Free Particle Movements Simulation in a 1-φ Gas Insulated Bus duct Using Dielectric Coating

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Abstract

The image charge effect on the Particle motion inside a Gas Insulated Bus duct (GIB) of single phase using epoxy resin coating of dielectric on the inner surface of GIB outer enclosure is presented in this paper. Taking into account many forces like drag, gravitational and the electrostatic acting on the free conducting particle, a mathematical model was derived. The differential equation of second order for the motion of the particle is solved and restitution coefficient was considered at each impact of particle with the GIB enclosure. At the particle locations, computation of electric fields instantaneously was made using the Charge Simulation Method (CSM). The motion of the metallic particle in the absence of image charge effect are compared with in the
presence of effect of image charge. Based on the results, it can be observed that the movement with effect of image charge is more than the movement without effect of image charge. Using 100kV, 145kV, 175kV and 220kV class, the simulation is worked for several bus configurations with aluminum and copper particles inside GIB. Analysis of all the results were done and presented in this paper.

**Key Words:** Metallic Particle, Gas Insulated Bus duct, Dielectric coating, Charge Simulation Method.

1 Introduction

Basically, in a GIB, a compressed Sulphur Hexafluoride (SF6) gas chambers are enclosed with live parts. Although, SF6 gas shows greater dielectric strength, the voltage withstand of SF6 within the GIB is decreased to the greater extent due to existence of metallic particles. So, the performance of electrical insulation of GIB is greatly affected by these particles and in the survey of CIGRE, it was found that failures about 20% in GIB are be the because of various contaminations of metallic particle presence in the form of particles of loose in nature[1]-[3]. Compressed GIS reliability will be improved, if these particles are eliminated [4],[5]. Different control of particle conducting methods and deactivation have been suggested[6,7] and coating of the dielectric of the outer enclosure on the inner surface is among them. This work mainly describes the metallic movement of the particle in dielectric coated GIB (1-). with electric field in the presence and absence of image charge effect. In GIB, Charge Simulation Method (CSM) is the method used for computing the electric fields. In this work, by using dielectric coating of the inner surface of the outer enclosure with a light shade of epoxy resin micron thickness, the performance of the dielectric will be improved, thereby reducing the particle movement and the lift-off field increases.

2 GIB MODELING TECHNIQUE

A single phase GIB consisting of conductors with coated dielectric outer enclosure with filled SF6 gas as shown in fig.1 is taken
into account. It is assumed that a particle (filamentary type) is resting on the coated dielectric of the outer enclosure on the inner surface of GIB. Different mechanisms of charging the particles are: 

1. Through dielectric coating, conduction
2. Micro discharges between dielectric coating and the particle [4].

The particle begins to lift and move, once the particle possess the charge in the electric field direction having overcome all the forces due to its own drag and weight [5,6,7]. The simulation takes into account different parameters like its weight, viscosity of the gas, the macroscopic field at the location of the particle, Reynolds number, restitution coefficient and drag coefficient [6].

Fig. 1 Single phase common enclosure GIB

The motion equation can be stated as,

\[ M \frac{d^2y}{dt^2} = F_e - mg - F_d \]  

Where \( m \) = particle mass, \( y \) = vertical direction displacement, \( F_e \) = force due to Electrostatic, \( g \) = gravitational constant, \( F_d \) = Force due to drag. The equation of motion of the particle utilizing all forces can be stated as [3-5]:
In Fig. 2, the particle charging circuit model through the dielectric coating is as shown. \(C_g\) is the capacitance between the particle and the phase conductor and \(C_c\) is the capacitance between the particle capacitance and the enclosure. The metallic particle lift-off field \(E_{lo}\) can be obtained as,

\[
m\ddot{y}(t) = \left[ \frac{\pi \varepsilon_k \sqrt{E(t)}}{\ln \left( \frac{2l}{r} \right)} - \frac{V \sin \theta}{[l - y(0)] \ln \left( \frac{2l}{r} \right)} \right] \cdot mg \\
\cdot \hat{y}(t) \pi r (6 \mu K_d \hat{y}) + 2.656 \mu [\rho_p \hat{y}(0)]^{1/3}
\]

