CALCULATION OF THE ELECTRIC FIELD ON AN INSULATOR STRING USING THE FINITE ELEMENTS METHOD

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ABSTRACT

In this paper the authors attempt to study the electric field on an insulator string. Essentially, the problem is to calculate the electric field distribution around the insulator and inside the insulator when it is stressed by power frequency voltage. The Finite Element Analysis (FEA) program OPERA was used to carry out the electromagnetic analysis on the insulator. This program uses the finite element method to solve the partial differential equations that describe the field. The OPERA-2d/ST & ADETEC programs return field parameters, including the electric field intensity distribution as well the distribution of the potential on the surface of the insulator. The simulation results have been compared with experimental results, which have been obtained in the High Voltage Laboratory of National Technical University of Athens. Furthermore, an attempt to simulate the pollution on the surface of the insulator has been carried out. For this analysis the wet pollutant on the insulator surface has been approached with a thin layer, which has specific properties of the pollutants. It has been ascertained that the dielectric stress of the insulator under pollution is significantly higher than under normal conditions. 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.

1. INTRODUCTION

Insulators strings are used for suspension of overhead transmission lines. The insulators constitute one of the most important parts of the transmission lines as the flashover of polluted insulator can cause breakdown of transmission network. A polluted layer on HV insulators is very frequent in industrial and coastal regions. It has been considered that the flashover occurs more frequently in polluted insulators. Several numerical computation methods have been developed for computing electric fields and potential in studying the behaviour of polluted insulators.

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 [1]. Results given by their method are compared with analytical solutions (potential, currents) and with measured values (potential, leakage current). Also a finite element method to solve low frequency complex fields in insulators with rotational symmetry is commonly used [2]. A domain decomposition approach for finite elements method calculation of electric field of insulators applied on high-voltage transmission lines is presented [3]. The previous method gives the possibility to examine the effects of various hardware structures such as line and tower configurations and grading devices and ensures to model very complex geometry without extra high computational effort. Calculating the low frequency complex electric field in insulators a quasi-static approximation, which permits the decoupling of Maxwell’s equations, has been presented [4]. A finite difference method to calculate the electric field in polluted insulator with asymmetric boundary conditions has been proposed by Morales et al [5]. Their method is based on neglecting the displacement currents that circulate through the porcelain and through the air, in comparison with the conduction currents that circulate over the semiconductive pollution layer covering the insulator.

OPERA-2d [5] is a suite of programs for 2-dimensional electromagnetic field analysis. The programs use the finite element method to solve the partial differential equations (Poisson's, Helmholtz, and Diffusion equations) that describe the behaviour of fields. The OPERA-2d ST (statics) program can solve electrostatic and magnetostatic problems. The ADETEC solver provides field solution modules that address designs with conducting - dielectric materials under steady state and transient conditions. The solver was developed as part of an advanced CAD package codenamed ADETEC [2, 7], customised for the design of electric insulating components. This project was funded under the EU Framework V Growth Initiative.

2. EXPERIMENTAL APPARATUS AND TEST RESULTS

The work reported in this paper refers to the calculation of the electric field on an insulator string using the finite elements method. The examined cap-and-pin type insulator is used in insulator strings for the suspension of 150 kV overhead transmission lines crossing coastal and industrial areas, with remarkably high pollution. The geometrical characteristics of the investigated insulator are the diameter, which is 254 mm, the height, which is 146 mm, and the creepage distance, which is 305 mm.

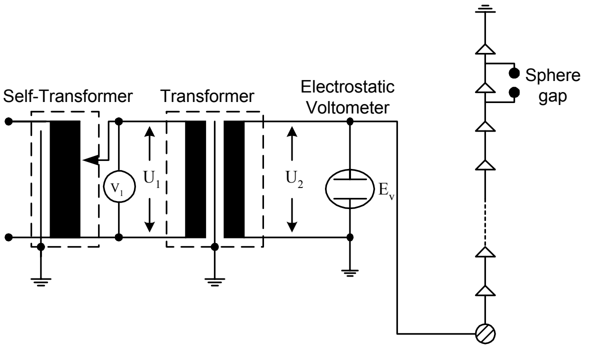

Figure 1: Experimental set-up.

