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Computation of Electric Field for FGM Spacer Using Di-Post Insulator in GIS

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Abstract

The Gas Insulated Substation (GIS) have various advantages like Compactness, immunity from environmental conditions, high operational reliability, low maintenance cost. In a number of GIS installations, the main design considerations involved in gas insulated equipment are at cone insulator, gas and metal interface. Hence there is a need for control of electric stresses in order to reduce internal discharges, surface discharges to the enclosure surface. In conventional approach, in order to reduce such distortion of electric field, many techniques are applied like, control of the spacer shape, additional shielding of electrodes for relaxation of electric field around spacer and low permittivity of spacer material. The new techniques of Functionally Gradient Material (FGM) spacer has been proposed in this paper. In this paper the applicability of FGM spacer for gas insulated power apparatus has been verified. In the FGM spacer, a spatial distribution of permittivity for the control of the electric field distribution in and around the spacer is used. The electric field calculations for several types of FGM spacers have been carried out using Finite Element Method (FEM). The electric field distribution along the radial distance of the spacer insulator have been obtained for various FGM materials and results are compared.

Keywords: Electric Field distribution, FGM, FEM, Modelling of Di-post insulator

Introduction

The present and future trend in electric power equipment tends to be compact and be operated under higher voltage. The modular design of GIS offers a high degree of flexibility to meet layout requirements of both substations as well as power station switchgear, making efficient use of available space. GIS technology has reached a stage of application where wide ranges of GIS equipment up to highest voltage of 800kV are available with many unique features. With the rise in operating voltages in the equipment, the solid insulators play the most critical role for electrical insulation. To improve the insulation performance of the solid insulators, we need to control electric field distribution around the solid insulators [3-5]. However, conventional techniques for the control of electric field lead to the complicated structure of insulators and increase the manufacturing cost. Then, it is necessary to propose a new concept on insulators with keeping their simple structure and configurations. With the use of FGM application to the solid spacer the properties of the insulator can be changed to get the required relative permittivity at required location[6-8]. In this paper, we propose a computer-aided optimization and simulation technique for FGM application. In the optimization process, permittivity distribution of the FGM insulator is sequentially modified for minimizing the electric field stress in and around FGM insulators. Investigations have been carried out in applicability of a Functionally Gradient Material (FGM) for the spacer for use in GIS. The electric field calculations in and around the FGM spacer has been carried out, from the viewpoints of reduction of electric field distributions, a number of spatial distributions of relative permittivity ε_r in spacer have been investigated. The results are compared between optimized FGM spacer, with one of conventional spacer which has a uniform distribution of permittivity. From the calculation results, we confirmed that the proposed optimization method could calculate novel field distributions for different permittivity's, which have higher performance of the field control effect. Confirmation on the significant effect of the FGM spacer for the improvement of the electric field distribution and applicability for gas / solid composite insulation system.

Concept of FEM

The finite element technique is to derive nodal potential equations from the maximization of a functional, constructed by integrating an appropriate combination of the electromagnetic variables over the space of the finite element. The basic grid mesh is usually formed from sets of interconnected triangles whose vertex co-ordinates may be conventionally varied if optimization of a particular problem with respect to geometry required. The method may be applied to electrostatic and time varying situations.

The Finite element method allows us to solve large scale, complex, electromagnetic field problems, posed through simple and general data structures. For this reason, it is one of today's best accepted methods.

The static electric field E, is described by means of the electric scalar potential, V as

$$E = -\text{grad } V$$

Satisfying the differential equation

$$-\mathrm{div}\ (\varepsilon\ \mathrm{grad}\ V) = 0 \qquad \text{in } \Omega$$

Where Ω is the problem region and ε is the permittivity. The boundary conditions are of dirichlet type on electrodes with given potentials, that is on the surface Γ_E.

