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Comparison of Radial Movement of Metallic Particles in a Single Phase Gas Insulated Busduct

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Abstract

Compressed Gas Insulated Substations (GIS) consist basically of a conductor supported on insulators inside an enclosure, which is filled with sulphur hexafluoride gas (SF6). The voltage withstand capability of SF6 bus duct is strongly dependent on field perturbations such as those caused by conductor surface imperfections and by conducting particle contaminants. The particles can be lifted by the electric field and migrate to the conductor or insulators where they initiate breakdown at voltages significantly below the insulation characteristics of the SF6 gas. In this project a single phase enclosure with outer diameter as 137mm and inner conductor diameter of 40mm is considered for analysis and compared with a single phase enclosure with outer diameter as 152mm and inner conductor diameter of 55mm with aluminium, copper and silver particles of size 10mm in length and 0.25 as radius present on the enclosure . To study the behaviour of Metallic Particles in the presence of power frequency voltages applied to single-phase gas insulated bus duct. The maximum movement of Aluminium, Copper and Silver particles for applied voltages of 75 kV, 100 kV, 132kv, 145 kV, and 200 kV are determined. The simulation results have been presented and analyzed.

Index Terms: Metallic Particles, Electric Field, Gas Insulated Substations, Particle Contamination.

Introduction

Sulphur hexafluoride is the electric power industry’s Preferred gas for electrical insulation and, especially, for arc quenching current interruption equipment used in the transmission and distribution of electrical energy. Compressed Gas Insulated Substations (GIS) and Transmission Lines (CGIT) consist basically of a conductor supported on insulator inside an enclosure, which is filled with SF6 gas. As one is aware of the attractive features of a Gas Insulated Substation (GIS), they also suffer from certain drawbacks. One of them is the outage due to seemingly innocuous conducting particles, which accounts for nearly 50% of the GIS failures. The contaminants can be produced by abrasion between components during assembly or operations. Flash over in a GIS is, in general, associated with longer outage times and greater costs than in a conventional air insulated substation. A conducting particle can short-circuit a part of the insulation distance, and thereby initiate a breakdown, especially if electrostatic forces cause the particle to bounce into the high field region near the high voltage conductor.

A study of CIGRE group suggests that 20% of failure in GIS due to the existence of various metallic contaminations in the form of loose particles. These particles may exist on the surface of support insulator, enclosure or high voltage conductor. Under the influence of high voltage, they can acquire sufficient charge and randomly move in the gap due to the variable electric field. Several authors have reported the movement of particles with reference to a few parameters. The presence of contamination can therefore be a problem with gas-insulated substations operating at high fields. The purpose of this work is to develop techniques, which will formulate the basic equations that will govern the movement of metallic particles like aluminium, copper and silver particles. The specific work reported deals with the charge acquired by the particle due to macroscopic field at the tip of the particle, the force exerted by the field i.e., electric field on the particle, drag due to viscosity of the gas and random behaviour during the movement. In this paper an optimized design of GIS by changing the inner and outer diameter to 40mm and 137mm is considered for analysis and compared with a single phase enclosure with outer diameter as 152mm and inner conductor diameter of 55mm with aluminium, copper and silver particles of size 10mm in length and 0.25 as radius present on the enclosure. It is required to be done because competitive prices of several manufactures of GIS and cost of gas are increasing. The results will have a bearing on the extent of reduction of inner diameter of the HV electrode and the overall volume. This will provide information on the extent of particle movement for the same condition of the gas and particle geometry. Power systems designed to function at the fundamental frequency are prone to unsatisfactory operation and, at times, failure when subjected to voltages and currents that contain substantial harmonic frequency elements. The movement pattern for higher voltages class has been also obtained.

Modeling Technique of GIB

Figure 1 shows a typical horizontal busduct comprising o fan inner conductor and an outer enclosure, filled with SF6 gas is considered for the study. A particle (wire) is assumed to beat rest at the enclosure surface, until a voltage sufficient enough to lift the particle and move in the field is applied. After acquiring an appropriate charge in the field, the particle lifts and begins to move in the direction of the field after overcoming the forces due to its own weight and drag. The s simulation considers several parameters e.g.: the macroscopic field at the location of the particle, its weight, viscosity of the gas Reynold's number, drag coefficient and coefficient of restitution on its impact to the enclosure. During the return flight, a new charge on the particle is assigned, based on the instantaneous electric field.

