J. Basic. Appl. Sci. Res., 2(8)7866-7875, 2012
© 2012, TextRoad Publication

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Influence of Spacer Defects and Adhered Metal Particles on Electric Field Intensifications in GIS

Ammar Anwar Khan*, Yasin Khan, Nazar H. Malik, Abdulrehman A. Al-Arainy

Department of Electrical Engineering, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia

ABSTRACT

Solid insulators commonly known as spacers are used in Gas Insulated Switchgears (GIS). Significant field intensifications can occur due to defects in spacers or due to the presence of conducting particles on the spacer surface. Such field intensification can lead to the failure of GIS. This paper studies the surface field distribution of commonly used disc shaped insulating spacer. Maxwell 3D software is used for simulation purposes which is capable of performing 2 dimensional or 3 dimensional electrostatic simulations. The effect of defects such as protrusions or depressions, adhered conducting particles and relative permittivity of spacer material on the field intensification was reported in this paper. The method of inserted electrode that can help in reduction of field intensity at the triple junction has also been reported. Permittivity of spacer material has significant effect on the spacer surface field distribution. Moreover, the location of spacer surface defect or adhered particle has significant effect on the extent of the field intensification. Detailed results are presented in this paper.

Key words: GIS, Maxwell, Spacer defects, Electric field, Conducting particles, Inserted electrode, SF_6, Insulation.

1. INTRODUCTION

Gas insulated switchgears (GIS) are widely used in electrical power industry due to their many benefits. Insulating spacers are used to provide support to the high voltage (HV) conductor and maintain an adequate clearance between the HV conductor and the grounded enclosure in the GIS. A spacer generally forms the weakest link in GIS due to the field intensifications that occur at the spacer surface due to spacer design, system configuration and presence of any defect. Normally SF_6 gas or its mixture with some other gas(es) is used as the insulation medium [1, 2]. Since SF_6 gas is highly sensitive to even microscopic regions of intensified field and the reliability of the system is challenged due to the presence of such microscopic regions of the high electric field intensity. Under such conditions, partial discharge or even complete flashover may occur on the spacer surface. In the high-pressure gas insulation, such events usually occur when solid conducting particles are present in the gas [3, 4]. The breakdown strength of GIS is also strongly influenced by the roughness of the spacer surface and defects produced from improper manufacturing and/or handling [3]. Moreover, GIS can be contaminated with non-conducting and conducting particles, produced due to mechanical abrasion or arcing occurring during operation of the isolating switches and circuit breakers. The presence of a conducting particle in GIS can strongly influence the dielectric performance of the system. The effect of particle depends on the type, location and density of the particle. The reason a charged particle adhere to spacer easily is when a charged particle is in contact with a spacer, an induced electrostatic force acts in the direction perpendicular to the spacer. In this case, if the frictional force between the particle and spacer surface overcomes the gravitational force acting on the particle, the particle remains adhered to the sphere.

Studies reported on scaled models and on actual spacers with fixed particle on spacer surface have revealed drastic reduction in the breakdown strength [5, 6]. Therefore knowledge of the electric field intensity around the spacer defects and conducting particles contributes towards a better understanding of the spacer surface flashover phenomenon. References [7-9] discussed the behavior of field distributions in cone shaped spacers and studied the effect of relative permittivity of spacer material on the field distribution of such spacers. However, spacer surface field distribution in case of defects, presence of particles or changes in relative permittivity of spacer material need investigations in disc shaped spacers that are commonly used in GIS setups. In this paper, the finite element method (FEM) is used to determine the electric field distribution on the spacer surface. This method is a very useful technique for solving field problems. FEM solves the problem by minimization of the energy within the region of interest, whether the field is electric or magnetic, of Laplacian or Poissonian type, by dividing the region into triangular elements for two-dimensional problems or tetrahedrons for three- dimensional problems [7]. FEM has many advantages when applied to electric field

***Corresponding Author:** Ammar Anwar Khan. Department of Electrical Engineering, College of Engineering, King Saud University, Riyadh 11421, Saudi Arabia, Email: amkhan@ksu.edu.sa

problems; the most important one is that it is readily applicable to non-homogeneous systems as well as to anisotropic systems.

This paper discusses the field distribution of disc shaped and cone shaped spacers commonly used in the GIS. The effects of spacer defects and conducting particles adhering to the spacer surface are also examined in this study. Dimensions and location of defects, particles and relative permittivity of the spacer material are varied. Technique of inserted electrodes [10] is investigated and it is observed that this technique can be successfully used to reduce the field intensity around the triple junction. Proper design of inserted electrode can help in the field reduction and reliability improvement of the GIS.