(2)

where \(K\) is a constant.

\[
E_{lo} = K \left[ \left(1 + \frac{C_c}{C_g}\right)^2 + \frac{1}{R^2 \omega^2 C_g^2} \right]^{0.25} \left( \frac{\rho_c \theta}{s} \right)^{0.5}
\]

(3)

Where \(K\) is a constant.

3 PARTICLE MOTION SIMULATION

The Particle motion simulation knowledge in a GIB needs the charge magnitude possessed by the particle at the location of metallic particle and electrostatic field present. In GIB, Charge Simulation Method is used for calculating electric field based on the work of Nazar H. Malik et al.[8] and H. Singer [9].
3.1 CHARGE SIMULATION METHOD

Figure 3 describes the concept basic behind the ambient electric field computation at any time using charge simulation method in GIB of single phase.

At point $p(x,y)$, the Electrostatic field in the absence of the image charge is computed as

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

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

At point $p(x,y)$, the Electrostatic field in the presence of image charge is computed as

$$E_x = \sum_{i,j \neq 1}^{n} \frac{\lambda_i}{2 \pi \varepsilon} \left[ \frac{x - x_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} - \frac{(R_e/d)(x-x_i)}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \right]$$  \hspace{1cm} (6)

$$E_y = \sum_{i,j \neq 1}^{n} \frac{\lambda_i}{2 \pi \varepsilon} \left[ \frac{y - y_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} - \frac{(R_e/d)(y-y_i)}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \right]$$  \hspace{1cm} (7)
3.2 MONTE-CARLO TECHNIQUE

Using 4th Order RK method, the metallic particle equation of motion is solved and it specifies the radial direction movement. Calculation of movement in axial direction of the metallic particle was done using method of Monte-carlo simulation based on J.Amarnath et al\[1\],\[2\],\[5\] works. Using Advanced C Language Program, computer simulations was done in GIB with diameter of inner conductor 27.5mm and diameter enclosure of 76mm for 100kV, 145kV, 175kV and 220kV applied voltages. Particles like Aluminum and copper are assumed on the enclosure surface.

4 RESULTS AND DISCUSSIONS

Using RK 4th order method and Monte-Carlo Technique, metallic particle motion equation was solved for particles like aluminium and copper and the results are obtained. Determination of the Electric fields was done by the absence of image charge mentioned in (4) and (5) equations and in the presence of image charge with equations (6) and (7). Table I and Table II show the aluminium and copper particles movement patterns for voltages of power frequency. 512 fictitious charges in conductor and with 1.5 assignment factor are considered for computing electric field in single phase GIB for the presence and absence of image charges with charge simulation method. In all the cases discussed, radius of particles like aluminium and copper are taken into account as 0.01 mm, length as 12 mm, restitution coefficient as 0.9 and gas pressure as 0.4Mpa.

Table I Aluminum and Copper particles Peak Radial Movements in the presence and absence of image charge effect

