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Field Distribution on the Surface of a Spacer in Gas Insulated Systems (GIS) with Protrusions and Depressions

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Abstract

Solid insulating spacers are one of the critical components affecting reliable performance of Gas Insulated Systems (GIS). The breakdown strength of GIS is strongly influenced by the roughness of the spacer's surface and defects produced from improper manufacturing. So it is essential to determine the electric field distribution along the spacer surfaces and hence evaluate the degree of their reliability. Electric field distribution at the protrusions, dispersions on the surface of the spacer plays a critical factor affecting the breakdown of spacer. In this work the effect of spacer defects , protrusions and dispersions on the value of Electric field distribution on the surface of the spacer is studied. The Finite Element Method is employed to compute the electric field for both the cases of spacer defects. It is an efficient technique for solving field problems.

Introduction

Gas Insulated Systems(GIS) are widely used in the electric power industry. Typically, solid insulators are required to provide support of stressed conductors in the system. Solid insulating spacers in GIS represent the weakest points in these systems. The breakdown strength of GIS is strongly influenced by the roughness of the spacer's surface and defects produced from improper manufacturing [1]. Several troubles and system outages have been reported all over the world due to spacer's failures. Normally, pure SF_6 or SF_6/N_2 mixtures at high pressures are used to insulate the system [2,3]. The presence of spacers, results in complex-dielectric field distribution. It often intensifies the electric field particularly on the spacer's surface. The insulation ability of SF_6 is highly sensitive to the maximum electric field, and furthermore the insulation strength along a spacer's surface is usually lower than that in the gas space [4]. Due to the previously mentioned spacer's troubles, they should be precisely designed to realize more or less uniform field distribution along their surfaces. Also to decrease its value as low as possible keeping in mind the optimum leakage path. 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 [3,5-7]. Insulation materials may contain protrusions and depressions in the manufacturing process for various reasons. The presence of these defects has deleterious effects on the electrical performance of insulation, as it is the source of partial Discharges(PD), which contribute to insulation degradation, and eventually cause breakdown of the insulation .

In this paper the finite element method (FEM) is used to determine the electric field distribution on the spacer's surface. FEM concerns itself with minimization of the energy within the whole field region of interest, whether the field is electric or magnetic, of Laplacian or Poisson type, by dividing the region into triangular elements for two-dimensional problems or tetrahedrons for three- dimensional problems [8].

Calculation Technique

Several research workers have calculated the field distribution on spacers surfaces using the charge simulation method (CSM). Acceptable results were obtained by this method. However, the choice of the number and charges types; point, ring and line charges need tedious trial and error methodology which is time consuming. In this paper the Finite Element Method (FEM) is used to determine the electric field distribution on the spacer's surface. It is an efficient technique for solving field problems. FEM concerns itself with minimization of the energy within the whole field region of interest, whether the field is electric or magnetic, of Laplacian or Poisson type, by dividing the region into triangular elements for two dimensional problems or tetrahedrons for three dimensional problems [9]. Under steady state the electrostatic field within anisotropic dielectric material, assuming a Cartesian coordinate system, and Laplacian field, the electrical energy W stored within the whole volume U of the region considered is:

$$W = \frac{1}{2}\int_U \varepsilon |gradV|^2 \, dU \tag{1}$$

$$W = \frac{1}{2}\iiint_U \left[\varepsilon_x \left\{\frac{\partial V_x}{\partial x}\right\}^2 + \varepsilon_y \left\{\frac{\partial V_y}{\partial y}\right\}^2 + \varepsilon_z \left\{\frac{\partial V_z}{\partial z}\right\}^2\right] dxdydz \tag{2}$$

Furthermore, for GIS arrangement, when we consider the field behavior at minute level the problem can be treated as two dimensional (2D) [9]. The total stored energy within this area-limited system is now given according to:

$$\frac{W}{\varphi} = \frac{1}{2} * \varepsilon \iint \left[\left\{ \frac{\partial V_x}{\partial x} \right\}^2 + \left\{ \frac{\partial V_y}{\partial y} \right\}^2 \right] dxdy \tag{3}$$