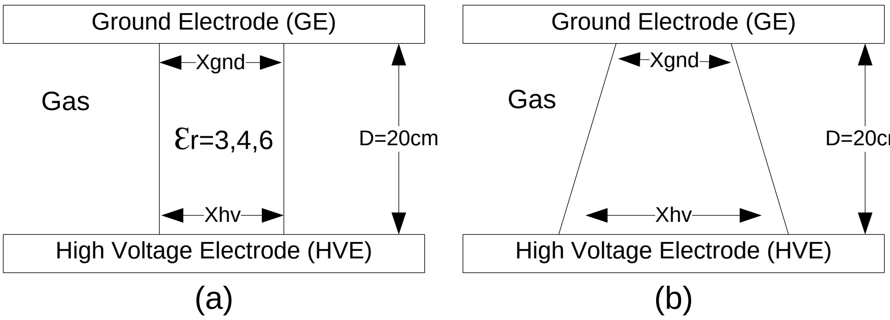

Figure 1. Common types of solid spacer configurations; (a) Disc shaped and, (b) Cone shaped

1. SIMULATION METHOD

For simulation purposes, both disc shaped or cone shaped spacers are considered in the two parallel plane electrode arrangements (axisymmetric) as shown in Fig.1. Voltage applied to the high voltage electrode is kept at 100 kV in all cases and separation between the high voltage and the ground electrodes is kept 20 cm. In addition to the solid spacer, gas is assumed as the insulation medium between the electrodes. Solid spacer permittivity ($\mathcal{E}_r$) is assumed as 3, 4 and 6 for this study. Table 1 details the list of symbols and abbreviations used in this paper. Maxwell 3D v14 is used for the electrostatic field calculations. It is a comprehensive software package capable of performing 2D and 3D electrostatic field simulations.

Table 1. Symbols and Abbreviations

Symbols	Descriptions
Xgnd	Width of spacer at ground electrode
ε_r	Relative permittivity of spacer material
Xhv	Width of spacer at high voltage electrode
D	Separation between the electrodes
d	Depression or protrusion diameter
Dr	Distance of protrusion, depression or particle away from high voltage electrode.
L	Length of particle
W	Width of particle
Dg	Depth of inserted electrode at ground side
Wg	Width of inserted electrode at ground side
Dh	Depth of inserted electrode at high voltage side
Wh	Width of inserted electrode at high voltage side

Followings studies are considered in this paper:

1) Field distribution along the spacer surface for disc shaped and cone shaped spacers.
2) Effect of changing the relative permittivity of spacer on the spacer surface field distribution.
3) Effect of spacer defects and adhered particle's length and location on the spacer surface field distribution. Spacer defects considered are spacer surface protrusions and surface depressions
4) Effect of inserted electrode in case of cone shaped and disc shaped spacer on spacer surface field distribution.

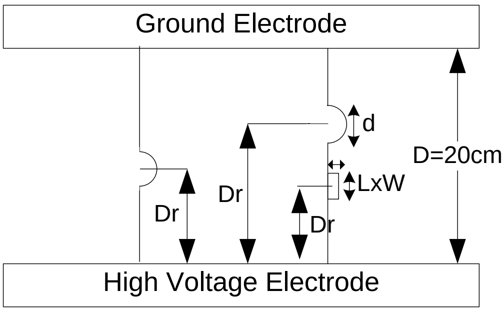

Figure 2. Defects (protrusion or depression) of solid spacer and adhered metallic particle.

Hemispherical protrusion or depression is introduced on the spacer surface. Fig.2 illustrates the protrusion, depression and adhered particle on a disc shaped spacer. Defects and adhered particles are assumed to be present at the different locations (*Dr*) w.r.t. HVE on the surface of the spacer. *Dr* values used are 0.05cm, 2cm, 6cm, 10cm, 14cm, 18cm and 19.95cm from the high voltage electrode. Four values of protrusion/depression diameter are used i.e., *d*= 1mm, 2mm, 3mm and 4mm. Particle length (*L*) of 1mm, 1.5mm, 2mm and 2.5mm are used to study the field intensification along the spacer surface.

2. Results and Discussions

2.1 Field Distribution on the Surface of Spacers

From dielectric performance and practical considerations, the triple junction regions (i.e., regions where gas, solid spacer and electrodes meet) are important. For cone shaped spacer, the triple junction at high voltage electrode forms an obtuse angle whereas the one at the ground electrode forms an acute angle. Generally, the acute angle triple junction region exhibits more intensified field and hence is the most critical region. This is also true in case of presence of spacer surface defect or particle near the high voltage electrode.

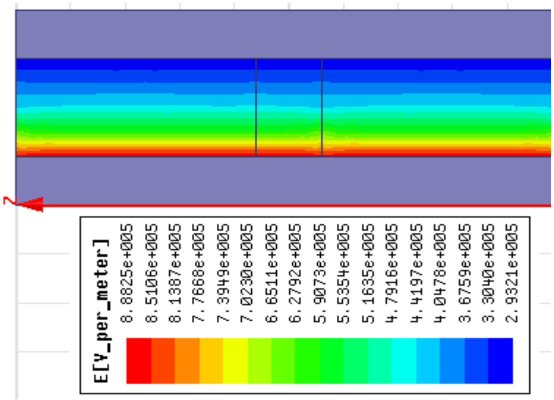

Figure 3. Field distribution in disc shaped spacer configuration.

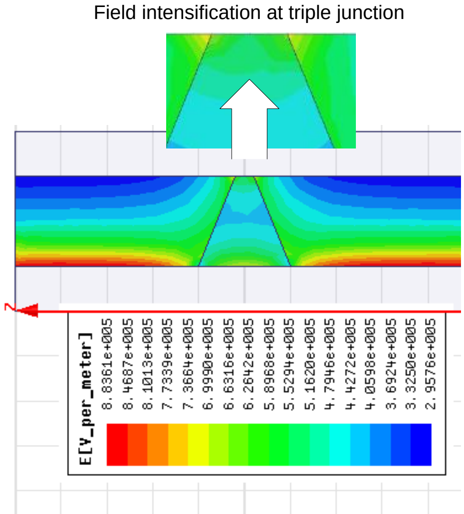

Figure 4. Field distribution in cone shaped spacer configuration with maximum field intensification at acute angle of triple junction.

