International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-9, July 2019

Field Stress Control of a Functionally Graded Disk Type Spacer in a Gas Insulated Bus Duct with Metal Inserts

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Abstract*: High voltage electric utilities are hindered with certain difficulties like high stress distribution and insulation damage that are needed to be taken care for reliable operation of the system. In a Gas Insulated bus duct, high field stress along the spacer surface especially at the contact point of the conductor, insulator and gas (called triple junction) is a major factor affecting the insulation strength. Research studies of shaping the spacer were found effective in controlling the stress distribution but found to be complicated in real time application. In this paper, functionally graded materials of disc type spacer with different permittivity are proposed for controlled field stress distribution at the spacer surface. Electric field calculations with different gradings from high to low and U shape are done. Properly shaped metal inserts are incorporated to have a uniform stress distribution along the spacer.

***Index Terms*: Electric Field Stress, FGM, GIS, Spacer.**

I. INTRODUCTION

High voltage power equipments are becoming denser and subjected to high stress leading to insulation failure. Insulator design plays a vital role in improving the reliability of the system. In GIS the solid supporting structures called spacers are vulnerable to more stress and their design is of concern. The point of contact of the conductor, gas and spacer called the triple point junction in Gas insulated bus duct is highly stressed region and is responsible for major insulation failures. Switchgear design in GIS needs thorough field distribution at the supporting structures called spacers, which is important for healthy operation of the system.

Several methods have been implemented so far to enhance the efficiency of the insulation and decrease the intensity of the electric field in practical gas-insulated switchgear. These methods make the geometry of the spacer more complicated, though. A novel method based on Functionally Graded Metals (FGM) has been suggested in the latest years to enhance the Break Down Voltage (BDV) of solid insulators while maintaining its structure. Some researchers [9-13] explored the design and optimization techniques for FGM spacers individually and analyzed the spacer-SF_6 gas interface's E-field distribution. However, there are still some problems with FGM's design, manufacturing and performance evaluation prior to industrial use. One of the problems is efficient techniques of design is to distribute the dielectric material's properties that could be used for a variety of strong spacer geometries. Furthermore, since only a few kinds of material allocation can be accomplished through the centrifugal force technique (ascending, descending, U shape, etc.), flexible manufacturing technique for FGM spacers is still needed. Efforts such as shape control to achieve field stress uniformly along the spacer surface and integrating metal inserts to minimize TJs ' electrical field pressure were efficient. As seen in GIS at the triple junction, it is an intersection where the electron emission is most favored.

In this paper, the conventional spacer geometry of the disk type is taken for which field study. On the spacer surface and also at the triple point, the electrical field stresses generated by the spacer type of the disk are determined. Three kinds of graded insulators with different permittivity are used to analyze the electrical field stress on the spacer surface as well as at the triple point at either end of the spacer i.e. at the internal end of the conductor or at the end of the container. It is discovered that the electrical field stress on the spacer surface is kept uniform, the electrical field stress is not preserved at the minimum value at the critical junctions created by the conductor, strong insulator and SF_6 gas. Metal inserts at the triple point intersection are regarded as a means of reducing stress. The results are presented and analyzed at triple point junction for the reduction of field stress.

II. INSULATION AND ELECTRIC FIELD ALONG SPACER SURFACE

The two primary isolating media used in a GIS are the SF_6 insulating gas and the strong isolating media called the spacers. The frequently used insulating materials are alumina or silica-filled epoxy matrix for GIS and its associated applications. The present generation is making use of high voltage GIS equipments to meet the rise in energy consumption. Insulation plays an important role with the increase in voltage rating. To improve the performance of the equipments, a constant monitoring on electric field distribution on the spacer surface in GIS is required.

Spacer configuration control, low permittivity materials application to the spacer, addition of shielded electrodes for relaxation of electric field, insertion of a thin film made of a low conductivity material on the spacer surface are few methods to

Revised Manuscript Received on July 09, 2019

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improve the insulation performance. However, these techniques make the spacer geometry more critical. Spacer's permittivity, shape, dimensions, parameters affect the electric field distribution. To achieve more or less uniform field distribution along the surfaces of the spacer, keen observation is to be made on the design of spacer. Efforts should always be made to reduce the field value as low as possible. There are different techniques like charge simulation method, FEM, etc., to calculate the electric field distribution value. FEM technique is considered to be more efficient to calculate the electric field distribution on and around the spacer surface.

