Image Charge effect on Metallic Particle Movement in a single phase Gas Insulated Bus Duct with Dielectric Coated Enclosure

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ABSTRACT

This paper presents the movement of a wire particle inside a single phase GIB(Gas Insulated Bus duct) .The movement of a particle is not only influenced by the electric fields produced by the conductor but also effected by the fields due to its Image charge .In view of this ,the present work analyzes the effect of Image charge also on the movement of the particle .The equations governing the motion of the particle due to Image charge has been developed, for the first time, to obtain the particle trajectories. Further, the enclosure in a GIB may be coated with a dielectric material to restore some of the dielectric strength of the compressed gas that is lost due to surface roughness and contamination with conducting particles. Hence, simulation has been carried out to study the effect of fields on the motion of the particle with and without Image charge effect and also with and without dielectric coating on the enclosure. Trajectories obtained for various voltages of aluminum and copper particles are presented and duly discussed.

Keywords: *Metallic particles, electrostatic effect, image charge effect, gas insulated substations, gas insulated transmission line, gas insulated bus duct*

INTRODUCTION

The development and design improvement of GIS and Gas Insulated Transmission Line (GITL) equipment has progressed rapidly worldwide during the last few years because of the excellent insulation properties of sulfur hexafluoride (SF_6) gas [1].

The conducting particles can either be free to move in the GIB or they may stick to an energized electrode or to an enclosure surface. It is a fact that free conducting particles in GIB could decrease the insulation strength radically.

In practical systems it is very difficult to remove conducting particle contamination in GIB. Such contamination may be caused by mechanical aberration, incorrect assembling and movement of conductors under load cycling [2].

It is well known that free conducting particles drastically reduces the dielectric strength of GITL systems. In practical systems it is so hard to stay away from metallic particle contamination. The most likely causes for such contaminations are mechanical abrasion, movement of conductors under load cycling and vibrations during shipment. Such particles are drastically reducing the break down voltages as a result of their movement in the electric field.

In a horizontal Coaxial system with particles laying within surface of the enclosure, the movement of such particles is irregular in nature. The irregularity subject to the coefficient of restitution and angle of incidence while moving toward the conductor. The coefficient of restitution being the ratio of incident and rebound velocities and is dependent on conductor surface roughness. The presence of contamination can there fore be a problem with gas insulated substations operating at high fields. 20% of failures in GIS are because of the presence of different metallic pollutions as free particles. If the effects of these particles could be disposed of, this would work on the reliability of compressed gas insulated substations.

At the time of manufacturing of GIS equipment, care should be is taken to ensure that all components are free from metallic particles. However, metallic contaminants are unavoidable in installed systems. Several methods of conducting particle control and deactivation have been proposed and some of these in current use are:

a. Electrostatic trapping.
b. Use of adhesive coating to immobilize particles.
c. Discharging of conducting particles through radiation.
d. Coating conducting particles with insulating films.
e. Dielectric coating on the inner surface of the outer enclosure.

Conductors in compressed GIS system may coated with a dielectric material in order to restore some of the dielectric strength of the compressed gas which is lost due to surface roughness and contamination with conducting particles. The improvement in the dielectric strength of the system, because of coating, can be credited to the accompanying impacts:

- Coating reduces the degree of surface roughness on conductors thus decreasing the local electric fields which can be responsible for initiating a discharge. Experiments show significant improvement in breakdown strength due to coating.
- The resistance of dielectric coating impedes the development of pre-discharges in the gas, thus increasing the breakdown voltage.

Free conducting particles situated inside the GIB enclosure acquire free charge through a low resistance contact with the enclosure. An electrostatic force applied on the particle, and at a suitable worth of the particle, and at a fitting worth of the applied voltage this force is adequate to overcome the gravitational force, thus resulting in levitation and movement of conducting particle.

Once the particle is lifted, the attracting force on the particle because of the image charge decline, so that the resultant upward force increases and the particle moves more rapidly [3].

Hypothetically determined outcomes show that without considering the image charge effect, the electric field for rms voltage of 100 KV(Line to Line) is 314 KV/mm,While considering the image charge effect the electric fields for the same rms voltage 100 KV is 628 KV/mm.

So there will be a 100% increase in electric field. Charge Q, attained by the particle is improved due to the increase in the electric field E. As a result, the movement of metallic particle in GIB increases.

