

Particle Contamination In A Three Phase Common Enclosure Gas Insulated Bus Duct

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Abstract

In this context of changing and challenging market requirements, Gas Insulated Substation (GIS) has found a broad range of applications in power systems for more than two decades because of its high reliability, easy maintenance and small ground space requirement etc. SF₆ has been of considerable technological interest as an insulation medium in GIS because of its superior insulating properties, high dielectric strength at relatively low pressure and its thermal and chemical stability. SF₆ is generally found to be very sensitive to field perturbations such as those caused by conductor surface imperfections and by conducting particle contaminants. 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. 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. The purpose of this paper is to develop techniques, which will formulate the basic equations that will govern the movement of metallic particles like aluminum, copper in a coated as well as uncoated busduct.

Keywords: GIS, Busduct, Particle Contamination

I. Introduction

Demand for electrical power has become one of the major challenges faced by the developing countries. Considering the relatively low per capita power consumption, there is a constant need for power capacity addition and technological upgradation whereas non-conventional energy systems have proved to be good alternative sources for energy. In developing countries like India most of the additional power has been met by conventional electric sources. Hence, the emphasis has shifted towards improving the reliability of transmission and distribution systems and ensuring that the innovations are not harmful to the environment.

Several authors conducted experiments on insulating particles. Insulating particles are found to have little effect on the dielectric behaviour of the gases [1-8]. However the presence of atmospheric dust containing conducting particles, especially on the cathode, reduces the breakdown voltage.

Free metallic particles originate mainly from the manufacturing process, from mechanical vibrations, or they may originate from moving parts of the system such as breakers or disconnectors. Depending on the shape of the particles, as well as the geometry and voltage levels of the system, the particles get more or less influenced by the electric field which, in turn, makes them hazardous to the electrical system. The particles may be conducting or insulating in nature, the latter being less harmful. Conducting contaminants effects are more pronounced at higher gas pressures. Such a particle, after acquiring an appropriate charge in the field, lifts and begins to move in the direction of field, having overcome the forces due to its own weight and drag in the inter electrode gap thus causing flashover in the bus duct. In Gas Insulated Substations (GIS), a large number of restrikes occur across the switching contacts when disconnect switch or circuit breaker is operated. Each strike leads to generation of a VFTO (Very Fast Transient Oscillation). VFTO thus generated have rise-times in the range of a few nano seconds and is followed by high frequency oscillations. Even though their magnitudes are lower than Basic Insulation Level of the system, they contribute to reduction in the life of insulation in the system due to their frequent occurrences. Also under VFTO, the dielectric strength of SF₆ in presence of free metallic particles is reduced considerably and may lead to flashover and thereby a ground fault.

Conducting particles placed in a uniform ac field lift-off at a certain voltage. As the voltage is raised, the particles assume a bouncing state reaching a height determined by the applied voltage. With a further increase in voltage, the bounce height and the corona current increase until break down occurs [9]. The lift off voltage is independent of the pressure of gas. After the onset of bouncing, the offset voltage is approximately 30% lower than the lift-off voltage.

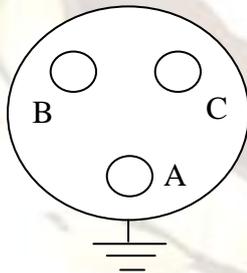
Several methods of conducting particle control and de-activation are given. Some of them are:

- Electrostatic trapping
- Use of adhesive coatings to immobilize the particles
- Discharging of conducting particles through radiation, and
- Coating conducting particles with insulating films

The work reported in this paper deals with the movement of metallic particle in 3-phase common enclosure Gas Insulated Busduct with uncoated and coated enclosure. In order to determine the axial movement in an uncoated enclosure system, the Monte-carlo technique has been adopted in conjunction with motion equation. The present paper deals with the computer simulation of particle movement in 3-phase common enclosure GIB with coated as well as uncoated system. 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 on the particle, drag due to viscosity of the gas and random behaviour during the movement. Wire like particles of aluminium and copper of a fixed geometry in a 3-phase busduct have been considered. The results have been compared with the particle movement in uncoated and coated busduct. The movement pattern for higher voltages class has been also obtained. Monte-carlo technique has been adopted for determining the axial movement of the particle. It has been assumed that at every time step the particle can have a maximum movement 1^0 to 4^0 from vertical.

2. Modeling Technique

The Fig. 1 and Fig. 2 show a typical horizontal three phase busduct with and without dielectric coating.



