MOVEMENT OF METALLIC PARTICLE IN AN ISOLATED CONDUCTOR GAS INSULATED BUSDUCT(GIB) WITH CHARGE SIMULATION METHOD

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ABSTRACT: Present paper deals with the movement of free conducting particles inside a single phase Gas Insulated Busduct. A two dimensional mathematical model has been proposed for determining the movement pattern of a metallic particle in a Gas Insulated Busduct by considering all the forces acting on the particle. The particle resting on the inner side of the outer enclosure is chosen. The forces like gravitational, drag and the electrostatic are functions of particle geometric parameters, electrostatic charge acquired by the particle and the electric field at the particle location, the drag coefficient and Reynold's number. The coefficient of restitution of particle was considered at every impact with the enclosure of Gas Insulated Busduct. The second order differential equation for the particle motion is solved iteratively. Electric fields at the instantaneous particle locations were computed using the Charge Simulation Method(CSM). The movements of metallic particle were compared with analytical field calculation and charge simulation field calculation methods. It is observed from the results, the movement for analytical method is more than the charge simulation method. The simulation carried out for various bus configurations with different aluminium and copper particles inside 100kV, 132kV, 145kV and 175kV class. The results have been analyzed and presented in this paper.

I INTRODUCTION

Conventional air insulated substations have many problems such as pollution by salt or dust, meteorological difficulties, safety and also suffer variations in the dielectric capability of air to withstand varying ambient conditions and deterioration of the exposed components due to oxidization and the corrosive nature of the environment. The size of the sub-station is also substantial due to the poor dielectric strength of air. Hence there is a need to replace the conventional transmission lines and substations with underground cables and Gas Insulated Substations (GIS).

Electrical insulation performance of compressed gas insulated sub-station is adversely affected by metallic particle contaminants. SF6 gas has very high dielectric strength, but withstand voltage of GIS is drastically reduced due to the presence of metallic particles which may lead to high electrical stress and thus micro discharges[1,2,7]. Free conducting metallic particles, depending upon their location, shape, size and electric field, may lead to serious deterioration of the dielectric strength of the GIS system and also one of the major factors which causing breakdown of the system and leading to unexpected breakdown in power.

Free conducting particles may have any shape or size, may be spherical or filamentary (wire like) or in the form of fine dust and may be free to move or may be fixed on to the surfaces. Free wire like particles made of conducting material is more harmful and their effects are more pronounced at higher electric fields [5,7]. The origin of these particles may be from the manufacturing process, from mechanical vibrations or from moving parts of the system like breakers.

The work reported in this paper deals with the effect of electric field on movement of metallic particle in single phase isolated conductor Gas Insulated Bus duct. An advanced C language software program is developed for computation of instantaneous electric field based on CSM and particle movement in a single phase Gas Insulated Bus duct. The particle movement further depends on the charge acquired by the particle due to macroscopic field at the tip of the particle, the force exerted by the electric field on the particle, drag due to viscosity of the gas and random behavior during the movement. Wire like particles of aluminum and copper of a fixed geometry in a single phase bus duct have been considered and in order to determine the axial and radial movement in an enclosure, Monte-Carlo technique has been adopted in conjunction with motion equation with the assumption that at every time step the particle can have a maximum movement in a solid angle of 1^0 from vertical.

II MODELING TECHNIQUE OF GIB

For this study a typical horizontal busduct comprising of an inner conductor and an outer enclosure, filled with SF6 gas as shown in figure.1 is considered.