A dielectric coating on the inside surface of a GIB enclosure should inhibit the movement of metallic particles. The electric field necessary to lift a particle resting on the bottom of a GIB enclosure is much increased due to coating.

If the enclosure is coated, as the applied voltage is increased sufficiently, the

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particle will acquire sufficient charge to lift against gravity [4].

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 1 has been considered for the analysis of without Image charge effect on the particle.

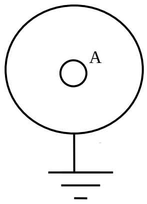

Fig. 1: *A Typical Single Phase Gas Insulated Bus Duct.*

While showing up at a mathematical method for the development of particles inside a busduct, different properties of gas molecule as well as electrical properties of the system has been considered. Understanding the dynamics of a metallic molecule in a coaxial electrode system is of crucial significance for deciding the impact of metallic contamination in a gas insulated substations (GIS).

The dynamic equation comprises the gravitational force on the particle, charge acquired by the particle, field intensity at the particle location, and drag force, gas pressure, restitution co-efficient and the Reynold's number.

A molecule is thought to be very still at the enclosure surface, it exchanges charge with the enclosure under the impact of electric field present there. If the electrostatic force on the particle over comes the gravitational and frictional force on it, the molecule lift-off from the rest position. During return flight, another charge on the molecule is assigned based on the instantaneous electric field.

The equation of motion for a particle can be expressed as

$$m\frac{d^2y}{dt^2}=F_e-mg-F_d \quad (1)$$

Where m = mass of the particle.
y = displacement in vertical direction
g = gravitational constant
F_e = electrostatic force
F_d = drag force

The direction of drag force is constantly opposed to the direction of motion. The motion equation using all forces can consequently be expressed as:

$$m\ddot{y}(t)=\left[\frac{\Pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right)-1}\times V\times 292.48\times 10^3\right]\left(\frac{1}{76-x}\right)\sin\omega t$$

$$-mg-y(t)\Pi r\left[6\mu K_d\left(\dot{y}\right)+2.656\left[\mu\rho_g l\,\dot{y}\right]^{0.5}\right] \quad (2)$$

The above condition (4) is a second order non-linear differential equation for movement of a metallic molecule. To settle the motion equation Runge-Kutta 4th order method is adopted

CONDUCTION THROUGH A DIELECTRIC COATING

On account of GIS, by utilizing a covering with a light shade within the fenced in area, it is simpler to identify pollutions like metallic particles or bits of dielectric material in the system. Charging of metallic particles in touch with a coated cathode is principally founded on two deferent charge mechanism.

- Conduction through a dielectric coating
- Micro discharges between the particle and the coating (for high electrical fields and lower gas pressures)

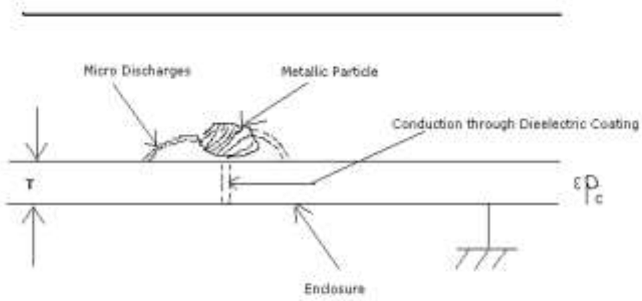

Fig. 2: *Charge Mechanism of a Metallic Particle on a Dielectric Coating.*

The geometry described in Figure 2 can be represented by a circuit model as shown in Figure 3 C_g represents capacitance between the conductor and the particle whereas Cc represents capacitance between the particle and the enclosure. The conductance G represents the part of the dielectric coating where the Charging current is flowing.

The solution of the above equation for the electric field near the surface of the enclosure yields electric field (E_{L0}).

