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Effect of Particle Dimensions on Its Movement in Three Phase Gas Insulated Busduct

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Abstract
The gas insulated switchgear (GIS) provides highly reliable, high-safety compact substations by making use of the excellent insulation and the arc extinction performance of SF_6 gas. Although SF6 gas offers very excellent insulation characteristics, this very merit may serve disadvantageously, reducing insulation performance in the existence of metallic particles. Internal flashover in SF6 gas, in particular, which can lead to dielectric breakdown accidents, causes a big problem from the viewpoint of GIS reliability.
In the present work, simulation has been carried out for particle movement by using the equation of particle motion in an electric field. The effect of various parameters like radii and length of particles on various types of particles for various ac power frequency voltages has been examined and presented. The electric field effect on the particle movement requires the calculation of the electric field which is calculated by using analytical method and Charge Simulation Method (CSM). Metallic contaminations of Cu and Al have been considered for the above study. Typically a GIB of inner and outer dia 55/152mm has been considered. Particles of radii varying from 0.15 to 0.3mm and length from 8mm to 15mm have been used for simulation. Co-efficient of restitution and pressure have been held constant at 0.9 and 0.4 Mpa respectively.
Keywords: *particle contamination, CSM, analytical method*

I. INTRODUCTION

The gas insulated switchgear (GIS) provides highly reliable, high-safety compact substations by making use of the excellent insulation and the arc extinction performance of SF_6 gas. For the past 10 years in particular, GIS's 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. Although SF_6 gas offers very excellent insulation characteristics, this very merit may serve disadvantageously, reducing insulation performance in the existence of metallic particles. Internal flashover in SF_6 gas, in particular, which can lead to dielectric breakdown accidents, causes a big problem from the viewpoint of GIS reliability. Thus, extensive studies have been conducted on the insulation characteristics with metallic particles included in the GIS; however, they are mostly related to single-phase buses. Although 3-phase buses are expected to soon prevail, there are few reports on 3-phase buses. On the other hand, for the reason of its compactness and low cost, application of the 3-phase GIB has been increasing; it will have greater importance in the future.

Metallic particles in GIB / GIS have their origin mainly from the manufacturing process or they may originate from moving parts of the system, such as breakers and disconnectors. They may also originate from mechanical vibrations during shipment and service or thermal contraction or expansion at joints. Metallic particles can be either free to move in annular gap or they may be stuck either to the conductor electrodes or to an Insulator surface (spacer, busing etc.). If metallic particle crosses the gap and comes into contact with the inner electrode, the particle acts as protrusion on the surface of the electrode. This may lead to reduction in breakdown strength of the gap.

In the present simulation work for the motion of metallic particles (Al, Cu wires) busduct of 55mm / 152mm inner and outer diameter is considered. The particle is on the surface of the enclosure and the enclosure is earthed. The schematic diagram of a typical compressed 3-Φ Gas insulated busduct is shown in Fig. (1). The field on the particle has been calculated analytically and by using charge simulation method.

The principle of the CSM is to simulate an actual field with a field formed by a finite number of imaginary charges situated inside conductors or near the interface of dielectric media. The CSM presents good accuracy and high speed of computation, characterized by the following points:

- It contains no singular points where a computation point coincides with a source point.

- Potential and field strength are both given explicitly in analytical expressions without numerical integration and differentiation.
- It gives a smooth, rounded surface by nature as it substitutes an equipotential surface for a conductor (electrode).

II. METALLIC PARTICLES IN CONTACT WITH BARE ELECTRODES

For this study a typical three phase common enclosure horizontal busduct filled with SF_6 gas comprising of three inner conductors with image charges and an outer enclosure with inner side coated by epoxy dielectric material as shown in fig.1 is considered.

