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Effect of Particle Length and Radius on Movement of Metallic Particle in Single Phase Gas Insulated Bus duct

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Abstract: **The invention of SF6 insulation gas has revolutionized not only the technology of circuit breakers but also the organization of electrical power transmission lines and substations. Gas Insulated Substations have found a broad range of applications in power systems for more than thirty years because of their high reliability, easy maintenance and small ground space requirement. Metallic contaminants are inexorable in GIS systems and most common causes are mechanical vibrations during shipment and service, thermal expansion/contraction at expansion joints. Free metallic particle contaminants in Gas Insulated Bus duct adversely affect the insulation performance because they can cause serious deterioration of the dielectric strength and thereby the breakdown voltage of the GIS system is reduced. Research studies reveal that free metallic particles seriously decreases breakdown voltage of Gas Insulated Systems. This paper deals with the effect of particle length on the moment of metallic particle in single phase gas insulated bus duct. The simulation of movement of aluminum and copper wire like particles are carried out for various bus voltages 75kV, 100kV, 145KV. The results of the simulation have been presented and analyzed.**

Key words: Charge simulation method, Analytical Method, Gas Insulated Bus duct, metallic particle and Maximum radial movement.

I. INTRODUCTION

Gas Insulated Systems (GIS) are widely used in single phase and three phase electrical apparatus. The compressed SF6 gas has outstanding insulation and arc quenching properties and makes the GIS system more reliable and maintenance free. SF6 gas has very high dielectric strength, but it's withstand voltage within the GIS is drastically reduced due to the presence of metallic particles which may lead to high electrical stress and thus micro discharges. Metallic particles in GIS have their origin mainly from the manufacturing process or they may originate from moving of strength of structure due to aging makes the structure unreliable from the safety point of view. parts of the system such as breakers and disconnections. They may also originate from mechanical vibrations during shipment and service or thermal contraction/expansion at joints. Metallic particles can be either free to move in the GIS bus or they may be struck either to an energized electrode or to an insulator surface (spacer, bushing etc.). If a metallic particle crosses the gap and comes into contact with the inner electrode or if a metallic particle adheres to the inner conductor, the particle will act as a protrusion on the surface of the electrode, and the voltage required for breakdown of the GIS will be dramatically decreased. A metallic particle struck on an insulator surface in a GIS will also cause a significant reduction of the breakdown voltage. There are different methods of solving electrical fields. The choice of the method depends upon the type of the problem to be solved. Sometimes a combination of two or more methods could be applied to get better results [1, 2]. Even though SF_6 has very high dielectric strength, probability of flashover is increased by the presence of conducting particles, which may lead to very high electrical stresses and micro discharges [17,6,19]. Free conducting particles are in different shapes. The shapes are spherical or horizontal wire or vertical filamentary (wire) particle. If free wire particles are made up with conducting material, the effects of these are more on the with stand voltage at higher electric fields [18,19] The work reported in this paper deals with the effect of particle length and radius on movement of metallic particle in 1-Φ isolated conductor gas insulated bus duct (GIB). Instantaneous electric fields and particle movements are computed by using Analytical, Charge simulation (CSM), Finite element (FEM) and Finite deference (FDM) methods.

II. MATHEMATICAL MODELING:

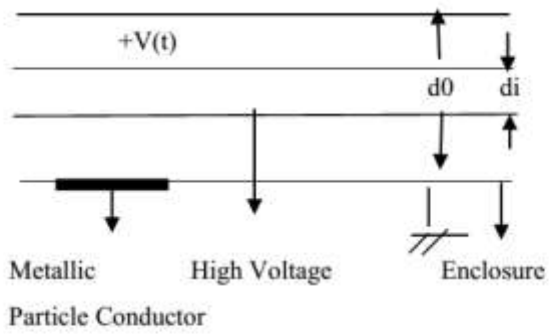


Fig. 1. Schematic diagram of a typical 1- phase gas insulated bus duct.