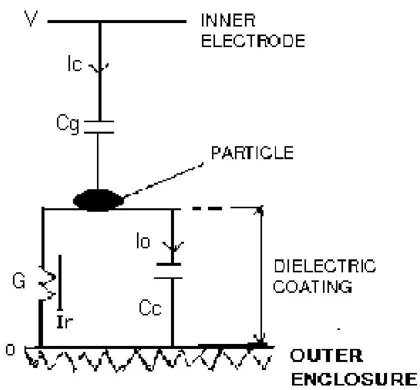

Fig. 3: *Circuit model of particle charging through the dielectric coating.*

$$E_{L0}=\left[\frac{mg}{\frac{K}{\omega}B(\phi)r_0\ln\frac{r_0}{r_i}}\right]^{0.5}\left[R\left[1+\frac{C_C}{C_g}\right]^2+\left[\frac{1}{R^2\omega^2C_g^2}\right]^{0.5}\right]^{0.5}=K\left[\left[1+\frac{C_C}{C_g}\right]^2+\frac{1}{R^2\omega^2C_g^2}\right]^{0.25}\left(\frac{\rho_c T}{S}\right)^{0.5}$$

Where K is a constant. It can be noted that E_{LO} is approximately proportional to square root of the thickness and resistivity of the dielectric.

Case (ii): With Image Charge Effect

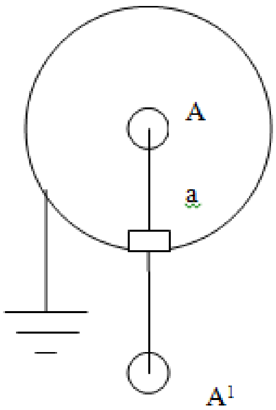

Fig. 4: *A single phase Gas Insulated Bus duct.*

Figure 4. Shows a horizontal single phase bus duct has been considered for the examination of image charge impact. In figure 4 represents the conductor and A^1 be the image of the conductor A and 'a' signifies the molecule which is appointed to be very still in the fenced in area surface, just underneath the conductor A, until a voltage sufficiently adequate to lift the molecule and move in the field is applied.

Subsequent to securing a fitting charge in the field, the molecule lifts and starts to move toward field having overcome the force because of its own weight and drag. The simulation considers several parameters for example the macroscopic field at the surface of the particle, its weight, Reynold's number, coefficient of restitution. The strategy for field estimations for image charge impact is given below.

EXPRESSION FOR ELECTRIC FIELD

Let the particle move to a distance ‘x’ form the inner surface of the enclosure at the point ‘a’ in figure 4. From the figure 4, the variables in the general formula are:

x = position of the particle in the enclosure.
h = Distance between centre of the conductor and enclosure.
r = Radius of the conductor.

General expression for electric field intensity due to conductor A includes the image charge effect is given as:

$$E = \frac{1}{2\ln\left(\frac{2h}{r}\right)}\left(\frac{1}{h-x}+\frac{1}{h+x}\right)V_m \sin\omega t \qquad (4)$$

By substituting the values of h, r & Vm in the equation (4) becomes:

$$E = V \times 292.48 \times 10^3 \left(\frac{1}{76-x}+\frac{1}{76+x}\right)\sin\omega t. \quad KV/mm \qquad (5)$$

Where E is the resultant electric field.

The motion equation is assumed by

$$m\ddot{y}(t) = \left[\frac{\Pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right)-1} \times V \times 292.48 \times 10^3\right]\left(\frac{1}{76-x}+\frac{1}{76+x}\right)\sin\omega t$$

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

SIMULATION OF PARTICLE MOTION

The investigation of the movement of moving metallic particles in GIS requires a good knowledge on the charge of the molecule. Several authors have recommended answers for the movement of a wire like metallic molecule in an isolated particle busduct system.

Computer simulation of the movement of metallic wire particles were done on single-phase GIB of 55mm diameter of inner conductor and 152 mm diameter of the outer enclosure with 75kv and 132kv voltages applied to inner conductor. Aluminum and copper wire like particles were considered to be present on enclosure surface.

RESULTS AND DISCUSSIONS

The particle is taken as 10mm in length with 0.25mm radius. At first the particle is supposed to be resting at the bottom of the enclosure and positioned vertically. Table shows the maximum radial movement of the particle in a single phase isolated Gas Insulated Bus duct of Aluminum and Copper particles by considering with and without Image charge effect on the particles are shown in the. Figure 4 to Figure 11 for applied voltages of 75KV and 132KV respectively.

It is observed in the Figure 4 and Figure 5, that the maximum movement of the Aluminum particle is greater when considering Image charge effect on the particle than without Image charge effect at a given voltage of 75KV. The simulated results of maximum movement of particles are shown in Table.