Where (W/φ) is thus an energy density per elementary area dA. Before applying any minimization criteria based upon the above equation, appropriate assumptions about the potential distribution V(x, y, z) must be made. It should be emphasized that this function is continuous and a finite number of derivatives may exist. As it will be impossible to find a continuous function for the whole area A, an adequate discretization must be made. So all the area under consideration is subdivided into triangular elements hence:

$$\frac{W}{\varphi} = \frac{1}{2} * \varepsilon * \sum_{i=1}^{n} \left[\left\{ \frac{\partial V_x}{\partial x} \right\}^2 + \left\{ \frac{\partial V_y}{\partial y} \right\}^2 \right] * A_i \tag{4}$$

Where n is the total number of elements and Ai is the area of the i^{th} triangle element. So the formulation regarding the minimization of the energy within the complete system may be written as

$$\frac{\partial X}{\partial\{V(x,y)\}} = 0\,; Where\ X = \frac{W}{\varphi} \tag{5}$$

Electric Field along Spacer Surface

Spacer Profile

Electrostatic field optimization of the profile of the Spacer-SF_6Gas interface was studied as a means of improving the dielectric performance of epoxy spacers. A composite shaped spacer was modelled which combines the advantage of the long leakage distance of a cone shaped profile with that of the quasi-uniform field distribution of a disc-shaped profile. The optimization procedure is based on control of the field distribution (dependent on geometry parameters only) at the spacer surface by shaping the spacer profile. For geometric r_o(outer enclosure radius)-r_i(Inner conductor radius) is taken to be 100mm.A 1Volt is applied to anode while the cathode is grounded . It was assumed that no surface charge is accumulated on convex and concave sides of spacer. Figure 1 shows the initial shape of the spacer and importance regarding field optimization is given to the concave side of spacer as the junction formed by dielectric-SF_6-Electrode at cathode end is more vulnerable to flashovers. The optimized spacer profile is given in Figure 2. Electric field stress along the concave side of spacer is given in Figure 3 and electric field stress for optimized spacer profile is obtained for r=28mm as given in Figure 4.

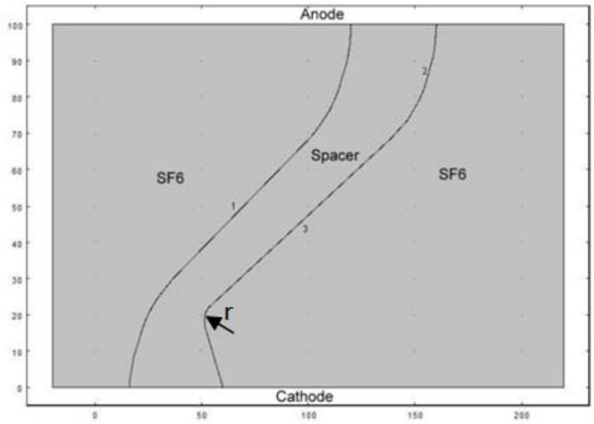

Figure 1: Initial Spacer Profile

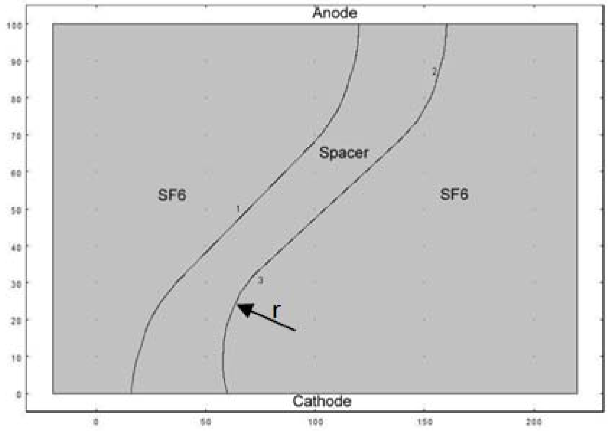

Figure 2: Optimized Spacer Profile

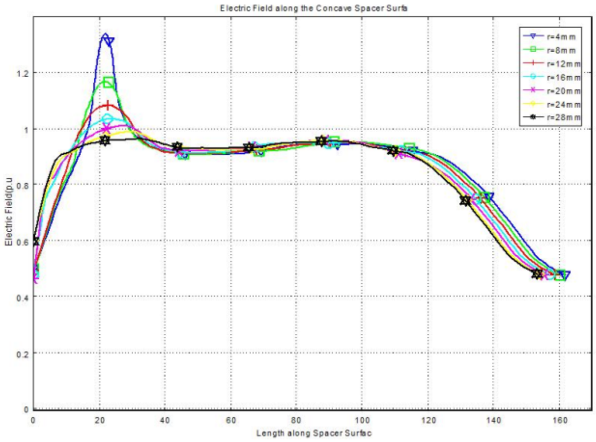

Figure 3: Electric Field Stress along the concave spacer surface for variable ‘r’