A, B, C are the conductors

Fig. 1 A typical 3-phase common enclosure GIB

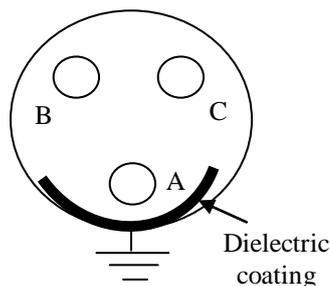


Fig. 2 Typical 3-phase common enclosure GIB with dielectric coating

The enclosures are filled with SF₆ gas at high pressure. A particle is assumed to be at rest at the enclosure surface, just beneath the busbar A, 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 air 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.

3. Theoretical Study

Many authors [1-4] have suggested solutions for the motion of a sphere or a wire like metallic particle in an isolated busduct system. The theory of the particle charge and the electrostatic force on the particle is discussed elsewhere [5]. The motion equation is given by

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

Where, y is the direction of motion and F_d is the drag force. The direction of the drag force is always opposed to the direction of motion. For laminar flow the drag force component around the hemispherical ends of the particle is due to shock and skin friction.

Very limited publication is available for the movement of particle in a three-phase busduct, however the equation of motion is considered to be same as that of an isolated phase busduct.

4. Simulation of electric field in 3-phase busduct with and without coating

The charge acquired by the vertical and horizontal wire particles in contact with a bare enclosure and coated enclosure can be expressed as given by Srivastava and Anis [2].

The electric field in 3-phase common enclosure GIB electrode system at the position of the particle can be written as

$$E(t) = E_1(t) + E_2(t) + E_3(t)$$

Where, $E(t)$ is the resultant field in vertical direction due to the field of three conductors on the surface of the particle at the enclosure.

$E_1(t)$, $E_2(t)$ and $E_3(t)$ are the components of the electrical field in vertical direction. The gravitational force and drag forces are considered as described by several authors.

5. Simulation of Particle Motion

Computer simulations of the motion of metallic wire particles were carried out on GIB of 64mm inner diameter for each enclosure and 500mm

outer diameter with 400KV applied to inner conductors with 120° phase difference.

A conducting particle 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)
- Drag Force (Fd)

Software was developed in C language considering the above equations and was used for all simulation studies.

6. Results and Discussions

Fig. 3 shows the movement of aluminium particle in radial direction for an applied voltage of 400KV rms. During its movement it makes several impacts with the enclosure. The highest displacement in radial direction during its upward journey is simulated to be 65mm. As the applied voltage increases the maximum radial movement also increases as given in Table 1. However, it is noticed that even up to a voltage of 100kv, the particle could not bridge the gap. Further calculations may reveal the limiting voltage to enable the particle to reach the high voltage conductor. A graphical representation of radial movement in relation to axial movement is given by Monte-carlo technique as shown in Fig. 4. The movement of copper particle was determined for 400kv with similar parameters as above and found to have a maximum movement of 18mm in radial direction as shown in Fig. 5. The movements are also calculated for other voltages.

The movement of copper particle are also given in Table 1. It is noticed that the movement of copper particle is far less than aluminium particle of identical size. This is expected due to higher density of copper particle. The axial and radial movement of aluminium and copper particles are calculated using Monte-carlo technique for three voltages i.e. 245kv, 300kv and 400kv with a solid angle of 1°. It is significant to note that for all the cases considered, there is no change in maximum radial movement, even when Monte-carlo method is applied. A relatively high value of axial movement is achieved with the random angle of 1°. As expected the axial movement of copper particle is lower than the aluminium. The movement of aluminium and copper particles for a coated enclosure surface is shown in Fig. 6 and 7 respectively. It can be seen that the movement has been far less than that of an uncoated system.

Table 1 : Axial and Radial movement of aluminium and copper particles

Simulation time : 1 sec

Voltage	Type	Max. Radial Movement (mm)	Monte-Carlo ($\square = 1^\circ$)	
			Radial (mm)	Axial (mm)
245KV	Al	28	28	320
	Cu	13	13	280
300KV	Al	32	32	340
	Cu	14	14	300
400KV	Al	65	65	600
	Cu	18	18	340

Table 2 : Axial and Radial movement of aluminium and copper particles with coated electrodes, thickness 50 micro meter

Simulation time : 1 sec

Voltage	Type	Max. Radial Movement (mm)	Monte-Carlo ($\square = 1^\circ$)	
			Radial (mm)	Axial (mm)
245KV	Al	0.001	0.001	100
	Cu	0.0001	0.0001	90
300KV	Al	0.02	0.02	210
	Cu	0.002	0.002	183
400KV	Al	0.4	0.4	195
	Cu	0.014	0.014	190