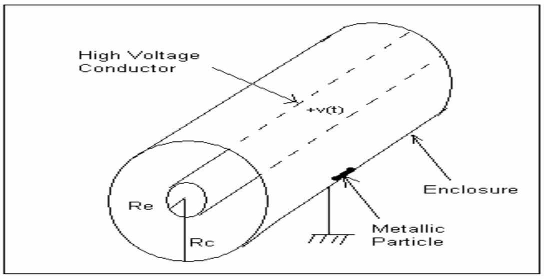

Figure 1: Typical Single Phase Gas Insulated Busduct

A wire like contaminated metal particle is assumed to be at 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 simulation considers several parameters such as the macroscopic field at the location of the particle, its weight and 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. 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 et.al. [6]. The gravitational force acting on a particle of mass 'm' is given by

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

Where F_g = gravitational force on metallic particle, g = acceleration due to gravity.

The expression for the electrostatic force acting on metallic particle is given by

$$F_e = KQE \qquad (2)$$

Where Fe is Electrostatic Force, K is the correction factor less than unity, Q is the particle charge, E is the ambient electric field.

E(t) is ambient electric field at any time 't' in a co-axial electrode system and can be calculated either by using analytical method or by using charge simulation method.
In analytical method ambient electric field at any time in single phase Gas Insulated Busduct can be calculated by using following equation,

$$E(t) = \frac{V \sin \omega t}{[\mathrm{Re} - y(t)] \ln \left[\frac{\mathrm{Re}}{Rc} \right]} \qquad (3)$$

Where V Sin ωt is the supply voltage on the inner electrode, R_e is the enclosure radius, R_c 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.

From the dynamics of a metallic particle in a coaxial electrode system, movement of contaminated metallic particle in a Gas Insulated System can be determined. By calculating the metallic particle movement pattern, the probability of particle crossing a coaxial gap and causing a flashover can be estimated. The lift-off field required by the particle resting on the inner surface of the outer enclosure electrode can be estimated by solving the metallic particle motion equation. A conducting metallic particle moving under the external electric field will be subjected to Electrostatic force (F_e), Gravitational force (F_g) and Drag force (F_d).

The movement pattern of the particle is simulated by using following the motion equation:

$$m \frac{d^2 y}{dt^2} = F_e - mg - F_d \qquad (4)$$

Where m = mass of the particle, y = displacement in vertical direction, Fe = Electrostatic force, g = gravitational constant, F_{d} = Drag Force.

The motion equation using all forces can therefore be expressed as[3,4]:

$$m \ \ddot{y}(t) = \left[\frac{\Pi \varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \times \frac{V \sin \omega t}{[r_0 - y(t)] \ln\left(\frac{r_0}{r_i}\right)} \right]$$

$$- mg - \dot{y}(t) \Pi r \left[6 \mu K_d \left(\dot{y} \right) + 2.656 \left[\mu P_g l \dot{y} \right]^{0.5} \right] \qquad (5)$$

The above equation is a second order non-linear differential equation and it is solved by using Runge- Kutta 4th Order Method.

III SIMULATION OF PARTICLE MOTION

The study of the motion of moving metallic particles in GIS requires a good knowledge of the charge acquired by the particle and electrostatic field present at the metallic particle location. The equations are primarily based on the work of Felici et.al [10]. The electric field at the metallic particle location is calculated using Charge Simulation Method based on the work of Nazar H. Malik et.al[8] and H.Singer[9] and also with analytical electric field calculation method using equation (3). The charge acquired and movement of the particle is determined for the electric fields calculated by analytical field calculation method and charge simulation methods separately.

Charge Simulation Method: Figure. 2 depicts basic concept behind the calculation of ambient electric field at any time in single phase Gas Insulated Busduct using charge simulation method[8,9].

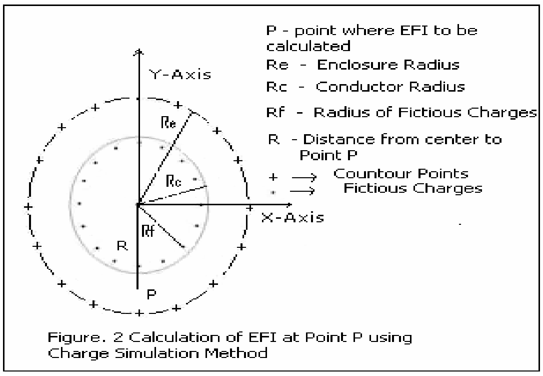

Figure. 2 Calculation of EFI at Point P using Charge Simulation Method

Figure 2: Calculation of Electric Field Intensity at Point ‘p’ using Charge Simulation Method.

