EFFECT OF SPACER DEFECTS ON THE ELECTRIC FIELD DISTRIBUTION ON THE SURFACE OF THE SPACER IN GAS INSULATED SYSTEMS

D.Deepak Chowdary[1], J.Amarnath[2]

[1] Dr.L.Bullayya College of Engineering for Women, Visakhapatnam, Andhra Pradesh, India
[2] Jawaharlal Nehru Technological University, Hydarabad, Andhra Pradesh, India
*Email: <duvvada_27@yahoo.co.in>

Abstract: Solid insulating spacers represent the weakest points in Gas Insulated Systems (GIS), and several troubles and systems outages have been reported all over the world due to spacers failure. Solid insulating spacers are one of the critical components affecting reliable performance of GIS. So it is essential to determine the electric field distribution along the spacer surfaces and hence evaluate the degree of their reliability. The breakdown strength of GIS is strongly influenced by the roughness of the spacer's surface like protrusions and depressions and defects produced from improper manufacturing. One of these forms is the loss of adhesion at electrode/epoxy interface which leads to initiating delamination. Bulk dielectric failure of spacers can be attributed to delamination at the electrode/epoxy interface. High field at a minute void located in the spacer may result in partial discharges in the void which may, over a period of time lead to insulation failure. Electric field distribution at the protrusions, dispersions on the surface of the spacer, delamination and voids plays a critical factor affecting the breakdown of spacer. In this work the effect of spacer defects like protrusions, dispersions, delamination and voids of various shapes and dimensions 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 all the cases of spacer defects. It is an efficient technique for solving field problems.

1 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 small gaseous voids in the manufacturing process for various reasons. The presence of voids 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 [8]. Field experiences indicated that bulk dielectric failure of spacers can be attributed to delamination at the electrode/epoxy interface [9].

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 [10].

2 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 [10]. 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:

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

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

Furthermore, for GIS arrangement, when we consider the field behaviour at minute level the problem can be treated as two dimensional (2D) [11]. The total stored energy within this area-limited system is now given according to:

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

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:

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

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

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

The calculations carried out in this paper were obtained using COMSOL. It is a software package with very high accuracy and large facilities for the finite element analysis of two-dimensional, three dimensional planar and axisymmetric problems in electrostatics. Also it can be used to simulate and calculate the electric field and voltage distribution as well as field mapping on and around the spacer's surface under various conditions.

3 ELECTRIC FIELD ALONG SPACER SURFACE

3.1 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.