Fig.3 and Fig.4 show the electrostatic field distribution for disc and cone shaped spacer configurations in the absence of any spacer surface defects or conducting particles. Regions with field intensifications are obvious at the acute angle triple junction in case of cone shaped spacer and at the high voltage electrode in case of the disc shaped spacer. Fig.5 gives the comparison of spacer surface field distribution profiles among cone shaped and the disc shaped spacers. It should be noted that the average stress along the spacer surface have a value of about $5x10^5$ V/m. The results of Fig.5 show that the cone shaped spacer has field which is close to the average value of field in the gap. However, for disc shaped spacer, the field is significantly different from the average value for most of the region.

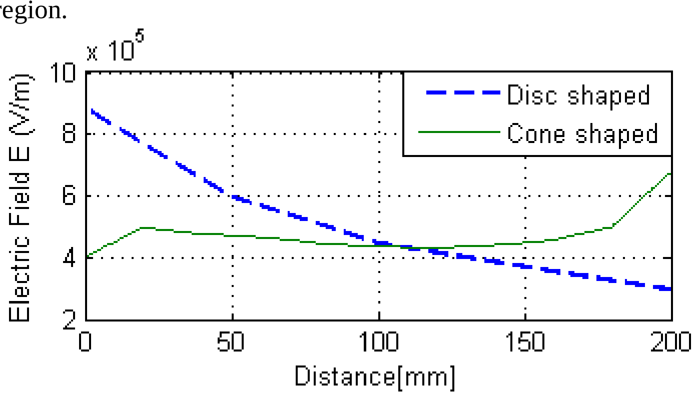

Figure 5. Field distribution along the spacer surface for disc shaped and cone shaped spacers (Spacer ε_r=6).

2.2 Effect of Defects on the Surface Field Distribution

Fig.6 shows the field intensification in the vicinity of protrusion, depression and adhered particle. The field intensification due to adhered metallic particles is extremely high as compared to the one produced by spacer surface protrusion or a surface depression. It is for this reason that the region around the particle serves as the weak point inside GIS and can lead to partial discharge or even breakdown in extreme cases.

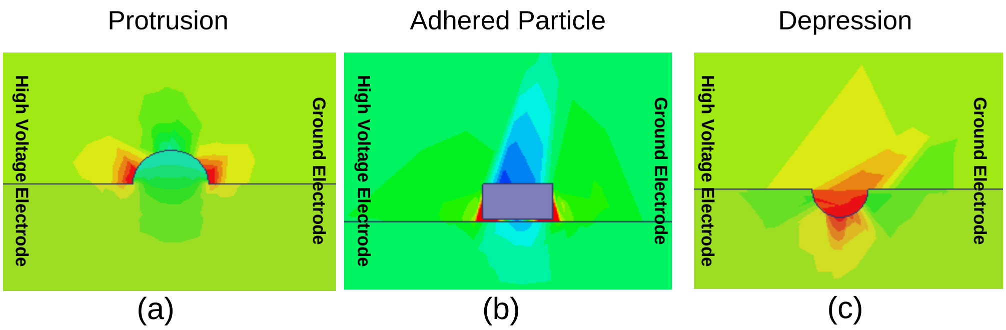

Figure 6. Field distribution around: (a) protrusion, (b) adhered particle and (c) depression.

2.3 Effect of Relative Permittivity on Surface Field Distributions in the Presence of Defects at Different Locations

Reference [8] investigated the effect of changing the relative permittivity ($\mathcal{E}_r$) of the spacer material in cone shaped spacers without defects and it was noticed that $\mathcal{E}_r$ has significant effect on the field near the triple junction. In disc shaped spacer, changing the relative permittivity of solid spacer has no effect on the electric field near the triple junctions except on the extent of field intensifications due to presence of spacer surface protrusions or surface depressions. Figs.7 and 8 show the effect of changing the relative permittivity of disc shaped spacer with surface defects i.e., protrusions and depressions respectively. The diameter of the protrusion or the depression is taken as *d*=1mm. It is assumed to be located at different positions i.e., *Dr*= 0.05cm, 2cm, 6cm, 10cm, 14cm, 18cm and 19.95cm. It is noticed that changing the relative permittivity of solid spacer has an effect on the field intensifications due to spacer surface depressions or protrusions. The extent of field intensification due to defects increases with the increase in the spacer relative permittivity. However field intensification due to defect decreases as the position of defect shifts away from the high voltage electrode. Thus, spacer material, surface defect type and location of defect are all important factors which control the spacer performance.