The Electrostatic field at point ‘p(x,y)’ in figure. 2 is calculated by using the following equation

$$E_x(t) \;=\; \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[\frac{x - x_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}} \right] Sin \quad \omega t \tag{6}$$

$$E_y(t) \;=\; \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[\frac{y - y_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}} \right] Sin \quad \omega t \tag{7}$$

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[9]. Fictitious charges with assignment factor[8,9] are considered inside of inner conductor of GIB for calculating electric field in Charge Simulation Method.

Monte-Carlo Technique: The motion equation of metallic particle is solved by using RK 4^{th} Order method and it gives movement in the radial direction only. The Axial movement of the metal particle is calculated by using Monte-carlo Technique based on the works of J.Amarnath et.al[3,4].

Computer simulations of motion for the metallic wire particles were carried out using Advanced C Language Program in GIB with inner conductor diameter 55mm and enclosure diameter of 152mm for 100kV, 132kV, 145kV and 175kV applied voltages. Aluminum and copper wire like particles were considered to be present on enclosure surface.

IV RESULTS AND DISCUSSIONS

The results are obtained by solving metallic particle motion equation using RK 4^{th} order method and Monte-Carlo Technique for aluminium and copper particles. The Electric fields are determined by using analytical field calculation method as given by equation (3) and Charge Simulation Method by using equations (6) and (7).

Table 1 and Table 2 are showing the movement pattern of aluminium and copper particles for power frequency voltages. 1024 factitious charges with assignment factor of 1.5 are considered for calculating electric field with charge simulation method in single phase GIB.

During application of power frequency voltage, the moving metallic particle makes several impacts with the enclosure and the maximum radial movement increases with increase of applied voltage. For Aluminium metallic particles with electrical field calculated by using analytical method, the maximum radial and axial movements are 30.84 mm and 778.03 mm for 100kV and these radial and axial movements increase with increase of applied voltage. For 175kV, Aluminium particle crosses the gap between enclosure and inner conductor of GIB. For electric field determined by using Charge Simulation Method, maximum radial and axial movements of Aluminium particles are 7.04 mm and 207.04 for 100kV. These radial and axial movements are increasing with increase of applied voltage and reaching maximum values of 20.65 mm and 515.46 mm for 175kV. Table 1 shows the maximum radial and axial movements for aluminium particles for different volages. Similarly for Copper particle with electric field determined by analytical method, the maximum radial and axial movements are 10.04 mm and 68.61 mm where as there is no movement either in radial or axial direction with electric field computed by using charge simulation method. The maximum radial and axial movements of Copper particle are increasing with increase of voltage and for 175kV these maximum movements are reaching 23.58 mm and 145.06 mm for analytically calculated electric field and 6.29 mm and 134.01 mm for electric field determined by using Charge Simulation Method. Table. 2 represents Copper particle maximum radial and axial movement for different voltages.

The radius of aluminium and copper particles in all cases are considered as 0.2 mm, length of the particle as 12 mm, restitution coefficient[4,5] is 0.9 and SF_6 gas pressure is 0.4MPa.

Table 1. Maximum Radial and Axial Movement of aluminum particles with electric fields calculated using by analytical method and Charge Simulation Method.

Sl. No.	Volt-age in kV	Movement with analytical method in mm		Movement with CSM in mm	
		RM	AM	RM	AM
1	100	30.84	778.03	7.04	207.67
2	132	49.75	1011.08	13.43	349.63
3	145	59.81	998.49	15.75	394.29
4	175	*CG	*CG	20.65	515.46
RM – Radial Movment AM – Axial Movement *CG – Crossing Gap					

Table 2. Maximum Radial and Axial Movement of copper particles with electric fields calculated using by analytical method and Charge Simulation Method.