The movement of copper molecule is additionally given in Table. It has been seen that the most extreme development of Copper extreme development the Aluminum particle even of same size and applied voltage.

This is because of the greater density of Copper particle. It is additionally seen that as the voltage increases, the most extreme development of Aluminum and Copper particles increments essentially

Figure 6 and Figure 7 show that the maximum movement of the Copper particle is greater in case of considering Image charge effect than without Image charge effect on the particle at a given voltage of 75KV.

The movement of Aluminum and Copper particles by considering with and without Image charge effect on the particle for the voltage of 132KV is shown in Figures 8 to 11. It has been seen that the vertical movement of the particle increases when the particle is impact by Image charge effect.

Table 1: *Radial movement of Aluminum and Copper particles with and without image charge effect (200 μ m dielectric coating).*

Voltage	Type	Max. Radial movement(mm) (Without Image charge effect)	Max. Radial movement(mm) (With Image charge effect)
75KV	Al	0.0868	1.1350
	Cu	0.0040	0.1614
132KV	Al	0.8314	3.1623
	Cu	0.0678	1.0506

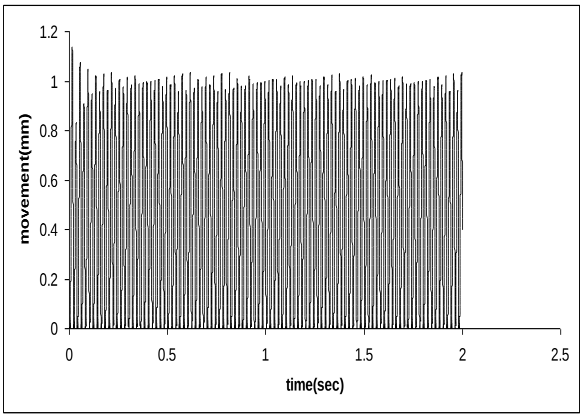

Fig. 4: *Particle movement with image charge effect in a 1-phase GIB for 75KV/Al/10mm/0.25mm radius for a 200μm dielectric coated enclosure*

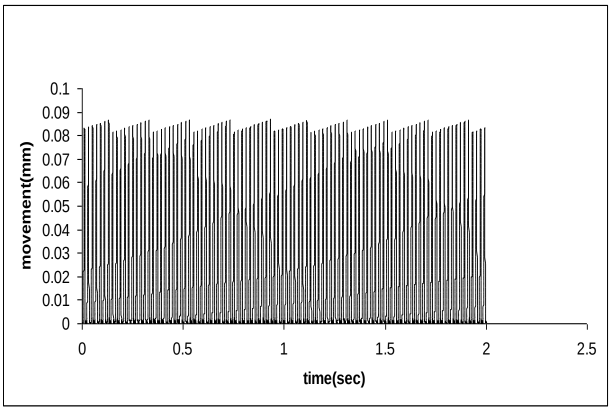

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Fig. 5: *Particle movement without image charge effect in a 1-phase GIB for 75KV/Al/10mm/0.25mm radius for a 200μm dielectric coated enclosure.*

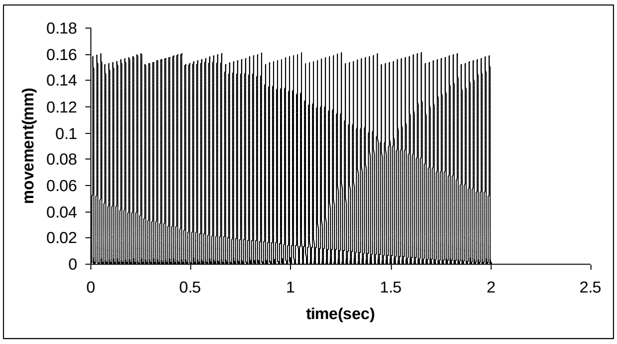

Fig. 6: *Particle movement with image charge effect in a 1- phase GIB for 75KV/Cu/10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