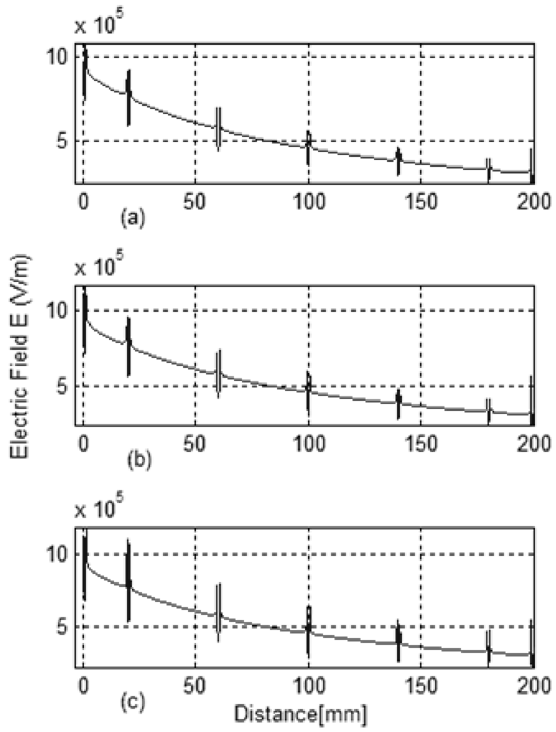

Figure 7. Effect of changing the relative permittivity of disc shaped spacer with protrusions of *d*=1 mm located at *Dr*= 0.05cm, 2cm, 6cm, 10cm. 14cm, 18cm and 19.95cm from the high voltage electrode: (a) $\mathcal{E}_r$=3, (b) $\mathcal{E}_r$=4 and (c) $\mathcal{E}_r$=6.

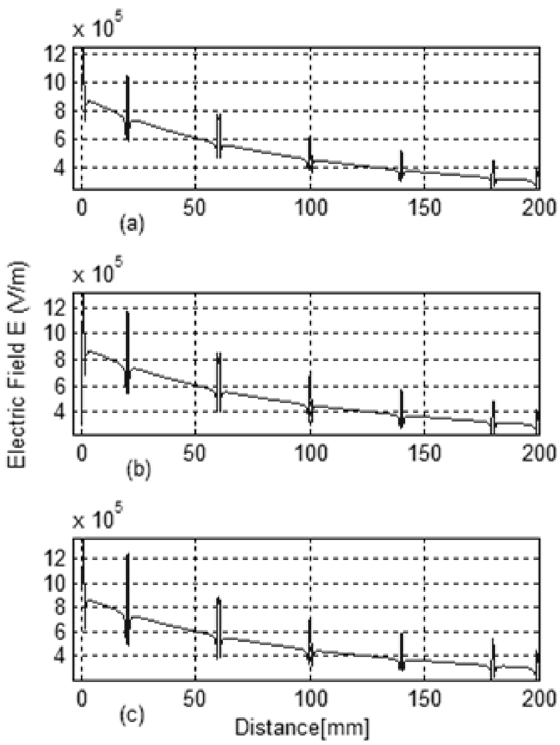

Figure8. Effect of changing the relative permittivity of solid disc shaped spacer with depressions of *d*=1 mm located at *Dr*= 0.05cm, 2cm, 6cm, 10cm. 14cm, 18cm and 19.95cm from the high voltage electrode: (a) $\mathcal{E}_r$=3, (b) $\mathcal{E}_r$=4 and (c) $\mathcal{E}_r$=6.

It is clear from the results of Figs.7 and 8 that the extent of field intensification in both defects is more critical when the defect is near high voltage electrode and the intensification decreases towards the ground electrode. However maximum effect of a defect is noted for surface depression of *d*=1mm located at 0.05cm near the high voltage electrode in which case the field intensification is about 16% more than the one caused by the protrusion of same size and located at the same place. Field intensification due to depression in case of $\mathcal{E}_r$=6 is about 10% more than that with $\mathcal{E}_r$=3 whereas in case of protrusion with $\mathcal{E}_r$=6 it is about 9% more than with $\mathcal{E}_r$=3 in disc shaped spacer.

2.4 Effect of Relative Permittivity on Surface Field Distributions in the Presence of Adhered Particle at Different Locations

Fig.9 shows the effect of changing the position of metallic particle along the surface of the spacer. The effect of metal particle is more pronounced when the particle is near the high voltage electrode and its effect decreases as the particle moves away from the high voltage electrode towards the ground electrode. On the other hand, the extent of field intensification increases as the spacer relative permittivity is increased. Field intensification due to particle of length (*L*) for relative permittivity $\mathcal{E}_r$=6 is about 43% more than that for $\mathcal{E}_r$=3 as is clear from Fig.9. The extent of intensification in case of conducting adhered particle is extremely severe as compared to spacer surface defects. Field intensification due to particle of *L*=1mm is about 150% more than that of depression of *d*=1mm located at 0.05cm from the high voltage electrode.

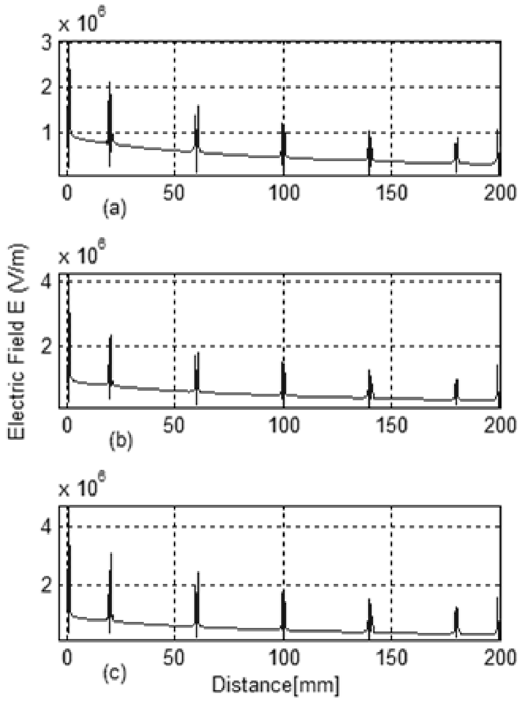

Figure 9. Effect of changing the relative permittivity of solid disc shaped spacer with particle of *L*=2 mm located at *Dr*= 0.05cm, 2cm, 6cm, 10cm. 14cm, 18cm and 19.95cm from the high voltage electrode: (a) $\mathcal{E}_r$=3, (b) $\mathcal{E}_r$=4 and (c) $\mathcal{E}_r$=6.