The aim of our experiments was the study of the distribution of the voltage in an insulator string. The test arrangement is shown in Fig. 1. It includes a 230 V self-transformer frequently found in industrial environments. Through this self-transformer, a 110V/55kV transformer is fed. The voltage is measured by two methods. The first method is using the voltmeter V_1 in the primary part of the transformer and then transforming the low voltage U_1 in high voltage multiplying by the voltage transformer ratio (a). The second method is using an electrostatic voltmeter E_v and measuring the high voltage U_2 in the secondary part of the transformer [8, 9]. The average U_t of the two values is the voltage applied across the ten insulator string:

$$U_{ti} = \frac{U_{1i} \cdot a + U_{2i}}{2} \tag{1}$$

At one edge of the insulator string (10th insulator) is connected a transmission line and the other edge (1st insulator) is grounding. The first insulator is placed near the tower and the tenth is placed near the transmission line. In parallel with i-insulator is connected a sphere gap. The capacitance of the sphere gap is very small compared to the capacitance of the insulator, so it can be neglected.

Increasing the voltage U_t, which is applied to the insulator string, the sphere gap critical voltage U_d is being reached. The percentage of the voltage P_i, which is applied in the i-insulator, is given by

$$P_i = \frac{U_d}{U_{ti}} \cdot 100\% \tag{2}$$

The parasitic capacitances are the reason that the distribution of the voltage in each insulator is not uniform. Moving the sphere gap in each of the ten insulators and calculating the rates P_i for each insulator the critical voltage of the sphere gap is calculated by the equation

$$\sum_{i=1}^{10} P_i = U_d \cdot \sum_{i=1}^{10} \frac{1}{U_{ti}} = 1 \tag{3}$$

The experiment has been repeated for three different insulator strings, which are consisting of ten discs with the same geometrical characteristics. The experimental results for all the investigated strings are shown in Fig. 2. The experimental results for the second string are presented in Table 1.

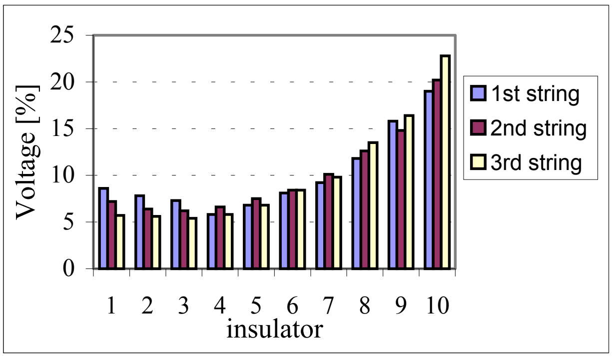

Figure 2: The percentage voltage in each insulator.

Table 1: Experimental results for the 2nd string.

a/a of insulator	U_{1i} (V)	U_{2i} (kV)	U_{ti} (kV)	P_i (%)
1	70	35.0	35.0	7.2
2	79	39.5	39.5	6.4
3	82	41.0	41.0	6.1
4	77	38.5	38.5	6.5
5	67	33.5	33.5	7.5
6	60	30.0	30.0	8.4
7	50	24.5	24.8	10.2
8	40	20.0	20.0	12.6
9	34	17.0	17.0	14.8
10	25	12.5	12.5	20.2

3. SIMULATION

In time-varying problems, the electric and magnetic fields are normally solved in a coupled manner. Assuming that inductive effects are negligible in semi conducting dielectrics problems, the software solves the equation:

$$\nabla \cdot \varepsilon_c \nabla V = 0 \tag{4}$$

where

$$\varepsilon_c = \varepsilon_o \varepsilon_r - j\frac{\sigma}{\omega} \tag{5}$$

Special routines have been developed by Vector Fields [7] to support complex permittivity and thus complex electric scalar potential.

The insulator, which is simulated in this paper, is shown in Figs. 3 and 4. 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 modelling. However, the resulting compromising assumption was that the ceiling of the test laboratory was modelled as a continuous earth (instead of a single earth wire). Assumptions also needed to be made for the electric properties of the constituting materials, especially cement, the conductivity and permittivity of which is very difficult to ascertain.

The density of the finite elements is higher in the critical regions of the insulator where higher accuracy is required and the electric properties of the materials are such that the electric field intensity changes rapidly, as shown in Fig. 4.