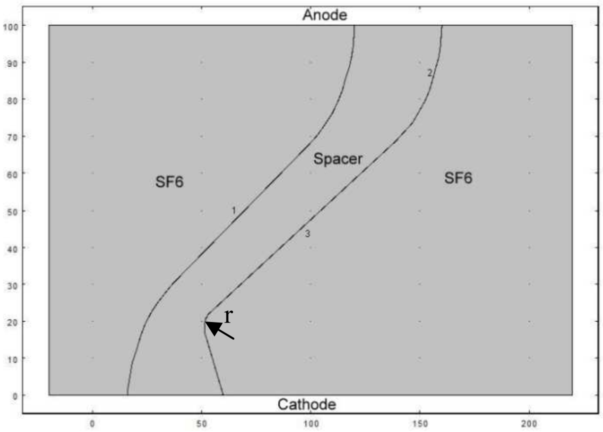

Figure 1: Initial Spacer Profile

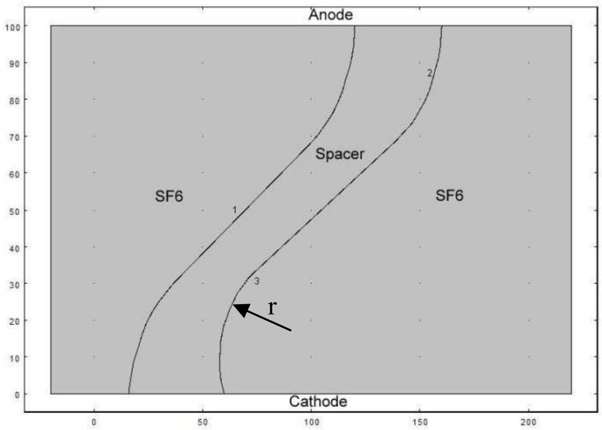

Figure 2: Optimized Spacer Profile

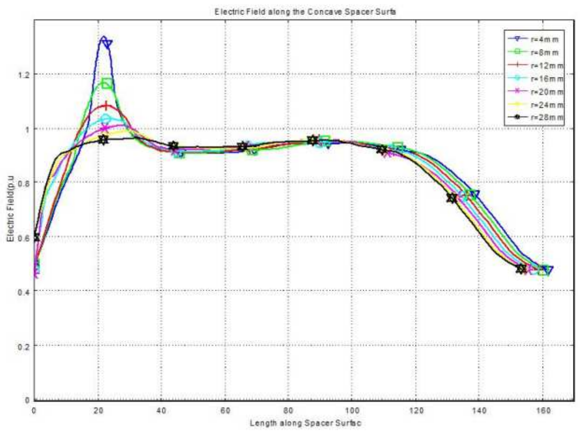

Figure 3: Electric Field Stress along the concave spacer surface for variable 'r'

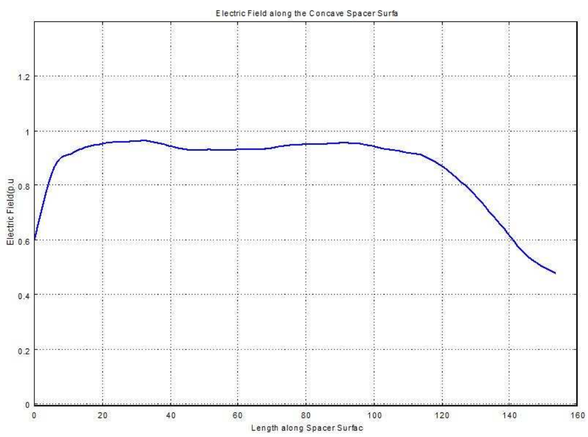

Figure 4: Optimum Electric Field Stress along the concave spacer surface for r=28mm

4 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 (rdep, rpot, depx, depy, prox, proy). Where rdep and rpot are the spacer's depression radius and protrusion 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 hemi-sphere protrusion and depression with different diameters and variable positions on the surface of spacer.

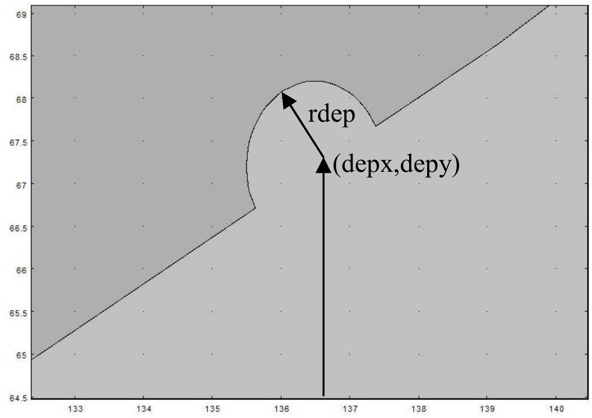

Figure 5: Depression on the concave side of spacer.

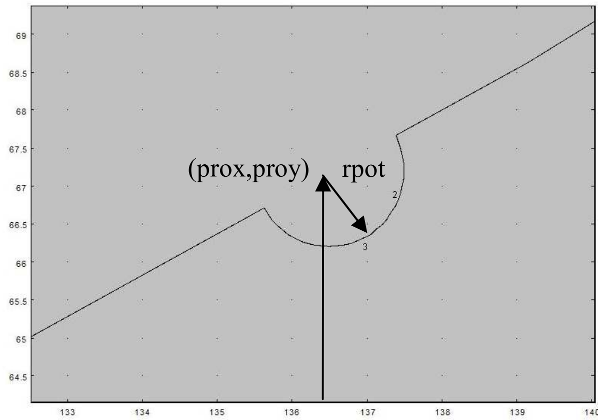

Figure 6: Protrusion on the concave side of spacer.