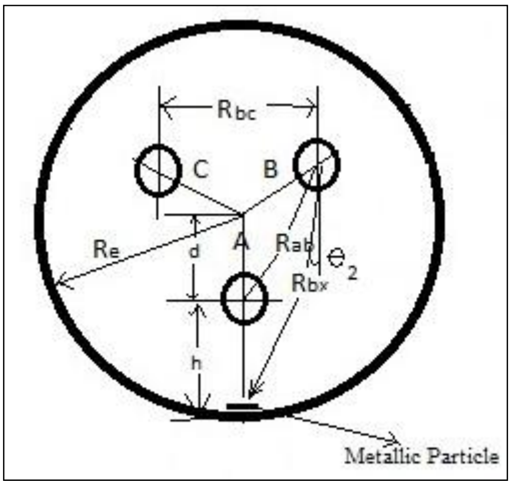


Fig. 1 3-Φ common enclosure Gas Insulated Busduct

In fig. 1 A, B, and C represents three phase high voltage conductors, A', B', and C' are respective images of A, B and C, 'd' is the distance between GIB axis to any phase conductor axis, 'h' is the minimum distance between any phase conductor axis to enclosure inner surface and R_e is enclosure radius. R_{bc} is distance between B and C phase conductors, R_{bx} is distance between B phase conductor and metallic particle and $R_{b'x}$ is distance between B Phase image conductor and metallic particle.

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.

Lift-off field for a particle:

In order to lift a particle from its position of rest the electrostatic force on the particle should balance its weight.

Hence,

$$F_e = F_g \quad \text{i.e.} \quad QE = mg \quad \text{........ (1)}$$

Where F_e = electrostatic force
g = gravitational force

Charge on the particle:

A horizontal wire particle resting on a bare electrode gets charged in the presence of external electric field 'E' and is given by

$$Q_{hw} = 2\pi\epsilon_0 rlE \quad \text{......... (2)}$$

Where r is the radius of the horizontal particle
l is the length of the horizontal particle.

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

$$0.715[(2\pi\epsilon_0 rlE_{LO})E_{LO}] = \pi r^2 l\rho g \quad \text{............ (3)}$$

From above equations,

$$E_{LO} = 0.84\sqrt{\frac{\rho g r}{\epsilon_0}} \quad \text{................ (4)}$$

Theory of Particle motion:

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)

Electrostatic Force:

The charge acquired by a vertical wire particle in contact with naked enclosure can be expressed as:

$$\text{Qnet} = \frac{\pi \in_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \quad \text{................ (5)}$$

Where l is the particle length,
r is the particle radius,
$E(t_0)$ is the ambient electrical field at t = t_0.

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:

$$E(t) = \frac{V \sin\omega t}{[r_0 - y(t)]\ln\left[\frac{r_0}{r_i}\right]} \quad \text{................. (6)}$$

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:

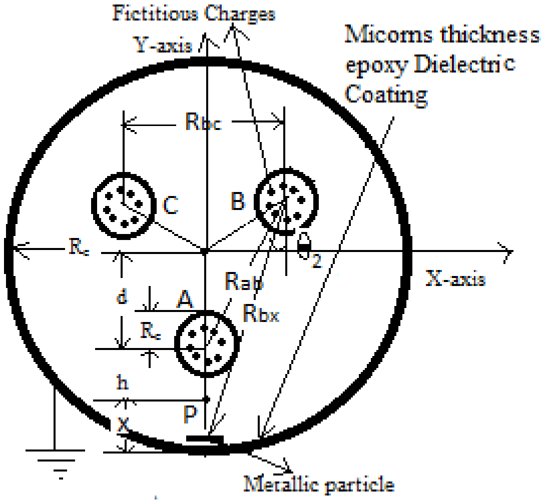


Figure 2 Calculation of Electric Field Intensity at Point 'P' using Charge Simulation Method without image charge effect.

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

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

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

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. Fictitious charges with assignment factor are considered inside of inner conductor of GIB for calculating electric field in 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 :

$$F_e = K\, Q_{net}\, E(t) \quad \text{............................ (7)}$$

where K is a correction factor smaller than unity.