The TJs metal inserts and recessed electrodes are introduced to minimize the electrical field pressure but to the disadvantage of complicated shape design and manufacturing. A new model has been developed for the design of conventional shaped support insulators with distributed permittivity. Modulating the distribution of permittivity along the length of the spacer can be controlled to obtain the field stress as required. By applying centrifugal forces after integrating fillers of distinct diameters, permittivity-graded materials are processed in order to achieve the permittivity distribution appropriate for achieving standardized field distribution. The permittivity stays continuous throughout the product as the filler density is continuous throughout the product where, as in GL-FGM, elevated permittivity filler density is increased in the centrifugal direction by which elevated permittivity can be acquired at one end and small permittivity at the other end. Low permittivity filler such as Al_2O_3 is produced in GH-FGM density to accumulate in the centrifugal direction to achieve a trait with low permittivity at the centrifugal end and elevated permittivity at the other end. In U-FGM, two fillers of distinct diameters are produced by applying centrifugal forces to acquire permittivity features to accumulate at either end.

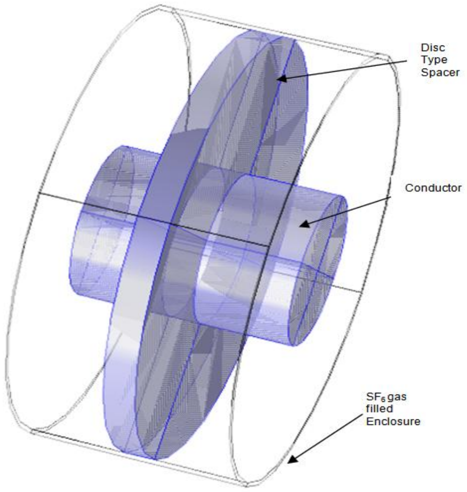

Fig 1: Disk Type FGM Spacer

III. ELECTRIC FIELD DISTRIBUTION WITH METAL INSERTS

Metal inserts are used to decrease the stress of the electrical field at TJs by modulating the metal inserts shape there by reducing the probability of occurrence of ground flashes. These are incorporated at either ends of the spacer and the Field Stress at Anode and Cathode Junctions is shown in Figs. 2 to 5.