The schematic diagram of a typical compressed Gas insulated bus duct is shown in Fig. (1). When the electrical field surrounding the particle is increased, an uncharged metallic particle resting on a bare electrode will gradually acquire a net charge. The charge on the particle is a function of the local electrical field and shape, orientation and size of the particle. When the electrostatic force exceeds the gravitational force the particle will lift [20-24]. Lift-off field for a particle can be estimated as [25-28]. In order to lift a particle from its position of rest the electrostatic force on the particle should balance its weight. Hence,

$$Fe = mg \qquad (1)$$

Where

Fe = electrostatic force

g = gravitational force

The particle resting on a enclosure gets charged in the presence of external electric field 'E' and is given by [3-8].

$$Q_{hw} = 2\pi \in_0 r\,l\,E \qquad (2)$$

$$0.715\left((2\pi \in_0 rl\,E_{L0})E_{L0}\right) = \pi r^2 \rho l g \qquad (3)$$

Where r is the radius of the horizontal particle l is the length of the horizontal particle. The lift-off field of an ideal cylindrical horizontal wire particles with the correction factor 'K' 0.715 [9] is given by,

$$E_{L0} = 0.84\sqrt{\frac{\rho g r}{\in_0}} \qquad (4)$$

Once the particle has lifted from a horizontal to a vertical position the charge will increase significantly. The sudden increase of charge will most likely lift the particle from the electrode. Conducting particles placed in a uniform ac field lift-off at a certain voltage. As the voltage is raised, the particles assume a bouncing state reaching a height determined by the applied voltage. With a further increase in voltage, the bounce height and the corona current increase until break down occurs [10].

III. SIMULATION OF PARTICLE MOTION

In simulation, the net charge of moving particle between bounces is assumed to be constant and the effect of charges on the particle is neglected. The equations are primarily based on the work of Feliciet.al [15]. The electric field at the metallic particle location is calculated using Charge Simulation Method based on the work of Nazar H. Malik et.a1[16] and H.Singer[9] The electric field in a coaxial electrode system at position of the particle may calculate using any of the following methods.

- ❖ Analytical Method
- ❖ Charge Simulation Method
- ❖ Finite Difference Method
- ❖ Finite Element Method

3.1 Analytical method:

Electric Field calculation in Single phase Gas Insulated Bus duct:

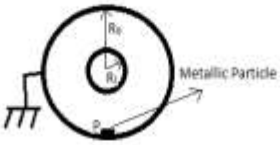


Figure 1: Single Phase Gas Insulated Bus duct with Metallic Particle resting on inner surface

Using analytical method the electric field 'E(t)' at time instant 't' in Gas Insulated Bus duct at point 'P' as shown in figure 1 is,

$$E(t) = \frac{Vm\ \mathrm{Sin}\ \omega t}{[R_0 - y(t)]\ln\left[\frac{R_0}{R_i}\right]} \qquad (5)$$

Where, V_mSinωt is the supply voltage of inner conductor of GIB,R_o - inner radius of outer enclosure, R_i - inner conductor radius and y(t) - the inner surface of enclosure to upward moving metallic particle.

3.2 Charge simulation method (CSM):

The actual electric field is simulated by a number of discrete simulation charges which are located inside the conductorsin the Charge Simulation Method. The potential at any point is calculated by following the equation

$$V_i = \sum_{j=1}^{n} Pij.\, qj\ i = j = 1, \ldots\ldots, n \qquad (6)$$

Where pij= potential coefficient related to the potential of the j_{th} charge at the i_{th} point.qj= simulation charge, n = number of charge.

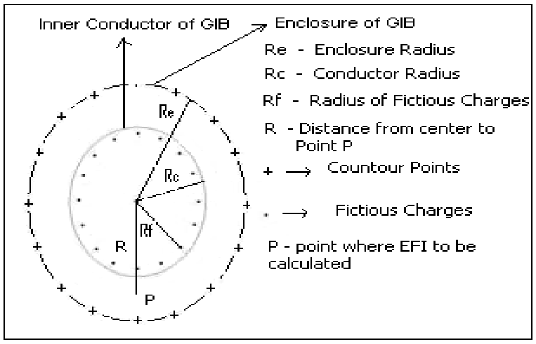


Figure 2: Basic Concept of Charge Simulation Method without image charges

The electrostatic field 'E' at point 'P(x, y)' ' without image charge is calculated by using the following equations:

$$E_x = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon}\left[\frac{x - x_i}{\sqrt[3]{(x - x_i)^2 + (y - y_i)^2}}\right] \qquad (7)$$

$$E_y = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon}\left[\frac{y - y_i}{\sqrt[3]{(x - x_i)^2 + (y - y_i)^2}}\right] \qquad (8)$$

Where $E_x(t)$, $E_y(t)$ are Electrostatic field components at time instant 't' along X(Horizontal) and Y(Vertical)-axes respectively, x, y are coordinates of point 'P' where Electric field is to be calculated, x_i, $y_i$are coordinates of i^{th} fictitious charge, 'n' is the total number of fictitious charges, λ_i is line charge density of i^{th} fictitious charge.