2.5 Effect of Defect and Adhered Particle Size on Surface Field Distribution

Fig.10 shows the effect of changing the size of surface depression i.e., *d*=1mm, 2mm, 3mm and 4mm located at a fixed location of *Dr*=10cm. It is noticed that field intensity is increased as the size of the depression is increased. Field intensity due to depression of *d*=4mm is about 14% more than that of *d*=1mm. However, even for smaller sized depression there is an appreciable field intensification.

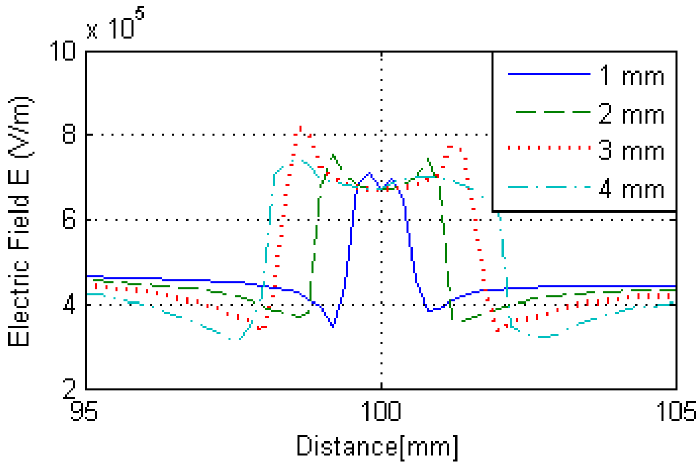

Figure 10. Effect of changing the size (*d*=1mm, 2mm, 3mm and 4mm) of depression in disc shaped spacer located at 10cm from high voltage electrode.

Similar to the case of depression, the size of protrusion on the spacer surface affects the value of field intensification. The field intensification increases as the size of spacer surface protrusion is increased as shown in Fig.11. Field intensification due to protrusion of *d*=4mm is about 60% more than that of *d*=1mm.

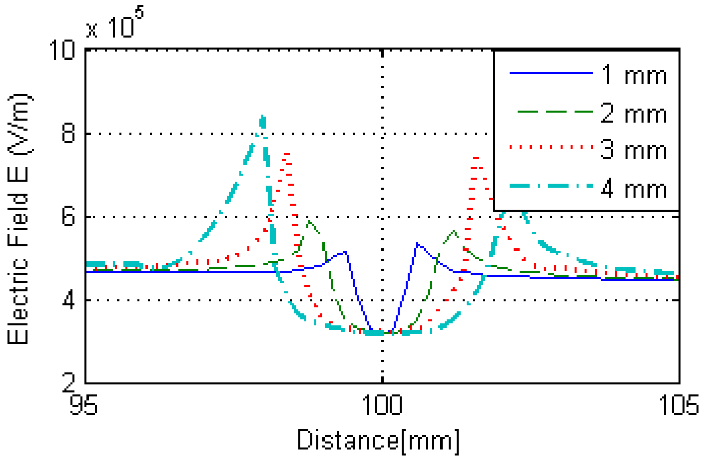

Figure 11. Effect of changing the size (*d*=1mm, 2mm, 3mm and 4mm) of protrusion in disc shaped spacer located at 10cm from high voltage electrode.

Fig.12 shows the effect of changing the length (*L*) of adhered metallic particle on the surface field. It is observed that the increase in the particle length increases the field around the particle for disc shaped spacer. Moreover, field intensification due to conducting particle of *L*=2.5mm is about 122% more than that for particle of *L*=1mm.

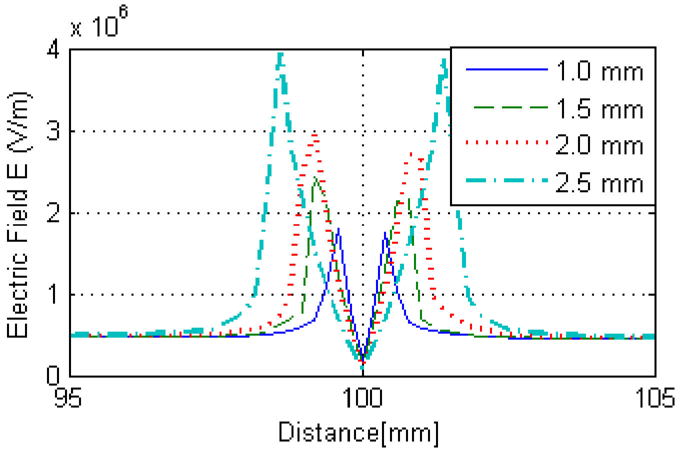

Figure 12. Effect of changing the length (*L*) of wire particle on disc shaped spacer located at 10cm w.r.t. high voltage electrode.

