EXPERIENCE USING THE BOUNDARY ELEMENT METHOD IN ELECTROSTATIC COMPUTATIONS AS A FUNDAMENTAL TOOL IN HIGH VOLTAGE SWITCHGEAR DESIGN.

ABSTRACT

In this paper the Boundary Element Method (BEM) is discussed from an industrial user point of view. First we analyse the advantages of using the BEM specifically for three-dimensional electrostatic computations. Two examples are presented. One model is an epoxy rod between two coaxial electrodes in which the electrical field distribution around metal inserts, H.V. shields and along the creepage distance is required. Also shown is the calculation of the change of field configuration after a discharge between the contacts of a disconnector. In these examples, a three dimensional analysis is necessary because of the geometry of the problem.

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J. Lopez-Roldan, P. Ozers
Reyrolle ; Rolls-Royce T&D
UNITED KINGDOM

T. Judge, C. Rebizant
Integrated Engineering Software
CANADA

R.Bosch, J. Munoz
Catalunya Polytech.Univ.
SPAIN

Abstract

In the last ten years we have seen fast development in the computational methods used in all fields of engineering. The possibility of getting rapid and accurate models of High Voltage (H.V.) Switchgear can reduce considerably the high cost of development testing.

In this paper the Boundary Element Method (BEM) is discussed from an industrial user point of view.
First we analyse the advantages of using the BEM specifically for three-dimensional electrostatic computations.
Two examples are presented. One model is an epoxy rod between two coaxial electrodes in which the electrical field distribution around metal inserts, H.V. shields and along the creepage distance is required. Also shown is the calculation of the change of field configuration after a discharge between the contacts of a disconnector. In these examples, a three dimensional analysis is necessary because of the geometry of the problem.

These kinds of problems are often found in H.V. engineering and were resolved in the past using much less accurate two-dimensional approximations.

Introduction

Anybody familiar with the design of H.V. Switchgear can realise the slow progress electrical insulation development has experienced in the last 20 years, especially compared with others fields such as electronics.

Nevertheless, the fast development in recent years of computational methods has made it possible to resolve electrostatic problems, which in the past we had to approximate by rough models and many expensive tests.

These new computational techniques open the door to, if not radical innovation, at least a significant time and cost reduction in the optimisation of the H.V. Switchgear design (2).

Boundary Element Method

The Boundary Element Method (BEM) is a numerical method for the solution of boundary value problems. In electrostatics, Maxwell's equations are the governing equations (1). That is, at every point where the surrounding media is continuous:

$$\overline{\nabla} \times \overline{E} = 0$$

and

$$\overline{\nabla} \cdot \overline{D} = \rho_v$$

Where $\overline{E}$ is the electric field intensity, $\overline{D}$ is the electric field density defined as $\overline{D} = \varepsilon \overline{E}$, and ρ_v is the volume charge density in the region with dielectric constant, ε .

On interfaces between dielectrics the following condition must be satisfied:

$$n \cdot (\overline{D}_1 - \overline{D}_2) = \rho_s$$

Where the normal vector, $\overline{n}$, points from medium (2) into medium (1).

A scalar electric potential, ϕ, can then be defined such that:

$$\overline{E} = -\nabla \phi$$

Using the BEM, material interfaces are replaced with equivalent surface charges and the potential can then be calculated using:

$$\phi(r) = \frac{1}{\varepsilon_0} \left\{ \int_v G(r,r')[\rho_v(r') + \rho'_v(r')]dv' + \int_s G(r,r')[\rho_s(r') + \rho'_s(r')]ds' \right\}$$

Where G is the three-dimensional free space Green's function:

$$G(r, r') = \frac{1}{4\pi} \frac{1}{|r - r'|}$$

ρ_v and ρ'_v are the real and equivalent volume charges respectively in each volume, v; and ρ_s and ρ'_s are the real and equivalent surface charges on each surface s, respectively.

The electric field is computed using a similar expression in which the Green's function is replaced with the gradient of the Green's function.