$V=V_0$ on Γ_E and Neumen type on the surface Γ_D where the normal component of the electric flux density vanishes as on symmetry planes.

$$\varepsilon \frac{\partial V}{\partial n} = 0 \qquad on \qquad \Gamma_d \qquad (1)$$

The problem region Ω is subdivided into finite elements that are sub regions in which the scalar potential is interpolated from the nodal potential values by polynomials of low order. Hence the potential approximated as

$$V \approx V^{(n)} = \sum_{j=1}^{n+n_d} V_j N_j = V_D + \sum_{j=1}^{n_d} V_j N_j \qquad (2)$$

Where $n=n_D$ is the total number of nodes in the finite element mesh, V_j is the approximate value of the potential in the J^{th} node and n_i is the shape function associated with this node [1]. In the n_D nodes ($j=n+1, n+2, ...n+n_D$) lying on the surface Γ_E the potential is given, so the function V_D is known and satisfies the dirichlet boundary condition [2] by setting the approximation in the differential equations multiplying it by the shape functions associated with the nodes not on Γ_E (weighing functions) and integrating over the problem region Ω. Taking account of the Neumann boundary condition [2] the following set of algebraic equations is obtained.

$$\sum_{j=1}^{n} V_j \int_{\Omega} \varepsilon\, grad\, N_j\, d\Omega = -\int_{\Omega} \varepsilon\, grad V_d\, .grad\, N_i\, d\Omega \qquad (3)$$

Since the shape functions are only non zero in the few finite elements containing the node associated with them, matrix of this equations system is extremely sparse, it can be advantageously solved by the method of conjugate gradients to yield the nodal potential values and hence the electric field distribution.

Concept of FGM

GIS designs often use gas tight spacers to separate different bus compartments. It is preferable to limit the bulk field to below 4kV/mm (rms). Most spacers are cast, filled epoxy resin systems. Resins are usually bisphenol A, cycloaliphatic or hydantoin. Fillers are necessary for good thermal and tracking properties and minimal shrinkage during casting. Although silica and quartz have been used. The epoxy formulations are, however, proprietary. Silica/quartz fillers are subject to corrosion damage when SF_6 arcing by-products are present. In the FGM solid insulators, spatial distributions of permittivity are given for the control of the electric field distribution in and around the solid insulators. Conventional materials have constant permittivity distribution on the contrary, FGMs have continuously graded permittivity distribution by the arrangement of filler particles. Material A as a matrix is considered to be epoxy for example. As a filler, Al_2O_3, SiO_2 or TiO_2 particles are applied with several 10 μm diameter. In order to relax the stress concentration, the application of FGM is expected to be effective by giving the suitable permittivity (ε_r) distribution inside the insulators.

Modelling of FGM Spacer

In this paper Electric Field is obtained by applying FEM on FGM Di-post type spacer for GIS under 650kV impulse voltage. A single phase bus duct with aluminum enclosure, aluminum conductor and Di-post insulator is modeled as shown in Fig. 1 in a two dimensional axis. Diameter of the enclosure is 226mm, conductor diameter 89mm and insulation thickness is taken as 30mm from the conductor. The void is been filled with SF_6 gas. The analysis is done with the Di-post type spacer for 4 types [9] as shown from Fig-2.