Sl. No.	Volt age in kV	Movement with analytical method in mm		Movement with CSM in mm	
		RM	AM	RM	AM
1	100	10.04	68.61	*NM	*NM
2	132	16.07	234.52	2.92	33.87
3	145	18.5	187.01	3.72	102.93
4	175	23.58	145.06	6.29	134.01
RM – Radial Movement AM – Axial Movement *NM – No Movement					

Figure 3 to Figure 9 shows the movement patterns of copper and aluminum particles in Electric Field calculated by using Charge Simulation Method for power frequency voltages of 100kV, 132kV, 145kV and 175kV rms respectively.

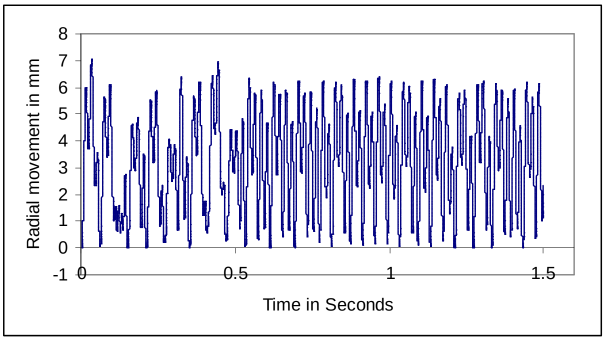

Figure 3: Al particle movement for 100kV

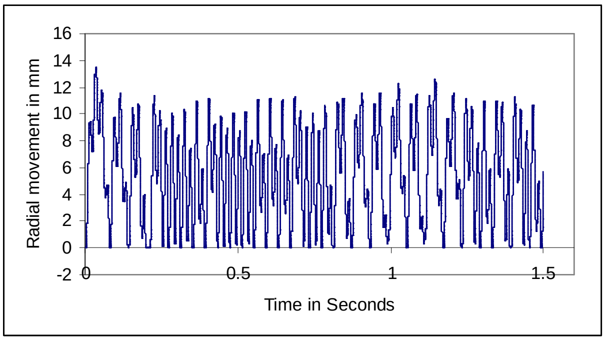

Figure 4: Al particle movement for 132kV

