# Image Charge Effect on Metallic Particle in Single Phase Gas Insulated Busduct (GIB)

K B V S R Subrahmanyam [1], J.Amarnath [2]
[1] Vaagdevi College of Engineering, Warangal, AP, India
[2] J N T U H College of Engineering, Hyderabad, AP, India
Email: libra_22@rediffmail.com
amarnathjinka@yahoo.com

**ABSTRACT:** Present paper analyses effect of image charge on the movement of free conducting particles inside a 1-phase Gas Insulated Bus duct. A two dimensional mathematical model was proposed for dynamic simulation of particle movement inside the enclosure by taking into account all the forces acting on the particle, gravitational, drag and the electric field forces. These forces are functions of particle geometric parameters, electrostatic charge acquired by the particle and the electric field at the particle location, the drag coefficient and Reynolds's number by using Charge Simulation Method(CSM). The results have been presented and analyzed in this paper.

## INTRODUCTION

Demand for electrical power has become one of the major challenges faced by the developing countries like India. Hence, the emphasis has shifted towards improving the reliability of transmission and distribution systems and ensuring that the innovations are not harmful to the environment.

Rapid urbanization and overgrowing population is making the task of expanding transmission network very difficult due to right of way problem and limited space availability. In addition, conventional air insulated substations have many problems such as pollution by salt or dust, meteorological difficulties, safety etc. Hence, there is a need to replace the conventional transmission lines and substations with underground cable and Gas Insulated Substation (GIS) to overcome the above problems. Due to its many advantages, most of the utilities and industrial units are opting for Gas Insulated Substations.

In our country, a few GIS units have been in operation and a large number of units are under various stages of installation. Although, GIS has been in operation for several years, some of the problems need full attention. These problems include generation of over voltages during switching operations like enclosure faults and particle contamination.

The understanding of the dynamics of a metallic particle in a coaxial electrode system is of vital importance for determining the effect of metallic contamination in a Gas Insulated bus duct. If the motion pattern of a metallic particle is known, the probability of particle crossing a coaxial gap and causing a flashover can be estimated.

In this paper to determine the particle trajectory in GIB with Charge Simulation Method[2,3] with Image Charge Effect is considered. The particle trajectory was computed for copper, aluminum and silver wire like particles. The results have been presented and analyzed in this paper.

## MATHEMATICAL MODELING.

A typical 1-phase horizontal Gas Insulated bus duct has been considered for the analysis. The diameter of the enclosure has been considered to be 152mm with the conductor diameter of 55mm.

When the electric field surrounding a particle is increased, an uncharged metallic particle resting on a bare electrode will gradually acquire a net charge. The charge accumulated on the particle is a function of the local electrical field, orientation, shape and size of the particle. When the electrostatic force exceeds the gravitational force, the particle will lift from the original position. A further increase in the applied voltage will make the charged particle move into the inter-electrode gap.

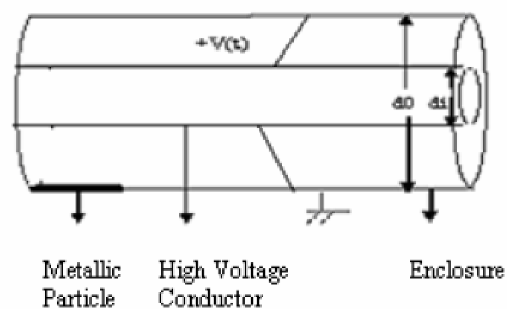


**Fig.1** Schematic Diagram of a typical Single Phase Gas Insulated Bus duct

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**

Where Fg = Gravitational force
g=acceleration due to gravity

When a particle is positioned near or on the surface of the enclosure, the image charges, due to the presence of the grounded enclosure, have to be considered. This can be realized by including a correction factor, K in the expression of the electrostatic force.

**Fe = KQE**

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

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

Where
VSinwt 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.