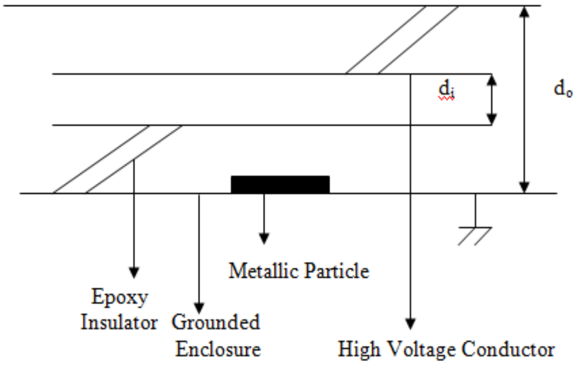

Figure 1: Typical Single Phase Gas Insulated Bus duct.

For particles on bare electrodes, several authors have Suggested expressions for the estimation of charge on both vertical/horizontal wires and spherical particles. The equations are primarily based on the work of Felici[3]. The lift-off field for a particle on the surface of an electrode can be estimated by solving the following equations.

The gravitational force acting on a particle of mass 'm' is given by

$$Fg = mg \tag{1}$$

The expression of the electrostatic force can be expressed as

$$Fe = KQE \tag{2}$$

E (t) in a co-axial electrode system can be expressed as

$$E(t) = \frac{V \sin(\omega t)}{\left[(r_0 - y(t)) \ln \left(\frac{r_0}{r_i} \right) \right]}$$

Where

VSinωt is the supply voltage on the inner electrode,

r_0 is the enclosure radius,

r_i is the inner conductor radius

y(t) is the position of the particle which is moving upwards, the distance from the surface of the enclosure towards the inner electrode.

The motion of the particles is simulated by using the equation

$$m\ddot{y}(t) = Fe - Fg - Fd$$

The motion equation using all forces can therefore be expressed as

$$m\ddot{y}(t) = \frac{\pi \in_0 l^2 E(t_0)V \sin \omega t)}{\left[\left[\ln\left(\frac{2l}{r}\right)-1\right](r_o - y(t))\ln\left(\frac{r_0}{r_i}\right)\right]}$$

$$- mg - \dot{y}(t)\pi r(6\mu K_d(\dot{y}) + 2.656[\mu \rho_g l\dot{y}(t)]^{\frac{1}{2}}$$

The motion equation is a second order non-linear differential equation and in this paper, the equation is solved by using Runge-Kutta 4th Order Method

Results and Discussions

To determine the movements of aluminium, copper and silver particles of size 10mm in Length and 0.25 mm as radius for applied voltages of 75kV, 100kV, 132kV, 145kV and 200kV in a single phase uncoated GIB with bus duct dimensions 152 as outer diameter and inner conductor diameter of 55mm is taken. The Maximum movement is calculated for all the above mentioned voltages. An optimized design of single Phase GIS by changing the inner and outer diameter is considered for analysis with bus duct dimensions of 137 mm, 40 mm as outer and inner diameters respectively and the results are compared on the extent of particle movement for the same condition of the gas and particle geometry. The Maximum Radial movement of aluminium, copper and silver particles for applied voltages of75kV, 100kV, 132kV, 145kV and 200kV is given in Table I. Fig. 2 to Fig.7 show the movement patterns of aluminium, copper and silver particles with the application of power frequency for 152/55 mm busduct. It can be noted from Table I that peak movement in radial direction for aluminium particle is higher than that of copper and silver. This behaviour is expected due to heavyweight of copper and silver particles than those of aluminium of the same size. Movement patterns of aluminium, copper and silver particles with the application of power frequency for 137/40 mm busduct are shown in Figures 8 to 13. The results show that the maximum movement is decreased in 137mm/40 mm bus duct than with 152 mm / 55 mm bus duct as the electric field of the busduct conductor is decreased

Table 1: Radial Movement of Aluminium Copper and Silver Particles in a Single Phase 152/55 &137/40 Busduct.

