MOVEMENT OF METALLIC PARTICLE CONTAMINANTS OF VARIOUS DIMENSIONS IN 1-Ø DIELECTRIC COATED GAS INSULATED BUSDUCT

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ABSTRACT

Metallic particles in Gas Insulated Substation (GIS) have their origin mainly from the manufacturing process or they may originate from moving parts of the system, such as breakers and 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, in terms of partial discharges and breakdown. Coating with thin layer of epoxy type dielectric material on inner surface of outer enclosure of Gas Insulated Busduct can increase the breakdown voltage of Gas Insulated System.

In the present work, the Metallic contaminations of Cu and Al of various dimensions have been considered. The simulation has been carried out for various power frequency voltages. 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. Typically a GIB of inner and outer diameter 55/152mm has been considered. Wire like particles of radii varying from 0.01 to 0.04mm 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

Gas Insulated Substation (GIS) is a compact, multi-component assembly enclosed in a ground metallic housing which the primary insulating medium is compressed sulphur hexafluoride...
(SF6) gas. It generally consists of the components like Bus bars, Circuit Breakers, Disconnecting switches, Earthing switches, Current transformers, Voltage transformers etc. Gas insulated Substations have found a broad range applications in power systems over the last three decades because of their high reliability, Easy maintenance, small ground space requirements etc. Although GIS has been in operation in several years, some of the problems are needful attention. These problems include VFTO during switching operations or earth faults and transient enclosure voltages and particle contamination. 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. Under the influence of high voltage, they can acquire sufficient charge and randomly move in the gap due to the variable electric field.

A) The necessity of this study

Extremely high dielectric properties of SF6 have long been recognized. Compressed SF6 has been used as an insulating medium as well as arc quenching medium in electrical apparatus in a wide range of voltages. Gas Insulated Substations (GIS) can be used for longer times without any periodical inspections. Conducting contamination (i.e. aluminum, copper and silver particles) could, however, seriously reduce the dielectric strength of gas-insulated system

B) The origin of these particles

Metallic particles in GIS have their origin mainly from the manufacturing process or they may originate from moving parts of the system, such as breakers and disconnectors. 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 (spacer, bushing etc. A metallic particle stuck on an insulator surface in a GIS will also cause a significant reduction of the breakdown voltage

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, in terms of partial discharges and breakdown.

Conductors in a GIS/GITL system may be coated with a dielectric material to restore some of the dielectric strength of the compressed gas, which is lost due to surface roughness and contamination by conducting particles. The improvement in the dielectric strength of the system due to coating can be attributed to several effects. Coating reduces the degree of surface roughness on conductors. Also, the high resistance of the coating impedes the development of predischarges in the gas, thus increasing the breakdown voltage (Morcos et al., 2000). The electric field necessary to lift a particle resting on the inside surface of a GIB enclosure is much increased due to the coating. With coated conductors the particle will acquire a drastically reduced charge, thus the risk of breakdown initiated by a discharge is reduced significantly. Coating thickness has been varied from a few microns to several millimeters and the influence of coated electrodes on the insulation performance has been studied under ac voltages.

Fig. 1: Schematic diagram of a typical gas Insulated busduct
In the present simulation work for the motion of metallic particles (Al, Cu and Ag wires) busduct of 55mm / 152mm inner and outer diameter is considered. Also, the particle is on the surface of the enclosure and the enclosure is earthed. The schematic diagram of a typical compressed Gas insulated busduct is shown in Fig. (1).

II. METALLIC PARTICLES IN DIELECTRIC COATED GAS INSULATED BUSDUCT

Free conducting particles resting on dielectric coated inner surface of GIB enclosure gets charged because of two different mechanisms

- Conduction through the dielectric coating
- Partial discharges initiated at particle surface.

The equivalent circuit of the model is shown in fig. 2.

The charging current through metallic particle can be written as:

\[ I_c = \frac{V}{\left[R^2 \left(1 + \frac{c_c}{c_g}\right)^2 + \frac{1}{\omega^2 c_g^2}\right]^{0.5}} = \frac{V}{\left[\frac{1}{g^2} \left(1 + \frac{c_c}{c_g}\right)^2 + \frac{1}{\omega^2 c_g^2}\right]^{0.5}} \]  \hspace{1cm} \ldots (1)

The charge acquired by particle is obtained by integrating equation

\[ Q(t) = \int_0^t I_c \sin(\omega t + \varnothing) \, dt \]  \hspace{1cm} \ldots (2)

The lift off field of the particle is given by the equation:

\[ E_{lo} = K \left[ \left(1 + \frac{c_c}{c_g}\right)^2 + \frac{1}{R^2 \omega^2 c_g^2}\right]^{0.25} \left(\frac{\rho_c}{s}\right)^{0.5} \]  \hspace{1cm} \ldots (3)

III. SIMULATION OF THE WIRE PARTICLE MOTION

The forces acting on the metallic particle contaminants are added and the movement of the particle in the gas insulated busduct is simulated using the following equations.
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:

$$Q_{net} = \pi \varepsilon_0 \frac{l^2 E(t_0)}{\ln \left( \frac{2l}{r} \right) - 1}$$