## SIMULATION OF PARTICLE MOTION

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

$$m\, d^2y/dt^2 = Fe - mg - F_d$$

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

$$Q_{net} = \frac{\pi \epsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1}$$

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:

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

where
y - is the velocity of the particle
α - is the viscosity of the fluid
r - is the particle radius
g - is the gas density
l - is the particle length
Kd (y) - is a drag coefficient

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

$$m\ddot{y}(t) = \left[\frac{\pi \epsilon_0 l^2 E(t_0)}{\ln(\frac{2l}{r}) - 1}\ X\ \frac{V\,Sin\omega t}{[r_0 - y(t)]\ln(\frac{r_0}{r_i})}\right] - mg$$
$$-\ \dot{y}(t)\,\pi r\left(6\mu K_d(\dot{y}) + 2.656[\mu\rho_g\, l\dot{y}\ (t)]^{0.5}\right)$$

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-Kutta 4th Order Method.

## CHARGE SIMULATION METHOD

### Basic Principle :

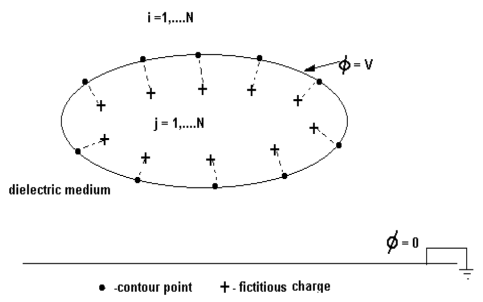


**Fig.2** Fictitious charges along with contour points for field calculation by CSM in homogeneous dielectric.

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 number of fictitious 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 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 effects 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:

$$\sum_{j=1}^{N} P_{ij} Q_j = V \qquad ... (1)$$

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. (1) is applied to N contour points, it leads to the following system of N linear equations for N unknown fictitious charges, then

$$[P]_{N\times N}\,[Q]_N = [V]_N \qquad .....(2)$$

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

Eqn. (2) 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. While the potential is found by Eqn. (1), the electric stresses are calculated by superposition of all the stress vector components.

In many cases the effect of the ground plane is to be considered for electric field calculation. This plane can be taken into account by the introduction of image charge. If floating electrodes are present, whose potentials are uniform but unknown, Eqn. (2) is modified to include the supplementary condition that the sum of inner charges on each floating electrode is zero. If the floating electrode has a net charge, the sum of its inner charges is equal to the known net charge value. In the present work,64 fictitious charges were considered with assignment factor(λ)of 1.5.

## FORMULATION FOR THE MOTION OF A PARTICLE IN GIB

Case ( i ) **: Without Image Charge effect**

A typical horizontal single-phase bus duct enclosed by the conductor 'A' shown in Figure 3 has been considered for the analysis of without Image charge effect on the particle.

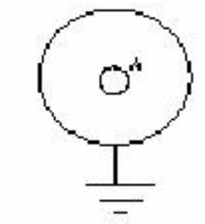


**Fig.3** A typical single phase Gas insulated bus duct

The expressions for the potential and field co-efficient are given below:

$$P_{ij} = \frac{1}{2\pi\epsilon} \ln \frac{\sqrt{(x-x_j')^2 + (y-y_j')^2}}{\sqrt{(x-x_j)^2 + (y-y_j)^2}}$$

Where
$x_j$`and $y_j$` are enclosure co-ordinates.
$x_j$ and $y_j$ are conductor co-ordinates.

$$E_x = \sum_{j=1}^{N} \frac{\lambda_j}{2\pi\varepsilon} \left[ \frac{x - x_j'}{(x-x_j)^2 + (y-y_j)^2} \right]$$

$$E_y = \sum_{j=1}^{N} \frac{\lambda_j}{2\pi\varepsilon} \left[ \frac{y - y_j'}{(x-x_j)^2 + (y-y_j)^2} \right]$$

Case (ii): **With Image Charge effect**

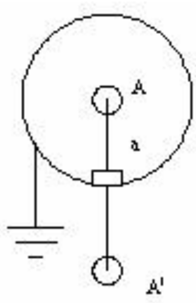


**Fig. 4** A typical single phase Gas insulated Bus duct.

Fig.4. Shows a horizontal single phase bus duct has been considered for the analysis of image charge effect. In fig.4. 'A' represents the

conductor and $A^1$ be the image of the conductor A and 'a' denotes the particle which is assigned to be at rest in the enclosure surface, just beneath the conductor A.

