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Finite Element Method Used to Calculate Magnetic Fields

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Abstract: *The increasing demand for electricity in different cities made it necessary to extend the existing high voltage network right up to the customer. The solid insulating material require in Gas Insulated systems (GIS) is to separate two compartments as well as to provide mechanical support for conductors. A maximum percentage of failures are due to improper design of the spacers shape hence there is a need to reduce internal field discharges. The triple junction point formed by interface of solid insulating spacer and SF6 gas. The breakdown ofSF6 gas insulation is adversely affected by the Presence of spacer especially at triple junction point, which is the weakest point at the GIS. Hence there is a need of controlling electric stresses at spacer surface. In order to reduce such stresses at the spacers used in the gas insulated systems the design of spacer is to be changed. For the study of the factors affecting the electric field distribution on the spacer's surface the finite element method (FEM) is used. The Finite Element Method is more accurate than other methods.*

Keywords: Spacer's shapes, Composite cone spacer, Triple junction point, Finite Element Method

I. INTRODUCTION

The present and future trend in electric power equipment tends to be compact and be operated under higher voltage. The point formed by solid insulating spacer and SF6 gas is the weakest point in Gas Insulated Systems (GIS). It is essential to determine the electric field stress distribution along the spacer surfaces and evaluate the degree of their reliability. The compact and modular design of GIS offers a high degree of flexibility to meet layout requirements of both power station switchgear as well as substations, making efficient use of available space. GIS technology has reached up to highest voltage of 800kV where wide ranges of GIS equipment are available with many unique features. With the increase in operating voltage range in the equipment's, the solid insulators play the most important as well as critical role for electrical insulation. To improve the insulation characteristics of the solid insulators, we have to control electric field distribution around the solid insulators. The spacers used in GIS should be precisely designed to realize more or less uniform field distribution along their surfaces. Effort is to be made to decrease the electric field value as low as possible. Spacer's profile is considered the main variable, which controls the field distribution and hence field uniformity can be achieved by adopting the appropriate profile. The profile of spacer was studied as a means of improving the dielectric performance of epoxy spacers. Also, the electric field at the junctions formed by the spacer-SF6 Gas- conductor(enclosure) known as triplejunctions also play a critical role in the design of spacers in Gas insulated systems. The FEM used to calculate the electric field distribution on and around spacer surface.

II. GAS INSULATED SUBSTATION

Simply put, in the GIS system, all the live components are enclosed in a grounded metal enclosure, then the whole system housed in a chamber full of gas. Gas insulated substations (GIS) primarily use Sulphur hexafluoride gas as the primary insulator. SF6 is nontoxic, maintains atomic and molecular properties even at high voltages, high cooling properties, and superior arc quenching properties.

In addition, is safe. SF6 has superior dielectric properties compared to other gases;

thereby provide favorable insulation for the phase to phase and phase to ground moderation. In the substation setup, the gas is contained in a grounded metal enclosure containing the conductors, current and voltage transformers, circuit breaker interrupters, switches, and lightning arrestors.

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A) Diagram and Working

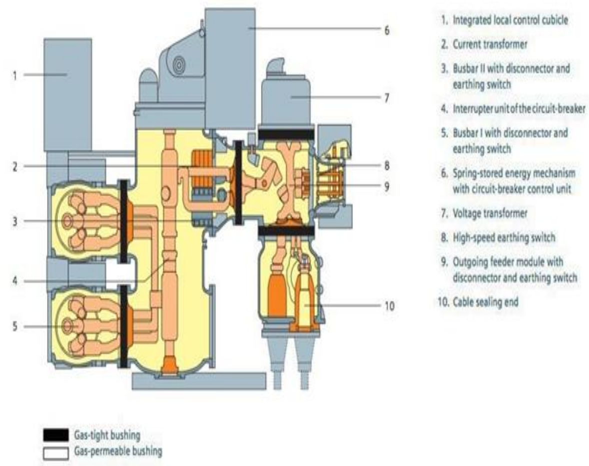

Figure 1.1 Model of Gas Insulated Substation

A point of note is that the GIS contain the same compartments and components as thenormal (AIS) setups. The only difference is the insulation medium, and of course the size. Thelive components and parts are insulated in metal enclosures filled with SF6 gas at moderate pressure. Each compartment housing the live part is gas tight, with respect to each other. Thisensures that the gas does not pass to the neighboring modules, as well as ensure that gasmonitoring is simpler and independent. 'O' rings are installed at the equipment and enclosureflanges to provide the gas tightness.
Another important installation is a gas monitoring system. This includes an integrated alarm system, automatic tripping, and lockout in case of low pressure due to leakage.

