Dynamics of Metallic Particle Contamination in Gas Insulated Substation (GIS)

K B V S R Subrahmanyam
EEE Dept, Vaagdevi College of Engineering, Warangal-506005, AP, India, libra_22@rediffmail.com

J. Amarnath
EEE Dept, J N T U H College of Engineering, Hyderabad-500085, AP, India, amarnathjinka@yahoo.com

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K B V S R Subrahmanyam[1], J.Amarnath[2]

[1] EEE Dept, Vaagdevi College of Engineering, Warangal-506005, AP, India
[2] EEE Dept, J N T U H College of Engineering, Hyderabad-500085, AP, India
E-mail: libra_22@rediffmail.com , amarnathjinka@yahoo.com

Abstract: This paper analyses the movement of free conducting particles inside a single phase Gas Insulated Bus duct(GIB).A two dimensional mathematical model was proposed for determining the movement pattern of metallic particle in GIB by considering all the forces acting on the particle like gravitational, drag and the electric field forces. These particles may be free to move in the electric field or may be fixed on the conductors, thus enhancing local surface fields. Electric fields at the instantaneous contaminated particle locations were computed using Charge Simulation Method (CSM).To determine the particle trajectory in a single phase Gas Insulated Bus duct (GIB), an enclosure diameter 152 mm and conductor diameter 55 mm is considered. The simulation of the particle movement was carried under different AC voltage levels like 100KV, 132KV, 145KV and 175KV class enclosure of GIB for aluminum, copper and silver particles. The results of the simulation have been presented and analyzed in this paper.

Keywords: Electric field, Gas insulated substations, Metallic particles, Particle contamination, Gas insulated bus duct.

I. INTRODUCTION

Air insulated power transmission and distribution substations have many problems such as pollution by salt or dust, meteorological difficulties, safety and 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. In order to enhance the life and reliability of a power transmission and distribution sub-station, it is desirable to protect the substation components from a corrosive and oxidizing environment. So there is a need to replace the conventional transmission lines and substations with underground cables and Gas Insulated Substations (GIS).The sensitivity of high pressure SF_6 gas to conducting metallic particles and dust is a serious limitation for practical applications. The insulation strength of compressed SF_6 is greatly reduced by the contamination in the form of conducting particles. Electrical insulation performance of compressed GIS systems is adversely affected by metallic particle contaminants. The accumulated field experience indicates that sources for such contamination are mechanical abrasions, movement of conductors under load cycling and vibration during shipment and service. These particles may be free to move in the electrical field or may be fixed to the conductors thus enhancing local surface fields.

In a horizontal co-axial system with the particles resting on the inside surface of the enclosure, the motion of such particles is random in nature. The dynamics of wire like particles in a horizontal co-axial system are studied because they approximately correspond to the type of particles encountered in practice. under an applied electric field, a conducting particle resting on the outer enclosure acquires a charge and lifts against the gravitational force when the electrostatic force is sufficiently high. So wires like particles made of conducting material are more harmful and their effects are more pronounced at higher gas pressures. Wire like particles of aluminum, copper and silver of 10mm in length and 0.25 mm as radius on a 1-phase bus duct enclosure have been considered. Some of the methods of conducting particle control and deactivation are:

· Electrostatic trapping
· Use of adhesive coatings to immobilize the particles
· Discharging of conducting particles through radiation,
· Coating conducting particles with insulating films

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 (GIB). An advanced C language software program is developed for computation of instantaneous electric field based on Charge Simulation Method(CSM) [2,3]and particle movement in a single phase Gas Insulated Bus duct. The particle trajectory was computed for copper, aluminum and silver wire like particles for different voltage levels. The results have been presented and analyzed in this paper.

II.   MODELING TECHNIQUE OF GIB

For the present study, a typical 1-phase horizontal   Gas Insulated bus duct has been considered. The diameter of the enclosure has been considered to be 152mm with the conductor diameter of 55mm.
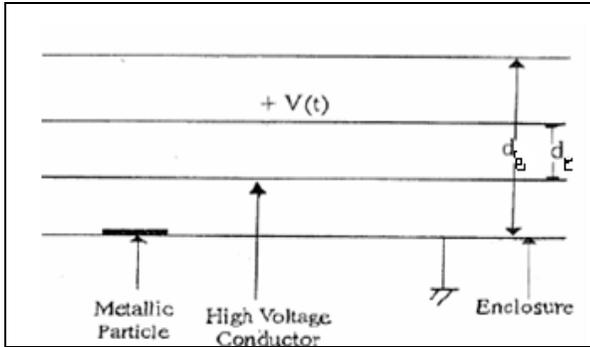

Fig.1 Schematic Diagram of a typical Single Phase Gas Insulated Bus duct

A particle (wire) 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 e.g.: the macroscopic field at the location of the particle, its weight, viscosity of the gas, Reynolds'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. The lift-off field for a particle on the surface of an electrode can be estimated by solving the following equations. The electrostatic force acting on a particle of mass 'm' is given by

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

Where Fg = Gravitational force

g=acceleration due to gravity

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

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

Where

K is the correction factor less than unity

Q is the particle charge

E is the ambient electric field.

