

ELECTRIC FIELD AND VOLTAGE DISTRIBUTION ALONG INSULATORS UNDER POLLUTION CONDITIONS

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Abstract: - The aim of this work is to study the behaviour of an insulator, which is usually used, and to verify the surface pollution influence on its dielectric behaviour. This paper presents the electric field and the voltage distribution along polluted insulators. Essentially, the problem is to calculate the electric field that is expanding in the area around the insulator and inside the insulator when it is stressed by power frequency voltage. The examined insulator is used in insulator chains for the suspension of overhead transmission lines crossing coastal and industrial areas, with remarkably high pollution.

For the electromagnetic field analysis two appropriate computer programs have been used. These programs, called OPERA-2d/ST and ADETEC, use the finite elements method to solve the partial differential equations that describe the field. These programs give results for the parameters of the field, the field intensity and the flux density. By solving this problem, the distribution of the potential on the surface of the insulator can be calculated. Furthermore, an attempt to simulate the pollution on the surface of the insulator has been carried out. For this analysis a thin film of a pollutant has been added on the insulator surface. By solving the new problems, the influence of the pollution on the electric field distribution on the insulator surface becomes clear. It has been ascertained that the dielectric stress of the insulator under pollution is significantly higher than under normal conditions. The results referring to clean insulators have been compared with those referring to polluted insulators. In addition the flashover conditions have been studied when the quantity of the pollution and consequently the conductivity of the pollution layer is changing. Furthermore, the simulation results have been compared to experimental ones; the relevant comparison was very satisfactory.

Key-Words: - Insulators, pollution, electric field, finite elements method.

Introduction

The knowledge of the distribution of the electric

field within and around high voltage equipment such as insulators, which are used for the suspension of overhead transmission lines, is a very important aspect of the design and the development of such equipment.

In recent years there is a rapidly growing interest in the mechanism of development of electrical arc around polluted insulators. A great number of projects are carried out and many studies have been published all over the world concerning the phenomenon of pollution flashover. In spite of these significant efforts it has become evident that there is not a fully acceptable explanation of the pollution flashover mechanism and that is the reason why there isn't still a general and efficient method in facing the problem.

The knowledge of the electric field is more useful when it refers to polluted insulators because under operation conditions a polluted layer on HV insulators is very frequent, especially in industrial and coastal regions. Airborne pollutants due to natural or industrial or even mixed pollution cover the surface of the insulators. As the surface becomes moist because of rain, fog or dew, the pollution layer becomes conductive because of the presence of ionic solids. The flashover in polluted insulators occurs more frequently and can even lead to blackout, Gonos et al (1).

Numerical methods have been developed for calculating the electric field and the potential within and around HV equipment. A calculation method, which is based on boundary integral equations, for electric fields and potential usable in the case of polluted insulator has been presented by Rasolonjanahary et al (2). Asenjo et al (3) have presented a quasi-static approximation for the calculation of the low frequency complex electric field in and around insulators. This approach permits the decoupling of Maxwell's equations. A finite difference method to calculate the electric field in and around polluted insulators with asymmetric boundary conditions has been proposed by Morales et al (4). Furthermore a finite elements method to solve low frequency complex fields in insulators with rotational symmetry is commonly used. Michaelides et al (5) have presented design methods of electric insulating components using the finite elements method.

Pollution tests on high voltage insulators have been standardized for ceramic and glass

insulators in the IEC 60 507 (6). The equivalent salt deposit density (ESDD) has been adopted widely as a parameter of pollution severity. An et al (7) have measured the conductance of the salt solution and have found a relationship between the conductance and ESDD.

In this paper an effort is made to simulate the phenomenon of flashover on porcelain insulators under pollution. The simulation results are compared with theoretical and experimental ones.

Experiments

The experiments were carried out according to the IEC norm (6) and were presented by Ikonomou et al (8). The industrial pollution was simulated according to the solid layer-cool fog method. The fogging procedure was carried out in a pollution chamber. The ratio of the pollution between the bottom and the top surface of the insulator was in the range of 2/1-3/1. The equivalent salt deposit density C on the insulator surface was the index for pollution severity.

