Simulation of the Electric Field on Composite Insulators Using the Finite Elements Method

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Abstract: - In this paper the authors attempt to study the distribution of the electric field on composite insulators around 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 aim of this work is to simplify the model of the simulated insulator in order to reduce the complexity and the calculation time of the simulation. First, the whole insulator model has been used to determine the potential distribution around and inside the insulator. Next, a simplified model is investigated. The results of the whole and of the simplified model have been compared. In addition, the simulation results before and after the simplification of the insulator model using the finite element method have been compared to the results of other researchers, which have used different method. Furthermore, the surface pollution influence on the dielectric behaviour of the insulators has been examined. Useful conclusions have been got out for the way that the polluted insulator model can be simplified.

Key-Words: - Composite insulators, pollution, electric field, finite element method, simulation.

1 Introduction

Composite insulators tend to replace porcelain and glass insulators because of the advantages that offer compared with the other categories of insulators. The most significant advantages are the light weight, the lower construction and installation cost and the better contamination performance than the porcelain and glass insulators [1].

The knowledge of the distribution of the electric field within and around high voltage equipment such as insulators, which are used for suspension of overhead transmission lines, is a very important aspect of the design and the development of such equipment. High levels of the electric field are possibly responsible for audible noise, electromagnetic pollution, partial discharge and premature aging of insulation. Electrical discharges may degrade the polymeric materials, which are used to the sheaths and the sheds of the HV composite insulators. Continuous discharges can lead to erosion of the material [2, 3].

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. The flashover in polluted insulators occurs more frequently and can cause breakdown of the transmission network [4].

Numerical techniques have been developed for calculating the electric field and the potential within and around HV equipment. Boundary integral equations have solved in order to study the electric field and potential of polluted insulator [5]. Calculating the low frequency complex electric field in insulators a quasi-static approximation, which permits the decoupling of Maxwell's equations, has been presented [6]. A finite difference method to calculate the electric field in polluted insulator with asymmetric boundary conditions has been proposed [7]. Furthermore a finite element method to solve low frequency complex fields in insulators with rotational symmetry is commonly used [8].

An effort to simplify the geometry of the insulator without significantly impacting on the accuracy of the computations of the electric field and voltage distribution around and inside the insulator has been attempted [2, 9].

In this paper an effort is made to simplify the model of composite polluted insulators in order to reduce the simulation demands of design time and computer memory. For the simulation of the environmental pollution a thin film of a pollutant has been added on the insulator surface.

2 Software

OPERA-2d [10] is a suite of programs for 2-dimensional electromagnetic field ana1ysis. The programs use the finite element method to solve the partia1 differential equations (Poisson's, Helmholtz, and Diffusion equations) that describe the behaviour of fields. 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 [8,11].

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

$$\nabla \cdot \vec{J} = \nabla \cdot \sigma \nabla V = 0 \qquad (1)$$

in addition to the electrostatic equation (Poisson)

$$\nabla \cdot \varepsilon \nabla V = -\rho \, , \qquad (2)$$

in case the model contains any materials of a non-zero conductivity σ [8,11].

3 Parameters of the insulators

Polymer suspension insulators consist of four parts: a core, polymer sheath (housing), polymer weathersheds and two end fittings. The core is usually made of fiberglass and the end fittings are made of steel or ductile iron. The sheath and the weathersheds of the investigated insulators are of the same material (silicon rubber). It is considered that the relative permittivity of the silicon rubber, respectively of the fiberglass is 4.3, respectively 7.2.

4 Simplified finite element model

4.1 Application 1: 34.5kV insulator

First a 34.5kV insulator with 12 sheds is studied. The symmetry of the insulator was exploited when creating the Finite Element Model, resulting in an axi-symmetric two dimensional problem. The insulator, which is simulated, is shown in Figs. 1. For the simulation a steady voltage of 1000V is applied at the bottom end fitting of the insulator and the ground is considered at the top end fitting.

Fig. 1: The Finite Element Model of the simulated insulator.

It has been observed that the same simulation results ensued from a model, which consists of a small number of sheds near the ends; this remark facilitates in simplifying the used model. A simplified model for the investigated insulator using four sheds (two at each end of the insulator) is shown in Fig.2 [9].

Fig. 2: The simplified Finite Element Model of the simulated insulator.

The potential distribution around and inside the insulator for the full and the simplified model is shown in Figs 3 and 4.