Ambient Electric Field in a co-axial electrode system can be expressed as

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

VSinwt 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.

The motion equation of a particle with a mass m, can   be expressed as:

$$m\, d^2y/dt^2 = Fe - mg - F_d \qquad (4)$$

Where Fd is drag force, y is the direction of motion (vertical axis).

Electrostatic Force:

From the equation the charge acquired by a vertical wire like particle in Contact with a bare enclosure can be expressed as

$$Q_{net} = \frac{\pi \in_0 l^2 E(t_0)}{\ln\left(\dfrac{2l}{r}\right) - 1} \qquad (5)$$

Where Qnet is the charge on the particle until the next impact with the enclosure, l is the particle length, r is the particle radius, E(t0) is the ambient electrical field at t =t0.

Drag force:

$$F_d = \dot{y}\, \pi r \left(6\mu K_d(\dot{y}) + 2.656\left[\mu \rho_g\, l\dot{y}\right]^{0.5} \right) \qquad (6)$$

where

y - is the velocity of the particle, α - is the viscosity of the fluid ,r - is the particle radius, ρg - is the gas density, l - is the particle length, Kd (y) - is a drag coefficient.
The influence of gas pressure on the drag force is given by empirical formula.

$$\rho g = 7.118 + 6.332p + 0.2032p \qquad (7)$$

where ρg= density ,p = Pressure of the gas. So, two initial conditions are necessary for solving m.y(t = 0+) = −Rm.y(t = 0)and y(t = 0+) = 0 where R is the restitution coefficient given by the ratio of incoming-to-outgoing impulses.

The motion equation using all forces can therefore be expressed as:

$$m\ddot{y}(t) = \left[\frac{\pi \epsilon_0 \, l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \times \frac{V \sin\omega t}{[r_0 - y(t)] \ln\left(\frac{r_0}{r_i}\right)} \right] - mg$$

$$- \dot{y}(t) \, \pi \, r \left(6 \mu \, K_d \, (\dot{y}) + 2.656 \left[\mu \, \rho_g \, l \, \dot{y} \, (t) \right]^{0.5} \right)$$

(8)

The above equation is a second order non-linear differential equation. It can be solved by using iterative methods .The equation is solved by using Runge-Kutta4thOrderMethod.

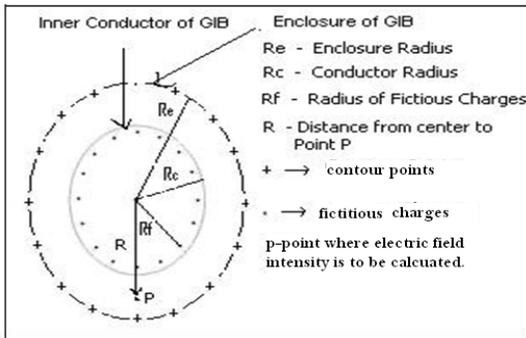### III. CHARGE SIMULATION METHOD

Basic Principle :

Fig 2.Concept of Charge Simulation Method (CSM)

The basic principle of conventional CSM is very simple. For the calculation of electric fields, the distributed charges on the surface of the electrode are replaced by N infinite length line charges placed inside the electrode as shown in Fig. 2. The types and positions of these fictitious charges are predetermined but their magnitudes are unknown. In order to determine their magnitude some selected points called contour points are selected on the surface of electrode. In the conventional CSM, the number of contour points is selected equal to the number of fictitious charges. Then it is required that at any one of these contour points ,the potential resulting from superposition of all the fictitious charges is equal to the known electrode potential. Let, Q_j be the jth fictitious charge and V be the known potential of the electrode. Then according to the superposition principle:

$$\sum_{j=1}^{N} P_{ij} Q_j = V \tag{9}$$

where P_{ij} is the potential coefficient, which can be evaluated analytically for different types of fictitious charges by solving Laplace's equation. When Eqn. (9) is applied to N contour points, it leads to the following system of N linear equations for N unknown fictitious charges, then

$$[P]_{NxN} \, [Q]_N = [V]_N \tag{10}$$

Where
$[P]$ = potential coefficient matrix,
$[Q]$ = Column vector of unknown charges
$[V]$ is the column vector of known potentials at the contour points

Eqn. (10) is solved for the unknown fictitious charges. As soon as the required charge system is determined, the potential and the field intensity at any point, outside the electrodes can be calculated.