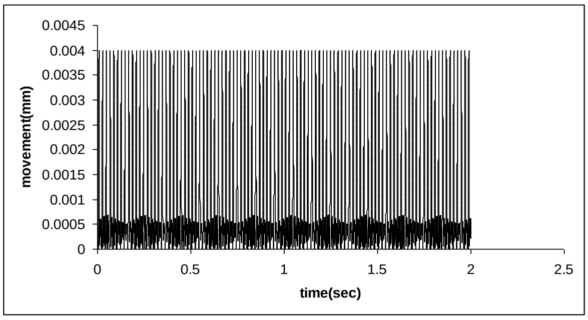

Fig. 7: *Particle movement without image charge effect in a 1-phase GIB for 75KV/Cu/10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

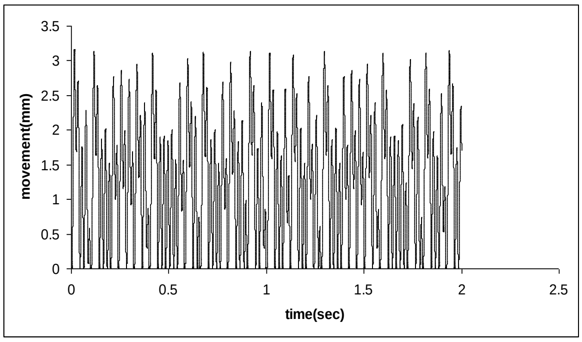

Fig. 8: *Particle movement with image charge effect in a 1-phase GIB for 132KV/Al/10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

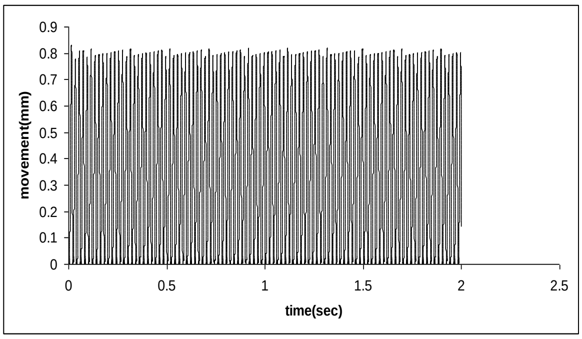

Fig. 9: *Particle movement without image charge effect in a 1-phase GIB for 132KV/Al/10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

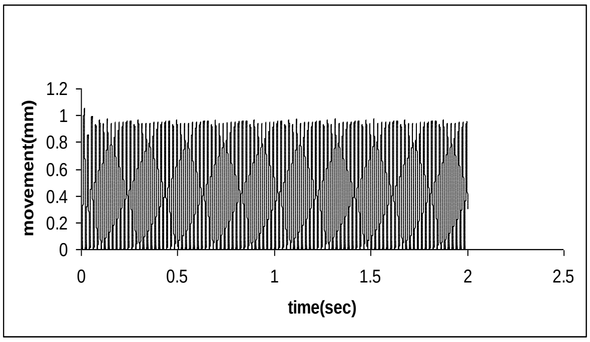

Fig. 10: *Particle movement with image charge effect in a 1-phase GIB for 132KV/Cu/10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

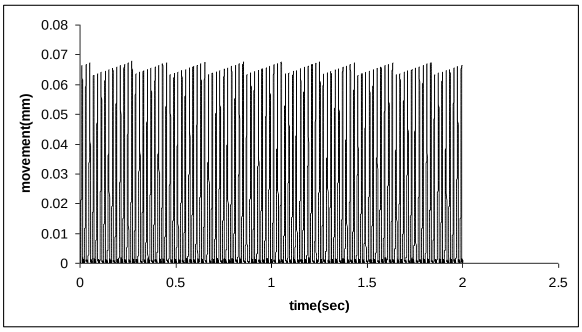

Fig. 11: *Particle movement without image charge effect in a 1-phase GIB for 132KV/ Cu /10mm/0.25mm radius for a 200µm dielectric coated enclosure.*

CONCLUSION

A maiden attempt has been made to develop a mathematical model to simulate the movement of a wire particle in single phase isolated GIB on bare electrode system considering the effect of field due to Image charge. The movement patterns of Aluminium and Copper metallic particles at 75KV and 132KV, under power frequency, with and without image charge effect on the particle have been studied .It has been observed that there is a significant increase in movement of the metallic particle when the image charge effect is considered. It has also been observed that the movement of the aluminum as well as copper particles in GIB greatly reduced when dielectric coating on the enclosure is considered.

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