B) Advantages of GIS

1. The earthed metal enclosure makes for a safe working environment for the attending personnel
2. Compartmentalized enclosure of the live parts makes for a very reliable system due to reduced disruption of the insulation system.
3. By reducing the distance between active and non-active switchgear parts, less space is required than in the normal AIS system: this comes in handy in densely populated areas and unfavorable terrain (minimum requirements for an AIS is about 47,000m2, while GIS with the same power properties will require approx. 523m2). For the AIS, thehighest element is approximately 28m, whereas for GIS you have 11m at the highestpoint for a 400kV substation.
4. Low maintenance requirements due to expedient design and protection against externalelements.
5. Under scheduled maintenance, SF6 neither ages nor depletes. There is no need to topup the gas levels throughout the equipment lifetime (approx. 40 years).
6. Quick assembly due to extensive pre-assembly.

C) Disadvantages of GIS

1. High installation costs compared to AIS systems
2. Procurement and supply of SF6 gas can be a problem especially in rough terrain andoff site locations. This further increases the costs
3. High level of maintenance is required. This requires highly skilled personnel
4. Internal faults tend to be very costly and severe when they occur. They often lead tolong outage periods. For example, the use of impure gas, as well as leakage due to 'O'ring failure, as well as presence of dust can lead to flashovers and explosions.

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III. FINITE ELEMENT METHOD (FEM) SOFTWARE

FEMM is a suite of programs for solving low frequency electromagnetic problems on twodimensionalplanar and axisymmetric domains. The program currently addresseslinear/nonlinear magnetostatic problems, linear/nonlinear time harmonic magnetic problems,linear electrostatic problems, and steady-state heat flow problems.

FEMM is divided into three parts:

· Interactive shell
· Triangle
· Solvers

A) Interactive shell

This program is a Multiple Document Interface pre-processor and a post-processor forthe various types of problems solved by FEMM. It contains a CAD like interface for laying outthe geometry of the problem to be solved and for defining material properties and boundaryconditions. AutoCAD DXF files can be imported to facilitate the analysis of existinggeometries. Field solutions can be displayed in the form of contour and density plots. Theprogram also allows the user to inspect the field at arbitrary points, as well as evaluate anumber of different integrals and plot various quantities of interest along user-defined
contours.

B)Triangle

Triangle breaks down the solution region into a large number of triangles, a vital part ofthe finite element process.

C) Solvers

Each solver takes a set of data files that describe problem and solves the relevant partialdifferential equations to obtain values for the desired field throughout the solution domain.

D) Finite Element Analysis

Although the differential equations of interest appear relatively compact, it is typicallyvery difficult to get closed-form solutions for all but the simplest geometries. This is wherefinite element analysis comes in. The idea of finite elements is to break the problem down intolarge number regions, each with a simple geometry (*e.g.* triangles). For example, Figure 1.2 shows a random semicircle broken down into triangles. Over these simple regions, the "true"solution for the desired potential is approximated by a very simple function. If enough smallregions are used, the approximate potential closely matches the exact solution.

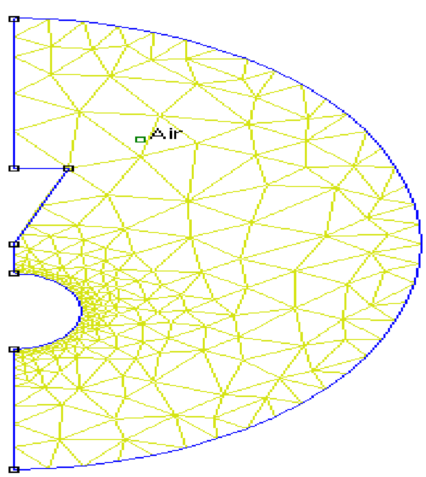

Fig.1.2 A Semicircle structure Broken down into triangles

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The advantage of breaking the domain down into a number of small elements is that the problem becomes transformed from a small but difficult to solve problem into a big but relatively easy to solve problem. Through the process of discretization, a linear algebra problem is formed with perhaps tens of thousands of unknowns. However, algorithms exist that allow the resulting linear algebra problem to be solved, usually in a short amount of time. Specifically, FEMM discretizes the problem domain using triangular elements. Over each element, the solution is approximated by a linear interpolation of the values of potential at the three vertices of the triangle. The linear algebra problem is formed by minimizing a measure of the error between the exact differential equation and the approximate differential equation as written in terms of the linear trial functions.