The expressions for the field co-efficient at any point 'p(x,y)' is calculated by using following equations:

$$E_x = \sum_{J=1}^{N} \frac{\lambda_J}{2\pi\varepsilon} \left[\frac{x - x_J}{\sqrt[3]{(x - x_J)^2 + (y - y_J)^2}} \right] \tag{12}$$

$$E_y = \sum_{J=1}^{N} \frac{\lambda_J}{2\pi\varepsilon} \left[\frac{y - y_J}{\sqrt[3]{(x - x_J)^2 + (y - y_J)^2}} \right] \tag{13}$$

Where λ_j is the j_{th} infinite line charge density and x,y are coordinates of point 'p' where EFI(Electric Field Intensity) is to be calculated ,(xj,yj) is j_{th} line charge coordinates and ε- absolute permittivity of the medium. The error in the CSM depends up on the type, number as well as the locations of the simulation charges, the locations of the contour points and the complexities of the profile of the electrodes and the dielectrics. In the present work, 1500 fictitious charges (N=1500) were considered with fixed assignment factor (λ) of 1.5.

IV. RESULTS AND DISCUSSIONS

The Electric fields are determined by using analytical field calculation method as given by equation (3) and Charge Simulation Method by using equations (12) and (13) based on the work of Nazar H. Malik et.al [2] and H.Singer et.al[3].By solving the metallic particle motion

equation using RK fourth order, results are obtained. Computer simulations of the motion of metallic wire like particles were carried out on GIB of 55mm inner diameter and 152mm outer diameter. Particles of size 10mm in length and 0.25mm as radius for applied voltages of 100KV,132KV,145KV and 175KV in a single phase uncoated GIB is taken for determining the movements of aluminum, copper and silver particles.

The maximum movement of aluminum, copper and silver particles for applied voltages of 100KV, 132KV, 145KV and 175KV is given in Table 1. Figs 3 to Fig.8 show the movement patterns of aluminum, copper and silver particles with the application of power frequency for 152/55mm bus duct for 100kV,132kV,145kV and 175KV.It can be observed from the simulation results that at higher voltage levels, movement increases rapidly especially for aluminum particle due to its lighter weight than copper and silver particles.

Fig 3. Movement of Aluminum particle for 100kV, 152/55mm Diameter.

Table 1. Movement of Aluminum, Copper, and Silver Particles in a Single Phase 152/55mm GIB.

N.M-No Movement

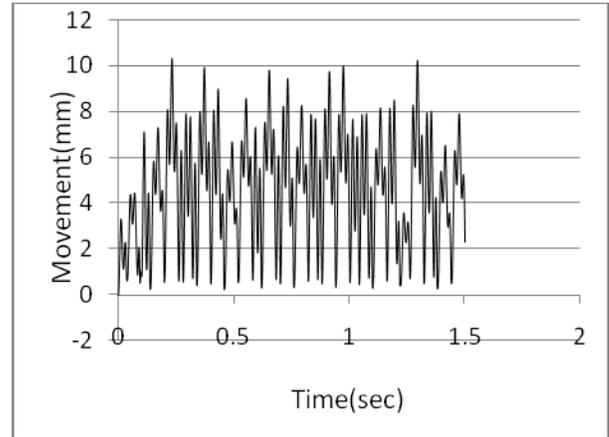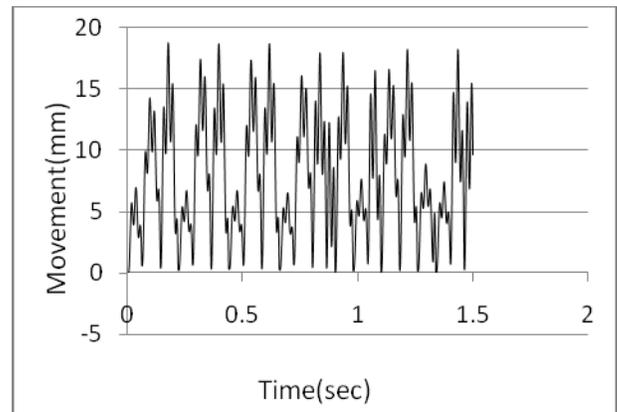| Voltage (KV)	Type of the particle	Max. Movement(mm) 152/55mm Enclosure
100	Al	10.31
	Cu	N.M
	Ag	N.M
132	Al	18.74
	Cu	N.M
	Ag	N.M
145	Al	22.05
	Cu	N.M
	Ag	N.M
175	Al	27.2
	Cu	8.52
	Ag	6.61

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Fig 4. Movement of Aluminum particle for 132kV, 152/55mm Diameter.