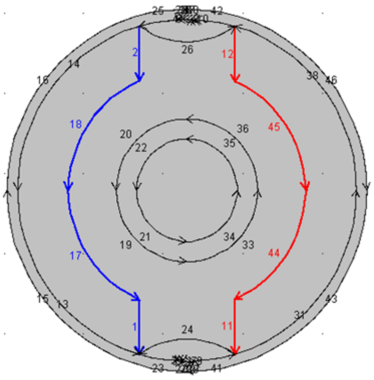

Figure-1. Geometry of the Di-post Insulator

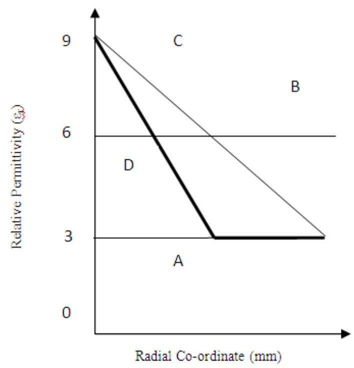

Figure-2. Distribution of Relative Permittivity in Spacer

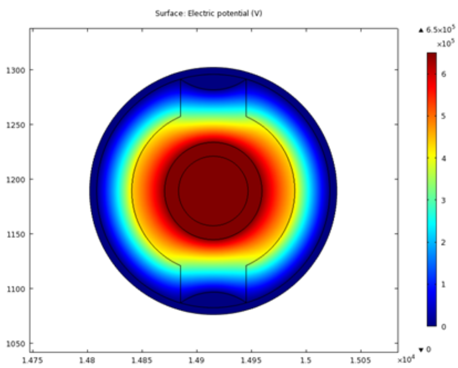

Figure.3 FEM Model of Type A FGM Spacer with ε_r=3

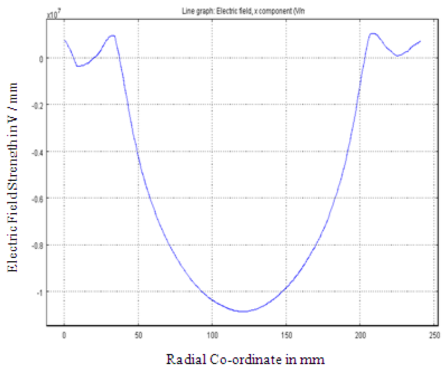

Figure.3a Electric Field Graph for Path-1 along X-axis

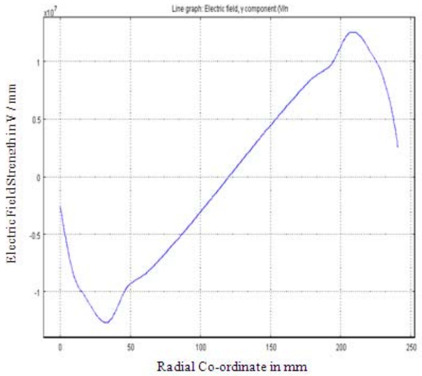

Figure.3b Electric Field Graph for Path-1 along Y-axis

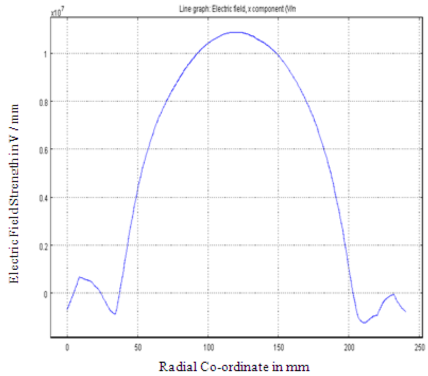

Figure.3c Electric Field Graph for Path-2 along X-axis

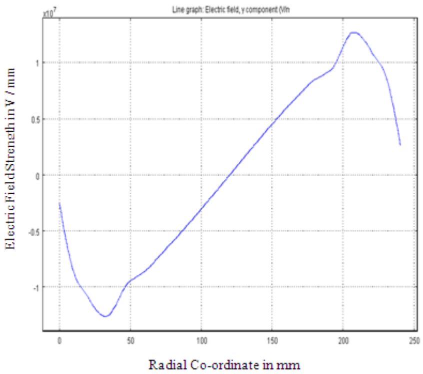

Figure.3d Electric Field Graph for Path-2 along Y-axis

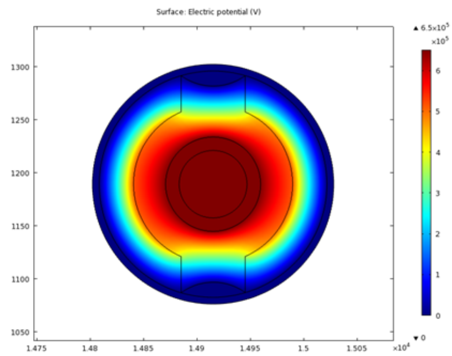

Figure.4 FEM Model of Type A FGM Spacer with ε_r=6

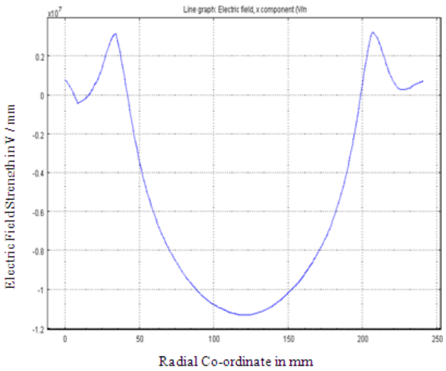

Figure.4a Electric Field Graph for Path-1 along X-axis