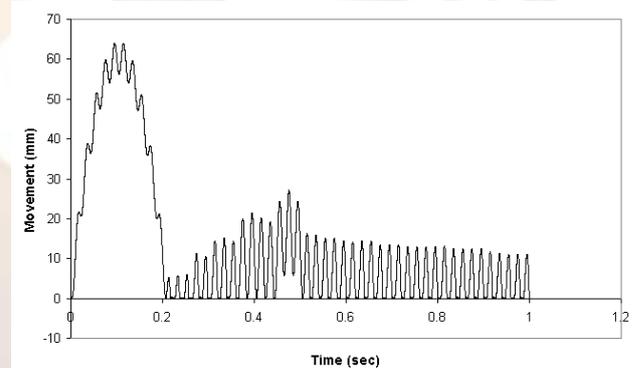


Fig. 3 particle Movement in 3-phase GIB (400KV/Al / 0.1mm / 10mm)

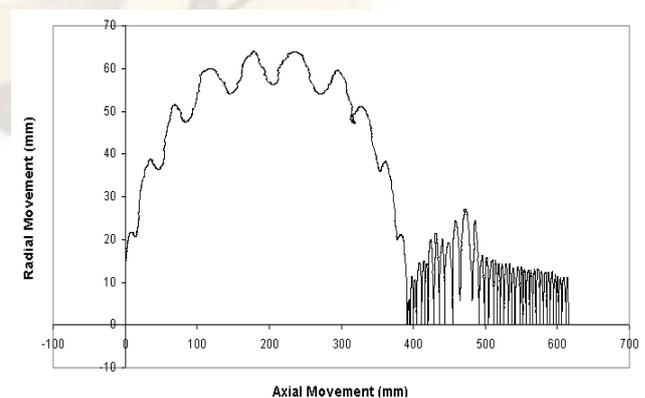


Fig. 4 particle Movement in 3-phase GIB (400KV/Al / 0.1mm / 10mm / 1° Monte-Carlo technique)

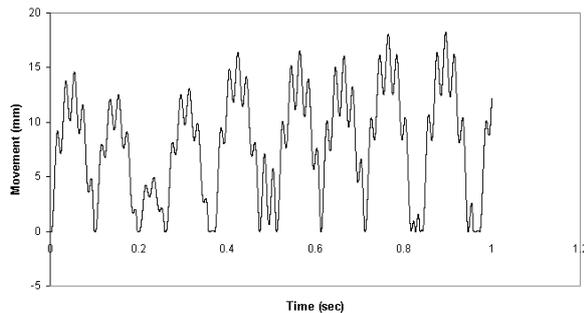


Fig. 5 : particle Movement in 3-phase GIB (400KV/Cu / 0.1mm / 10mm)

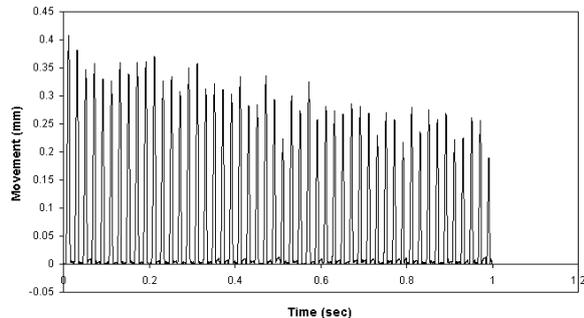


Fig. 6 : particle Movement in 3-phase GIB on coated electrodes (400KV/Al / 0.1mm / 10mm / 50 micro meter)

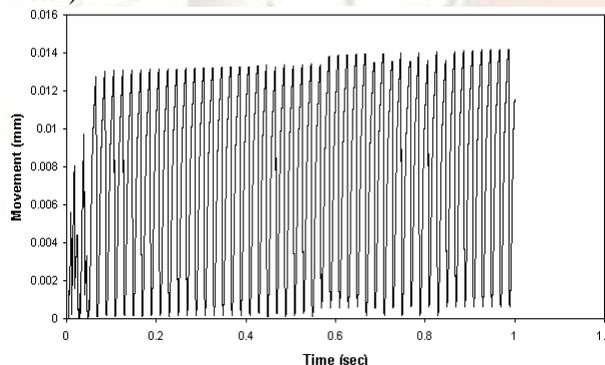


Fig. 7 : particle Movement in 3-phase GIB on coated electrodes (400KV/Cu / 0.1mm / 10mm / 50 micro meter)

7. Conclusions

A model has been formulated to simulate the movement of wire like particle in 3-phase common enclosure GIB on bare as well as coated electrodes. The results obtained are presented and analyzed. Monte-carlo simulation is also adopted to determine axial as well as radial movements of particle in the busduct. Distance traveled in the radial direction is found to be same with or without Monte-carlo simulation. The displacement on coated electrodes are found to be very less compared to uncoated electrode system.

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