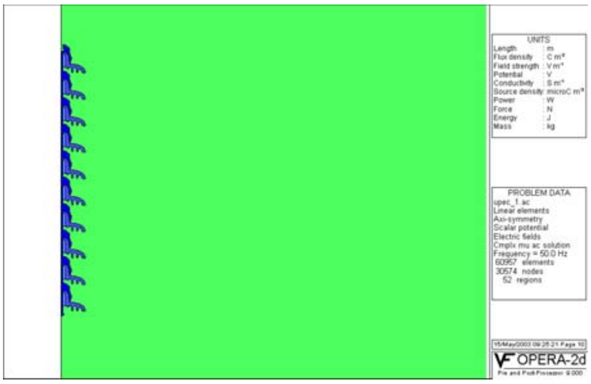

Figure 3: The Finite Element Model of the simulated insulator string.

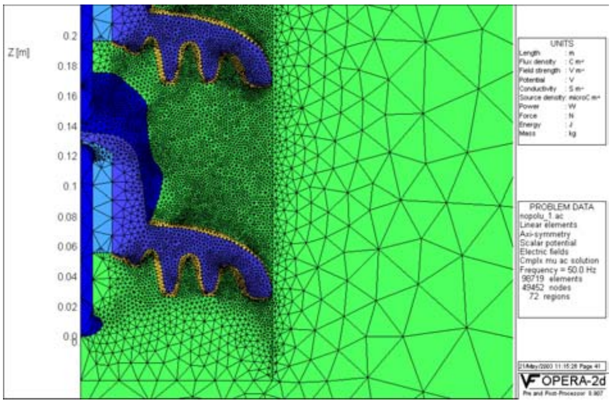

Figure 4: The Finite Element Mesh in a region of the simulated insulator string.

Fig. 5 illustrates the electric field distribution along a set of line running parallel (and at different distances) to the axis of the insulators. Fig. 6 indicates the voltages along the same lines. Owing to the capacitances existing between the discs, conductor and ground, the distribution of the voltage along the insulator is not uniform, the discs nearer the conductor being more highly stressed. This was confirmed with the experimental results.

Although good agreement was obtained between experimental results and FEA prediction, more work is needed to achieve even better agreement. The work needs to be focussed on obtaining accurate material data (permittivity and conductivity values) for the materials constituting the insulator (porcelain, cement, iron and the nature of pollution). Obtaining accurate electromagnetic properties for cement proved to be extremely difficult, as these are heavily dependent on the water content in it. It was also found that there is significant variation in the porcelain properties, as usage of three different sets of plates, produced three different voltage distribution histograms, which are shown in Fig. 2.

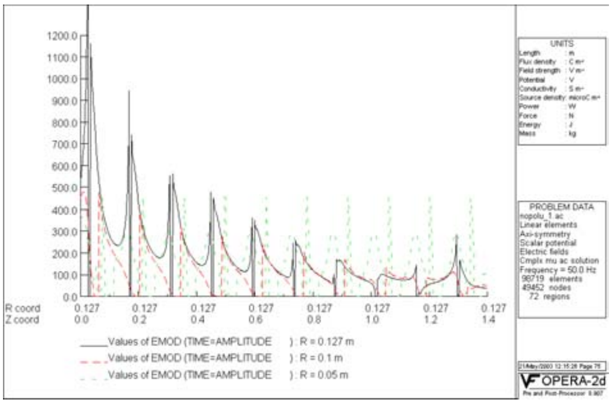

Figure 5: Electric Field along the non-polluted insulators.

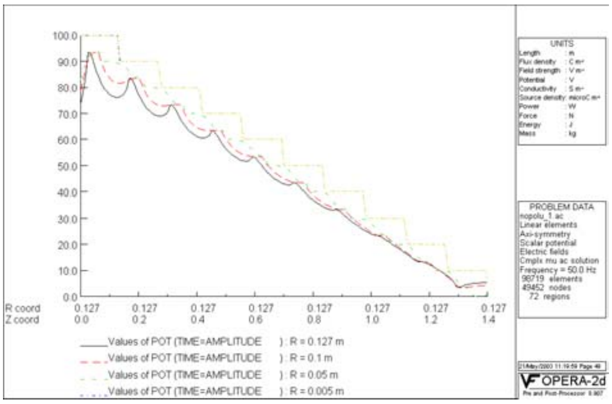

Figure 6: Voltage along the non-polluted insulators.