Figure.4b Electric Field Graph for Path-1 along Y-axis

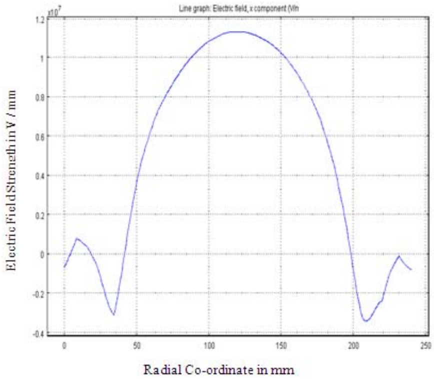

Figure.4c Electric Field Graph for Path-2 along X-axis

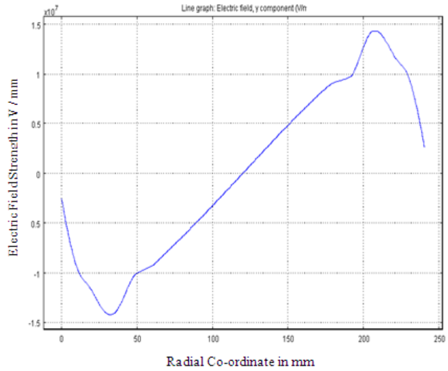

Figure.4d Electric Field Graph for Path-2 along Y-axis

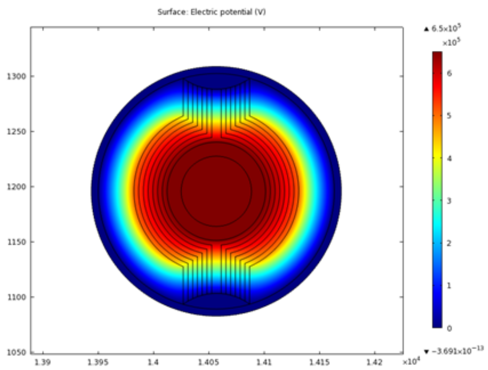

Figure.5 FEM Model of type C FGM Spacer with ε_r linearly varied from 9 to 3

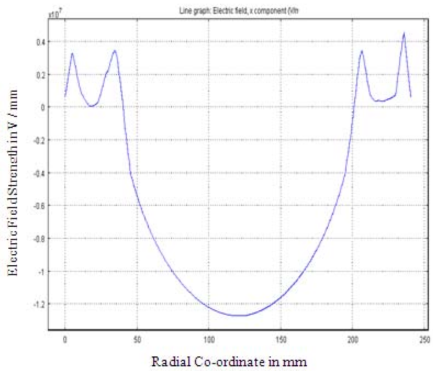

Figure.5a Electric Field Graph for Path-1 along X-axis

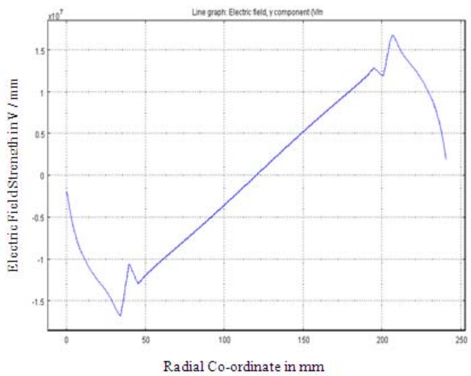

Figure.5b Electric Field Graph for Path-1 along Y-axis

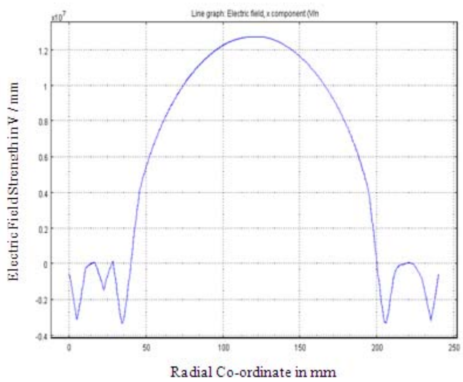

Figure.5c Electric Field Graph for Path-2 along X-axis

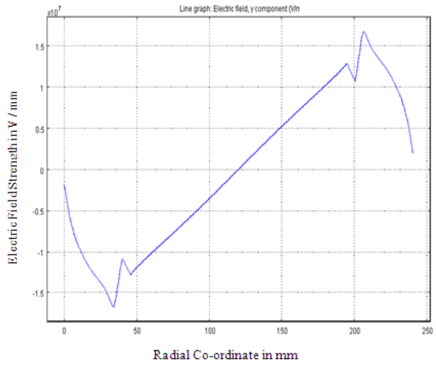

Figure.5d Electric Field Graph for Path-2 along Y-axis

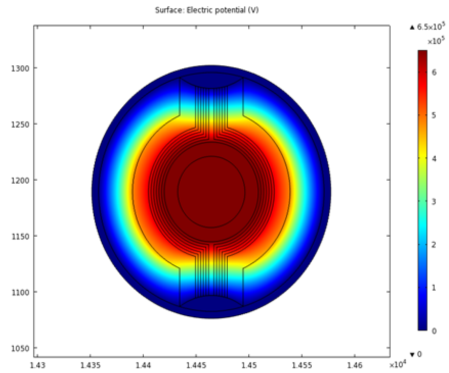

