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Electrostatic field effect on the movement of metallic particles in three phase common enclosure gas insulated busduct with and without image charges

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Abstract—Metallic particles can be either free to move in the GIS or they may be stuck either to an energized electrode or to an insulator surface. 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, and the voltage required for breakdown of the GIS will also cause a significant reduction of the breakdown voltage. 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. To determine the particle movement in a three-phase common enclosure Gas Insulated Bus duct (GIB) with Image Charge Effect an outer enclosure of diameter 500 mm and inner conductors of diameters 64 mm spaced equilaterally are considered. Aluminum, copper and silver particles were considered to be present on enclosure surface. The particle movement is calculated for various operating voltages. The results of the simulation have been presented.

Index Terms— Metallic particles, Image Charges, Gas Insulated Systems

1. Introduction

Gas insulated sub-station systems offer a compact, cost effective, reliable and maintenance-free alternative to the conventional air insulated sub-station systems. Their compact size offers a practical solution to vertically upgrade the existing sub-station and to meet the ever-increasing power demand in developing countries. the development of SF6 insulated switchgear was mainly driven by the aim to reduce the use of material and costs by still extremely high reliability. In a Gas Insulated Bus duct (GIB), all live parts are enclosed in compressed Sulphur Hexafluoride gas chambers, which are divided into a number of compartments or bays according to the layout or configuration of its several components. Basic components of the GIS bay are circuit breakers, disconnectors, Earthing switches, bus ducts, current and voltage transformers, etc. The inner live parts of GIS are supported by insulators called spacers, which are made of alumina filled epoxy material. The GIS enclosure forms an electrically integrated, grounded enclosure for the entire substation. Free conducting particles are most dangerous to GIS. These free conducting particles may have any shape or size, may be spherical or filamentary (wire like) or in the form of fine dust. Particles may be free to move or may be fixed on to the surfaces. They may be of conducting material or of insulating material. Particles of insulating materials are not so harmful as they have little effect on the insulating properties of gases. So wire like particles made of conducting material is more harmful and their effects are more pronounced at higher gas pressures. The origin of these particles may be from the manufacturing process, from mechanical vibrations or from moving parts of the system like breakers or disconnectors etc. The work reported in this paper deals with the movement of metallic particle in 3-phase common enclosure Gas Insulated busduct with and without images.. The simulation considers the particle movement in 3-phase common enclosure GIB with Electric field effect. The specific work reported deals with the charge acquired by the particle due to macroscopic field at the tip of the particle, the force exerted by the field i.e., electric field on the particle, drag due to viscosity of the gas and random behavior during the movement. Wire like particles of aluminum and copper of a fixed geometry in a 3-phase bus duct have been considered. The movement pattern for higher voltages class has been also obtained.

2. Modeling Technique

A typical horizontal three-phase bus duct shown in Figure 1 has been considered for the analysis.

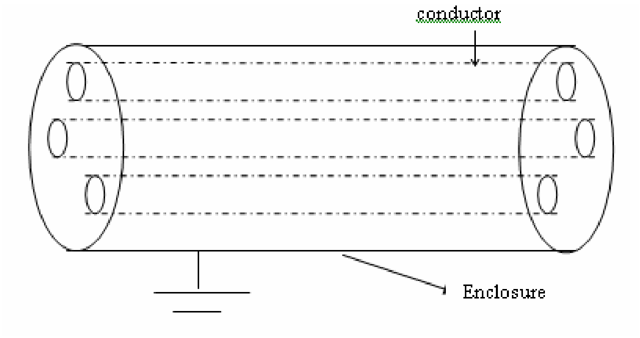

Fig. 1: A typical 3-phase common enclosure Gas insulated bus duct.

Understanding 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 System. 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. The lift-off field for a particle on the surface of an electrode can be estimated by solving the motion equation.