4.1 Effect of Spacer Depressions and Protrusions

For Spacer depressions and protrusions the Electric field stresses are computed for two cases: First the position of depression and protrusion is fixed and their respective radius are varied and the results are shown in Figure 7 and Figure 8. From the results it can be observed that with the variation of radius the electric field stress remains almost same for both the cases and the maximum electric field stress is found to be 1.3p.u. 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 9 and Figure 10. Protrusion and depression on the surface of the spacer is showing a profound effect when they are nearer to the Spacer-SF_6 Gas-Cathode junction end. The maximum electric field stress in the case of depression is almost constant independent of its position with a value of 1.4p.u. A protrusion at the Spacer-SF_6 Gas-Cathode junction end is having a maximum field stress of 2.1p.u.

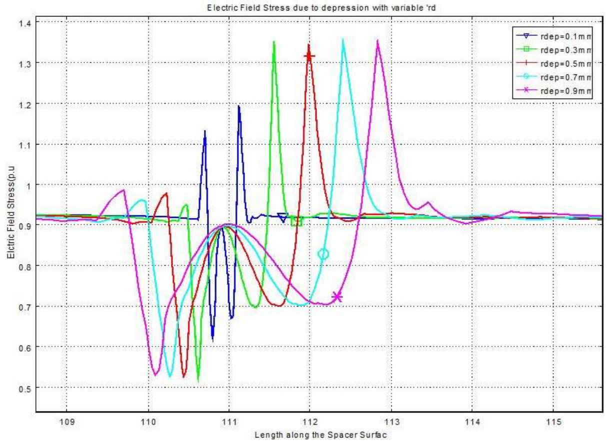

Figure 7: Electric Field stress due to a depression with fixed position and variable radius.

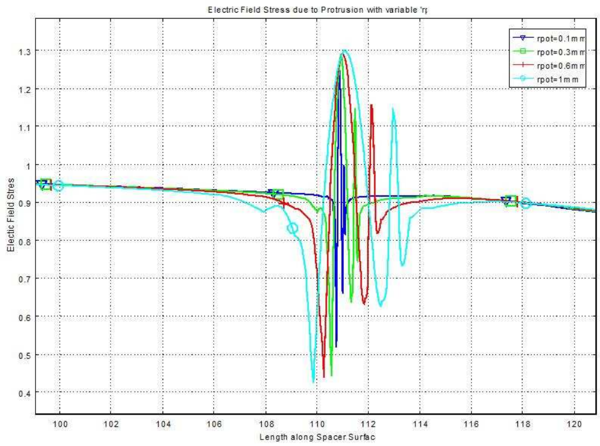

Figure 8: Electric Field stress due to a Protrusion with fixed position and variable radius.

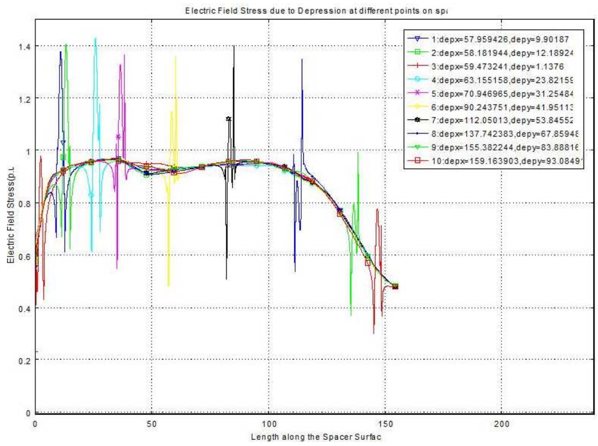

Figure 9: Electric Field stress due to a depression with fixed radius but variable position along the surface of the spacer.