3.3 Finite Element Method:

For finding solution using finite element method consist four steps and they are 1. Discretising the solution region into finite number of triangle elements, 2. Forming algebraic equations for all finite elements 3. Assembling the all elements of solution region through equations and 4. Solving system equations for finding voltages at all unknown triangle element nodes.

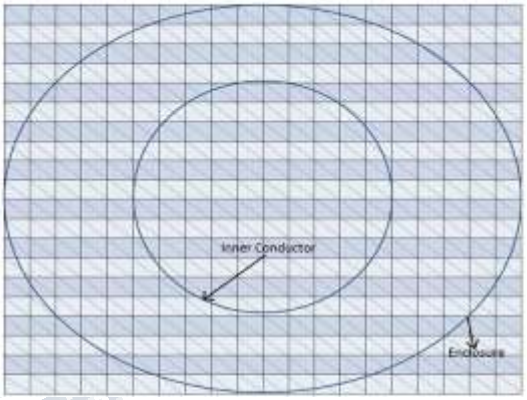


Figure 3: Finite Element Method for calculating potentials at element nodes of single phase Gas Insulated Bus duct.

The potential V_e within an element is approximated and the potential distribution in all elements is interrelated as potential is continuous across inter element boundaries and approximate solution using finite element method is,

$$V(x, y) = \sum_{e=1}^{N} V_e(x, y) \qquad (9)$$

Where N is number of elements of solution region.

Electric Field intensity at any point in Gas Insulated Bus duct is calculated by using following equation.

$$E = -\nabla V \qquad (10)$$

3.4 Finite Difference Method:

Finite difference method is simple numerical technique for solving partial differential equations. Solving the problem using this method usually consists of three steps and they are

1. Solution region is divided into grid nodes,

2. Forming set of linear algebraic equations on grid nodes of solution region and

3. Solving the algebraic equations for finding grid potentials

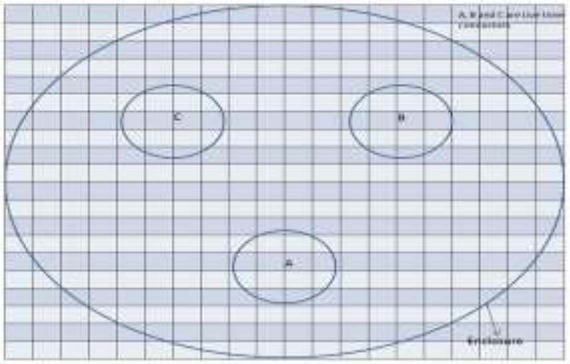


Figure 4:Dividing solution region into grid. nodes for Finite Difference Method for single phase Gas Insulated Bus duct Potentials at all free nodes can be calculated by applying finite difference approximation to Laplace's equation. The Laplace's equation is given as,

$$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} = 0 \tag{11}$$

Electric Field intensity at any point in Gas Insulated Bus duct is calculated by using following equation,

$$E = -\nabla V \tag{12}$$

IV. RESULTS AND DISCUSSIONS:

The particles movement is simulated for different particle lengths such as 8mm, 10mm, 12mm and 15mm with simulation time period of one second, particle radius 0.25mm, SF6 gas pressure0.45MPa and Restitution Coefficient 0.9 at 75kV, 100kV, 132kV and 145kV voltages.

Tables 1 to 6 are showing the maximum radial movements of Al and Cu particles obtained at different field calculation methods(namely analytical, finite difference and finite element methods). Similarly tables 7 to 12 shows maximum radial movements of Al and Cu particles obtained with field calculation method(charge simulation method) .

The maximum radial movements are almost equal if electric fields are calculated using analytical, charge simulation and finite element methods. But these movements are slightly less when electric field is calculated with finite difference method. Also it is found that the maximum radial movements relatively high when image charge is considered in electric field calculation.

Table1: Maximum Radial Movements of Al at different particle lengths for 75kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Field (mm)	With FEM Field (mm)
1	8.00	10.59	6.68	10.57
2	10.00	12.31	8.38	12.96
3	12.00	14.67	10.47	15.03
4	15.00	16.23	12.22	17.62

Table2: Maximum Radial Movements of Cu at different particle lengths for 75kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Field (mm)	With FEM Fiel
1	8.00	1.03	0.00	1.14
2	10.00	2.96	0.00	2.37
3	12.00	2.67	0.00	2.77
4	15.00	3.30	0.00	3.38

Table3: Maximum Radial Movements of Al at different particle lengths for 100kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Field (mm)	With FEM Field (mm)