IV. GIS WITH SPACER

The spacer is considered for the purpose of Finite Element Analysis. The spacer is simulated which is axisymmetric in nature. Dimensions for the said spacer geometry are taken from company drawing sheet. The dimension and placement of spacer assembly plays major role in analysis of electric field. Simulation is done for 1 kV and results can be extrapolated for 245 kV.

In case of GIS the live components and parts are insulated in metal enclosures filled with SF6 gas at moderate pressure. Each compartment housing the live part is gas tight, with respect to each other, hence spacer is used. This ensures that the gas does not pass to the neighboring modules as well as it provides the mechanical support for the whole assembly.

A) Simulation at 245kV

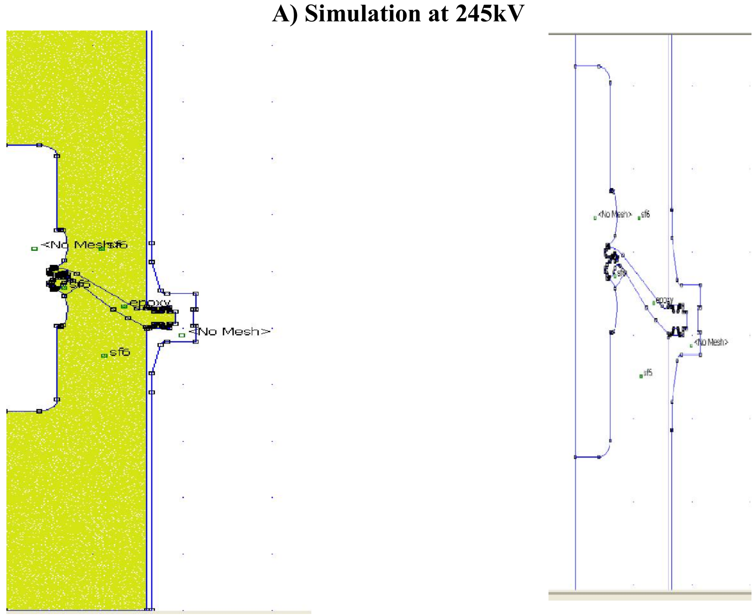

Figure 1.3 Model A for 245 kV A) Spacer model B) Meshing condition

Figure 1.3 (A) indicates that the basic model of spacer is selected for simulation purpose.

Figure 1.3 (B) shows the meshing condition for the spacer.

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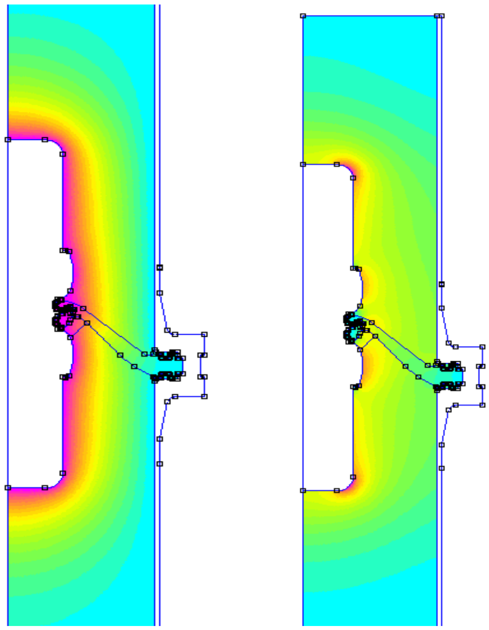

Figure 1.4 (A) indicates the Voltageplot for the given spacer
Figure 1.4 (B) indicate the Electric field stress plot.