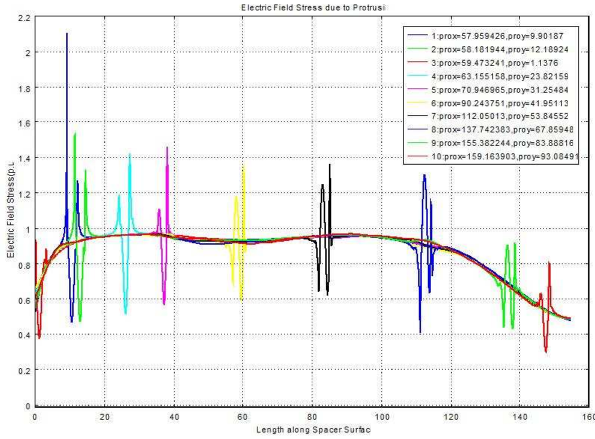

Figure 10: Electric Field stress due to a Protrusion with fixed radius but variable position along the surface of the spacer.

4.2 Effect of Spacer Voids and Delamination

A Spherical void is considered to be present in the spacer. Two cases are considered: In first case void position is fixed and radius is varied. In case two, radius of the void is fixed and its position is varied near to the surface of the spacer maintained at constant distance of 1.5mm from the centre of the void. From Figure 11 it can be observed that the variation of radius of the void at a fixed position does not show much effect on the electric field stress on the spacer surface. The radius of void is varied from 0.2mm to 0.9mm.

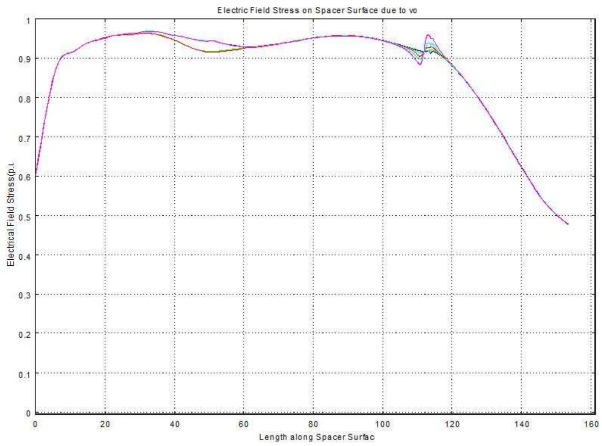

Figure 11: Electric Field stress due to a void with fixed position and variable radius.

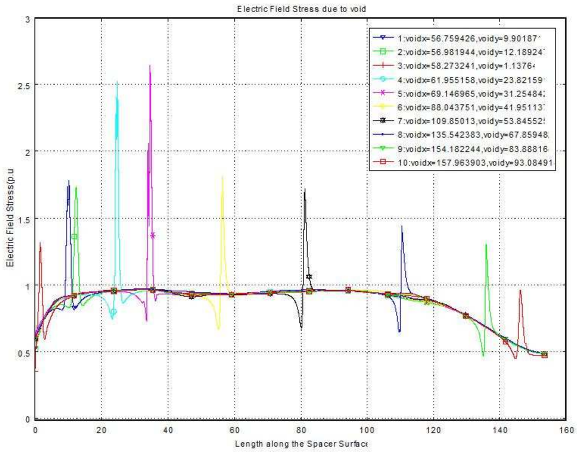

Figure 12: Electric Field stress due to a void with fixed radius but variable position maintained at 1.5mm from the centre of the void to the surface of the spacer.

Now as the position of the void is varied along the spacer surface maintaining a distance of 1.5mm from its centre to the spacer surface it was observed when the void is near to spacer-SF_6 Gas-Cathode junction the spacer-SF_6 Gas interface is experiencing a maximum electric field stress of 2.55p.u as shown in Figure 12.

Delaminations of 1mm, 0.1mm and 0.01mm thickness are considered at both ends of anode and cathode with varying lengths of 2.5mm,5mm, 7.5mm and 15mm. A 0.1mm delamination of length 15mm is shown in Figure 13. Figure 14, Figure 15 and Figure 16 shows the Electric field stress along the spacer surfaces for varying lengths with constant thickness. It can be observed from the graphs that the field stress increases as the thickness of delamination decreases and the effect is more on the side of Spacer- SF_6 Gas- cathode junction.