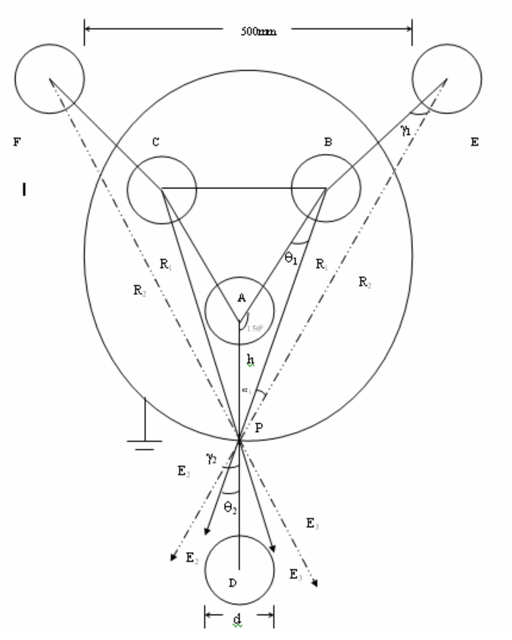

Fig. 2: 3-phase common enclosure Gas insulated busduct with Images

A conducting particle in motion in an external electric field will be subjected to a collective influence of several forces.The forces may be divided into Electrostatic force (FE),Gravitational force (mg) and Drag force (Fd).Figure 2 shows a horizontal three phase bus duct comprising of inner conductors spaced equilaterally in a metal enclosure with images. The enclosure is filled with SF6 gas at a high pressure(0.3 MPa). A particle is assumed to be at rest at the enclosure surface, just beneath the bus bar 2, until a voltage sufficient enough to lift the particle and move in the field is applied. After acquiring an appropriate charge in the field, the particle lifts and begins to move in the direction of field having overcome the forces due to its own weight and drag. The simulation considers several parameters e.g. the macroscopic field at the surface of the particle, its weight, Reynold's number, coefficient of restitution on its impact to both enclosures and viscosity of the gas. During return flight, a new charge on the particle is assigned based on the instantaneous electric field. The direction of drag force is always opposed to the direction of motion. The expression for drag Force is

$$F_d = \dot{y}\,\pi \mathrm{r}\left(6\mu \mathrm{K_d}\,(\dot{y}) + 2.656\left[\mu\rho_g\, \mathrm{l}\dot{y}\right]^{0.5}\right) \tag{1}$$

Where y is the velocity of the particle, μ is the viscosity of the fluid ,r is the particle radius, ρg is the gas density, l is the particle length and Kd (y) is the drag coefficient.

The motion equation without images is given by

$$\mathrm{m}\ddot{y}(t) = \frac{\pi \in_0 l^2\, E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1}\ \mathrm{x}\ 48.64\mathrm{x}10^3 \left[\left(\frac{1}{0.125\text{-}\ x}\right) + \left(\frac{\mathrm{Cos}\theta_2}{R_1}\right)\right]\mathrm{Sin}\omega t - mg$$
$$-\ \dot{y}(t)\,\pi r\,(6\mu K_d(\dot{y}) + 2.656(\mu r_g\ ly(t)^{0.5}) \tag{2}$$

The motion equation with images is given by

$$\mathrm{m}\ddot{y}(t) = \left[\frac{\pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \times V \times 243.2 \times 1000\right]\left[\left(\frac{1}{125 - x} - \frac{1}{125 + x}\right) + \left(\frac{Cos\gamma_2}{R_2} - \frac{Cos\theta_1}{R_1}\right)\right] Sin\omega t - mg$$
$$-\ \dot{y}(t)\pi r\left(6\mu K_d(\dot{y}) + 2.656\left[\mu\rho_g l\dot{y}(t)\right]^{0.5}\right) \tag{3}$$

To solve the motion equation Runge-Kutta 4th order method is adopted.

3. Simulation Of Particle Motion

In order to determine the random behavior of moving particles, the calculation of movement in radial directions was carried at every time step using rectangular random numbers.

