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# Analysis of Particle Contamination in Gas Insulated Busducts Operating on High Ac Voltages

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**Abstract –** The high reliability and safety provided by the compressed gas insulated substations (CGIS) has proved that the they are more advantageous than the conventional air insulated substations. All the parts of the GIS are enclosed in metal enclosures which are filled with $SF_6$ gas, which has higher breakdown strength than air. Although superior by the performance, the metallic particle contamination greatly hinders the electrical insulation performance of the Gas insulated substations. The free conducting particles, which arise from the parts of the GIS, are commonly found on the enclosure. They move randomly and on crossing the inter electrode gap and sticking to the inner electrode, they lower the breakdown voltage of GIS. In the present work, the movement of the commonly encountered aluminum and copper wire type metallic particle contaminants of different dimensions, in a single phase gas insulated busduct, are determined, operating under various AC voltages. The simulation results are presented and analyzed.

Key words- Metallic particle contamination, Gas insulated busduct, $SF_6$ gas

## I. INTRODUCTION

Since 1960, Gas insulated substations have been making remarkable progress, being rendered practical over wide voltage ranges from 66kV to the UHV class. They are likely to be further developed toward higher voltages and larger capacities, along with improvements toward higher compactness and lower cost [1]. In Gas Insulated Substations, all the live parts namely high-voltage conductors, circuit breakers, interrupters, switches, instrument transformers and lightning arresters are enclosed in $SF_6$ gas inside grounded metal enclosures. GIS is filled with a minimum of SF6 and is of modular design. It can be used for indoor and outdoor applications [2].

A study of CIGRE group suggests that 20% of failure in GIS is due to the existence of various metallic contaminations in the form of loose particles. The presence of contamination can therefore be a problem with gas insulated substations operating at high fields. The withstand voltage of compressed gas insulated transmission lines and apparatus has been known to drop severely due to the presence within the gas of contaminating conducting particles [3, 4, 6, 7, 9]. Under appropriate conditions the particle can move into the high field region and eventually cross the inter-electrode gap, thus causing a potential insulation hazard. The movement of such particles is random, complex and dependent on several parameters such as particle geometry and material, gas pressure, electrode configuration and the applied voltage level and wave shape [4]. 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. Consequently, voltage required for breakdown of the GIS may be significantly decreased [10]. If the effects of these particles could be eliminated, then this would improve the reliability of compressed gas insulated substation. It would also offer the possibility of operating at higher fields to affect a potential reduction in the GIS size with subsequent savings in the cost of manufacture and installation [8, 11].

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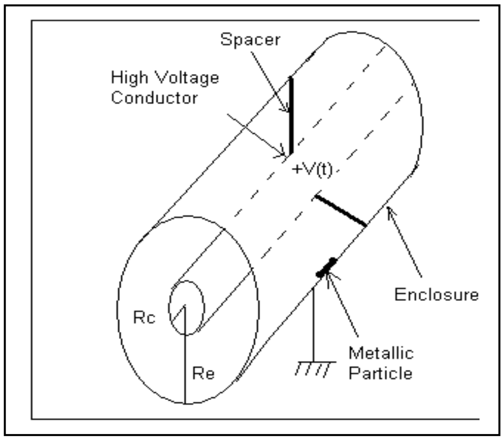


**Fig.1. Schematic diagram of a typical GIB**

In the present work, the effect of high Ac voltages on the movement of wire type aluminium and copper particles is studied in a single phase gas insulated busduct. Conventional dimensions of 241mm/89mm as the diameters of the outer enclosure and the conductor are considered. The design model is employed by most of the manufacturers, is also considered. The schematic diagram of a single phase gas insulated busduct is shown in Fig.1. The motion of the wire (particle) was Simulated using the charge acquired by the particles, the macroscopic field at the particle site, the drag coefficient, Reynold's number and coefficient of restitution [5].

## II. MODELING TECHNIQUE OF GIB

The forces acting on the metallic particle contaminants are added and the movement of the particle in the gas insulated busduct is simulated using the following equations.