Gravitational Force:

The gravitational force acting on metallic particle having mass 'm', length 'l', radius 'r', and particle material density 'ρ' is:

$$mg = \pi r^2 l \rho g \quad \text{.............. (8)}$$

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

Drag force:

The drag force plays important role in particle movement at higher gas pressures and at higher velocities of the particle in Gas Insulated Busduct. The drag force acts in opposite direction to particle motion and causes the loss of energy due to shockwaves and skin friction of metallic particle. In compressed Gas Insulated Systems energy dissipation due to shock waves for spherical particles more and for greater length to radius ratio particles skin friction energy loss is more.

The total drag force is given by,

$$F_d = F_{d1} + F_{d2} = \dot{y}\pi r(6\pi K_d(\dot{y}) + 2.656(\mu \rho_g l \dot{y})^{0.5}) \quad \text{........ (9)}$$

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

$$m\frac{d^2y}{dt^2} = F_e - F_g - F_d \quad \text{............... (10)}$$

Where F_d is drag force.

The above equation is solved by Runge-Kutta method to obtain radial movement with time, for various values of parameters.

III. RESULTS AND DISCUSSIONS

The radial movement of the particle contaminants is obtained by solving the motion equation of metallic particle using RK 4^{th} Order method. The Electric fields are calculated by using Charge Simulation Method as per the equations (7) and (8) and with Analytical Method using equation (6).

Computer simulations of motion for the metallic wire particles were carried out using Advanced C Language Program in GIB of inner and outer diameter of 55/152mm for 600KV, 800KV, 1000KV, 1200KV applied voltages. Aluminum and copper particles were considered to be present on the surface of enclosure.

The maximum movement of the both the aluminium and the copper particles was found to be less when the field is calculated using charge simulation method when compared to that of the field calculated using analytical method.

Table I and Table II are showing the maximum movement patterns of various aluminium and copper particles of different lengths with radius 0.25mm at different power frequency voltages. The movement of the Aluminium particle for fixed radius of 0.25mm at 600KV was observed to be 13.100mm for a length of 8mm while it was 25.25mm for a length of 15mm.The movements of the same particles when Charge simulation method is employed for field calculations were found to be 11.13mm and 20.16mm respectively.

Table III and Table IV are showing the maximum movement patterns of various aluminium and copper particles of different radii with length 12mm at different power frequency voltages. The movement of the Aluminium particle for fixed length of 12mm at 800KV was observed to be 40.42mm for a radius of 0.15mm while it was 21.569 mm for a radius of 0.30mm.The movements of the same particles when Charge simulation method is employed for field calculations were found to be 35.64mm and 14.884mm respectively.

The Maximum movement for aluminium and copper particles with variation of lengths of the particle for various voltages is shown in the Figs. 3 & 4 for field calculated using analytical method. Fig 5 & 6 show the movement pattern of the aluminium and copper particles for different lengths when the field is calculated using charge simulation method. The Maximum movement for aluminium and copper particles with variation of radius of the particle for various voltages is shown in the Figs. 7 & 8 for fields calculated using analytical method. Fig 9 & 10 show the movement pattern of the aluminium and copper particles for different radii when the field is calculated using charge simulation method.

Table I. Maximum Radial Movements of Al particle of r=0.25mm.

Sl.No.	l(mm)	Applied Voltage							
		600KV		800KV		1000KV		1200KV	
		AM	CSM	AM	CSM	AM	CSM	AM	CSM
1.	8	13.10	11.13	18.73	15.47	27.03	21.58	28.01	24.54
2.	10	17.29	13.35	24.17	18.39	29.07	21.89	30.65	29.29
3.	12	20.44	15.46	27.55	21.22	30.53	25.62	37.57	30.92
4.	15	25.25	20.16	27.62	26.93	33.96	32.38	37.27	36.65

Table II. Maximum Radial Movements of Cu particle of r=0.25mm.