... (4)

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:

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

... (5)

Where $V$ is the voltage on the inner electrode
$r_0$ 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:**

Fig. 3: Basic Concept of Charge Simulation Method without image charges
The Electrostatic field at point ‘p(x,y)’ is calculated by using the following equations:

\[ E_x(t) = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[ \frac{x - x_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \right] \] \hfill \ldots (6)

\[ E_y(t) = \sum_{i=1}^{n} \frac{\lambda_i}{2\pi\varepsilon} \left[ \frac{y - y_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}} \right] \] \hfill \ldots (7)

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 number of fictitious charges per phase, \( \lambda_i \) is line charge density of \( i^{th} \) fictitious charge.

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:

\[ F_e = K \cdot Q_{net} \cdot E(t) \] \hfill \ldots (8)

Where \( K \) is a correction factor smaller than unity.

**Gravitational Force:**

The gravitational force is given by

\[ mg = \pi r^2 l \rho g \] \hfill \ldots (9)

Where \( r \) is the radius of the particle

- \( L \) is the length of the particle
- \( g \) is the acceleration due to gravity
- \( \rho \) is the density of the particle

**Drag force:**

Drag is a result of energy dissipation in the shock wave near the particle and skin friction along the surface of the particle. In spherical particles shock wave energy dissipation and in wire particles skin friction is more significant. The direction of the drag force is always opposed to the direction of motion of particle.

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

\[ m \frac{d^2y}{dt^2} = F_e - mg - F_d \] \hfill \ldots (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.
IV. RESULTS AND DISCUSSIONS

The radial movement of the particle contaminants is obtained by solving the motion equation of metallic particle using RK 4\textsuperscript{th} Order method. The Electric fields are calculated by using Charge Simulation Method as per the equations (6) and (7) and with Analytical Method using equation (5).

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

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>l(mm)</th>
<th>75KV Analytical method</th>
<th>75KV CSM</th>
<th>100KV Analytical method</th>
<th>100KV CSM</th>
<th>132KV Analytical method</th>
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Table II: Maximum Radial Movements of Cu particle of r=0.25mm

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<th>75KV CSM</th>
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Table III: Maximum Radial Movements of Al particle of l=12mm

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

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**Fig 4:** Al particle radial movement for 75kV with analytically calculated field for r=0.01mm

**Fig.5:** Cu particle radial movement for 100kV with analytically calculated field for r=0.25mm

**Fig.6:** Al particle radial movement for 145kV with CSM calculated field for r=0.01mm

**Fig.7:** Cu particle radial movement for 132kV with CSM calculated field for r=0.01mm
Fig. 8: Al particle radial movement for 75kV with analytically calculated field for l=12mm

Fig. 9: Cu particle radial movement for 100kV with analytically calculated field for l=12mm

Fig. 10: Al particle radial movement for 145kV with CSM calculated field for l=12mm

Fig. 11: Cu particle radial movement for 132kV with CSM calculated field for r=0.25mm
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 75KV, 100KV, 132KV, 145KV, 175 KV and 220 KV applied voltages. Aluminum and copper wire like particles were considered to be present on the surface of enclosure. Monte-Carlo simulation is carried out to determine the axial movement of the aluminum and copper particles for the random angle of 20° for voltages ranging from 75kV to 400kV. The other parameters assumed for the simulation of Al and Cu particles in dielectric coated single phase GIB are dielectric coating thickness 200micrometers, pressure 0.4MPa and Restitution Coefficient 0.9.

Table I and Table II show the maximum movement patterns of aluminium and copper particles of different lengths with radius 0.01mm at different power frequency voltages. The movement of the Aluminium particle for fixed radius of 0.01mm at 75KV was observed to be 3.0493mm for a length of 8mm while it was 3.0902mm for a length of 15mm. The movements of the same particles when Charge simulation method is employed for field calculations were found to be 3.0472mm and 3.0881mm respectively.

Table III and Table IV show 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 75KV was observed to be 3.0771mm for a radius of 0.01mm while it was 1.0734 mm for a radius of 0.04mm. The movements of the same particles when Charge simulation method is employed for field calculations were found to be 3.0751mm and 1.0724mm respectively.

The Maximum movement for aluminium and copper particles with variation of lengths of the particle for various voltages is shown in the Figs. 4 & 5 for field calculated using analytical method. Fig 6 & 7 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. 8 & 9 for fields calculated using analytical method. Fig 10 & 11 show the movement pattern of the aluminium and copper particles for different radii when the field is calculated using charge simulation method.

V. CONCLUSION

The movement pattern of metallic particles with various dimensions in a 1-Ø dielectric coated gas insulated busduct has been simulated by formulating a mathematical model. The electric field is calculated using analytical method and charge simulation method. 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.

From the observations, of the investigations carried out on various power frequency voltages, it is clear that as the radius increases, maximum movement for any type of particle decreases while the maximum movement increases with the length of the particle.

VI. ACKNOWLEDGEMENTS

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