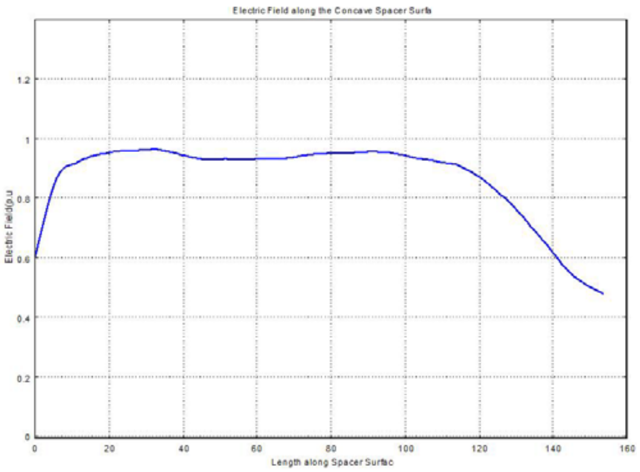

Figure 4: Optimum Electric Field Stress along the concave spacer surface for r=28mm

Effect of spacer defects

Spacer’s defects normally exist on their surfaces due to improper manufacturing or tools mishandling during installation. These are mainly divided into two categories: spacer's protrusions and depressions. Figures 5 and 6 show a schematic representation of the spacer's defects, these are characterized by three variables (rdepa,rdepb, rpota,rpotb, depx, depy, prox, proy). Where rdepa,rdepb and rpota,rpotb are the spacer's depression a,b axis radius and protrusion a,b axis radius respectively. And (depx,depy), (prox,proy) tells the position of the defects on the surface of the spacer. The results presented in this section are obtained for a elliptical shape protrusion and depression with different diameters and variable positions on the surface of spacer.

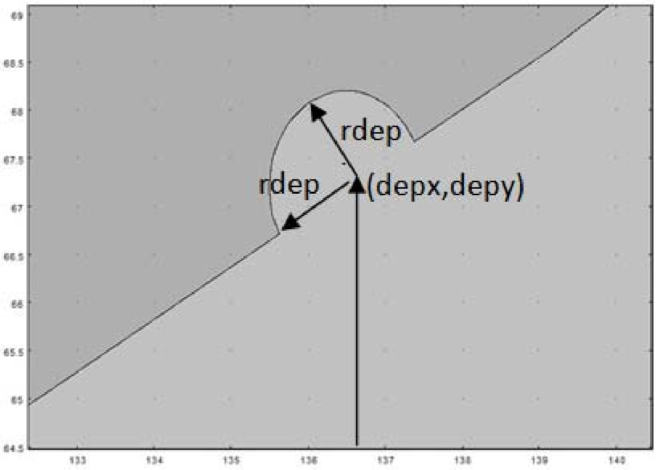

Figure 5: Depression on the concave side of spacer.

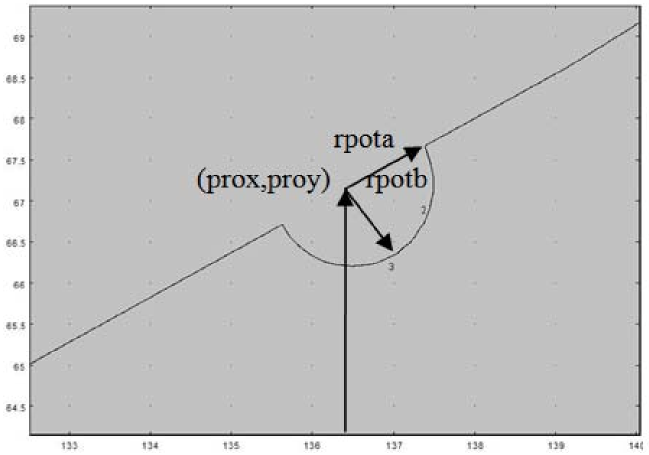

Figure 6: Protrusion on the concave side of spacer.