S.No.	l(mm)	Applied Voltage							
		600KV		800KV		1000KV		1200KV	
		AM	CSM	AM	CSM	AM	CSM	AM	CSM
1.	8	5.22	3.43	8.179	5.762	12.39	8.770	15.15	12.04
2.	10	6.87	5.12	11.01	7.771	13.83	12.21	19.05	14.98
3.	12	8.19	6.47	13.33	9.535	15.28	12.08	20.52	15.84
4.	15	11.32	8.65	16.30	12.53	19.45	15.25	28.80	19.93

Table III. Maximum Radial Movements of Al particle of l=12mm.

Sl.No.	r(mm)	Applied Voltage							
		600KV		800KV		1000KV		1200KV	
		AM	CSM	AM	CSM	AM	CSM	AM	CSM
1.	0.15	32.46	29.91	40.42	35.64	44.13	38.80	44.50	36.24
2.	0.20	21.92	21.45	35.04	27.99	41.73	35.77	42.17	35.47
3.	0.25	20.44	15.46	27.55	21.22	30.53	25.62	37.57	30.92
4.	0.30	14.36	12.14	21.569	14.884	25.99	21.14	27.81	26.10

Table IV. Maximum Radial Movements of Cu particle of l=12mm.

S.No.	r(mm)	Applied Voltage							
		600KV		800KV		1000KV		1200KV	
		AM	CSM	AM	CSM	AM	CSM	AM	CSM
1.	0.15	21.61	15.19	30.23	21.84	35.41	25.69	37.90	18.76
2.	0.20	12.32	9.224	15.43	14.47	22.38	18.67	28.09	21.05
3.	0.25	8.193	6.479	13.33	9.535	15.28	12.08	20.52	15.84
4.	0.30	5.5170	4.326	9.725	6.632	12.53	10.62	15.03	12.28

Fig.3: Al particle radial movement for 600kV with analytically calculated field for r=0.25mm

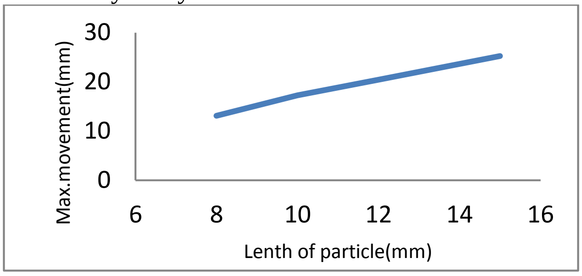


Fig.4:Cu particle radial movement for 800kV with analytically calculated field for r=0.25mm

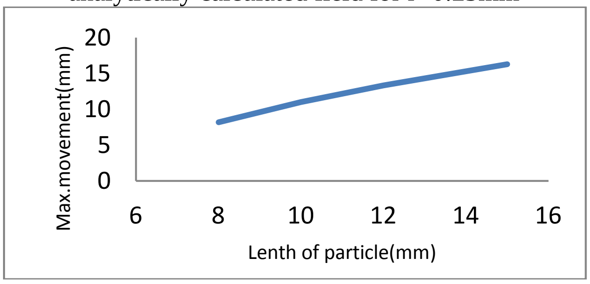


Fig.5:Al particle radial movement for 1000kV with CSM calculated field for r=0.25mm

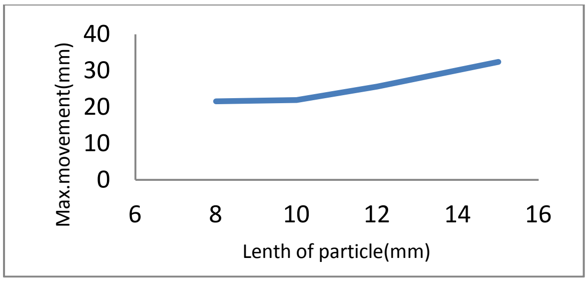


Fig.6Cu particle radial movement for 1200kV with CSM calculated field for r=0.25mm