Voltage (kv)	Type	Max. Radial Movement (1 DEG)	
		137/40 Enclosure	152/55 Enclosure
75	AL	11.9328	13.0185
	CU	NM	2.46105
	AG	NM	NM

100	AL	20.61889	24.2414
	CU	3.663005	5.054871
	AG	2.8805	3.9376
132	AL	27.89573	32.17047
	CU	10.08177	13.15618
	AG	8.05664	10.33701
145	AL	32.6565	38.9712
	CU	12.19126	10.74789
	AG	10.9826	13.1245
200	AL	56.04675	61.1335
	CU	15.8245	17.8026
	AG	20.91101	16.3405

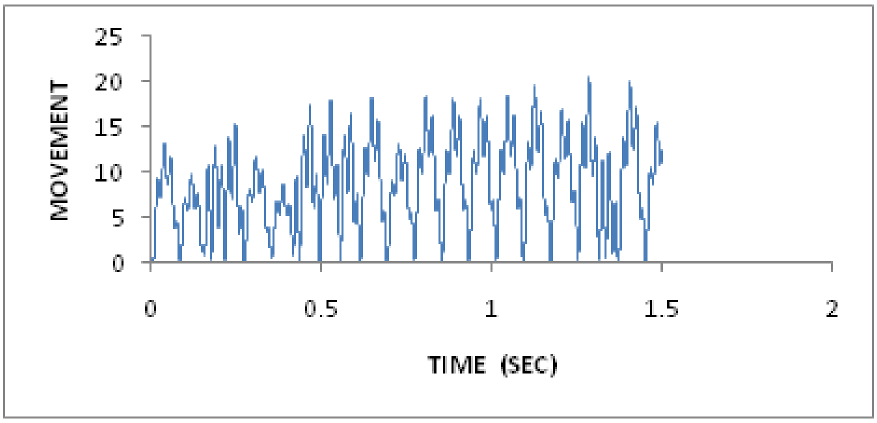

Figure 2: Movement pattern for sinusoidal voltage 10 mm/Al/100 KV/0.25 mm Radius.

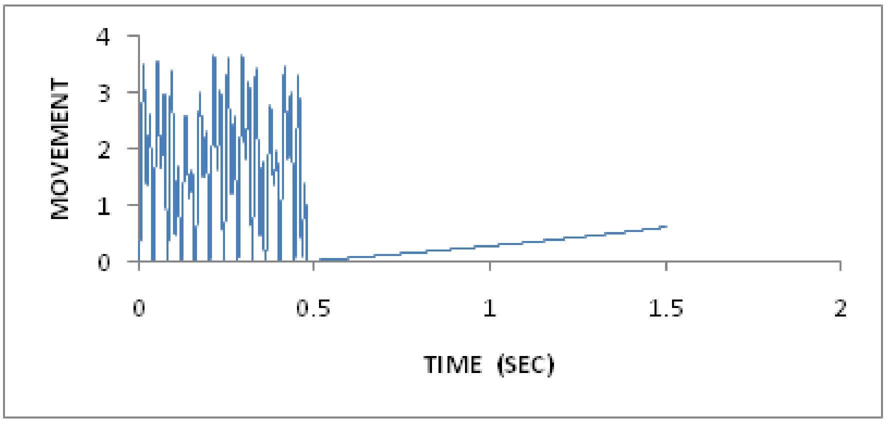

Figure 3: Movement pattern for sinusoidal voltage 10 mm/ Cu /100 KV/0.25 mm Radius.

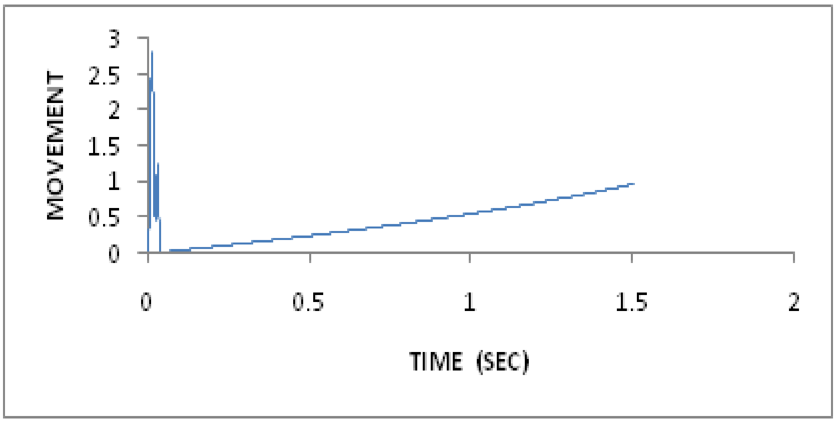

Figure 4: Movement pattern for sinusoidal voltage 10 mm/ Ag/100 KV/0.25 mm Radius.