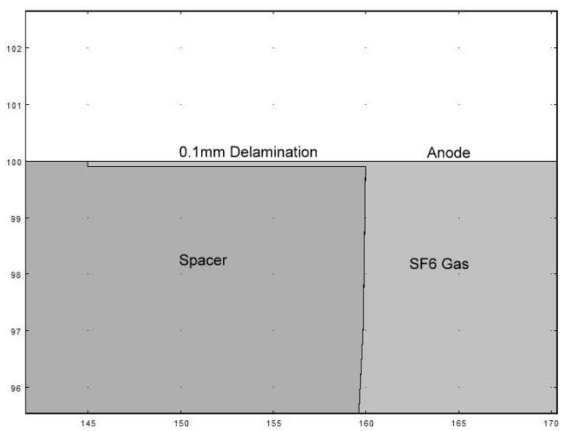

Figure 13: 0.1mm thickness delamination at anode.

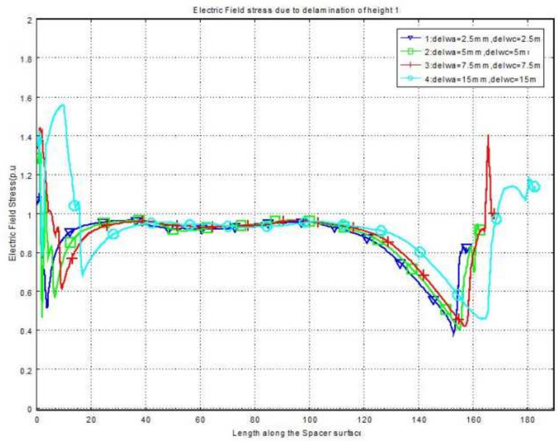

Figure 14: Electric Field Stress on Spacer surface for delamination of 1mm thickness.

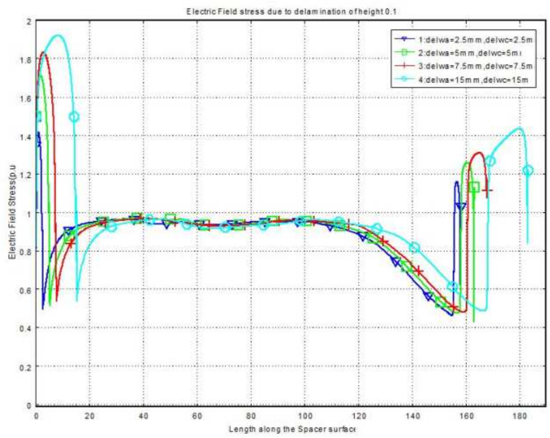

Figure 15: Electric Field Stress on Spacer surface for delamination of 0.1mm thickness.

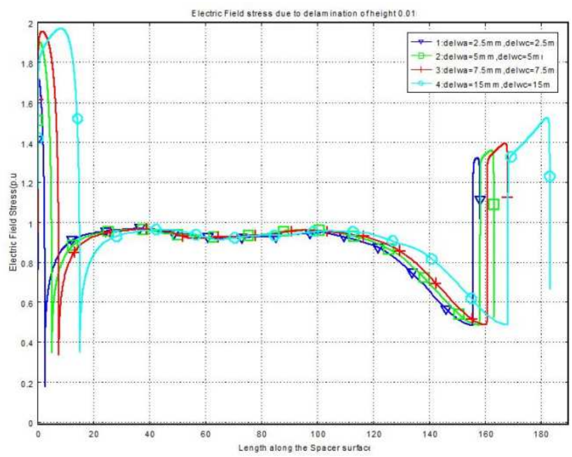

Figure 16: Electric Field Stress on Spacer surface for delamination of 0.01mm thickness.

5 CONCLUSION

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 various Spacer defects like depressions, protrusions, voids and delamination 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 all the spacer defects discussed in this work result in high electric field stress when the defect is near to spacer-SF_6 Gas- cathode junction.

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