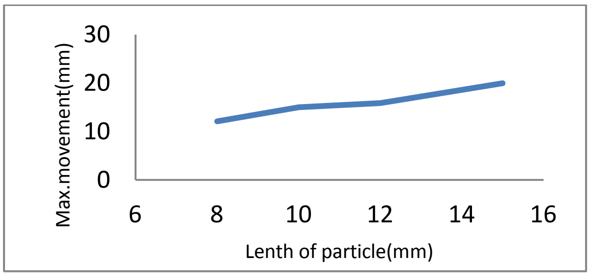


Fig.7: Al particle radial movement for 600kV with analytical field for l=12mm

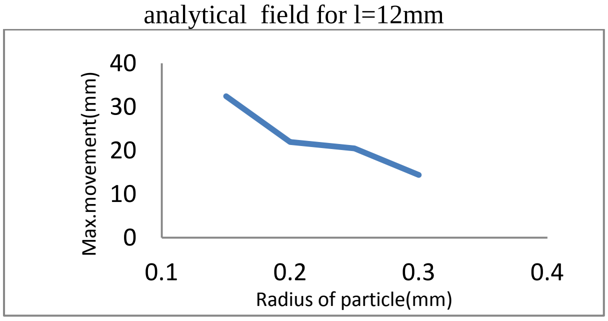


Fig8 :Cu particle radial movement for 800kV with analytically calculated field for l=12mm

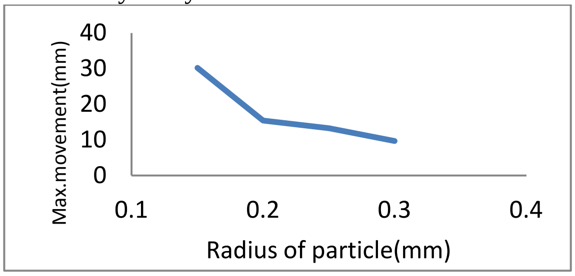


Fig.9:Al particle radial movement for 1000kV with CSM calculated field for l=12mm

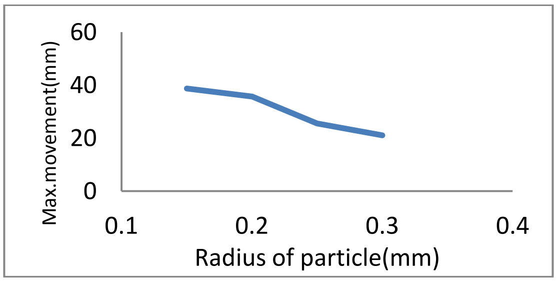
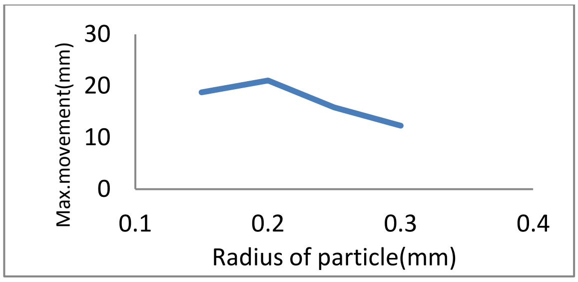


Fig.10 Cu particle radial movement for 1200kV with CSM calculated field for r=0.25mm



IV. CONCLUSION

The pattern of metallic particles with various dimensions in a 3-Ø gas insulated busduct has been simulated by formulating a mathematical model. The electric field is calculated using analytical method and charge simulation method. The observation of the Maximum movement for aluminium and copper particles with variation of radius and length of the particles reveal that as the radius increases, maximum movement for any type of particle decreases while an entirely opposite pattern of movement is seen for the increasing length of particle.

. All the above investigations have been carried out for various voltages under power frequency. The results obtained are analyzed and presented.

V. ACKNOWLEDGEMENTS

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