Mathematical model

A simple model for the evaluation of the flashover process of a polluted insulator consists of a partial arc spanning over a dry zone and the resistance of the pollution layer in series. The critical voltage U_c , which is the applied voltage across the insulator when the partial arc is developed into a complete flashover, is given by the following formula, Topalis et al (9):

$$U_c = \frac{A}{n+1} \cdot (L + \pi \cdot n \cdot D_m \cdot F \cdot K) \cdot (\pi \cdot A \cdot D_m \cdot \sigma_s)^{\left(\frac{n}{n+1}\right)}$$

where L is the leakage distance of the insulator, D_m is the maximum diameter of the insulator disc and F is the form factor. The arc constants A and n have been calculated using the least square method, Theodorakis et al (10). Their values are $A=131.5$ and $n=0.374$. The same constants have been recalculated using a genetic algorithm model by Gonos et al (11) and their new values are $A=124.8$ and $n=0.409$. The surface conductivity σ_s (in Ω^{-1}) is given by

$$\sigma_s = (369.05 \cdot C + 0.42) \cdot 10^{-6}$$

where C is the equivalent salt deposit density (ESDD) in mg/cm^2 .

The coefficient of the pollution layer resistance K in case of cap-and-pin insulators is given by

$$K = 1 + \frac{n+1}{2 \cdot \pi \cdot F \cdot n} \cdot \ln\left(\frac{L}{2 \cdot \pi \cdot R \cdot F}\right)$$

where R is the radius of the arc foot and is given by

$$R = 0.469 \cdot (\pi \cdot A \cdot D_m \cdot \sigma_s)^{\frac{1}{2 \cdot (n+1)}}$$

In case of stab-type insulators, K is defined as follows:

$$K = \frac{N \cdot (n+1)}{2 \cdot \pi \cdot F \cdot n} \cdot \left(\ln\left(\frac{4 \cdot L}{\pi \cdot N \cdot R}\right) - \ln\left(\tan\frac{\pi}{2 \cdot (n+1)}\right) \right)$$

where N is the number of sheds.

Software

OPERA-2d (12) is a suite of programs for 2-dimensional electromagnetic field analysis. The programs use the finite elements method to solve the partial differential equations (Poisson's, Helmholtz, and Diffusion equations) that describe the field. The ADETEC solver provides field solution modules that address designs with conducting - dielectric materials under steady state and transient conditions and is suitable for the design of electric insulating components (5).

The program solves a current flow problem and uses the results as an input to an electrostatic problem. The software determines the potential by solving the conduction (current flow) equation

$$\nabla \cdot \vec{J} = \nabla \cdot \sigma \nabla V = 0$$

in addition to the electrostatic equation (Poisson)

$$\nabla \cdot \epsilon \nabla V = -\rho,$$

in case the model contains any materials of a non-zero conductivity σ (5).

The structural analysis is carried out by separating the region of the model into triangular elements. The density of the finite elements mesh is higher in the critical regions of the insulator than in the rest area around it.

Investigated insulator

A cap-and-pin suspension insulator is studied in this paper. The investigated insulator is shown in Fig. 1. The maximum diameter of the insulator disc D_m is 254mm, the height H 146mm, the leakage length L 305mm and the form factor F 0.70.

The symmetry of the insulator was exploited when creating the Finite Element Model, resulting in an axi-symmetric two dimensional problem, and alleviating the need for computationally expensive three dimensional modeling. It is assumed that the relative permittivity of the porcelain is 6, Laughton and Say (13). For the simulation a steady voltage is applied at the bottom end fitting of the insulator and the ground is considered at the top end fitting.

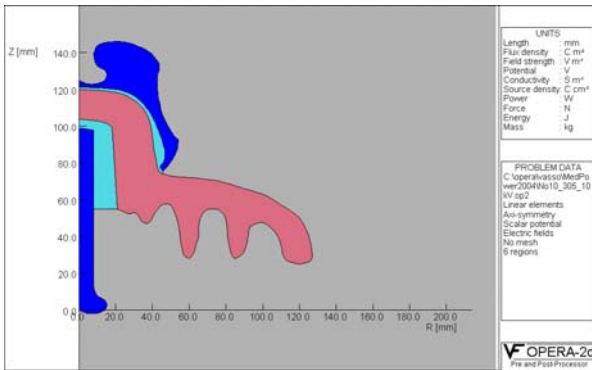


Figure 1: Investigated insulator.

Results

The above cap-and-pin insulator is studied when it is clean and when it is polluted. In order to simulate the pollution, a thin film of a pollutant has been added on the surface of the insulator. Heavy or light conditions of pollution were simulated by changing the thickness of this layer. Figures 2 and 3 illustrate the potential and the electric field distribution around and inside the insulator when there is no pollution.