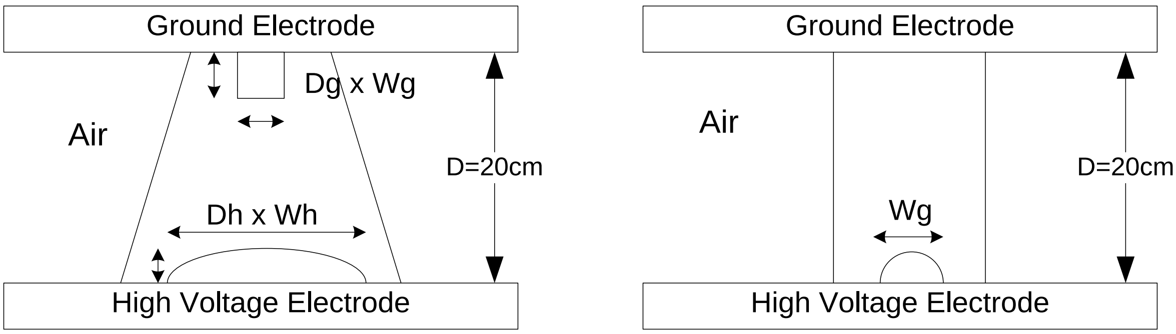

Figure 13. Inserted electrode configurations in cone and disc shaped spacers.

2.6 Effect of Inserted Electrode Dimensions on the Surface Field Distribution

The use of inserted electrodes can decrease the field intensifications at the triple junctions. This technique which was proposed in [10] can be used as a means of field evanescence at the triple junctions. Three different profiles of inserted electrodes i.e., rectangular, hemispherical and elliptical shaped of different dimensions are considered for this study. For each case, the effect of such insertions on the field at triple junction is examined. Fig.13 shows the inserted electrode configurations in cone shaped and disc shaped spacers. The change in the width (*Wg* or *Wh*) and depth (*Dg* or *Dh*) is studied for the two mentioned types of spacers. The dimensions of cone shaped spacer is *Xhv*=20cm and *Xgnd*=4cm whereas for disc shaped spacer, *Xhv*=*Xgnd*=12cm are used. Inserted electrode widths are taken as 1cm and 3cm while the depths are taken as

2cm and 4cm. Different combinations of these dimensions are used in this study Table 2 shows the legends and dimensions of the inserted electrodes.

Table 2. Configurations of the inserted electrodes.

Sr.	Legend	Inserted electrode on the HVE side (*DxW*)	Inserted electrode on the GE side (*DxW*)	Inserted electrode profile
1	C1*,D1**	Reference (without inserted electrode)		
2	C2.D2		1cm x 2cm	Rectangular
3	C3,D3		1cm x 4cm	Rectangular
4	C4,D4		3cm x 2cm	Rectangular
5	C5,D5		3cm x 4cm	Rectangular
6	C6,D6	1cm x 2cm		Rectangular
7	C7,D7	1cm x 4cm		Rectangular
8	C8,D8	3cm x 2cm		Rectangular
9	C9,D9	3cm x 4cm		Rectangular
10	D10	2cm		Hemispherical
11	D11	4cm		Hemispherical
12	D12	6cm		Hemispherical
13	D13	2cm x 1cm		Elliptical
14	D14	2cm x 3cm		Elliptical
15	D15	4cm x 1cm		Elliptical
16	D16	6cm x 3cm		Elliptical
17	C10		1cm	Hemispherical
18	C11		2cm	Hemispherical
19	C12		3cm	Hemispherical
20	C13		1cm x 1cm	Elliptical
21	C14		1cm x 3cm	Elliptical
22	C15		3cm x 1cm	Elliptical
23	C16		3cm x 3cm	Elliptical

* C denotes the cone shaped spacer; ** D denotes the disc shaped spacer.

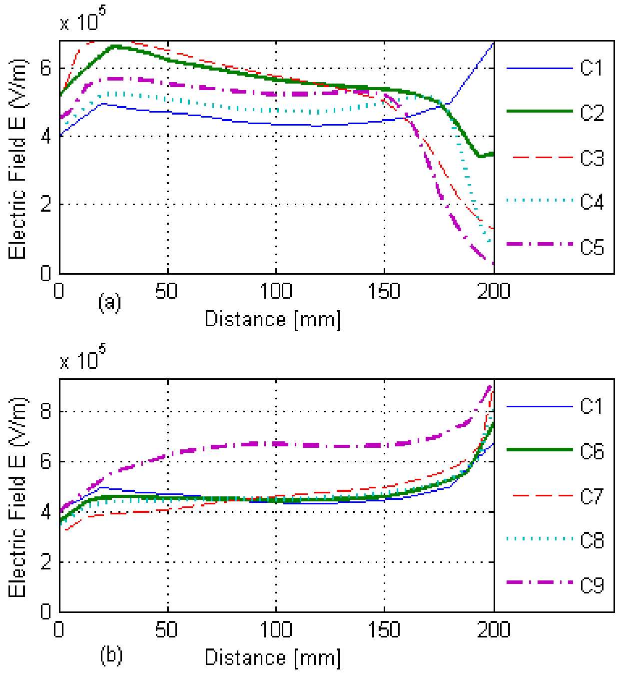

Figure 14. Effect of changing the inserted electrode dimensions in cone shaped spacer (a) inserted electrode at ground side (b) inserted electrode at high voltage side.