1	8.00	19.60	15.17	19.90
2	10.00	22.41	16.39	22.64
3	12.00	23.86	18.56	25.32
4	15.00	27.52	23.99	27.54

Table4: Maximum Radial Movements of Cu at different particle lengths for 100kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Field (mm)	With FEM Field (mm)
1	8.00	3.80	2.58	3.89
2	10.00	4.58	3.12	4.68
3	12.00	5.64	3.65	6.07
4	15.00	7.50	4.71	7.88

Table5: Maximum Radial Movements of Al at different particle lengths for 145kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Fiel	h FEM Field (mm)
1	8.00	30.45	27.84	31.22
2	10.00	35.23	31.40	33.46
3	12.00	37.85	29.27	40.23
4	15.00	44.29	32.26	46.35

Table6: Maximum Radial Movements of Cu at different particle lengths for 145kV

Sl.NO	Length (mm)	With Analy-tical Field (mm)	With FDM Field (mm)	ith FEM Field (mm)
1	8.00	9.54	4.94	11.78
2	10.00	13.77	9.26	12.08
3	12.00	15.94	8.20	15.67
4	15.00	18.91	13.25	18.26

Table7: Maximum Radial Movements of Al at different particle lengths for 75kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	10.49	19.96
2	10.00	11.55	21.63
3	12.00	14.53	24.38
4	15.00	16.49	27.34

Table8: Maximum Radial Movements of Cu at different particle lengths for 75kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	1.03	3.97
2	10.00	2.26	4.70
3	12.00	2.68	6.24
4	15.00	3.24	7.98

Table9: Maximum Radial Movements of Al at different particle lengths for 100kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	17.42	27.54
2	10.00	21.11	31.26
3	12.00	23.80	34.41
4	15.00	26.58	38.49

Table10: Maximum Radial Movements of Cu at different particle lengths for 100kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	3.77	8.90
2	10.00	4.38	10.87
3	12.00	5.47	13.42
4	15.00	6.49	15.63

Table11: Maximum Radial Movements of Al at different particle lengths for 145kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	29.54	48.50
2	10.00	31.61	48.50
3	12.00	37.69	48.50
4	15.00	44.29	48.50

Table12: Maximum Radial Movements of Cu at different particle lengths for 145kV with CSM Field (mm)

Sl.NO	Length (mm)	Without Image Charge	With Image Charge
1	8.00	10.98	20.84
2	10.00	12.74	23.36
3	12.00	14.98	26.70
4	15.00	18.67	26.27

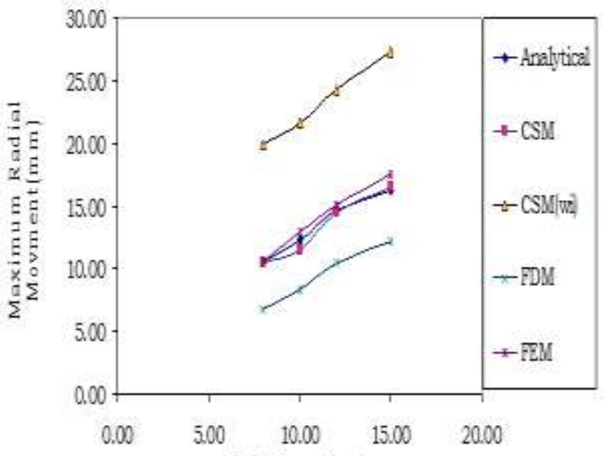


Figure 5 Variation of Particle Maximum Radial Movement with Al Particle Length at 75kV

From the results shown in tables 1 to 12 and figures 5 to 10 it can be inferred that Al and Cu particle radial movements are increasing with increase of length of the particle. It is also observed that maximum radial movements are almost equal when electric fields are calculated using analytical, charge simulation and finite element methods. Al and Cu particle movements are slightly less when electric field is calculated using finite difference method.