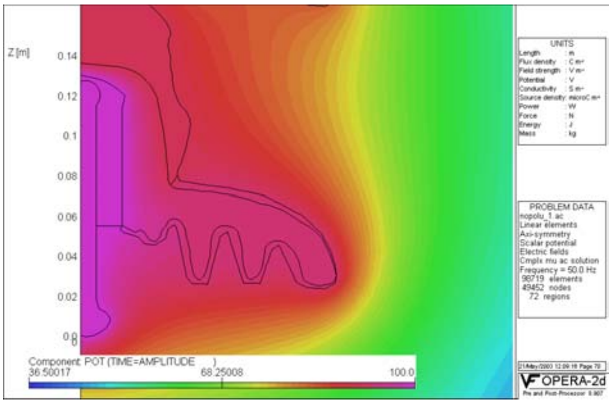

Figure 7: Potential contours around the tenth insulator.

Figs. 7 and 8 illustrate the voltage and electric field distribution around the 10th plate when there is no pollution in any of the insulators. Fig. 9 shows the voltage distribution around the 10th plate when all insulators are covered with a thin polluted layer. Fig. 10 shows the voltage distribution along a line running vertically through the edges of the insulators, for two different cases (with and without pollution).

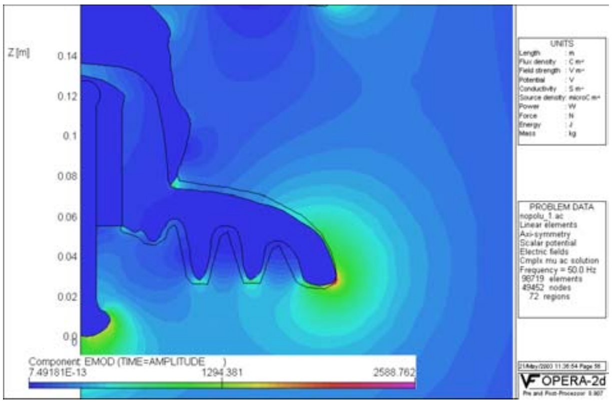

Figure 8: Electric Field Intensity around the tenth insulator.

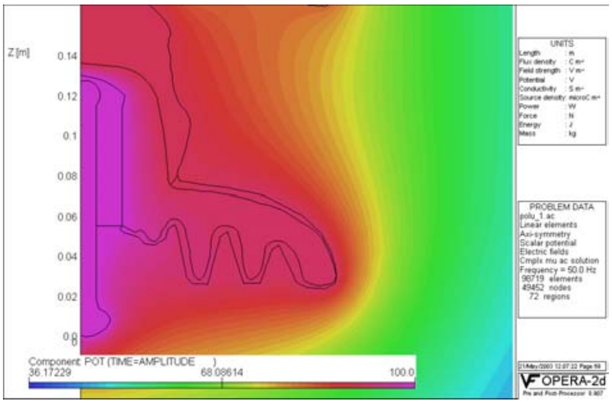

Figure 9: Potential contours around the tenth polluted insulator.

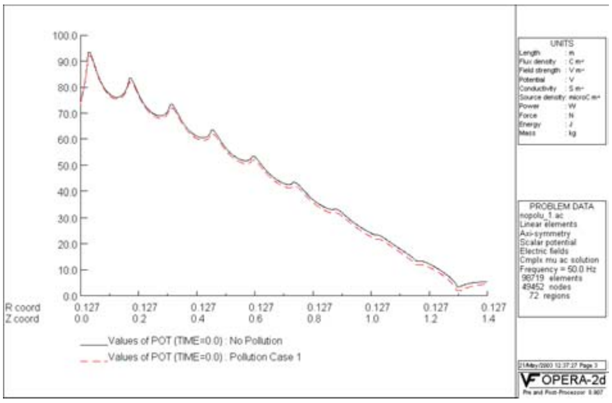

Figure 10: Voltage along the polluted and non-polluted insulators.

4. 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 to the selection of the right insulator type, depending on the local pollution severity of the area crossed by the overhead line. A very good agreement has been ascertained, by comparing the results of the experiments with those of the simulation. Although good agreement was obtained between experimental results and FEA prediction, more work is needed to achieve even better agreement. The work needs to be focussed on obtaining accurate material data (permittivity and conductivity values) for the materials constituting the insulator (porcelain, cement and iron).

5. REFERENCES

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