Effect of Protrusions and Depressions

For protrusions and depressions along the spacer surface the Electric field stresses are computed by keeping rpota and rdepa constant and varying rpotb and rdepb in the limit 0.01mm to 1mm in steps of 0.1mm and the results obtained are considered for two cases: First the position of depression and protrusion is fixed and their respective dimensions are varied and the results are shown in Figure 7 and Figure 8. Figure 9 shows the profile of a protrusion with varying rpotb with fixed rpota. From the results it can be observed that with the variation of radius the maximum electric field stress is found to be nearly 2.1p.u in the case of protrusion with 0.2mm rpota and 1mm rpotb, which is observed to be maximum from all the observed cases and nearly 1.3p.u in the case of depression with 0.2mm rdepa and 1mm rdepb dimensions. Secondly the radius of both depressions and protrusions are kept fixed but their position along the surface of the spacer is varied and the results are shown in Figure 10 and Figure 11. Figure 12 and Figure 13 show the positions of depression and protrusion at different positions on the spacer surface. In the case of elliptical shape protrusion and depression, depression on the surface of the spacer is showing a profound effect when it is nearer to the Spacer-SF_6 Gas-Cathode junction end. The maximum electric field stress in the case of depression is almost 3.7p.u. A protrusion is having a maximum field stress of nearly 2.1p.u.

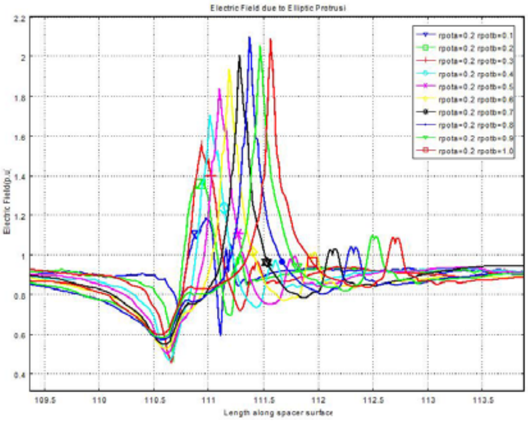

Figure 7: Electric Field stress due to a protrusion at fixed position.(rpota and rpotb are measured in mm)

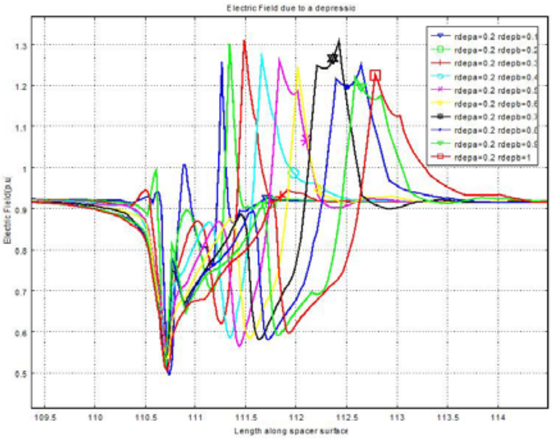

Figure 8: Electric Field stress due to a depression at fixed position.(rdepa and rdepb are measured in mm)

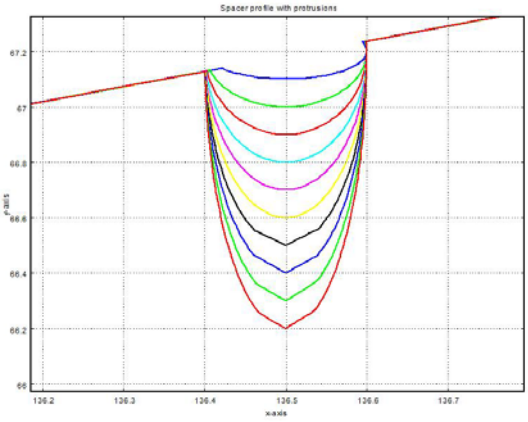

Figure 9: Protrusion profile along the spacer surface.