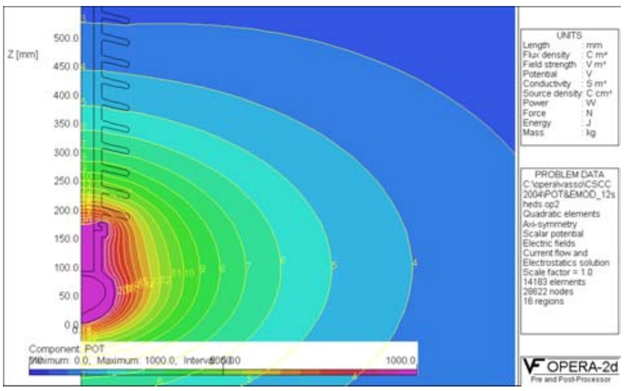

Fig. 3: Potential contours around and inside the insulator.

Fig. 5 illustrates the voltage distribution along the leakage distance of the insulator. Fig. 6 indicates the electric field along the same distance. Good agreement was obtained between the results, which was ensued using the full and the simplified model. A difference in the electric field distribution has been observed along the sheds, which have missed out in the simplified model of the insulator. In spite of this difference the simplified model gives the same maximum values of the electric field with the full model near the skipped sheds.

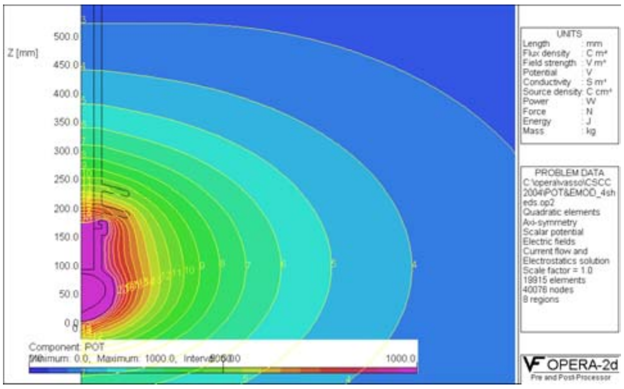

Fig. 4: Potential contours around and inside the insulator (simplified model).

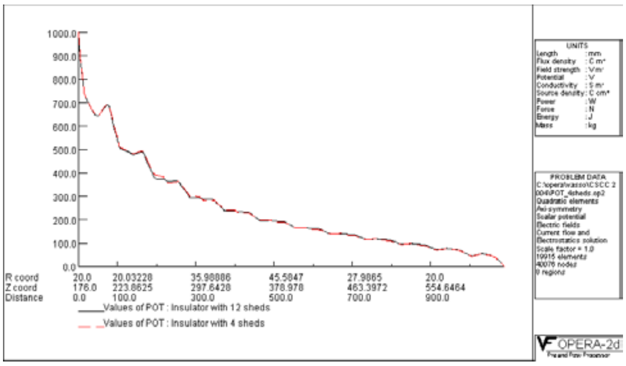

Fig. 5: Voltage along the leakage path of the insulator (full and simplified model).

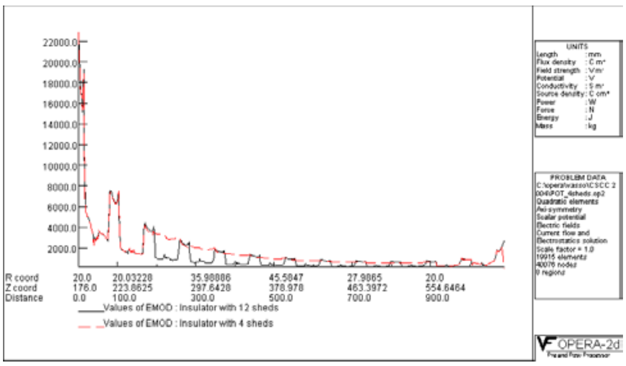

Fig. 6: Electric field along leakage path of the insulator (full and simplified model).

Furthermore, in this paper, a polluted model of the insulator is presented. For the simulation of the pollution all the sheds are covered with a thin polluted layer. The conductivity of the polluted layer has been considered equal with $40\,\mu S$. It has been observed that a pollutant layer has to be designed instead of the skipped sheds; this layer must be thicker in comparison to the layer along the sheds near the ends. It has to be about two times thicker. Figs. 7 and 8 illustrate the voltage distribution around and inside the polluted insulator for the full and the simplified polluted model respectively. A slight difference can be observed between the results of the full and the simplified method. The work needs to be focused on the way that the pollution will be simulated in the simplified model.