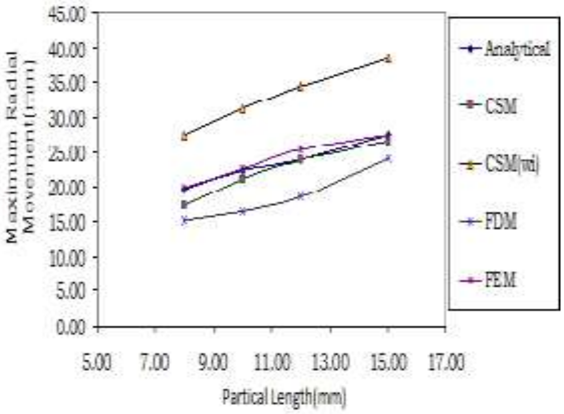


Figure 6 Variation of Particle Maximum Radial Movement with Al Particle Length at 100kV

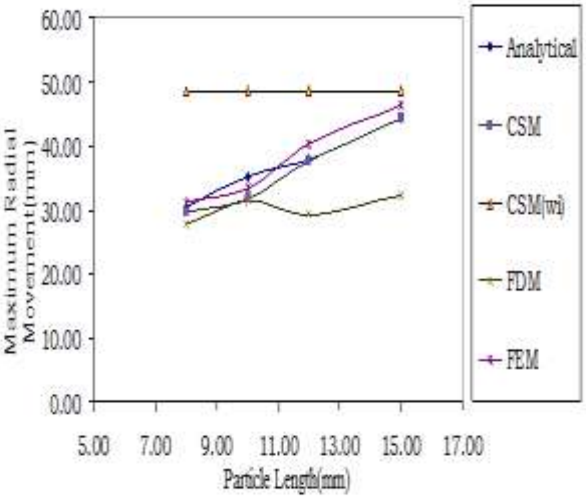


Figure 7 Variation of Particle Maximum Radial Movement with Al Particle Length at 145kV

The maximum radial movements for Al and Cu particles are relatively high when image is considered in electric field calculation using charge simulation method.

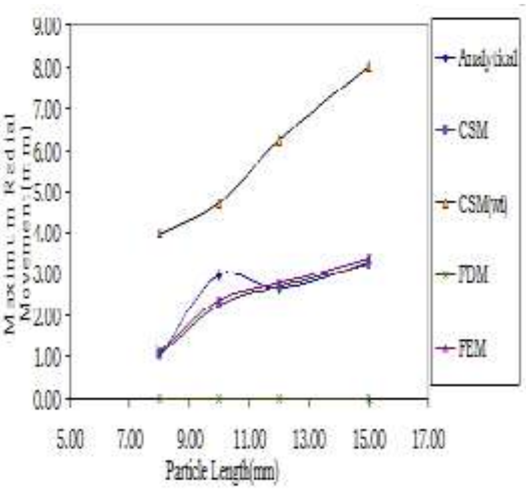
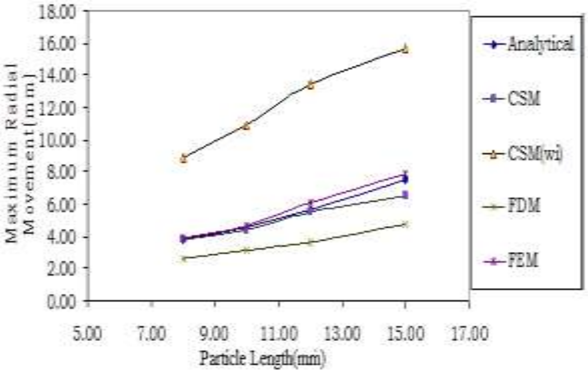


Figure 8 Variation of Particle Maximum Radial Movement with Cu Particle Length at 75kV



Fifure 9 Variation of Particle Maximum Radial Movement with Cu Particle Length at 100kV

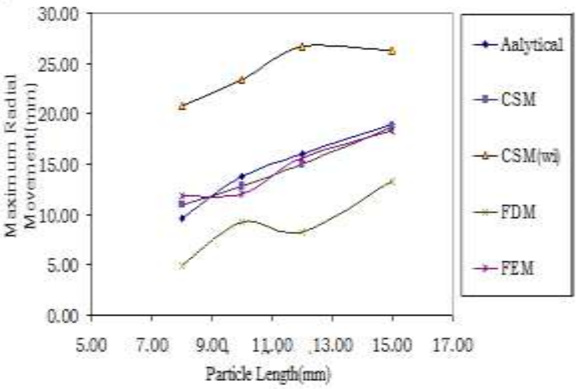


Figure 10 Variation of Particle Maximum Radial Movement with Cu Particle Length at 145kV

V.CONCLUSION:

A mathematical model has been formulated to simulate the particle movement in a single phase gas insulated bus duct. The movement patterns of aluminium and copper particles under different voltage conditions have been observed .from the results we can conclude that Al and Cu particle radial movements are increasing with increase of length of the particle. It is also observed that maximum radial movements are almost equal when electric fields are calculated using analytical, charge simulation and finite element methods. Al and Cu particle movements are slightly less when electric field is calculated using finite difference method.

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