A conducting particle in motion in an external electrical field will be subjected to a collective influence of several forces. The forces may be divided into:

- Electrostatic force ($F_e$)
- Gravitational force (mg)
- Drag force ($F_d$)

### A. Electrostatic Force:

The charge acquired by a horizontal wire particle in contact with naked enclosure in the presence of external electric field 'E' can be expressed as:

$$\boldsymbol{Q}_{\text{net}} = \boldsymbol{2\pi}\varepsilon_o \boldsymbol{rlE} \quad ....... \quad (1)$$

The lift-off field of ideal cylindrical horizontal wire particles with the correction factor 'K' 0.715 is given by,

$$\mathbf{E}_{\text{LO}} = \mathbf{0.84}\sqrt{\left(\frac{\rho g r}{\varepsilon_o}\right)} \quad ................ \quad (2)$$

Where $\in_0$ is the permittivity of free space?

ρ Is particle material density

r is the radius of particle

g is acceleration due to gravity

***Analytical Method:***

Disregarding the effect of charges on the particle, the electric field in a coaxial electrode system at position Of the particle can be written as:

$$E(t) = \frac{V \, \text{Sin}\,\omega t}{[r_0 - y(t)] \ln\left[\frac{r_0}{r_i}\right]} \quad ................ \quad \textbf{(3)}$$

Where V is the voltage on the inner electrode

$r_o$ is the enclosure radius,

$r_i$ is the inner conductor radius

Y (t) is the position of the particle which is the vertical distance from the surface of the enclosure towards the inner electrode.

***Charge Simulation Method:***

The Electrostatic field at point 'p(x,y)' is calculated by using the following equations:

$$E_x(t) = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[\frac{x - x_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}}\right] \quad (4)$$

$$E_y(t) = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[\frac{y - y_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}}\right] \quad (5)$$

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 number of fictitious charges per phase, $\lambda_i$ is line charge density of $i^{th}$ fictitious charge.

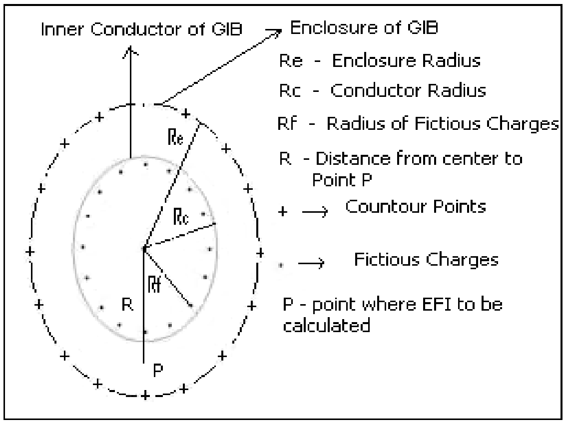


**Fig.2. Basic Concept of Charge Simulation Method**

Fictitious charges with assignment factor are considered inside of each conductor of GIB for calculating electric field in Charge Simulation Method. The electrostatic force relating charge and electric field E(t) is given by :

$$F_e = K\,Q_{net}\,E(t) \quad \text{.............................} \quad (6)$$

Where K is a correction factor smaller than unity.

*B. Gravitational Force:*

The gravitational force is given by

$$mg = \pi\, r^2\, l\, \rho\, g \quad \text{....................................} \quad (7)$$

Where r is the radius of the particle
l is the length of the particle
g is the acceleration due to gravity
ρ is the density of the particle

*C. Drag force:*

Drag is a result of energy dissipation in the shock wave near the particle and skin friction along the surface of the particle. In spherical particles shock wave energy dissipation and in wire particles skin friction is more significant. The direction of the drag force is always opposed to the direction of motion of particle.

The total drag force is given by,

$$F_d = F_{d1} + F_{d2} = \dot{y}\pi r\left(6\pi K_d(\dot{y}) + 2.656\left(\mu\rho_g l\dot{y}\right)^{0.5}\right) \quad \text{..} \ (8)$$

By considering all the forces the equation of motion can be written as

$$m\frac{d^2y}{dt^2} = F_e - mg - F_d \quad \text{..........................} \quad (9)$$

Where $F_d$ is drag force.