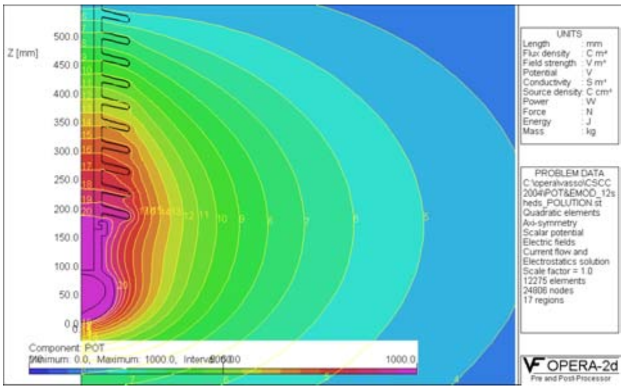

Fig. 7: Potential distribution around and inside the polluted insulator (full model).

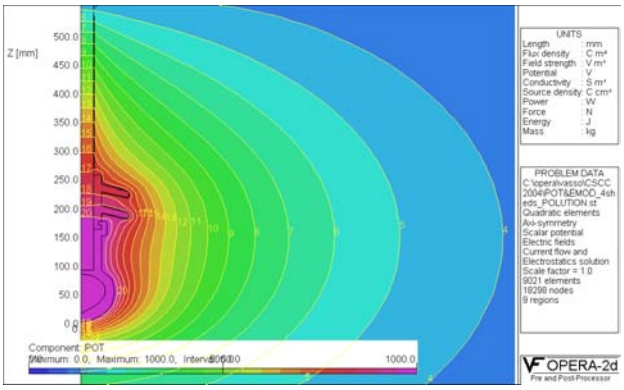

Fig. 8: Potensial distribution around and inside the polluted insulator (simplified model).

4.2 Application 2: 69kV insulator

Using a simplified polluted model, based on the previous study, a 69kV insulator with 21 sheds is simulated. The dimensions of the insulator are shown in Fig. 9.

For the simulation ten sheds (five at each end of the insulator) have been used. Potential and electric field distributions are shown in Figs. 10 and 11, respectively, for the investigated non-polluted insulator. Figs. 12 and 13 indicate the same distributions for a polluted insulator.

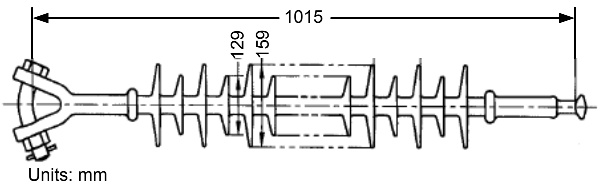

Fig. 9: A 69kV insulator.

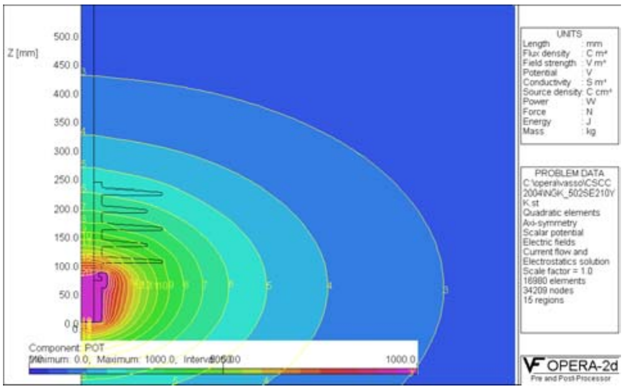

Fig. 10: Potential distribution around and inside the insulator.

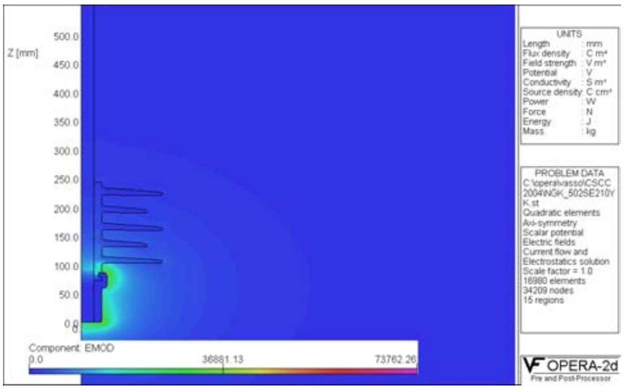

Fig. 11: Electric field distribution around and inside the insulator.