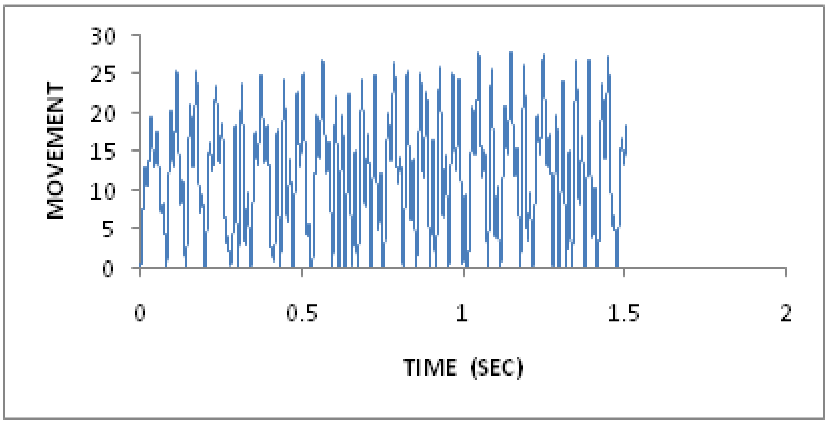

Figure 5: Movement pattern for sinusoidal voltage 10 mm/Al /132 KV/0.25 mm Radius.

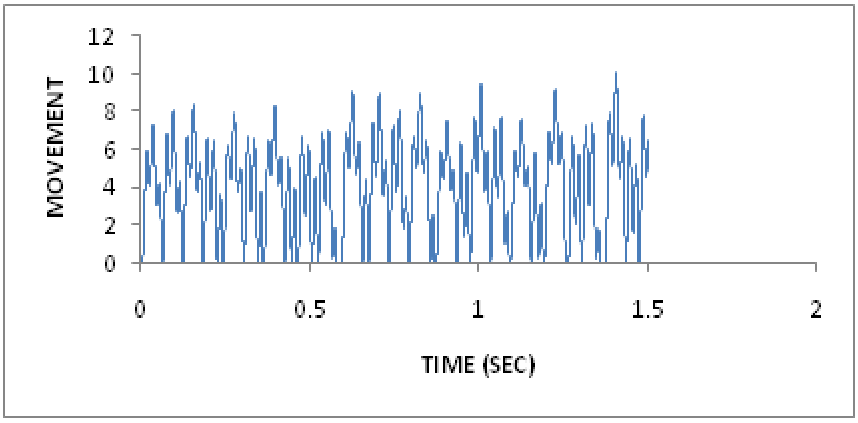

Figure 6: Movement pattern for sinusoidal voltage 10 mm/ Cu /132 KV/0.25 mm Radius.

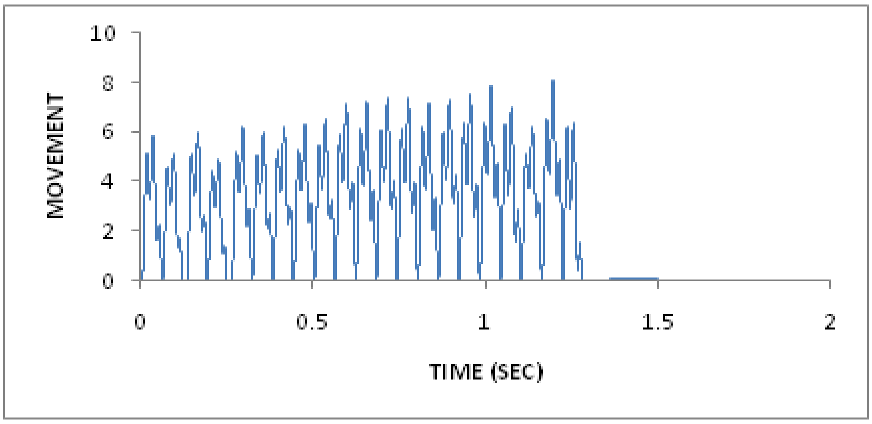

Figure 7: Movement pattern for sinusoidal voltage 10 mm/ Ag/132 KV/0.25 mm Radius.