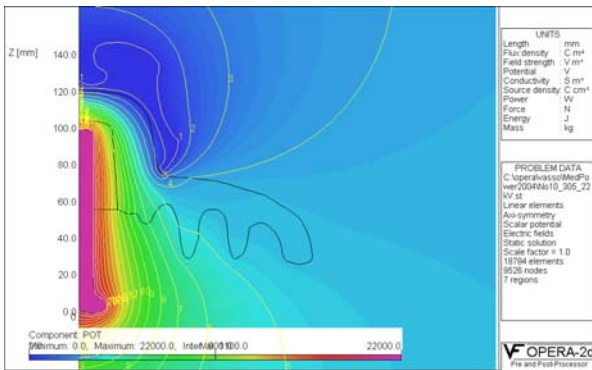


Figure 2: Equipotential contours around and inside of a non-polluted insulator.

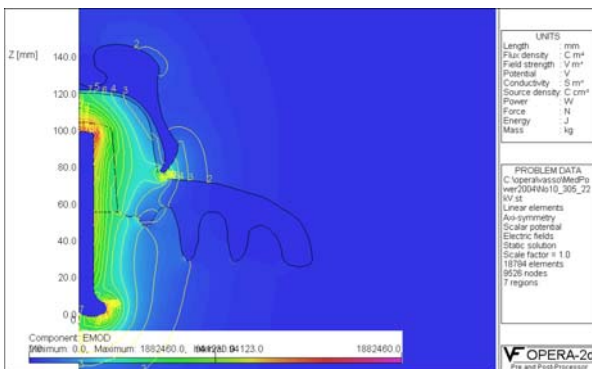


Figure 3: Electric field around and inside of a non-polluted insulator.

Figures 4 and 5 indicate the potential and the electric field distribution around and inside the insulator when the insulator is covered with a thin polluted layer. The applied voltage has been selected in accordance to the experimental results for the same pollution severity. Hence the phenomenon of the flashover has been simulated. Figures 6 and 7 show the potential and the electric field distribution around and inside the insulator when the insulator is covered with a thicker polluted layer than previously.

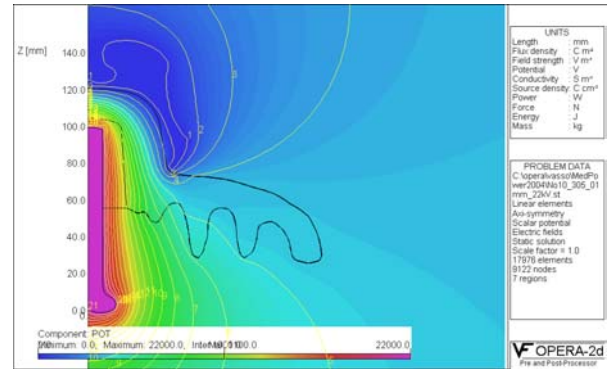


Figure 4: Equipotential contours around and inside of a lightly polluted insulator.

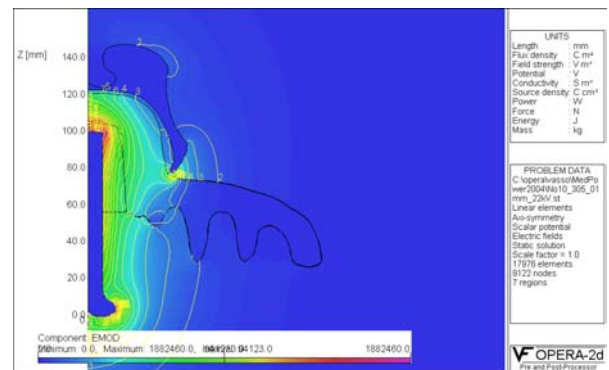


Figure 5: Electric field around and inside of a lightly polluted insulator.