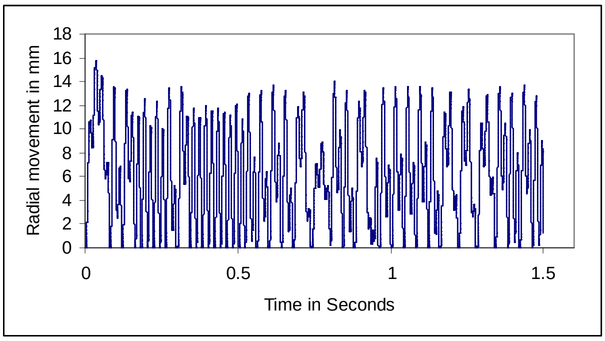

Figure 5: Al particle movement for 145kV

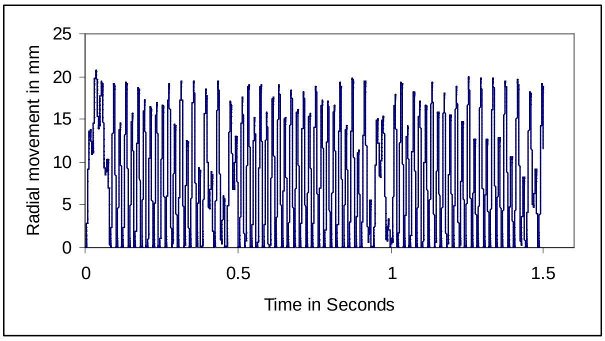

Figure 6 Al particle movement for 175kV

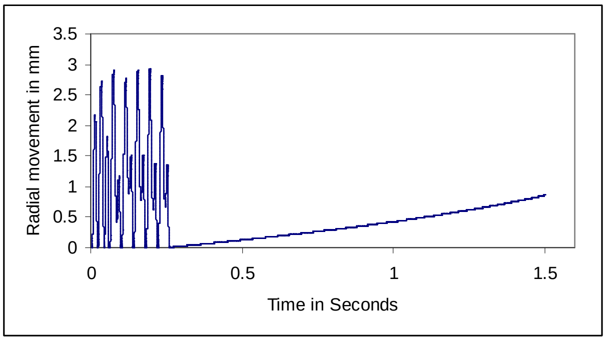

Figure 7: Cu particle movement for 132kV

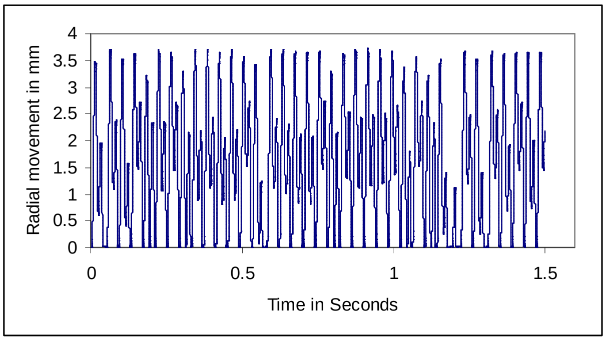

Figure 8: Cu particle movement for 145kV

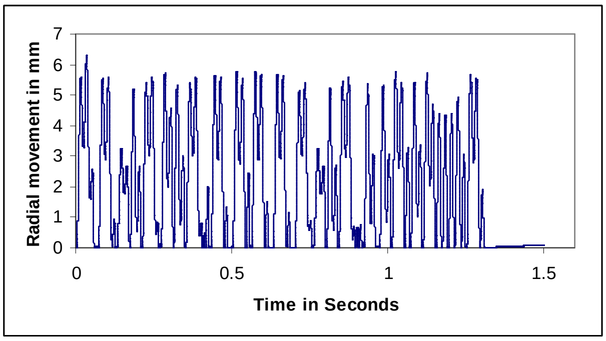

Figure 9: Cu particle movement for 175kV

Figure 10 and Figure 11 show movement pattern of Aluminium particle for 100kV and 132kV and Figure 12 to Figure 14 represent movement pattern of copper particle for 132kV, 145kV and 175kV in analytically calculated electric field.