Table I shows the radial movement of the particle in a 3- Phase Gas Insulated Bus duct without images. Table I shows the movement patterns of aluminum, copper and silver particles for applied voltages of 300 kV, 400 kV and 450 kV respectively without image charge effect. The radius of the particles in all cases is considered as 0.1 mm and length of the particle as 10mm. The highest displacement in radial direction during its upward journey is simulated to be 43.9 mm for 450 kV GIS.As the applied voltage increases the maximum radial movement also increases as given in Table I.

Table I ; Radial Movement Of Aluminum And Copper And Silver Particles **Without Image** Charge Effect In A Three Phase Gib Simulation Time: 1.5 Sec

Voltage(KV)	Type	Maximum Radial movement in mm for l=10mm, r=0.1mm
300	Al	16.67501
	Cu	N.M
	Ag	N.M
400	Al	36.9667
	Cu	6.989298
	Ag	N.M
450	Al	43.9099
	Cu	8.334185
	Ag	N.M

However, it is noticed that even up to a voltage of 300 kV the particle could not bridge the gap. The movement of copper particle is also given in Table I. It is noticed that the movement of copper particle is far less than aluminum particle of identical size. This is expected due to higher density of copper particle. The movement of aluminum, copper and silver particles with image charge effect is shown in Table II. From Table I and II it is inferred that with image charges the movement is high which reduces the reliability of GIS to operate for high voltages. similarly simulation has been carried out for the radial movement of metallic particles with a fixed length and variable diameter and with variable voltages.The results are tabulated from Table III to V for without image charges and from Table VI to VIII for with image charges.It has been observed that radial movement of particles increases with image charges compared to without image charges.Irrespective of image charges the particle movement of copper and silver decreases for a set of voltages. It is noticed that the movement of copper and silver particles is far less than aluminum particle of identical size. This is expected due to higher density of copper particle. The movement of aluminum, copper and silver particles without image with image charge effect is shown in Figures 3 to 7. It is also observed that if ratio of length to diameter decreases the radial movement of particles also reduced.

Table II: Radial Movement Of Aluminum And Copper And Silver Particles **With Image** Charge Effect In A Three Phase Gib Simulation Time: 1.5 Sec

Voltage(KV)	Type	Maximum Radial movement in mm for l=10 mm, r=0.1 mm
300	Al Cu Ag	34.54588 6.959618 N.M
400	Al Cu Ag	64.04347 17.68512 12.58007
450	Al Cu Ag	81.84347 26.63495 20.79749

Table III: Radial Movement of a particle with length of l=3mm and radius of 0.1mm, without image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.1mm
300	Al Cu	10.60946 1.685808
400	Al Cu	13.9275 2.223607
450	Al Cu	22.42901 2.819467

Table IV: Radial Movement of a with length of l=3mm and radius of 0.2mm without image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.2mm
300	Al Cu	2.000612 NM
400	Al Cu	2.639994 NM
450	Al Cu	3.451467 NM

Table V: Radial Movement of a with length of l=3mm and variable radius of 0.3mm without image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.3mm
300	Al Cu	1.936411 NM
400	Al Cu	1.148108 NM
450	Al Cu	1.514974 NM

Table VI: Radial Movement of a particle with length of l=3mm and radius of 0.1mm, with image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.1mm
400	Al Cu	26.25642 3.947927
450	Al Cu	30.21384 5.292176
500	Al Cu	30.29547 7.798945

Table VII: Radial Movement of a particle with length of l=3mm and radius of 0.2mm with image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.3mm
400	Al Cu	3.859268 NM
450	Al Cu	6.60082 1.196897
500	Al Cu	9.44003 1.584635

Table VIII: Radial Movement of with length of l=3mm and radius of 0.3mm with image charges

Voltage(KV)	Type	Maximum Radial movement in mm for l=3mm, r=0.3mm
300	Al Cu	1.71852 NM
400	Al Cu	2.389254 NM
450	Al Cu	3.343363 0.507054

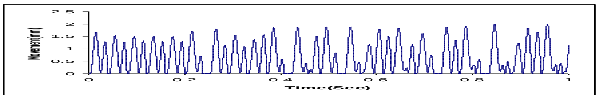

Fig 3: Particle Movement in a 3-phase 500/64 GIB without images for 400KV/AL/3mm/0.2mm radius.