B) Case I: Selection of HV conductor

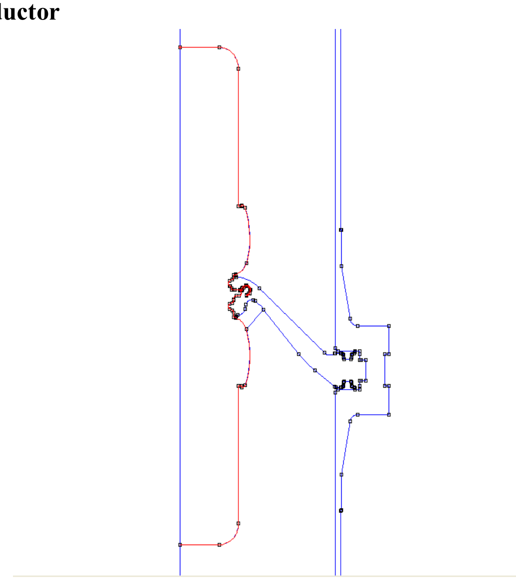

Figure 1.5 Selection of HV conductor

For the simulation purpose let's consider the first case of selection of HV conductor.
The red color in figure 1.5 indicates the HV conductor is selected.

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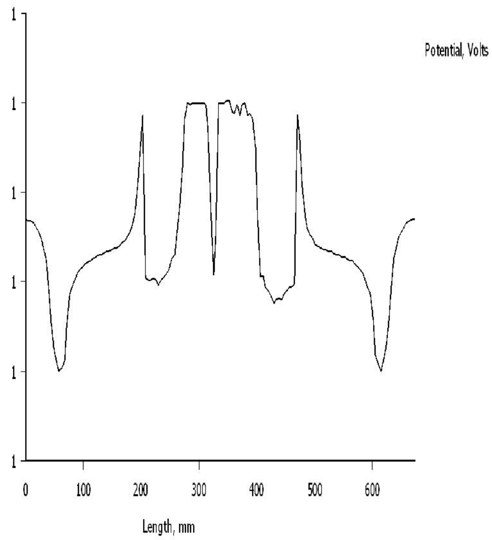

Figure 1.6 Graph of Insulating spacer - Voltage Plot

The figure1.6 is the voltage plot for 245kV model A indicates that the voltage at end is almost equal while at centre point it reaches the peak value continuously.

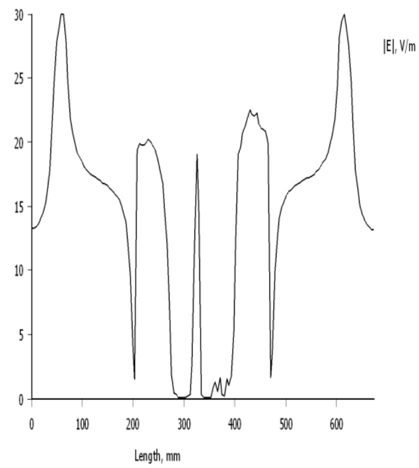

Figure 1.7 Graph of Insulating spacer -[E] Plot

While figure 1.7 ndicates that the [E] plot reaches peak value at ends and within limit at centre.

C) Case II: Selection of ground plane:

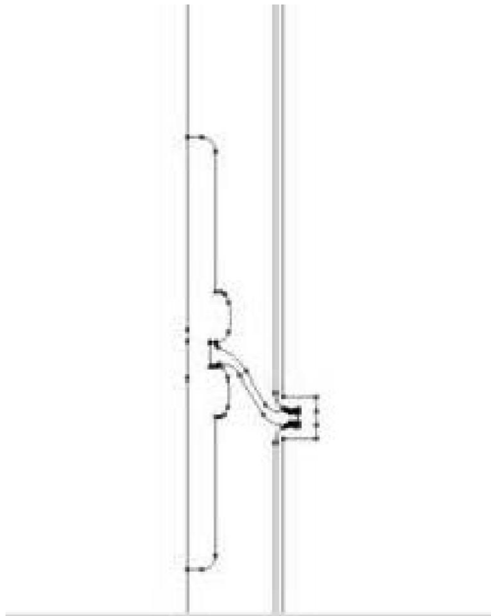

Figure 1.8 Selection of ground plane

For the simulation purpose let's consider the third case i.e. selection of ground plane.
The red color in figure 1.8 indicates the ground plane is selected.