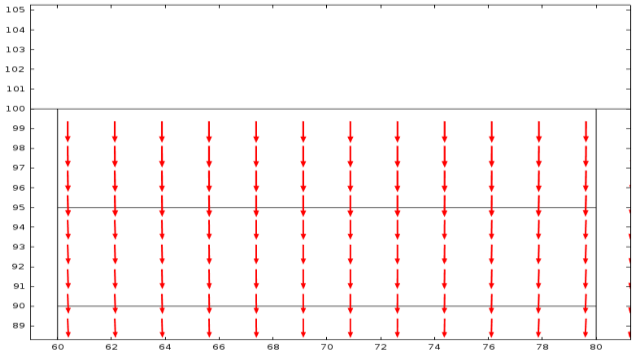

Fig 2: Quiver plot at Anode end / Type 1 / GH-FGM

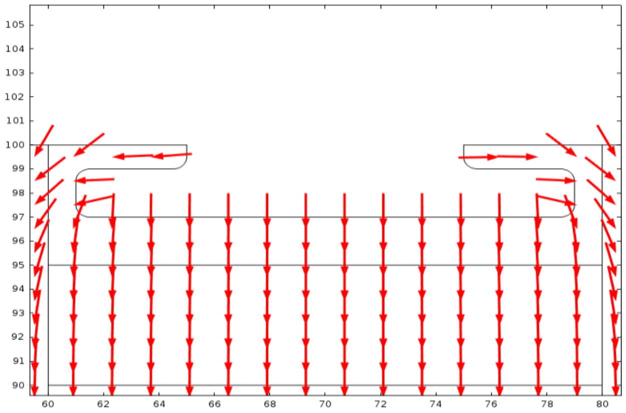

Fig 3: Quiver plot at Anode end / Type 1 / GH-FGM with MI

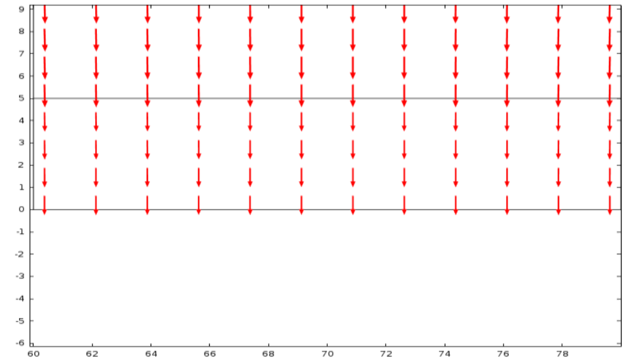

Fig 4: Quiver plot at Cathode end / Type 1 / GH-FGM

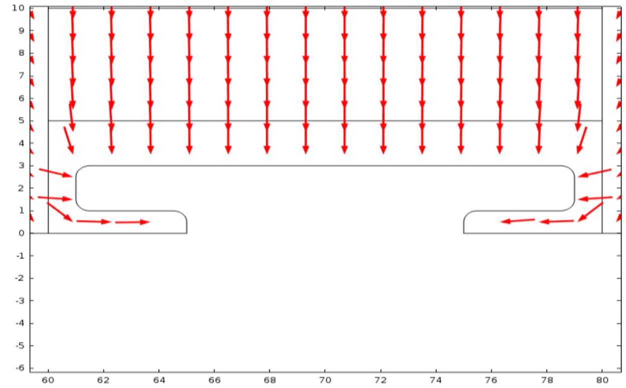

Fig 5: Quiver plot at Anode end / Type 1/ GH-FGM with MI

IV. RESULTS AND DISCUSSION

The two primary isolating media used in a GIS are the SF_6 gas and the strong isolating media called the spacers. The insulating material used is alumina or silica-filled epoxy spacer for GIS and its associated applications. A standard disk spacer with 80 mm length is taken in this work. The conductor is applied with 72.5 kV, 145 kV and 220 kV voltages. The permittivity of SF_6 gas is taken as 1.015. In Figs. 6 to 19, Field Stress along the spacer surface is shown with and without metal inserts.

