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# Calculation of Magnetic Field using Finite Element Method

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**Abstract:** *The increasing demand for electricity in various cities has necessitated extending high-voltage networks closer to end- users. In Gas Insulated Systems (GIS), solid insulating materials are crucial for separating compartments and providing mechanical support for conductors. A significant percentage of failures in GIS can be attributed to improper spacer design, which leads to internal field discharges.*
*The triple junction point, where the solid insulating spacer interfaces with SF6 gas, is particularly vulnerable. This junction is the weakest point in GIS, as the breakdown of SF6 gas insulation is negatively impacted by the presence of the spacer, especially at this critical location. Therefore, controlling electric stresses at the spacer surface is essential. To mitigate these stresses, improvements in spacer design are necessary. Factors influencing the electric field distribution on the spacer surface are analysed using the Finite Element Method (FEM), which offers higher accuracy compared to other approaches. This method is instrumental in optimizing spacer design and reducing electric field stresses in GIS.*

**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 triple junctions 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.

**A) Diagram and Working**

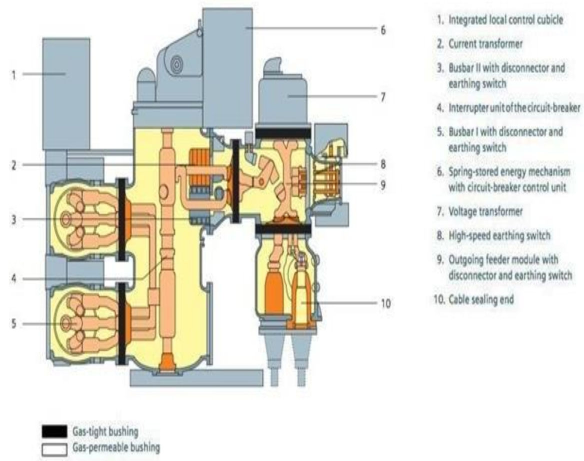


Figure 1.1 Model of Gas Insulated Substation

**GIS Design**

**Electric Field Distribution**: As you mentioned, the distribution of the electric field around the spacer surface plays a pivotal role in ensuring effective insulation. Improper field distribution, especially near spacer junctions, can lead to electrical breakdowns. The use of FEM (Finite Element Method) for calculating the electric field distribution around spacers is essential for identifying these weak spots and improving insulation reliability.

**Role of SF6 Gas**: SF6 gas serves as a superb insulating medium due to its high dielectric strength, arc-quenching capabilities, and stability at high voltages. This makes it especially suitable for GIS, where compactness and high-voltage operation are crucial. SF6 ensures that electrical stress on the insulators remains within safe limits, and its non-toxic nature ensures a safer operational environment.

**Spacer Design**: The profile of the spacer is directly responsible for the uniformity of the electric field distribution. A well-designed spacer profile can significantly reduce localized electric stress, enhancing the overall reliability of the GIS system. Your focus on improving dielectric performance through spacer design optimization is essential in high-voltage GIS applications.

**Modular Design**: One of the standout features of GIS is its compact and modular nature. The modular design allows GIS to be easily customized for various substation layouts while maximizing space efficiency. With high- voltage ratings such as 800 kV, GIS technology has advanced to meet the increasing demand for higher capacity in substations.

**Triple Junctions**: The electric field stress at the junctions formed by the spacer, SF6 gas, and conductor (also called triple junctions) is critical to the dielectric performance of GIS. As these points can become the most vulnerable areas in the system, understanding and controlling the electric field distribution at these junctions is key to preventing electrical failures and enhancing system longevity.

Applications and Benefits of GIS in Power Stations and Substations

**Space Efficiency**: GIS's compact design makes it an excellent choice for urban power stations and areas with limited space. Its ability to pack more components into a smaller footprint while maintaining high voltage ratings is a major advantage in dense urban environments.

**Safety and Reliability**: With SF6 gas providing superior insulation and arc-quenching properties, GIS systems offer high operational reliability, ensuring that substations can operate safely without frequent maintenance needs. The sealed nature of GIS further protects the system from environmental contaminants, contributing to its longevity and low failure rates.

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**Adaptability to Layouts**: The modularity and flexibility of GIS enable its use in a wide range of layouts. This adaptability ensures that GIS systems can meet the demands of different power station configurations and substation requirements while providing superior performance and minimizing space consumption.

**Challenges and Future Trends**

**Increasing Voltage Requirements**: As the demand for higher voltage equipment rises, GIS systems will need to continue evolving to handle voltages higher than 800 kV. This will likely involve further optimization of spacer designs, improved SF6 gas formulations, and new materials for solid insulators.

**Environmental Considerations**: Although SF6 is non- toxic, its environmental impact has raised concerns due to its high global warming potential. As such, there may be an increasing push toward developing alternative insulating gases or technologies to reduce the environmental footprint of GIS systems.

**Smart Monitoring and Maintenance**: As GIS systems become more complex and operate at higher voltages, incorporating smart sensors for continuous monitoring and predictive maintenance could become increasingly important. This would allow operators to detect potential issues early and ensure system longevity and reliability.