Fig.14 and Fig15 show two cases of inserted electrodes of different configurations: (i) inserted electrode on the high voltage side end of spacer and, (ii) inserted electrode on the ground side end of the spacer. The legends for Fig.14 to Fig.17 are detailed in Table 2. It is observed that insertion of electrode into the ground side of the cone shaped spacer decreases the field intensity at acute angle triple junction greatly, but at the same time it increases the field intensity along the most part of the spacer surface. In case of insertion of electrode into the high voltage side end of the spacer, field is increased near the triple junction (acute angle). However, if the inserted electrode depth and width is increased at the same time, the surface field increases beyond the reference value i.e., field value without any inserted electrode. This clearly suggests that the size of inserted electrode has to be carefully selected. Configuration of C4 (Wh=3cm, Dh= 2cm) is a good option for decreasing the field intensity at the triple junctions.

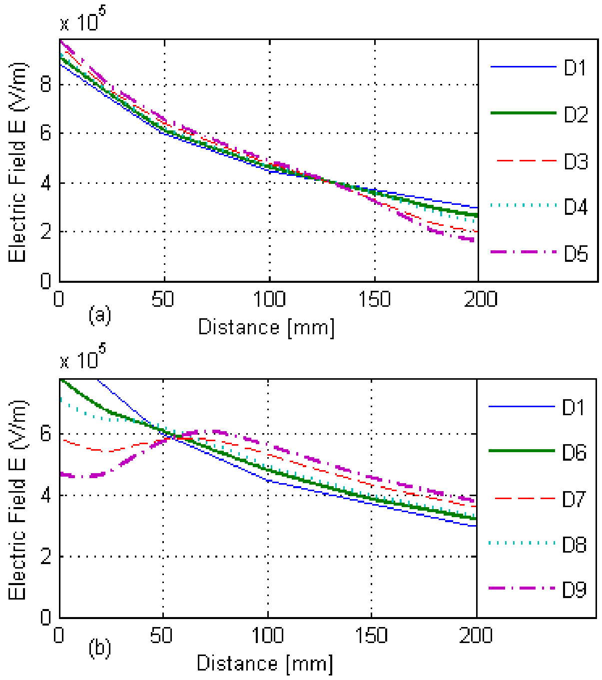

Figure 15. Effect of changing the inserted electrode dimensions in disc shaped spacer: (a) inserted electrode at ground side (b) inserted electrode at high voltage side.

Fig.15 shows that insertion of electrode into disc shaped spacer at the ground side end has no significant effect on the field at this triple junction but the insertion of electrode on the high voltage side end decreases the field greatly at such triple junction as represented by D9 in Fig.15. With the detailed optimization study, the exact dimensions for inserted electrodes can be estimated for both types of spacers which result in the maximum decrease of the field intensity around the triple junction. Fig.16 and Fig.17 show the effect of hemispherical and elliptical shaped inserted electrode in cone and disc shaped spacers, respectively. Width and depth of electrode in the three profiles i.e., rectangular, hemispherical and elliptical has significant effect on the field intensification near the triple junction. As evident from Figs. 16 and 17 C12, C16, D12 and D16 are good options for reducing the field intensification at the triple junctions. Thus proper design and optimization is necessary in this regards to select the best option that can optimally reduce the field intensification near the triple junction.

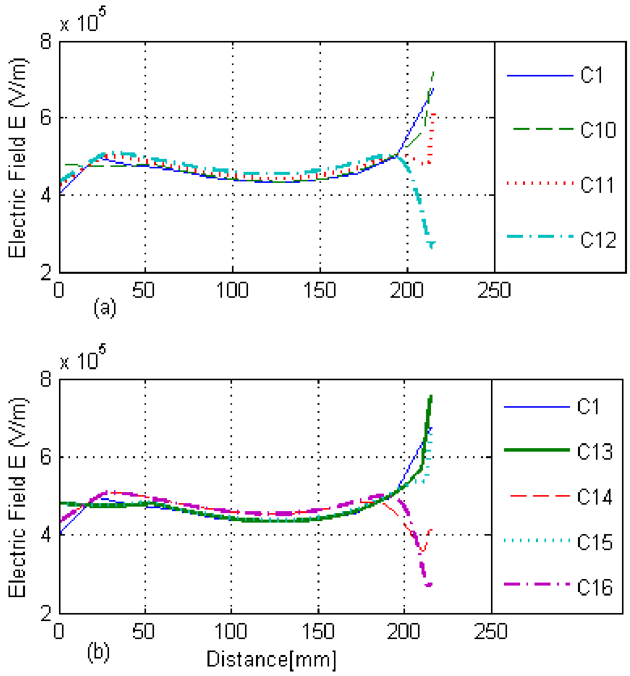

Figure 16. Effect of changing the dimensions of inserted electrode on the ground side end of the cone shaped spacer: (a) hemispherical inserted electrode (b) elliptical inserted electrode.