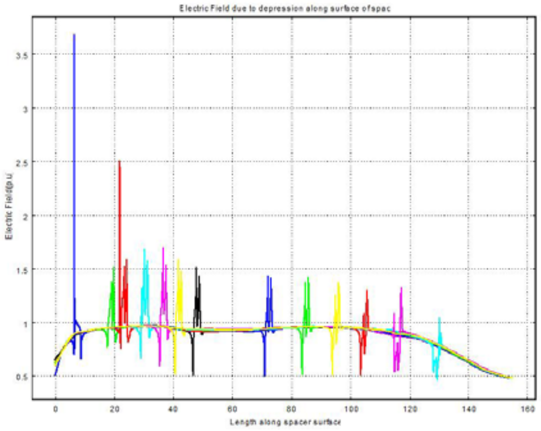

Figure 10: Electric Field stress due to a depression with fixed rdepa(0.2mm), rdepb(1mm) but variable position along the surface of the spacer.

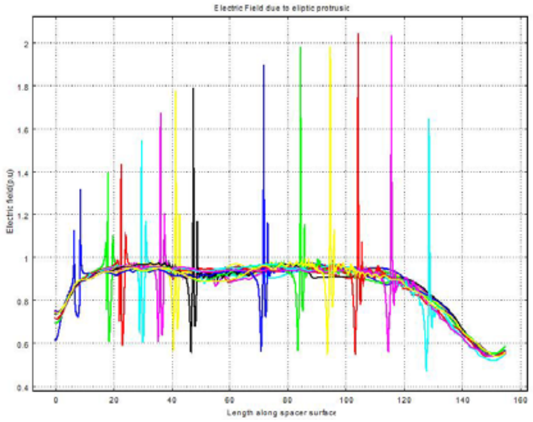

Figure 11: Electric Field stress due to a Protrusion with fixed rdepa(0.2mm), rdepb(1mm) but variable position along the surface of the spacer.

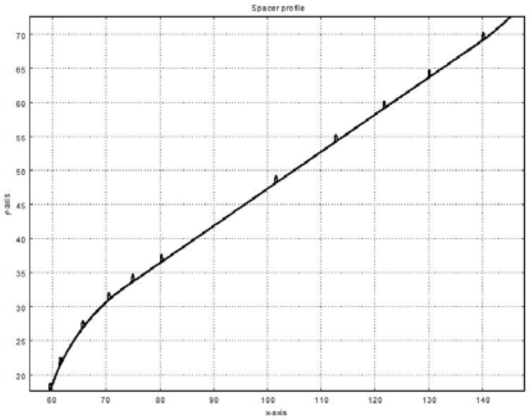

Figure 12: Depressions at different positions on the spacer.

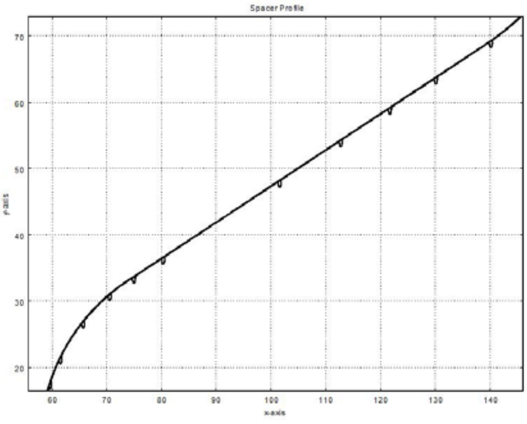

Figure 13: Protrusions at different positions on the spacer.

Conclusions

A key aspect in the design and optimization process of high voltage apparatus is the precise simulation and geometric optimization of the electric field distribution on electrodes and dielectrics. Precise knowledge of the electric field distribution enables the electrical engineer to prevent possible flashovers in critical areas of the device being designed. The geometrical shape of the electrodes has a significant influence on the resulting electrostatic field. When designing and optimizing high voltage components it is very important to know the electric field distribution on the electrodes and dielectrics. First a composite cone type spacer is optimized to obtain uniform field along the concave side of spacer. Effect of Spacer defects like depressions and protrusions on the Electric field stress distribution on the surface of the spacer are calculated. From the results it can be concluded that the size variation of the defects is showing less effect than the position change of the defect. The results also show that the elliptic depression discussed in this work resulted in high electric field stress when the defect is near to spacer-SF_6 Gas- cathode junction.

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