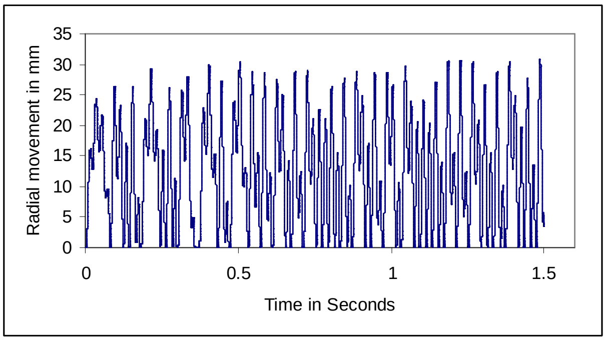

Figure 10: Al particle movement for 100kV

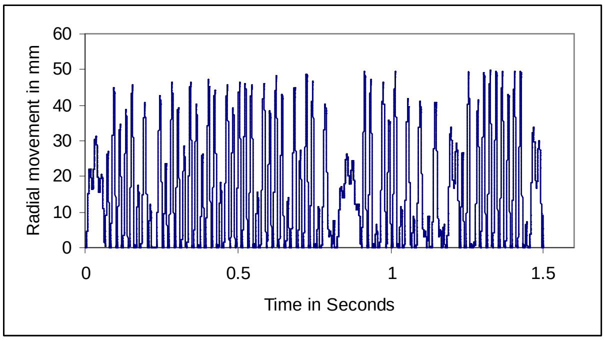

Figure 11: Al particle movement for 132kV

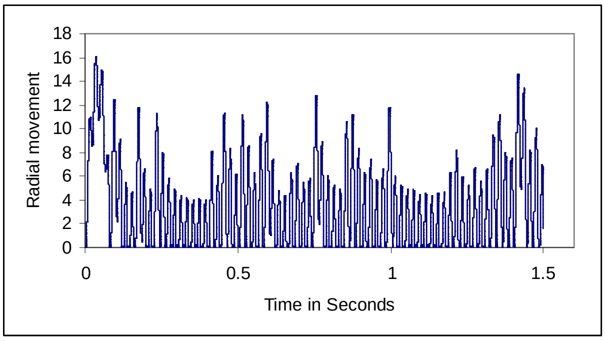

Figure 12: Cu particle movement for 132kV

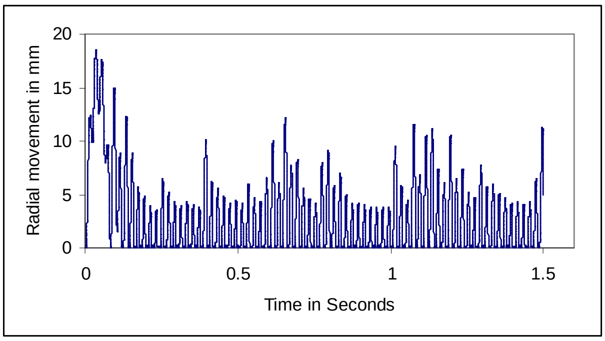

Figure 13: Cu particle movement for 145kV

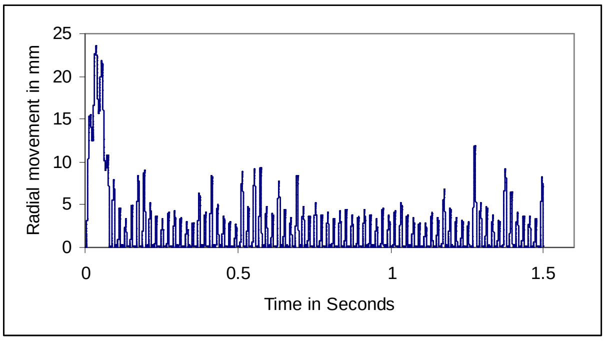

Figure 14: Cu particle movement for 175kV

V CONCLUSION

A model has been formulated to simulate the movement of wire like particle under the influence of electric field in single phase Gas Insulated Busduct. When electrostatic force exceeds the gravitational and drag forces the particle lifts from its position. A further increase in the applied voltage makes the particle to move into the inter electrode gap in the direction of applied field. At every voltage level the maximum movement of metallic particle is less when electric field is calculated with charge simulation method rather than analytical method. Maximum movement of this metallic particle increases the probability of a flashover. The influence of increased voltage level on the motion of the metal particles is also investigated. If the calculations, as described above, are performed at a higher voltage level, the particle will lift higher from the surface and the time between bounces will increase. The results obtained from the calculations show that additional information about the particle which could be obtained when voltage dependence is introduced in the calculations.

For instance, it can be noted that aluminum particles are more influenced by the voltage than copper or silver particles due to their lighter mass. This results in the aluminum particle acquiring greater charge-to-mass ratio. The coefficient of restitution, which denotes the ratio of outgoing to incoming velocities, is of vital importance for determining the maximum movement of particle. The results obtained are presented and analyzed. Monte-Carlo simulation is also adopted to determine axial as well as radial movements of particle in the busduct. Also it is observed that particle maximum movement in electric field calculated by using analytical method is more than the maximum movement in electric field calculated by using charge simulation method. All the above investigations have been carried out for various voltages under power frequency.

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