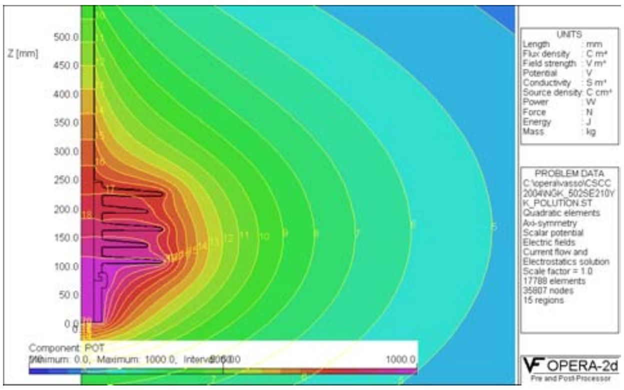

Fig. 12: Potential distribution around and inside the polluted insulator.

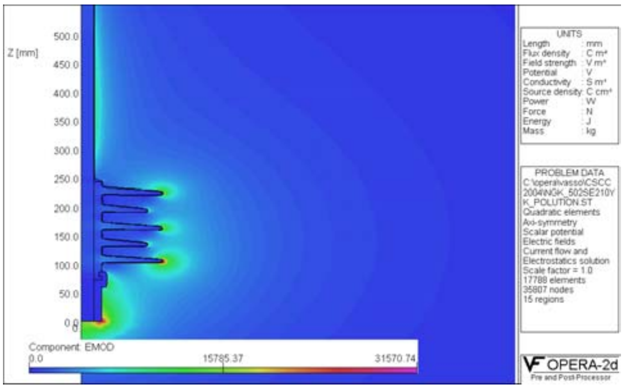

Fig. 13: Electric field distribution around and inside the polluted insulator.

Fig. 14 illustrates the voltage along a line running parallel to the axis of the non-polluted and the polluted insulator. Fig. 15 indicates the electric field distribution along the same line. The distribution of the voltage along the insulator is not uniform, the sheds nearer the conductor being more highly stressed. Furthermore, it is obvious that the polluted insulator is more highly stressed.

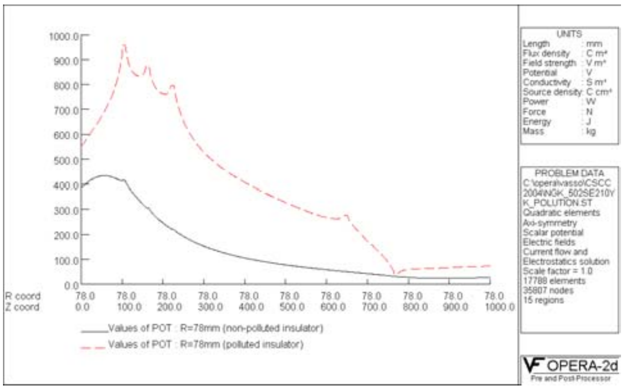

Figure 14: Voltage along the non-polluted and the polluted insulator.

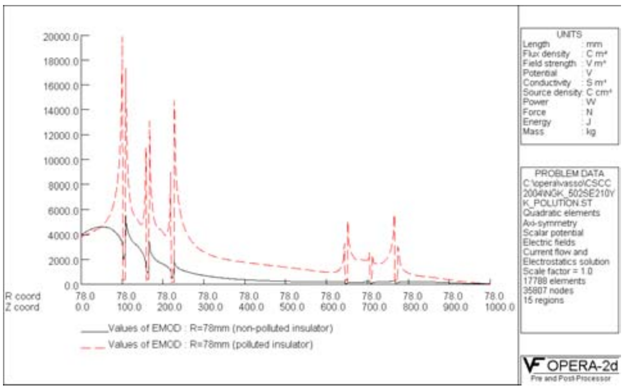

Figure 15: Electric Field along the non-polluted and the polluted insulator.

5 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. The distribution of the voltage along the insulator is not uniform, the part of the insulator nearer the conductor being more highly stressed. Also, the insulator is higher stressed under pollution conditions. By comparing the results of the full to those of the simplified model of the insulator, a very good agreement has been stated. Although a good agreement was obtained between the results of the polluted full model and the polluted simplified model, more work is needed to achieve even better agreement. The work needs to be focused on the shape of the polluted layer at the missed out sheds. Also, it is very important to obtain accurate material data (permittivity and conductivity values) for the materials constituting the insulator and the pollutant.

Acknowledgments:

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