## III. Results and Discussions

The radial movement of the particle contaminants is obtained by solving the motion equation of metallic particle using RK 4th Order method. Computer simulations of motion for the metallic wire particles were carried out using Advanced C Language Program in GIB of inner conductor and outer enclosure diameters of 89mm/241mm for different ac voltages. Aluminum and copper particles of different dimensions were considered to be present on the surface of enclosure. Two different dimensions of the particles with 20mm/0.25mm and 15mm/0.35mm of length and radius have been considered for this study, Table I shows the maximum movement patterns of various aluminium and copper particles with radius 0.25mm and length of 20mm at different power frequency voltages. Table II show the maximum movement patterns of various aluminium and copper particles with radius 0.35mm and length of 15mm at different power frequency voltages. The maximum movement of the aluminium and copper particles was observed to be approximately same when the field is calculated using analytical method and charge simulation method. However in spite of accuracy, the charge simulation method is assumed to give accurate results. The data clearly shows that the movement of aluminium particle has increased from 6.20 mm to 92.13 mm (calculated using analytical method) when the voltage is enhanced from 72.5 kV to 300 kV. Similar is the case of copper where the movement of the particles has increased to 6.37mm at 72.5 kV to 37.26 mm at 300 kV. At low voltages the copper particles, being denser than aluminium, cease to lift from the enclosure due to low lift off fields. The data indicates that the movement of the metallic particles varies with the dimensions of the particles. The study shows that as the length of the particles increases, the maximum movement increases while it decreases with an increase in the radius of the particle.

**Table I. Particle Maximum Radial Movements at different Voltages (l=20mm, r=0.25mm)**

| Voltage (kV) | Particle type | Max. Movement with Analytical Field(mm) | Max. Movement with CSM Field(mm) |
|---|---|---|---|
| 72.5 | Al | 6.20 | 5.88 |
| | Cu | NM | NM |
| 132.00 | Al | 29.66 | 26.92 |
| | Cu | 6.37 | 5.95 |
| 145.00 | Al | 34.15 | 33.28 |
| | Cu | 8.58 | 8.32 |
| 220.00 | Al | 53.04 | 50.94 |
| | Cu | 24.67 | 23.60 |
| 245.00 | Al | 64.44 | 63.74 |
| | Cu | 29.73 | 28.65 |
| 300.00 | Al | 92.13 | CG |
| | Cu | 37.26 | 39.76 |

**Table I. Particle Maximum Radial Movements at different Voltages (l=15mm, r=0.35mm)**

| Voltage (kV) | Particle type | Max. Movement with Analytical Field(mm) | Max. Movement with CSM Field(mm) |
|---|---|---|---|
| 72.5 | Al | 3.72 | 3.61 |
| | Cu | NM | NM |
| 132.00 | Al | 16.02 | 15.34 |
| | Cu | 2.92 | 2.79 |
| 145.00 | Al | 21.18 | 19.88 |
| | Cu | 3.62 | 3.57 |
| 220.00 | Al | 42.68 | 41.60 |
| | Cu | 13.12 | 12.26 |
| 245.00 | Al | 47.11 | 46.35 |
| | Cu | 17.34 | 16.69 |
| 300.00 | Al | 57.87 | 56.56 |
| | Cu | 27.57 | 24.42 |

CG-Crossing the Gap NM-No Movement

Fig.3 to Fig.5 show the maximum movements of the particles of different dimensions at different voltages.

Fig. 6. to Fig 9. Show the variation of maximum movements of aluminium and copper particles with variation of applied voltages.