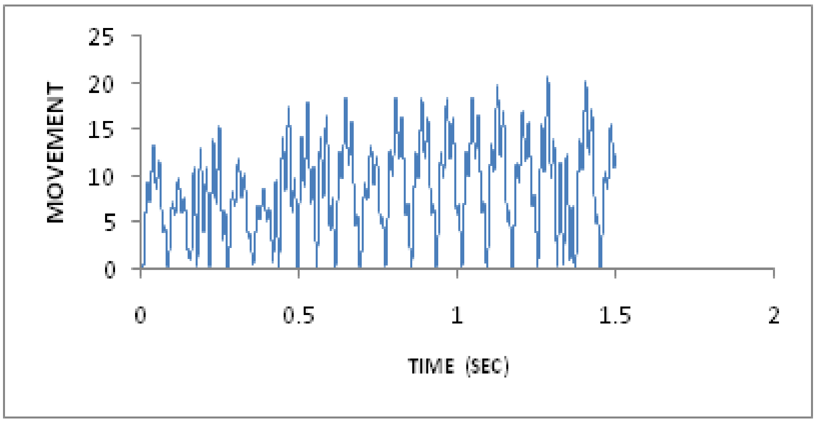

Figure 8: Movement pattern for sinusoidal voltage Al /100 KV/10 mm/0.25 mm radius.

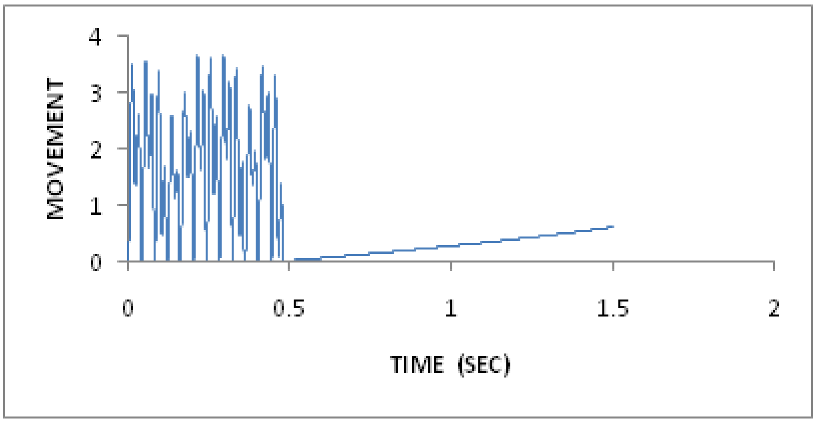

Figure 9: Movement pattern for sinusoidal voltage CU /100 KV/10 mm/0.25 mm radius.

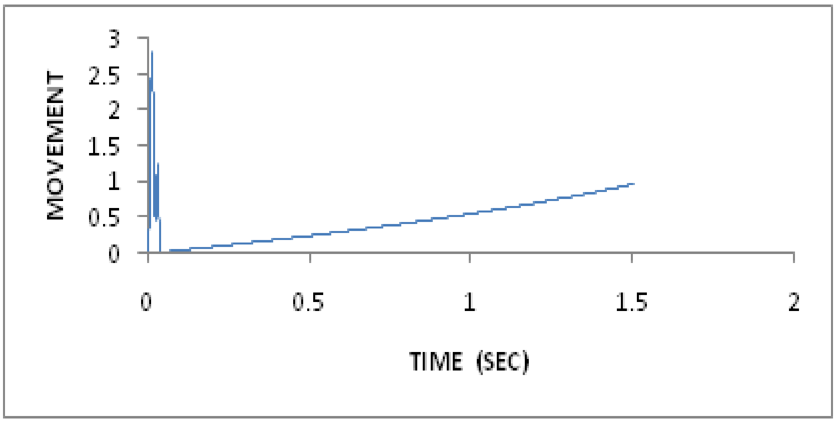

Figure 10: Movement pattern for sinusoidal voltage AG/100 KV /10 mm/0.25 mm radius.