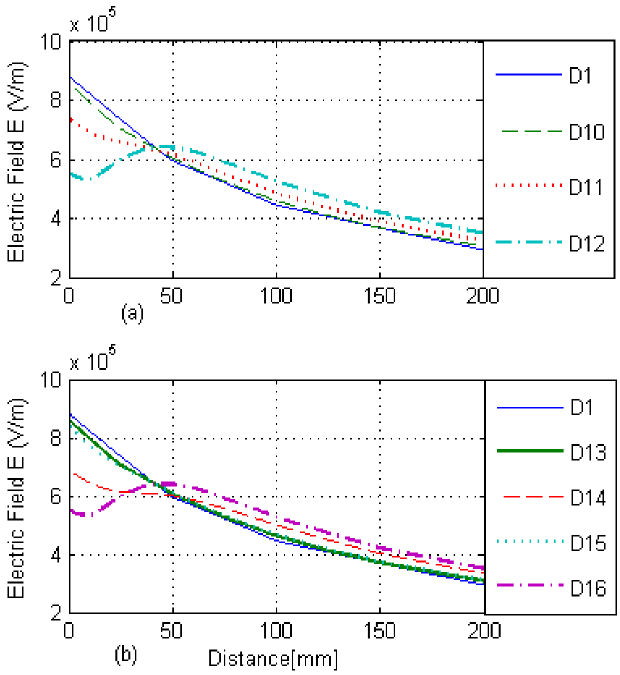

Figure 17. Effect of changing the dimensions of inserted electrode on the high voltage side end of the disc shaped spacer: (a) hemispherical inserted electrode (b) elliptical inserted electrode.

3. CONCLUSIONS

Spacers are very important part of all the GIS equipment. Breakdown strength of GIS is greatly influenced by the presence of conducting particles, spacer defects etc. In this paper, the effects of spacer defects, adhered conducting particle and relative permittivity of spacer material are reported in this paper. The method of inserted electrode is also reported that helps greatly in the reduction of field intensity at the triple junction. From the above results and discussions it is concluded that:

1) Position of protrusion, depression or particle adhering on the spacer surface has significant effect on the surface field intensification at the defect's location. Field intensification is greater if the defect is near the high voltage electrode and it gradually decreases as the defect shifts towards the grounded electrode. Moreover, increasing the defect size increases the field intensification around the defect.
2) Relative permittivity of spacer material has a significant effect on the extent of the field intensification due to defects located at different positions on the spacer surface. In case of disc shaped spacer, the extent of field intensification due to defects is increased with an increase in the relative permittivity. However, field intensification due to defect is decreased as the position of defect is shifted away from the high voltage electrode.
3) Field intensification due to adhered wire shaped conducting particle is much higher than that observed in the case of spacer surface defects.
4) Electrode inserted into the insulating spacer at the high voltage side end or the ground electrode side end can help in decreasing the field intensification at the triple junctions. Proper optimization of inserted electrode can be used as a tool for decreasing the field intensity at the triple junctions.

ACKNOWLEDGMENT

The authors are grateful to National Plan for Science and Technology (NPST), King Saud University Riyadh, Saudi Arabia for their technical and financial support provided vides their research project # 08-ENE216-02.

REFERENCES

1. Ermel M. et al, 2004. N2/SF6 mixtures for gas insulated systems. Task Force D1.03.10 of CIGRE WG D1.03: Technical Brochure No. 260, CIGRE Publication.

2. Takuma T., Endo F., Hama H., Matsumoto S. and Yuhima M., 2000. Interfacial Insulation Characteristics in Gas Mixtures as Alternative to SF_6, and Application to Power Equipment. In the proceedings of CIGRE Session 2000, Paper: 15-207.

3. Srivastava K. D. and Morcos M. M., 2001. A Review of Some Critical Aspects of Insulation Design of GIS/GIL Systems. In the Proceedings of Transmission and Distribution Conference and Exposition,pp: 787-792.

4. Braun J. M., Ford G. L., Fujimoto N., Riuetto S. and Stonet O. C., 1993. Reliability or GIS EHV Epoxy Insulators: The Need and Prospects for More Stringent Acceptance Criteria. IEEE Trans. Power Del., 8(1): 121-131.

5. Mazurek B., Cross J. D., and Van Heeswijk R. G. 1993. The Effect of a Metallic Particle Near a Spacer on Flashover Phenomena in SF_6. IEEE Trans. Dielectr. Electr. Insul., 28(2): 219-229.

6. Hasegawa T., Yamaji K., Hatano M., Endo F., Rokunohe T., and Yamagiwa T., 1997. Development of Insulation Structure and Enhancement of Insulation Reliability of 500kV DC GIS. IEEE Trans. Power Del, 12(1): 194-202.

7. Radwan R. M. and Abou-Elyazied A. M., 2006. Electric Field Distribution on Insulating Spacers in GIS Using the Finite Element Technique. In the Proceedings of Cigre Session14, Paper: A3-104.

8. Radwan R. M. and Abou-Elyazied A. M., 2006. Effect of Solid Spacers' Dimensions and Permittivity on the Electric Field Distribution in Gas Insulated Systems, In the Proceedings of The Eleventh International Middle East Power Systems Conference, pp: 234-239.

9. Radwan R. M. and Abou-Elyazied A. M., 2007. Effect of Spacer's Defects and Conducting Particles on the Electric Field Distribution Along Their Surfaces in GIS. IEEE Trans. Dielectr. Electr. Insul., 14(6): 1484-1491.

10. Khan Y., Okabe S., Suehiro J., Hara M., 2005. Proposal for New Particle Deactivation Methods in GIS. IEEE Trans. Dielectr. Electr. Insul., 12(1): 147-157.