In the particular case of electrostatic problems, the BEM has some distinct advantages over methods, such as the Finite Element Method (FEM) and Finite Difference Method (FDM), which use differential operators to compute the field. These advantages include:

BEM requires only the discretisation of dielectric and conductor surfaces, as illustrated in the two-dimensional case of a parallel plate capacitor shown in Figure 1. FEM and FDM require the problem space to be truncated at some arbitrary distance from the model of the device. The entire problem space up to the truncation then requires meshing. This is illustrated by the FEM mesh for the same parallel plate capacitor in Figure 2. The discretisation of only dielectric and conductor surfaces in the BEM reduces user input and storage requirements for the final solution.

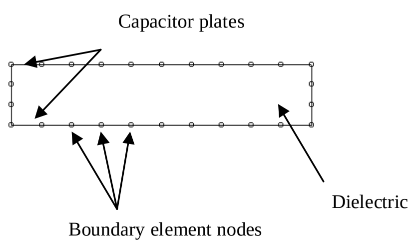

Figure 1. Boundary Element discretisation of a parallel plate capacitor model

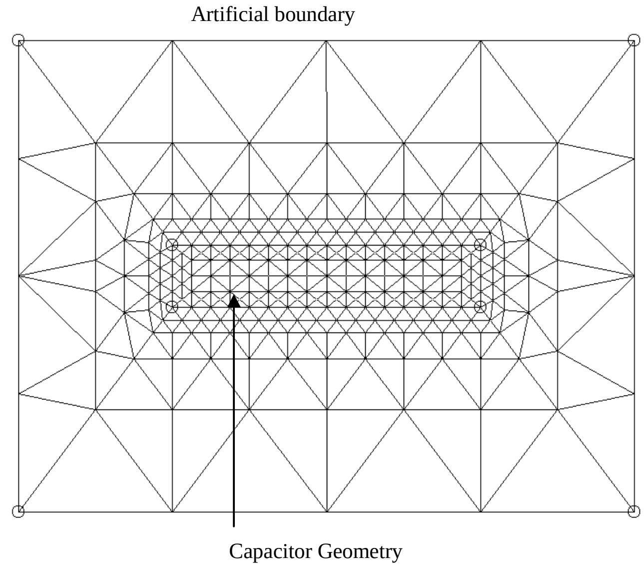

Figure 2. Finite Element mesh of a parallel plate capacitor model

BEM enforces the potential at infinity to be equal to zero. The fields and potentials can then be computed at any point including the interior of devices and the exterior space to infinity. FEM and FDM require an artificial boundary condition to be placed at the truncation of the problem space. This usually requires approximating the potential to zero or the derivative of the potential to some value at the truncated boundary.

There is an inherent smoothing effect when calculating the fields using integration as opposed to differentiation. Numerical differentiation is much more sensitive to numerical errors in the potential calculation. Smoothing algorithms can be implemented for numerical differentiation but their effectiveness is subject to the basic smoothing operator used.

Practical Applications

In the design of H.V. Switchgear the most common problem to be resolved is to find the electrical field distribution in a complex geometry consisting of insulating materials and metal parts at earth or H.V. potential.

Once the high electric field areas are identified, the geometric parameters may need to be modified and the computation repeated as necessary until the values of the E-field are reduced to a more uniform distribution or level, always giving consideration to the practical construction and economy of the component.

An example of this kind of application is represented in Figure 3. In a gas insulated substation an epoxy rod penetrates the grounded metal chamber and into the conductor assembly. As the rod interrupts the revolutionary symmetry of the coaxial elements, a 3D approach is necessary.

The insulated rod contains two metal inserts, one each at the earth and H.V. end. In order to design this piece it is necessary to know the maximum value and distribution of the electric field inside the resin to define the value of internal breakdown voltage and hence material suitability and along the outer surface of the resin to define the flashover voltage along the surface between the H.V. conductor and the grounded chamber.