The expressions for the potential and field co-efficient are given below:

$$P_{ij} = \frac{1}{2\pi\varepsilon}\ln\frac{\sqrt{(x-x_j)^2+(y-y_j)^2}}{\sqrt{(x-x_j)^2+(y+y_j)^2}}$$

$$E_x = \sum_{j=1}^{N}\frac{\lambda_j}{2\pi\varepsilon}\left[\frac{(x-x_j)}{(x-x_j)^2+(y-y_j)^2}-\frac{(x-x_j)}{(x-x_j)^2+(y+y_j)^2}\right]$$

$$E_y = \sum_{j=1}^{N}\frac{\lambda_j}{2\pi\varepsilon}\left[\frac{(y-y_j)}{(x-x_j)^2+(y-y_j)^2}-\frac{(y+y_j)}{(x-x_j)^2+(y+y_j)^2}\right]$$

## RESULTS AND DISCUSSIONS

To determine the movements of aluminum, copper and silver 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 with bus duct dimensions of 152mm as outer diameter and 55mmas inner diameter is taken. The maximum movement is calculated for with Image charges and without Image charges for all the above mentioned voltages.

The maximum movement of aluminum, copper and silver particles for applied voltages of 100KV, 132KV, 145KV and 175KV is given in Table 1. Figs 5 to Fig.10 show the movement patterns of aluminum, copper and silver particles with the application of power frequency for 152/55mm bus duct for 175KV.It can be noted from Table 1. that peak movement for aluminum particle is higher than that of copper and silver particles particularly with image charges. This behavior is expected due to its lighter weight than copper and silver particles .It can also be observed that with image charge effect, the electric field is more than that of without image charges.

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

| Voltage (KV) | Type of the particle | Max. Movement(mm) 152/55mm Enclosure | |
|---|---|---|---|
| | | With Image charges | Without Image Charges |
| 100 | Al | 10.51 | 10.50 |
| | Cu | N.M | N.M |
| | Ag | N.M | N.M |
| 132 | Al | 19.13 | 19 |
| | Cu | N.M | N.M |
| | Ag | N.M | N.M |
| 145 | Al | 22.42 | 21.71 |
| | Cu | 4.528 | 4.725 |
| | Ag | N.M | N.M |
| 175 | Al | 28.54 | 27.97 |
| | Cu | 8.757 | 8.714 |
| | Ag | 6.845 | 6.984 |