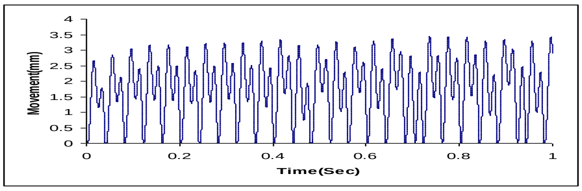

Fig 4: Particle Movement in a 3-phase 500/64 GIB without images for 500KV/AL/3mm/0.2mm radius.

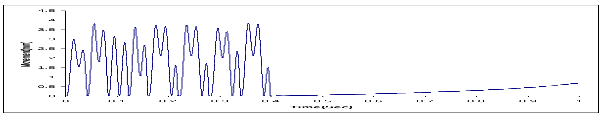

Fig.5:Particle Movement in a 3-phase 500/64 GIB with images for 400KV/AL/3mm/0.2mm radius.

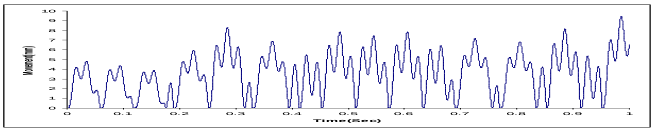

Fig.6: Particle Movement in a 3-phase 500/64 GIB with images for 500KV/AL/3mm/0.2mm radius.

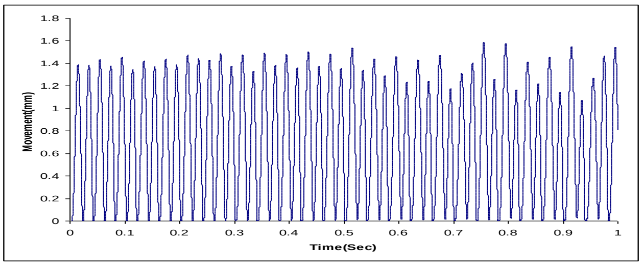

Fig.7: Particle Movement in a 3-phase 500/64 GIB with images for 500KV/Cu/3mm/0.2mm radius.

4. Conclusion

An uncharged metallic particle resting on bare electrode in a Gas Insulated System will gradually acquire charge due to the application of electric field around it. The charge accumulated is a function of Electric field, shape, size and orientation of the particle. When electrostatic force exceeds the gravitational and drag forces the particle lifts from its position. A further increase in the applied voltage makes the particle move into the inter electrode gap in the direction of applied field. This increases the probability of a flashover. The motion pattern of different metallic particles under different AC voltages been investigated in a three phase common enclosure for a pressure of 3 bar. The macroscopic electric field at the surface of the enclosure for the 3-phase system is calculated in Cartesian coordinates. The electric field has been used to determine the charge as well as the force on the particle. The radial movement is calculated using the standard equation of motion. It can be noted that aluminum particles are more influenced by the voltage than copper or silver particles due to their lighter mass. This results in the aluminum particle acquiring greater charge-to-mass ratio. The present work deals with the Image Charge Effect occurring in a Three Phase GIS. For this purpose, Electric Field due to Image Charges has been calculated and the results have been presented and analyzed. It is observed that because Image Charge there is an increase in the movement of the particle. In other words the particle will be further closer to the phase conductor compared to the case when no image charge exists. This may lead to partial discharges between the phase conductor and the particle at an early stage leading to arcing. Itis thus inferred that a image charge effect in GIS has more detrimental effect on the reliability of GIS.

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