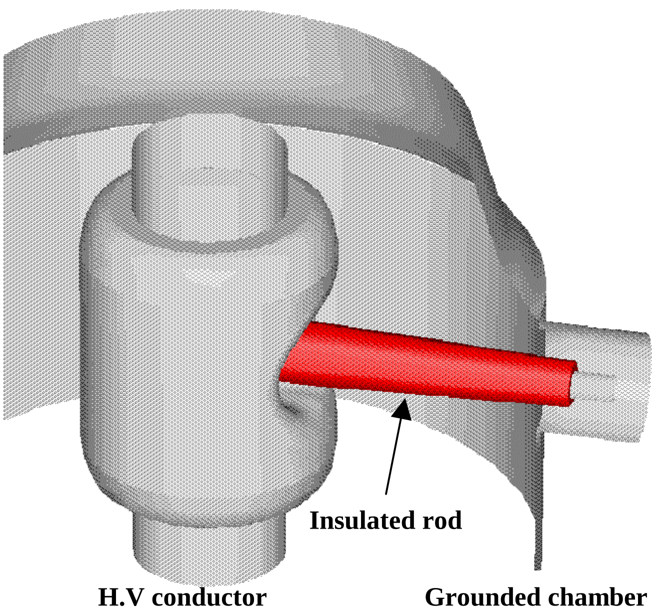

Figure 3. Insulated rod connecting the High voltage conductor and the grounded metal chamber in a Gas Insulated Substation

The geometry of the problem is divided into 5000 boundary elements. Figure 4 shows the element distribution around the electrodes and the external surface of the epoxy rod.

The results of the electrical stress analysis appear in Figure 5. It shows how the maximum internal stress in the epoxy resin is placed, as would be predicted, on the curvature radius of the H.V. electrode. The junction of the rod and the H.V. conductor is well shielded and shows low field values and consequently the maximum field on the rod surface is situated more central to the length.

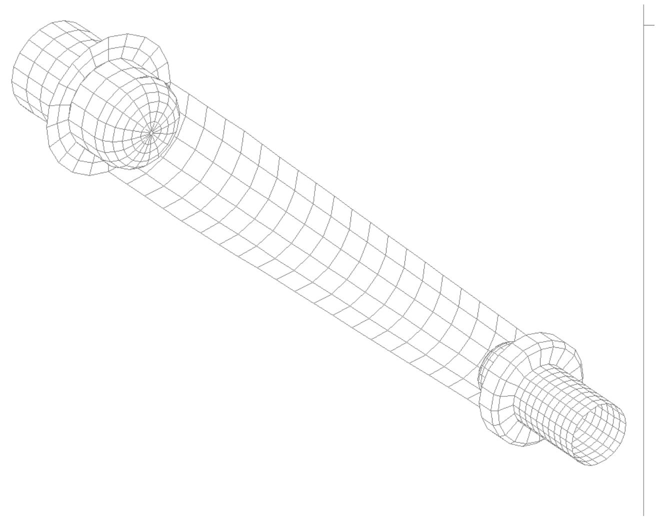

Figure 4. Boundary elements distribution around the embedded electrodes and the external surface of the insulated rod.

Once the field distribution is known, changes in geometry can be made if allowed by other manufacturing exigencies. In this case the curvature radius of the H.V. insert or its position with respect to the H.V. conductor will be modified.
The computation and above process are then repeated until the stresses and distribution are reduced to what is considered an acceptable level.

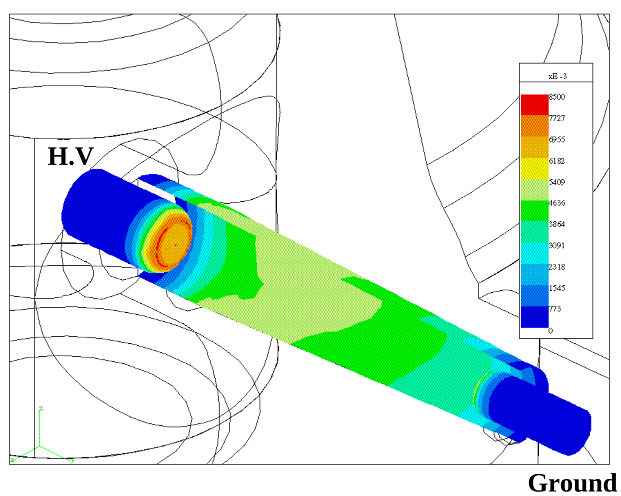

Figure 5. Electric field distribution (modulus) on the surface of contact between the epoxy resin and the embedded electrodes and on the external surface of the insulated rod.