Figure.6 FEM Model of type D FGM Spacer with optimized ε_r from 9 to 3

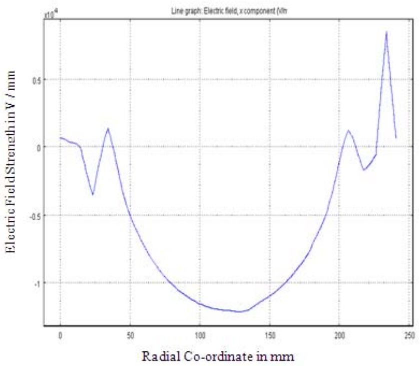

Figure.6a Electric Field Graph for Path-1 along X-axis

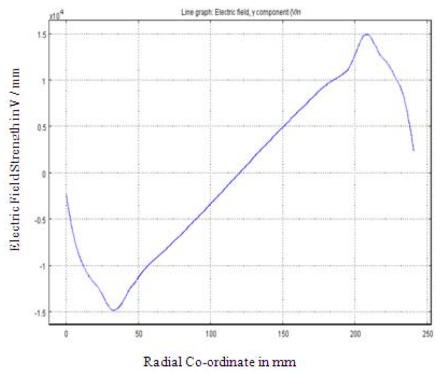

Figure.6b Electric Field Graph for Path-1 along Y-axis

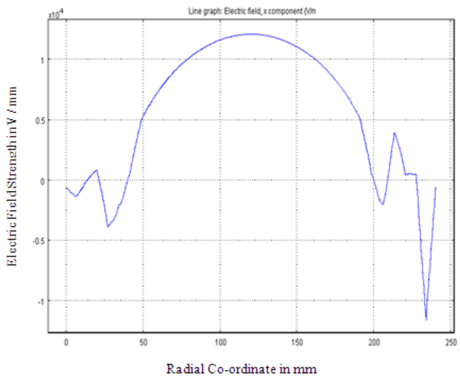

Figure.6c Electric Field Graph for Path-2 along X-axis

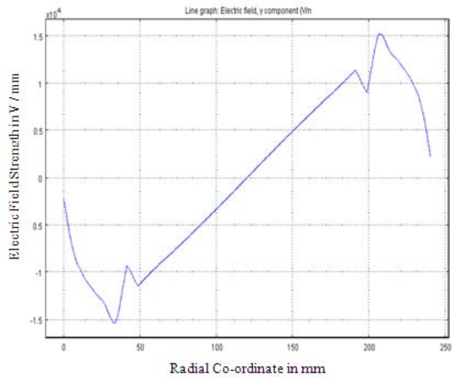

Figure.6d Electric Field Graph for Path-2 along Y-axis

Table.1:-Comparative Values for Di-post Insulator along X-axis for Path-1

RADIAL CO-ORDINATE (mm)	ELECTRIC FIELD STRENGTH ON DI-POST INSULATOR FD PATH-1 ALONG X-AXIS (V / mm)			
	TYPE-A	TYPE-B	TYPE-C	TYPE-D
	X (* 10^6)	X (* 10^6)	X (* 10^6)	X (* 10^6)
0	0.1	0.08	0.1	0.1
50	-0.4	-0.38	-0.58	-0.5
100	-1.4	-1.4	-1.21	-1.3
150	-0.99	-1.0	-1.18	-1.2
200	-0.12	0	0	-0.2
250	0.1	0.1	-0.2	0