A. Type 1: GH-FGM

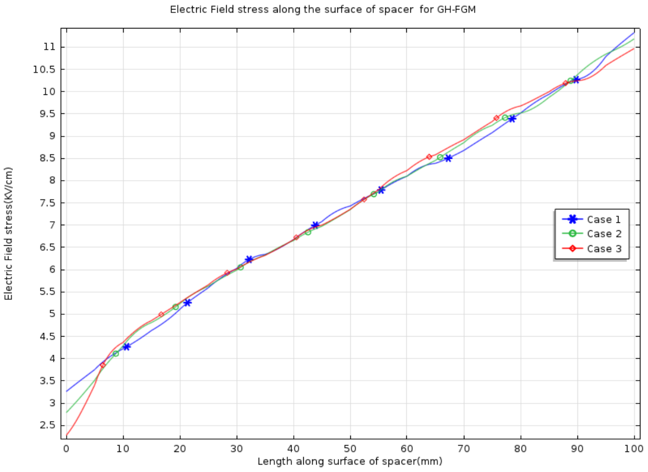

Fig 6: Field Stress for 72.5 kV without MI

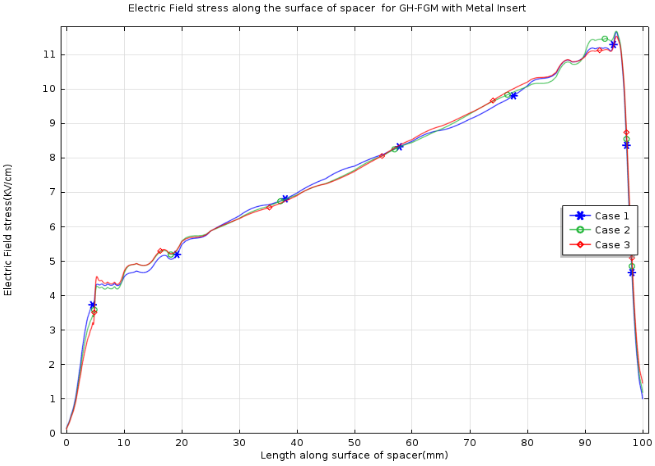

Fig 7: Field Stress for 72.5 kV / with MI

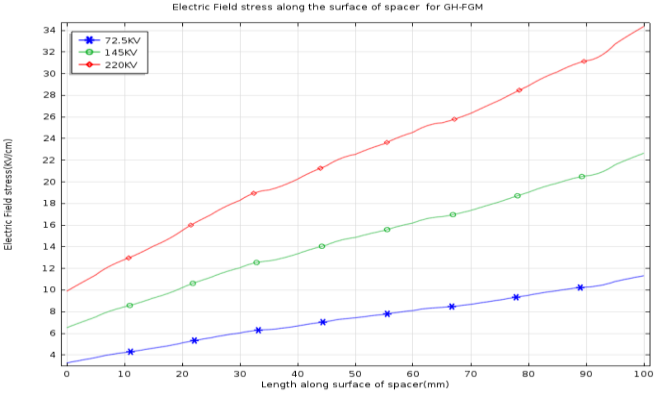

Fig 8: Field Stress for varying applied voltages / without MI

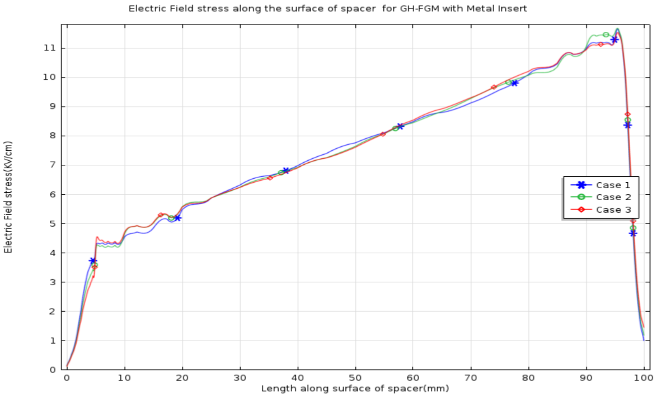

Fig 9: Field Stress with varying applied voltages / with MI

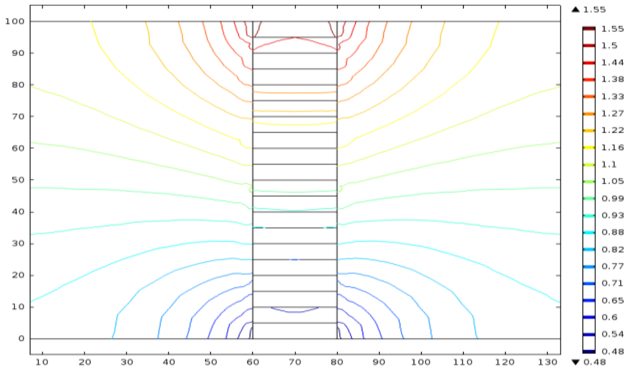

Fig 10: Field contour / 72.5 kV / without MI

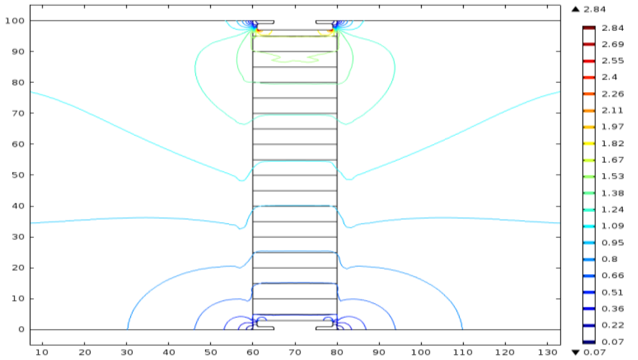

Fig 11: Field contour / 72.5 kV / with MI

B. Type 2: GL-FGM

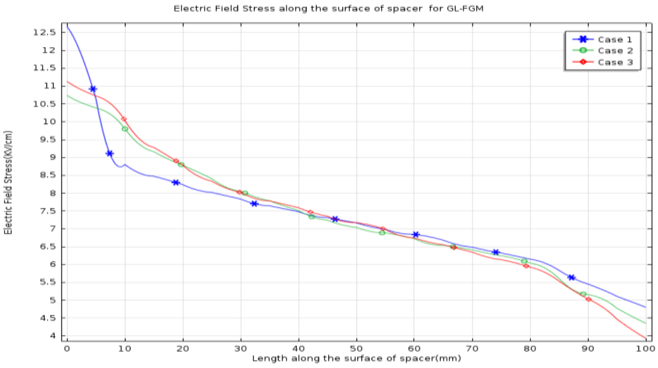

Fig 12: Field Stress for 72.5 kV / without MI

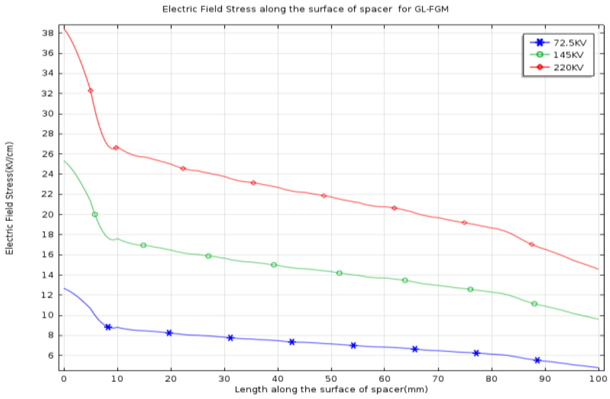

Fig 13: Field Stress for 72.5 kV / with MI

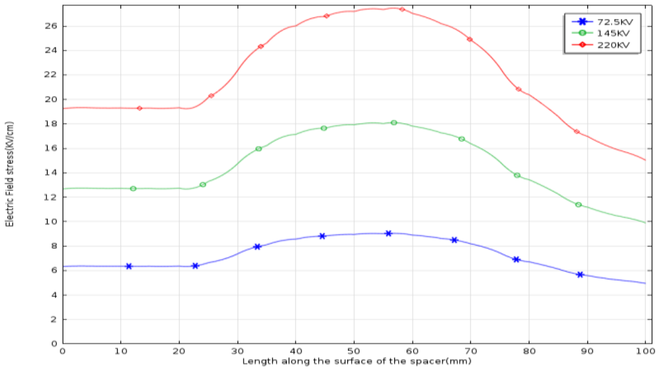