Most problems encountered in the design of Switchgear are of the type illustrated above. There are also occasions when it is necessary to predict the behaviour of the fields in a device under circumstances that will change the original electrostatic configuration. For example, the accumulation of static charge on insulators, pollution or transients provoked by discharge.

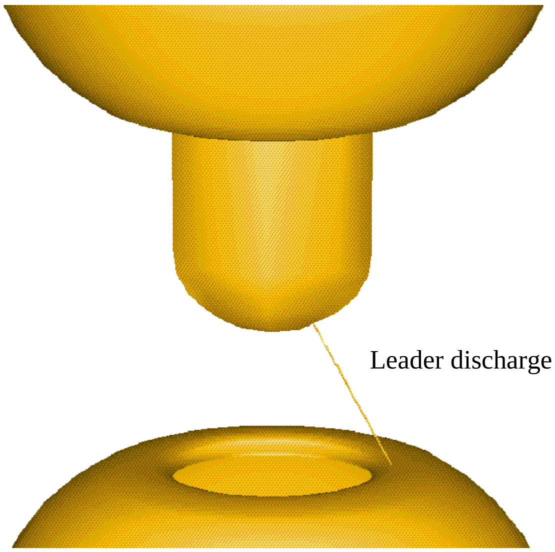

Figure 6. 3D simulation of the moment when a leader discharge bridges two electrical contacts in a GIS disconnector.

As an example Figure 6 represents a simulation of the moment a discharge leader bridges two disconnector contacts. The goal is to assess the possibility that the change in the voltage distribution could drive the leader to the enclosure out of the path between the contacts.

The leader becomes represented by a 1 mm diameter conductor between the disconnector contacts. This problem has often been resolved using a 2D calculation (3) but the asymmetry provoked by the discharge needs to be resolved in three dimensions.

Figure 7 illustrates the distribution of the equipotential lines in the plane of the discharge. As well as this, the E-field distribution around the discharge channel can also be examined.

Again, the analysis of this information will facilitate deciding which parameters have to be changed in the next computation (For example to centre the discharge, reduce its length or increase the shield effect of the contacts).

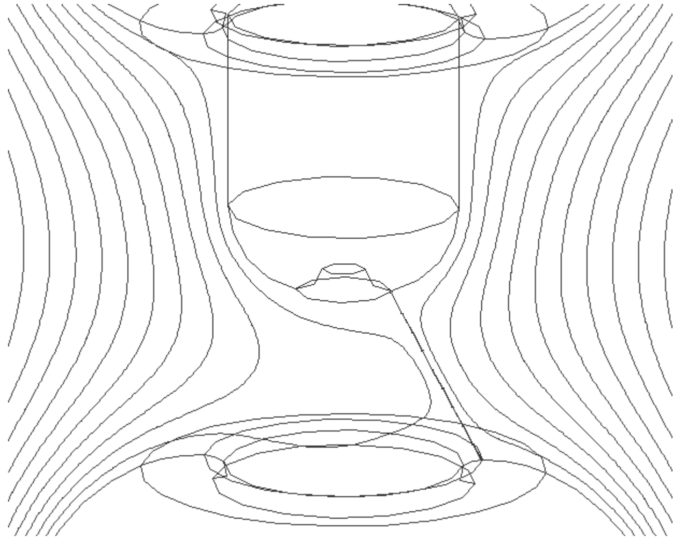

Figure 7 . Curves equipotentials in a seccion of the model represented in figure4.

Summary

A BEM based analysis tool is found to be ideally suitable for electrostatic computations in H.V. Switchgear design.

Several practical examples of common problems in Switchgear have shown how it is possible to get fast and accurate results of electric field distributions. Nevertheless, because it is not the only factor in the design, it is still the engineer who has to analyse the information from the computer and decide which changes to make in the optimisation process.

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