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Particle Type</th>
<th>Particle Movement in mm (Radial) (absence of Image Charges)</th>
<th>Particle Movement in mm(Radial) (presence of Image Charges)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100kV</td>
<td>Al</td>
<td>4.7939</td>
<td>8.3856</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>2.0213</td>
<td>3.2496</td>
</tr>
<tr>
<td>145kV</td>
<td>Al</td>
<td>8.3828</td>
<td>12.6510</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>3.4207</td>
<td>6.4768</td>
</tr>
<tr>
<td>175kV</td>
<td>Al</td>
<td>11.4322</td>
<td>16.9736</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>4.9225</td>
<td>8.8544</td>
</tr>
<tr>
<td>220kV</td>
<td>Al</td>
<td>15.0333</td>
<td>20.9076</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>7.2000</td>
<td>12.3247</td>
</tr>
</tbody>
</table>
Table I describes the peak movements in radial direction for aluminium and copper particles for several voltage levels in the presence and absence of effects of image charge. For Aluminium particles having no effect of image charge, the movement is 4.7939\,mm and in the presence of effect of image charge, the peak movement is 8.3856\,mm for 100\,kV and it is noted that these movements increase with applied voltage increase. The peak radial movement is 15.0353\,mm and 20.9076\,mm as shown above respectively at 220\,KV. Similarly, the radial movement is 7.5\,mm for in the presence and absence of image charge effect for Copper particles and 12.3247\,mm for the presence of image charges at 220\,KV. In a similar manner, for 220\,kV, the peak axial movement in the absence of effect of image charge is 66.9962\,mm for Aluminium particles and in the presence of effect of image charge is 65.6032\,mm. It can be observed that the Aluminium particles axial movements are rapidly increasing with voltage level up to 145\,kV and decreasing with voltage increasing up to 175\,kV and again axial movement is increasing with voltage up to 220\,kV. For 220\,kV, Peak axial movements are reaching 73.8958\,mm and 98.5393\,mm for electric fields calculated in the absence and presence of effects of image charge respectively. At 100\,KV, the peak movement in axial direction is 37.5593\,mm and 59.2602\,mm for Copper particles. Copper particles peak movements in axial direction are rising with voltage raise up to 175\,kV and after these peak axial movements are slowing down for Aluminium particles with increase of voltage. All the above results are tabulated in Table II shown below.

Table II Al and Cu particles Maximum Axial Movements in the presence and absence of image charge effect using Monte-Carlo simulation (10).

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Particle Type</th>
<th>Peak Movement(mm) in Axial direction(absence of Image Charges)</th>
<th>Peak Movement(mm) in Axial direction(presence of Image Charges)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100kV</td>
<td>Al</td>
<td>66.9962</td>
<td>65.6032</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>37.5593</td>
<td>39.2602</td>
</tr>
<tr>
<td>145kV</td>
<td>Al</td>
<td>84.8153</td>
<td>67.3423</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>55.9683</td>
<td>71.0600</td>
</tr>
<tr>
<td>175kV</td>
<td>Al</td>
<td>56.5460</td>
<td>79.0955</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>72.7006</td>
<td>118.7685</td>
</tr>
<tr>
<td>220kV</td>
<td>Al</td>
<td>73.8958</td>
<td>98.5393</td>
</tr>
<tr>
<td></td>
<td>Cu</td>
<td>99.0460</td>
<td>57.8653</td>
</tr>
</tbody>
</table>
Figs. 3 to 10 show the movement patterns in radial direction of aluminum and copper particles using CSM in the absence and presence of effect of image charge for voltage levels of 100kV and 220kV.
Fig. 6 Cu particle radial movement for 100kV with image charge effect

Fig. 7 Al particle radial movement for 220kV without image charge effect

Fig. 8 Al particle radial movement for 220kV with image charge effect

Fig. 9 Cu particle radial movement for 220kV without image charge effect

Fig. 10 Cu particle radial movement for 220kV with image charge effect
5 Conclusion

To simulate the particle movement, a mathematical model was developed in the presence of electric field in single phase GIB. It can be noted from the above results that particles made of Aluminium have greater impact on voltage compared to copper particles due to its lighter weight. Hence, the aluminum particle acquires higher ratio of charge-to-mass. A method named Monte-Carlo simulation was used for finding axial and radial particle movements in GIB. From the above results, it can be inferred that peak particle movement in electric field with image charge effect is more than without image charge. The performance of the insulation improves, if the inner surface of the outer enclosure was given dielectric coating of a light shade with micron thickness epoxy resin. This is done by the reduction of the charge on the particle and hence the peak movement reduces. All the above discussions were done for different voltage levels with frequency.

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