Fig 17: Field Stress for 72.5 kV / with MI

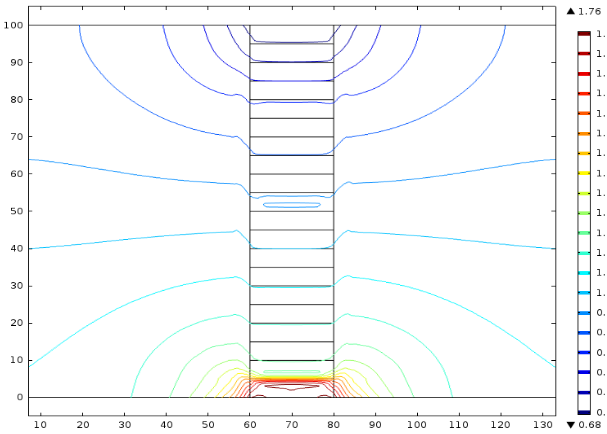

Fig 14: Field contour for 72.5 kV/ without MI

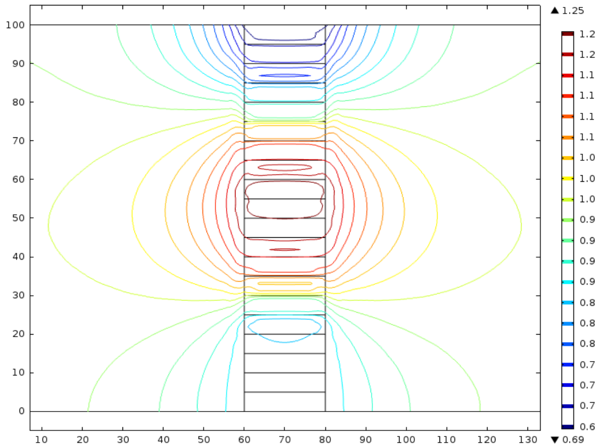

Fig 18 Field contour for 72.5 kV/ without MI

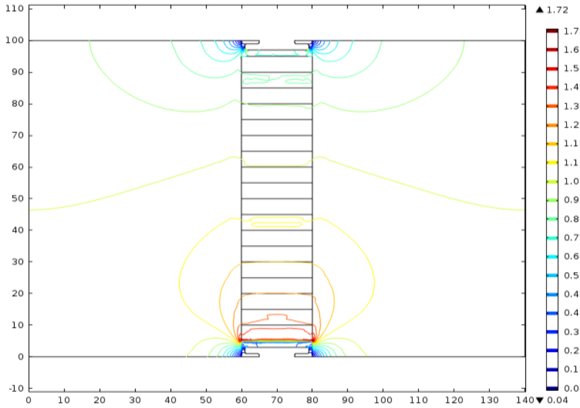

Fig 15: Field contour for 72.5 kV/ with MI

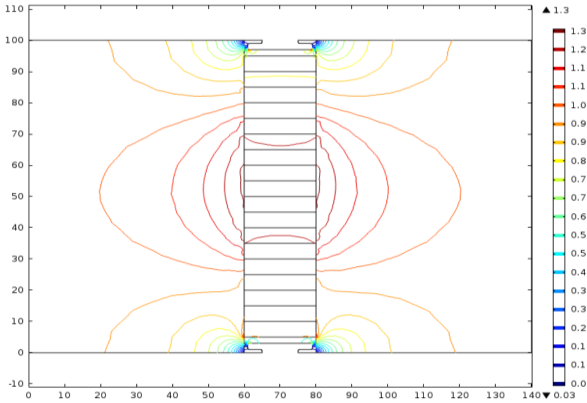

Fig 19: Field contour for 72.5 kV/ with MI

C. Type 3: U-FGM

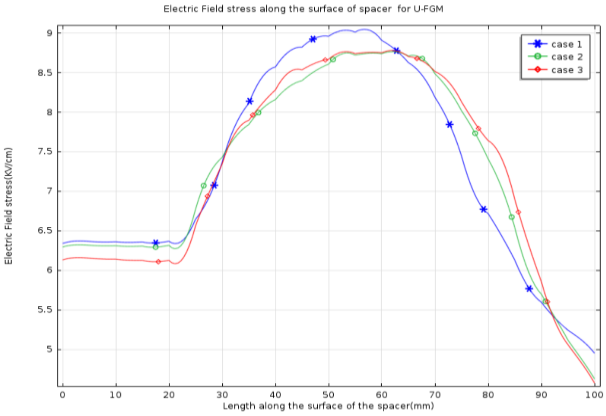

Fig 16: Field Stress for 72.5kV/ without MI

From Fig. 6, the field density is less for case 3 and high for case 1 because of high permittivity for case 3 and less permittivity for case 1. The field density in Fig. 7 had drastically reduced, compared with Fig. 6 because of the metal inserter, it means by moulding the shape of the spacer, Field stress at near and for the conductor is reduced. In Fig. 8, the field density had plotted to different types of voltages 72.5 kV, 132 kV and 220 k. Field density is gradually increased because of GH-FGM spacer, the permittivity is more at enclosing and low at conductor so, field stress at encloser is less and field stress at conductor is more .the field stress was reduced in Fig. 9 by the metal inserter. From Fig. 10 the red field near the conductor shows high stress and dark blue field at near the enclose shows low stress. The absence of field in Fig. 11 shows importance of the metal inserter. The Fig. 12, 13, 14 and 15 shows GL-FGM plots, here the permittivity levels are increased from enclosing to conductor so, the field is linearly decreased. The red contour field can be observed