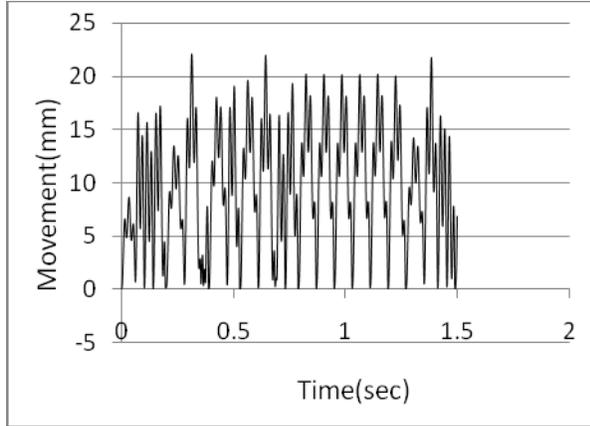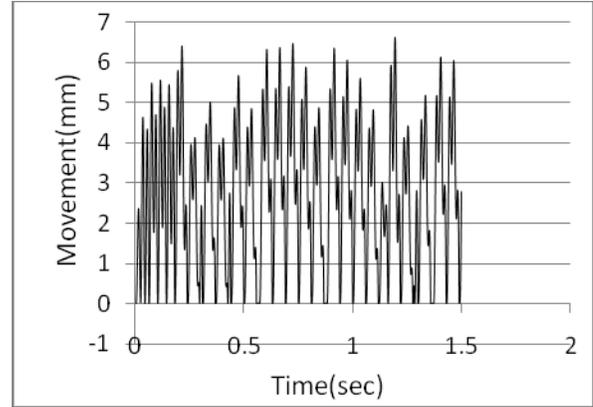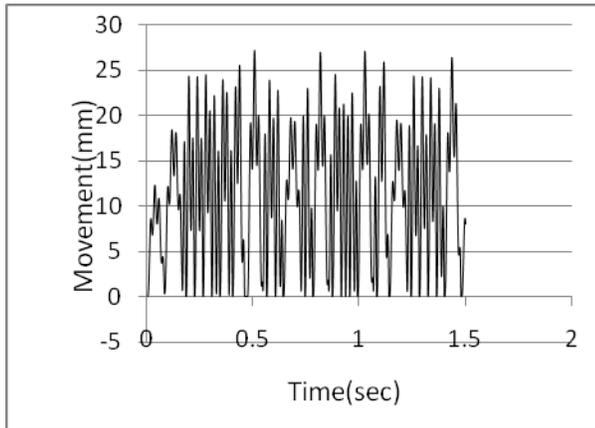**Fig 5**. Movement of Aluminum particle for 145kV, 152/55mm Diameter.

Fig. 6. Movement of Aluminum particle for 175KV, 152/55mm Diameter.

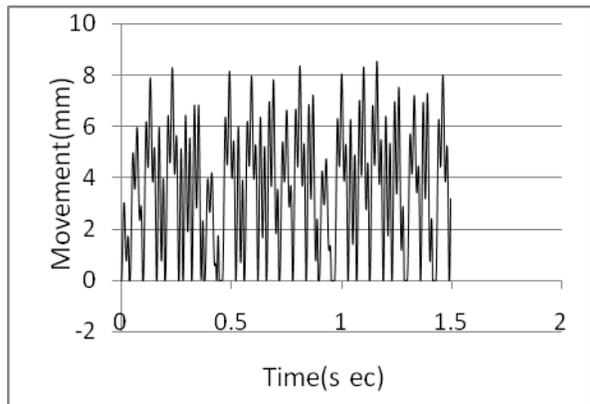**Fig. 7**. Movement of Copper particle for 175KV, 152/55mm Diameter.

Fig.8 Movement of Silver particle for 175KV, 152/55mm Diameter.

V. CONCLUSION

In the present work, modeling and simulation of particle trajectory of a single phase GIB with CSM has been proposed. It can be noted from table 1. Peak movement for aluminum particle is higher than that of copper and silver particles. This behavior is due to heavy weight of copper and silver particles than those of aluminum of same size. The movement patterns of Aluminum, Copper and silver metallic particles at 100kV ,132kV,145kVand175kV under power frequency on the particle have been studied by developing an advanced C- language software program. It can also be noted that aluminum particles are more influenced by the voltage than copper or silver particles due to their lighter mass. The results for various voltages like 100KV,132KV, 145KV,175KV have been analyzed and presented in this paper.

ACKNOWLEDGEMENT

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