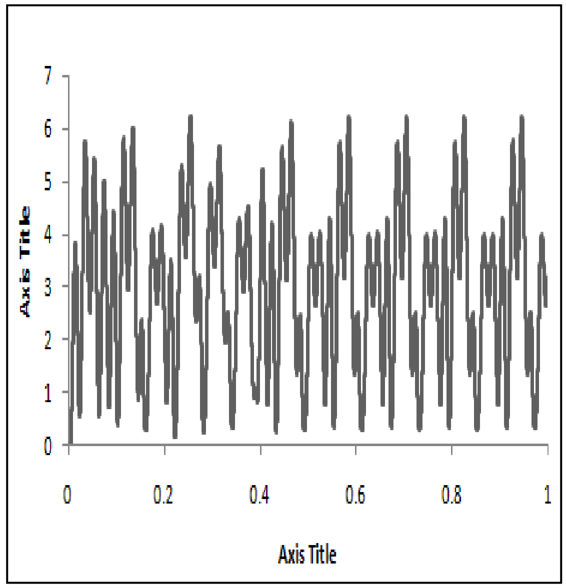


**Fig.3. Movement of aluminium particle (l=20mm, r=0.25mm) at 72.5 kV using Analytical field**

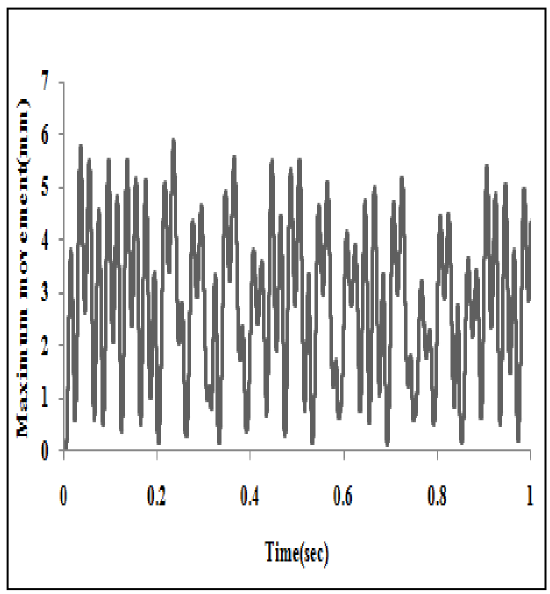


**Fig.4. Movement of aluminium particle (l=20mm, r=0.25mm) at 72.5 kV using Charge simulation method**

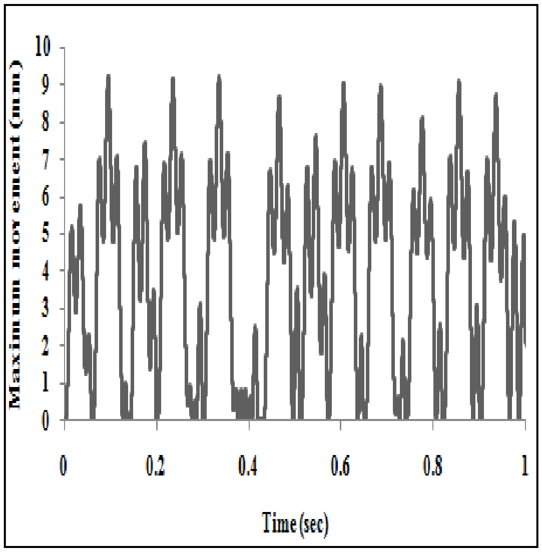


**Fig.5. Movement of copper particle (l=15mm, r=0.35mm) at 220 kV using Analytical method**

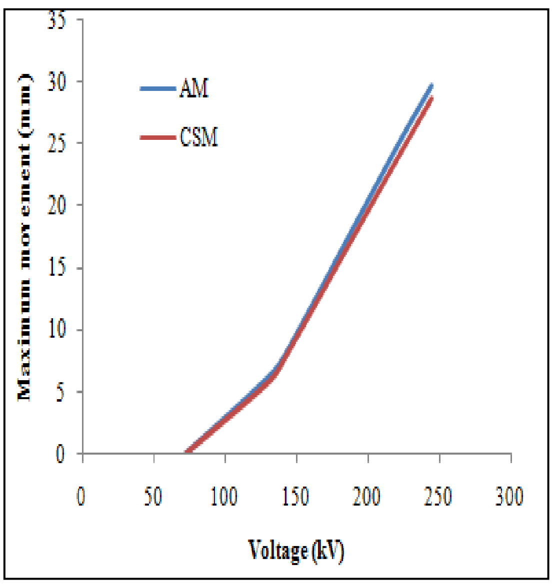


**Fig.6. Maximum movement of copper particles (l=20mm, r-0.25mm) at different voltages**

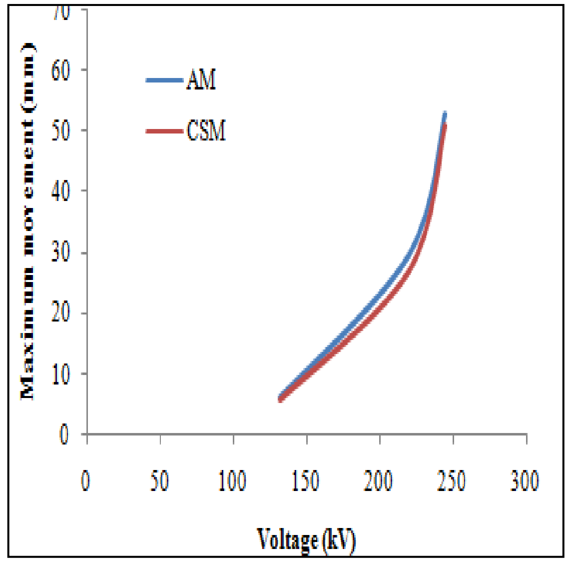


**Fig.7. Maximum movement of aluminium particle (l=20mm, r-0.25mm) at different voltages**

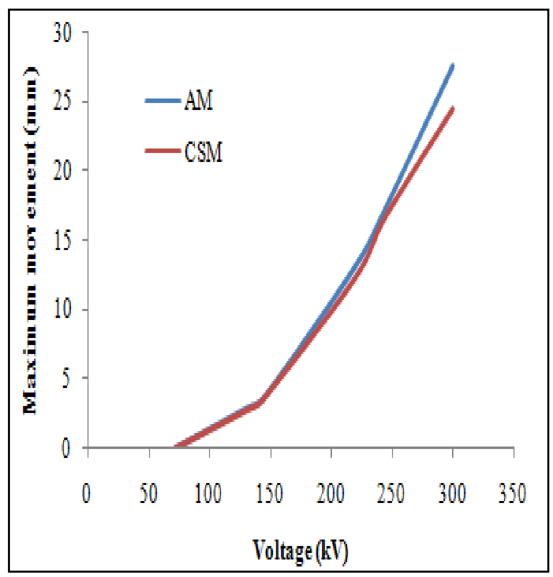


**Fig.8. Maximum movement of copper particles(r=0.25mm) of different lengths**

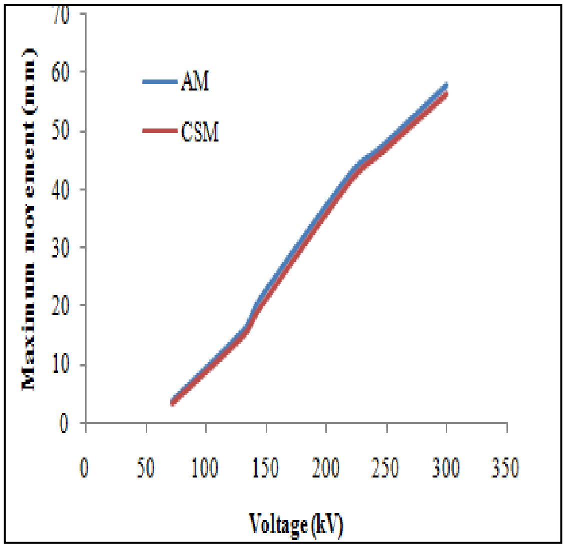


**Fig.9. Maximum movement of copper particles (l=10mm) of different radii**

## IV. CONCLUSION

The movement pattern of commonly encountered metallic particles in a 1-Ø gas insulated busduct has been simulated by formulating a mathematical model. The particles traverse longer distances at enhancing the voltage levels due to high lift off fields. Also the movement of copper particles is less when compared to that of aluminium particles because of their high density. The particles of greater lengths and lower radii are easily capable of crossing the gap between the enclosure and the conductor. The metallic particles with lower lengths and higher radii do not lift from the enclosure surface as the lift off field is higher when compared to the existing field.

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