N.M-No Movement

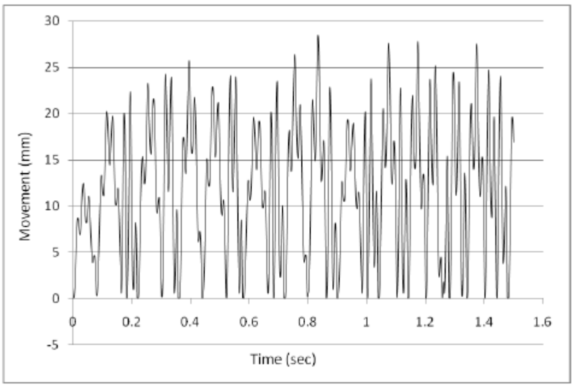


**Fig 5.** Movement of Aluminum particle for 175KV, 152/55mm Dia with Image Charges

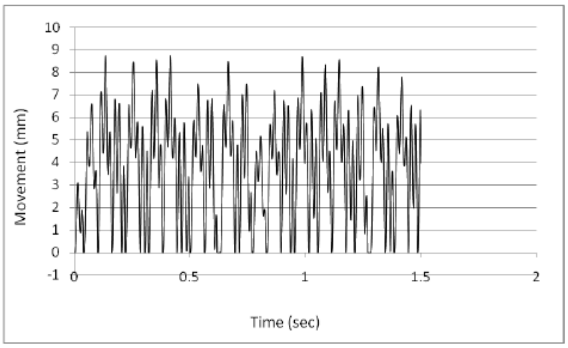


**Fig 6.** Movement of Copper particle for 175KV, 152/55mm Dia with Image Charges

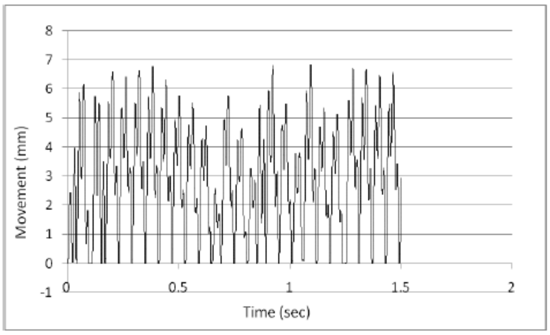


**Fig 7**. Movement of Silver particle for 175KV, 152/55mm Dia with Image Charges

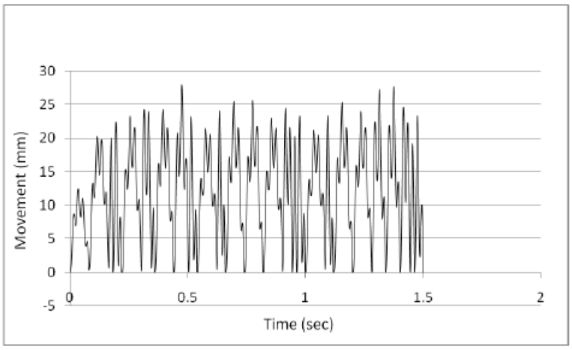


**Fig 8**. Movement of Aluminum particle for 175KV, 152/55mm Dia without Image Charges

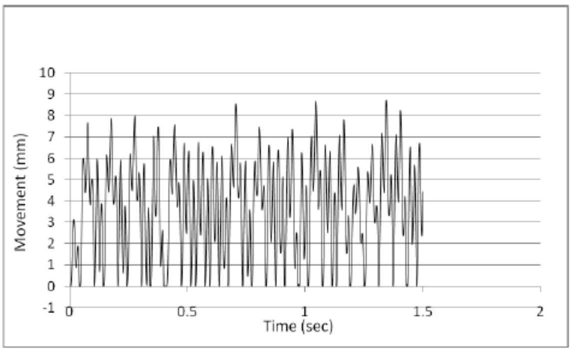


**Fig 9**. Movement of Copper particle for 175KV, 152/55mm Dia without Image Charges

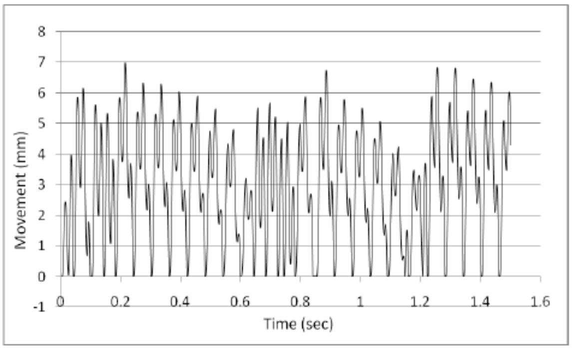


**Fig 10.** Movement of Silver particle for 175KV, 152/55mm Dia without Image Charges

## CONCLUSION

In this paper, modeling and simulation of particle trajectory of a single phase GIB with CSM has been proposed.It is observed from the results ,the field experienced for Image charge is very high compared to without image charges. consequently the movement also increase for an image charge effect. The results presented for variousvoltageslike 100KV,132KV,145KV,175KV have been analyzed. With image charge,the movement is more for higher voltages than without image charges..It is observed from the results that GIS can be operated reliably with lower voltages. Further the work can be extended to various dielectric material coatings on inner side of outer enclosure. Then the performance of GIS can be improved. Consequently GIS can be operated with higher voltages without any interruption.

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**Address of First Author:**

K.B.V.S.R.SUBRAHMANYAM
c/o Vaagdevi College of Engineering
Associate Professor, EEE Dept
Bolikunta,Waragal-506005,A.P,India.