## III. FINITE ELEMENT METHOD (FEM) SOFTWARE

FEMM is a suite of programs for solving low frequency electromagnetic problems on two dimensional planar and axisymmetric domains. The program currently addresses linear/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

**Interactive shell**

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

**Triangle**

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

**Solvers**

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

**Finite Element Analysis**

Core Concepts of Finite Element Analysis (FEA)

**Discretization of the Domain**:

As you pointed out, FEA works by dividing a complex geometry (like a semicircle) into smaller, simpler regions, usually **triangular elements**. This process is called **discretization**.

These simple regions have known mathematical properties and allow the problem to be broken into manageable chunks. By doing so, the problem is no longer unsolvable but becomes a large system of smaller, simpler problems.

Approximation with Simple Functions**:**

Over each discrete region (element), the solution is approximated by a simple function. For example, in your case, the potential (a solution to the differential equation) is approximated as a **linear interpolation** of the values at the vertices of the triangles.

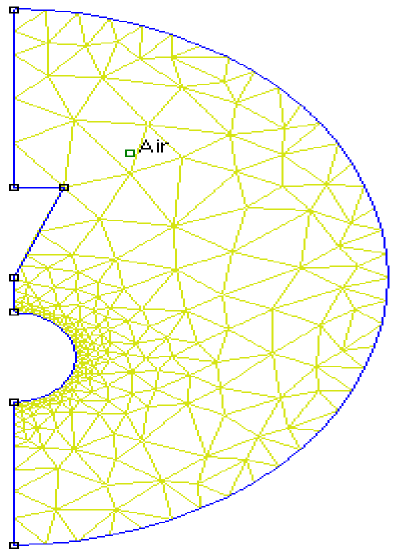


*Fig.1.2 A Semicircle structure Broken down into triangles*

## 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

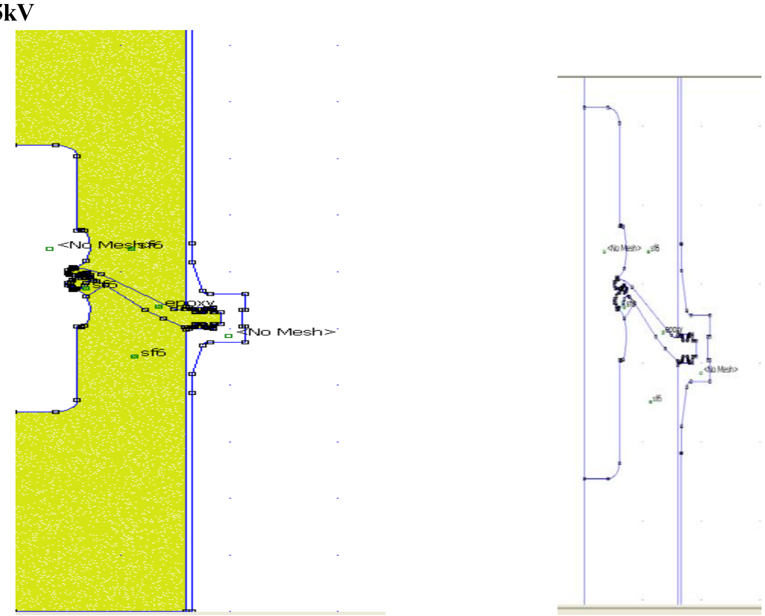


Figure 1.3 Model A for 245 kV A) Spacer model B) Meshing condition

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.

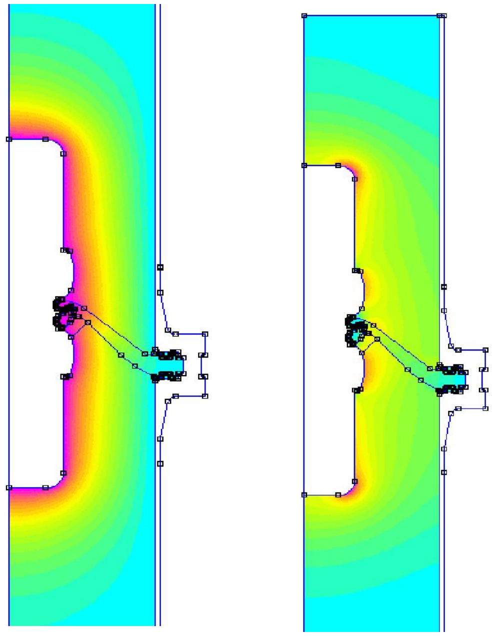

Figure 1.4 (A) indicates the Voltage plot for the given spacer
Figure 1.4 (B) indicate the Electric field stress plot.

## V. CONCLUSION

The study demonstrates the importance of **spacer design optimization** in GIS and highlights how **Finite Element Method (FEM)** can be a powerful tool in improving the reliability and performance of GIS systems. Spacer geometry significantly influences the electric field distribution, which in turn affects the overall effectiveness and longevity of the GIS equipment. By refining the spacer design through FEM, engineers can ensure that GIS systems function reliably at high voltages while minimizing the risk of electrical failure.

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