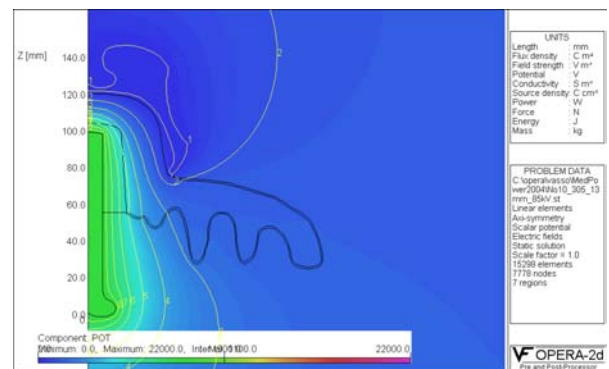


Figure 6: Equipotential contours around and inside a heavily polluted insulator.



Figure 7: Electric field around and inside of a heavily polluted insulator.

Figures 8 and 9 show the voltage distribution along a line running along the creepage distance of the insulator, for different severities of pollution.

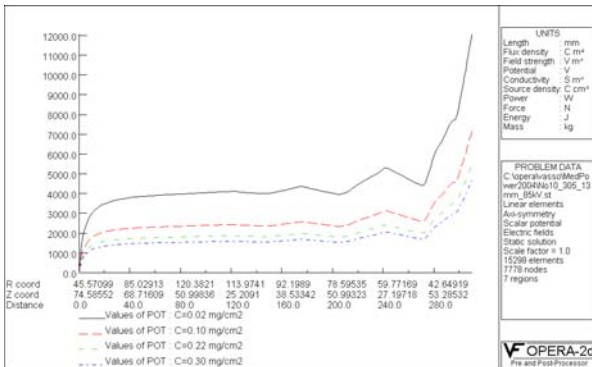


Figure 8: Voltage along the creepage distance of the polluted insulator.

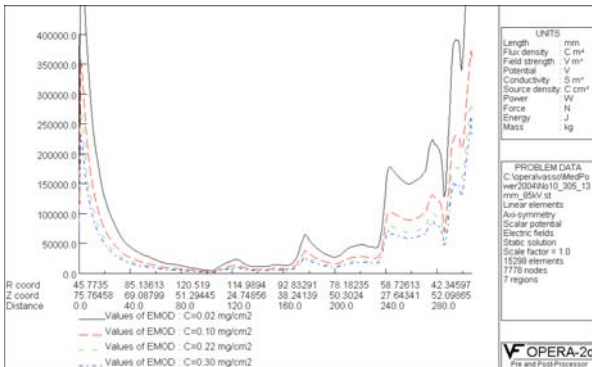


Figure 9: Electric field along the creepage distance of the polluted insulator.

In Figure 9 it is obvious that at the start and the end of the creepage distance the electric strength presents extremely high values. A fixed number of the extremely high values have been eliminated in order to calculate the average value of the critical electric field.

Figure 10 concentrates the experimental results, the results of the mathematical model and the simulation results. During the experiments the critical voltage U_c of the insulator was measured. In addition, by applying the mathematical model the mentioned critical voltage U_c is calculated as

well. Furthermore, the simulation program calculates the critical electric field E_c ; in order to compare the results, the following formula has been used:

$$E_c = \frac{U_c}{L}$$

where L is the leakage distance.

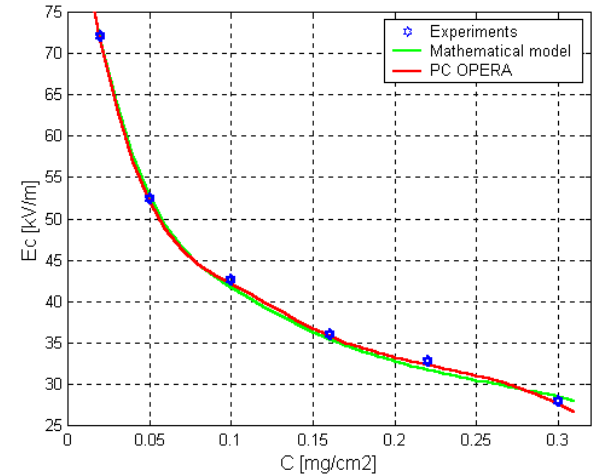



Figure 10: Critical electric field for the investigated insulator versus the pollution severity.

Conclusions

The studied approach is applicable to any insulator type, leading to reliable results in a very fast and economic way, helping the HV overhead line planners in the selection of the right insulator type, depending on the local pollution severity of the area crossed by the overhead line. As the equivalent salt deposit density increases, the flashover takes place in lower value of the applied voltage. A good agreement was achieved between the results of the experiments, those obtained using the mathematical model and those obtained using the simulation program.

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