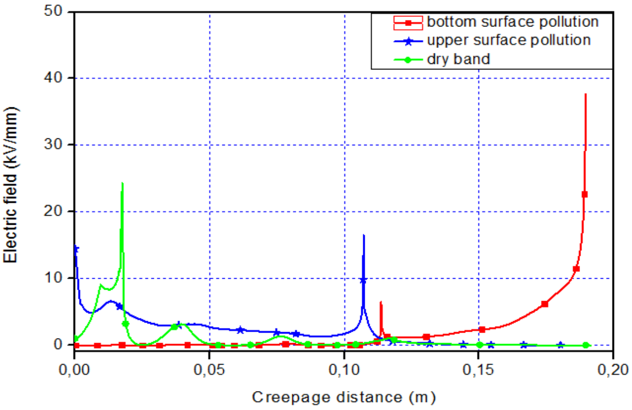


Fig.8. Electric field as a function of the creepage distance

When the insulator is dry and clean, it shows typical capacitive [19].However, the insulator is just as resistive in the case of pollution. The electric field strength is computed to find high stress areas where surface discharges may occur and to provide helpful information regarding surface pollution.

The type of pollution has an influence on the distribution of the potential and makes it non-uniform, which means that the insulator is not constrained in the same way, which favors the appearance of flashovers. This observation is in agreement with the electric field's distribution shown in fig. 6.

A critical issue that must be taken into account while studying insulators is the creation of dry bands at their surface. Research has indicated that the establishment of dry bands significantly affects the insulator's flashover.

Conclusion

This work's primary goal was to investigate the voltage distribution along cap and pin insulators in the presence of pollution.The finite element technique (FEM) was used in this investigation to examine various parameters for electro-geometry, including the impact of conductivity and the position of the pollution layer.

The potential distribution tends to linearize over the insulator's length when the pollution layer is present. The field distributio throughout the creepage route is significantly altered by the existence of a pollution layer on the insulator, although the electric field's magnitude is still similar to the clean case. From the obtained results we notice the increase in the conductivity of the polluted layer favors the voltage's irregular distribution along the surface of the insulator .

This cannot be stated for the distribution of the electric field, as pollution, even if uniform in shape, causes significant value peaks that result in a number of issues that eventually lead to flashover and premature aging.

Authors: *Dr. Assam Zorig, M'sila University 28000 Algeria, E-mail: assam.zorig@univ-msila.dz;Dr.Khaled Belhouchet M'sila University 28000 Algeria, E-mail: khaled.belhouchet@univ-msila.dz(Corresponding author); Dr. Lyamine Ouchen, g, University Ferhat ABBAS Setif – 1, Algeria, E-mail: amine.ouchen@yahoo.fr.*

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