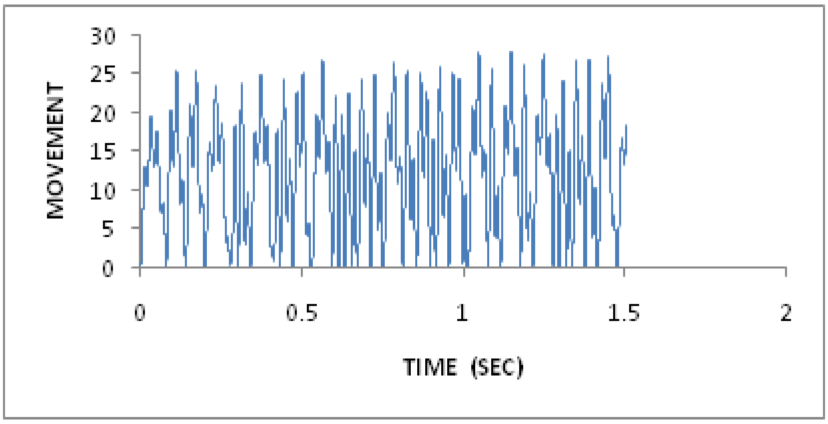

Figure 11: Movement pattern for sinusoidal voltage Al/132 KV/10 mm/0.25 mm radius.

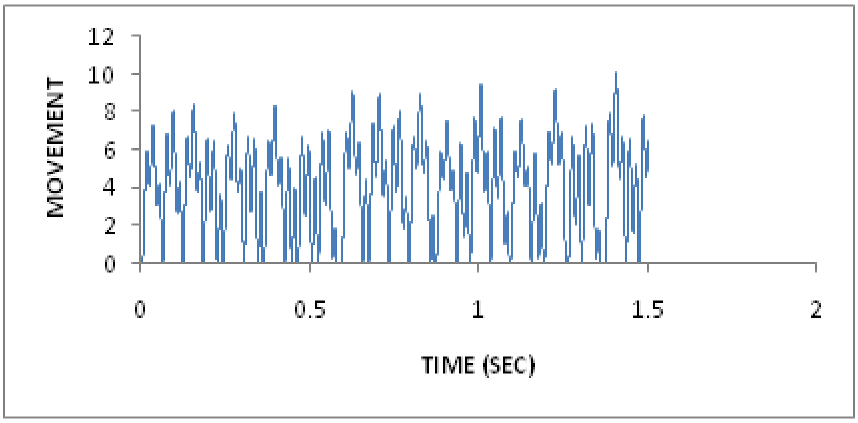

Figure 12: Movement pattern for sinusoidal voltage CU /132 KV/10 mm/0.25 mm radius.

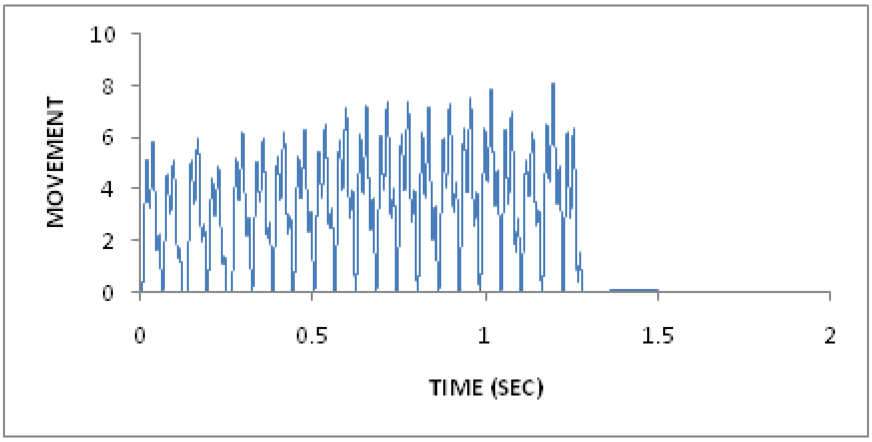

Figure 13: Movement pattern for sinusoidal voltage AG/132 KV/10 mm/0.25 mm radius.

Conclusion

It has been observed that metallic particle contamination is often present in GIS and such contamination adversely affects the insulation integrity. A conducting particle moving in an external electric field will be subjected to a collective influence of Electrostatic force, Gravitational Force and Drag Force. The maximum movement in radial direction of power frequency voltage for aluminium, copper and silver particles has been determined. An optimized design of GIS by changing the inner & Outer diameter to 40 mm and 137mm is considered for analysis and compared with a single phase enclosure with outer diameter as 152 mm and inner conductor diameter of 55 mm with aluminium, copper and silver particles of size 10 mm in length and 0.25 as radius present on the enclosure. The results show that the maximum movement is decreased in 137mm / 40 mm bus duct than with 152 mm/ 55 mm bus duct as the electric field of the busduct Conductor is decreased. From the simulation results it can be inferred that by reducing the busduct dimensions the quantity and cost of the gas is reduced and reliability of the GIS is improved.

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