Table 2:-Comparative Values for Di-post Insulator along Y-axis for Path-1

RADIAL CO-ORDINATE (mm)	ELECTRIC FIELD STRENGTH ON DI-POST INSULATOR FD PATH-1 ALONG Y-AXIS (V / mm)			
	TYPE-A	TYPE-B	TYPE-C	TYPE-D
	Y (* 10^6)	Y (* 10^6)	Y (* 10^6)	Y (* 10^6)
0	-0.25	-0.25	-0.2	-0.25
50	-0.98	-1.0	-1.4	-1.1
100	-0.3	-0.3	-0.4	-0.35
150	0.48	0.5	0.5	0.5
200	1.2	1.3	1.3	1.7
250	0	0	0	0

Table.3 Comparative Values for Di-post Insulator along X-axis for Path-2

RADIAL CO-ORDINATE (mm)	ELECTRIC FIELD STRENGTH ON DI-POST INSULATOR FD PATH-2 ALONG X-AXIS (V / mm)			
	TYPE-A	TYPE-B	TYPE-C	TYPE-D
	X (* 10^6)	X (* 10^6)	X (* 10^6)	X (* 10^6)
0	-0.08	-0.08	-0.04	-0.1
50	0.4	0.39	0.58	0.5
100	1.2	1.02	1.22	1.3
150	1.0	1.02	1.18	1.2
200	.01	0	0	0
250	-0.1	-0.1	0.1	0.25

Table.4 Comparative Values for Di-post Insulator along Y-axis for Path-2

RADIAL CO-ORDINATE (mm)	ELECTRIC FIELD STRENGTH ON DI-POST INSULATOR FD PATH-2 ALONG Y-AXIS (V / mm)			
	TYPE-A	TYPE-B	TYPE-C	TYPE-D
	Y (* 10^6)	Y (* 10^6)	Y (* 10^6)	Y (* 10^6)
0	-0.25	-0.25	-0.2	-0.25
50	-0.92	-1.0	-1.2	-1.2
100	-0.35	-0.3	-0.4	-0.4
150	0.48	0.5	0.5	0.5
200	1.25	1.35	1.2	1.0
250	0	0	0	0

Results and Discussions

In the present work, various types of FGM spacers as shown in Fig.3 to Fig.6 has been considered. In type A spacer, the value of the relative permittivity ϵ_r = 3 is constant, where as for type B spacer, the corresponding value of the permittivity ϵ_r = 6 right from high voltage electrode to enclosure. In type C spacer, the value of relative permittivity varies linearly from 9 to 3. In type D spacer, the value of relative permittivity varies linearly from 9 to 3 and then it becomes constant thereafter. The electric field graphs for various types of FGM spacer along the spacer surface have been presented in the Fig. 3a to Fig. 6f.The maximum field strength in various types of FGM spacer are shown in table 1 to table 6. In type-D spacer, the electric field stress is more reduced when compared to other spacer's Type A, B and C.

Conclusions

The improvements of electrical insulation performance of gas insulated apparatus propose the application of FGM spacer. In the FGM spacer, we have given the spatial distribution of the permittivity ϵ_r for the control of electric field distribution in around the spacer. From the viewpoint of the electric field reduction and field distribution improvement, the applicability of the FGM spacer is verified by the numerical electric field calculation. Conclusions from the computed results are as follows. The application of the FGM spacer could reduce the maximum electric field around, even if we apply very simple shape of spacer. The highly stressed electrode area and volume of gas space could be reduced. With the application of FGM spacer it is clearly observed that the maximum field strength is reduced when compared to other type's of spacers. The FGM spacer makes the electric field distribution more uniform and suitable for the improvement of the insulation performance of Gas Insulated apparatus.

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