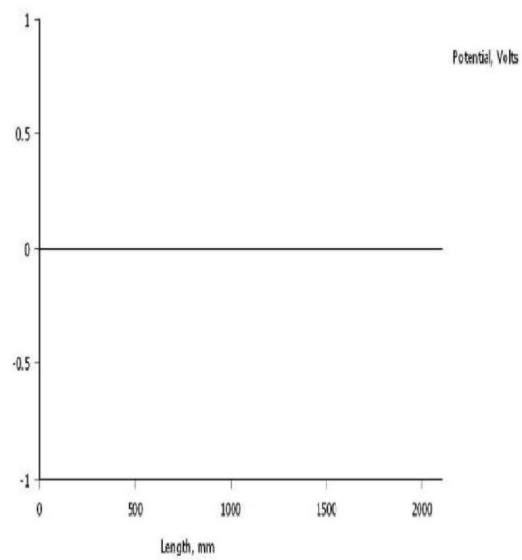

Figure 1.9 Graph of ground plane-Voltage Plot

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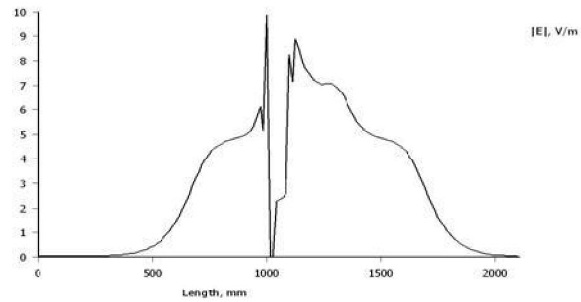

Figure 1.10 Graph of ground plane -[E] Plot

The Voltage plot Shown in figure 1.9 indicates that the voltage is zero on groundplane and [E] plot shown in figure 1.10 indicates that the Electric field stress near to thespacer is very high at end side it is very less.

D) Case III: Selection of insulating spacer

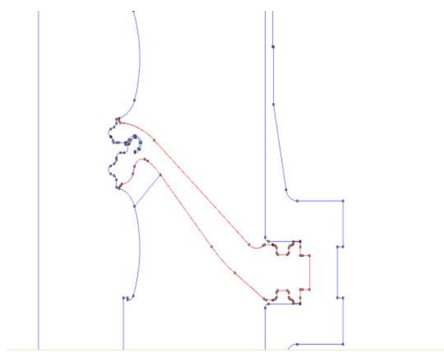

Figure 1.11 Selection of Insulating spacer

For the simulation purpose let's consider the second case i.e. selection of Insulating spacer. The red colour in figure 1.11indicates the Insulating spacer is selected.

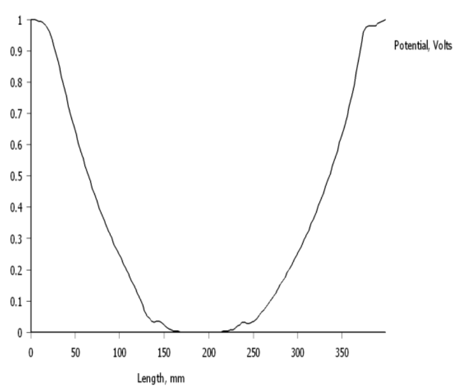

Figure 1.12 Graph of Insulating spacer-Voltage Plot

The figure 1.12 indicate that the voltage at end points of spacer is very high and at centre it is almost zero.

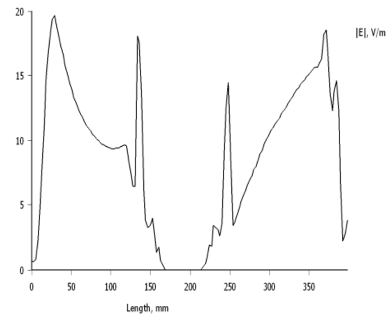

Figure 1.13 Graph of Insulating spacer [E] Plot

The figure 1.13 indicate that initially itself the spacer reaches the peak value then almost along the spacer surface the stress value is very high.

V. CONCLUSION

The work carried out was planned to optimize the spacers used in Gas Insulated Substation at 245 kV. Software used for simulation is Finite Element Method. The effect on Voltage distribution and Electric Field Stress Distribution were investigated for the cases when HV terminal, Insulating Spacer geometry and ground terminal were considered.

The conclusions drawn from the work carried out are as follows:

1. Numerical Technique based on Finite Element is a comprehensive study tool for optimizing and simulating spacers with complicated geometries for different ratings.
2. The geometrical shape of the spacer has a significant influence on the electric field distribution.

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