From the Fig 14 & 15 so, the field stress is more compared with GH-FGM. From Fig. 14, field density at near the enclose is very high than near the conductor because GL the permittivity near the enclose is low and the permittivity near the conductor is high. In Fig. 15, the contour plot with metal inserter shows less field density than the contour plot without metal inserter. As the permittivity is inversely proportional to field stress, that can be observed in U-FGM Fig. 16, 17. The contour field is little different from GH, GL contour field because of U shaped permittivity with respect to spacer length. From Fig. 18 the field concentration along the spacer is nonlinear, not as like in GH, GL. The field density at the near conductor, middle spacer and near enclose is low, high, and low. Because GU, it explains high permittivity at two points gives low field density and lower permittivity gives high field. In Fig. 19, the contour with MI plot shows less field along the surface of the spacer. The difference of field stress at near and for conductor without metal inserter shows approximately 12.9 – 12.23% from case 1 to case 3 for GH, GL, and U from Table1. The difference of field stress at near and for the conductor with metal inserter shows approximately 22.5 – 29.5% from case 1 to case 3 for GH, GL, and U from Table 2.The field stress with MI will be reduced from 12.9 -12.23%.

Table 1: Field Stresses In Kv/Cm Without Metal Inserts

		72.5 kV		145 kV		220 kV	
TYPE	Applied voltage	Outer Encloser	Inner Electrode	Outer Encloser	Inner Electrode	Outer Encloser	Inner Electrode
GH-FGM	Case 1	0.077	0.066	0.156	0.1338	0.237	0.2036
	Case 2	0.235	0.0676	0.155	0.135	0.236	0.2048
	Case 3	0.07737	0.0679	0.155	0.1355	0.235	0.2056
GL-FGM	Case 1	0.0673	0.077	0.134	0.156	0.204	0.238
	Case 2	0.0678	0.0776	0.1335	0.154	0.2055	0.2355
	Case 3	0.0678	0.077	0.1358	0.1548	0.2058	0.2349
U-FGM	Case 1	0.069	0.0719	0.1401	0.143	0.2118	0.217
	Case 2	0.0704	0.0704	0.1411	0.141157	0.213	0.2138
	Case 3	0.0711	0.0713	0.1414	0.1422	0.214	0.216

Table 2: Field Stresses In Kv/Cm With Metal Inserts

TYPE	Applied voltage	72.5 kV		145 kV		220 kV	
		Outer Encloser	Inner Electrode	Outer Encloser	Inner Electrode	Outer Encloser	Inner Electrode
GH-FGM	Case 1	0.0102	0.0072	0.02	0.0166	0.0282	0.022
	Case 2	0.008	0.007	0.0181	0.01363	0.0271	0.0214
	Case 3	0.008	0.0062	0.017	0.01254	0.0255	0.01962
GL-FGM	Case 1	0.0057	0.0095	0.014	0.02	0.0207	0.0282
	Case 2	0.0066	0.0089	0.0129	0.01815	0.02036	0.0266
	Case 3	0.0069	0.008	0.0144	0.01664	0.01999	0.0259
U-FGM	Case 1	0.0063	0.00709	0.0156	0.0142	0.0228	0.0214
	Case 2	0.0072	0.00724	0.0137	0.014	0.0209	0.02128
	Case 3	0.0066	0.0066	0.01351	0.0135	0.01999	0.02035

V. CONCLUSION

In gas-insulated structures, spacers are a significant element. Spacer Failures create breakdown of dielectric strength and flashover in many case. These failures are caused by non-uniform electrical field along the spacer surface and elevated field stress at triple point. For a better stress spread, accurate modeling of the spacer geometry is necessary as it enhances the component's life. FGM spacers are seen as a better alternative to shaping moulded spacers as FGM spacers keep their normal forms mitigating the issues of moulding and manufacturing. Electrical field stresses are calculated for all three types of FGM spacers. Metal inserts minimize the electrical field and are lowered to a value higher than 95% relative to their values without metal inserts and GL-FGM has achieved a maximum decrease in electrical field pressure at the triple junction.

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