Effect of electric field on movement of conducting particles in single phase GIB

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Abstract. Usually, the electric field can be determined for a simple physical system using analytical method in a GIB. But for a complex system, it is very complicated to find out and so, numerical methods like FDM, FEM, CSM are employed. Movement pattern i.e.peak radial movement simulation done for Al and Cu particles for field calculation using CSM for levels of voltages namely 75kV, 100kV, 132kV, 145kV, in a 1-Φ GIB. For Simulating Aluminium and Copper particles movement, peak radial and axial movements needs thorough particle dynamics understanding. Simulation is done by taking into account many forces like drag, gravitational and the forces of electrostatic in nature on particle and a mathematical modelling was done. Detailed analysis was made and, in this paper, all the results of simulation are shown.

Key words. Gas Insulated Bus duct (GIB), Finite Difference Method (FDM), Finite Element Method (FEM), Charge Simulation method (CSM), Breakdown (B.D)

1. Introduction
Now days, Gas Insulated Substation (GIS) has become more popular as it offers more benefits compared to Air Insulated Substation (AIS). Keeping in view of safety and environmental considerations, GIS is widely used to eradicate problems like dust & salt pollution, land problems etc. Hence, there is necessity of shifting from the AIS to GIS. Also, according to survey, around 30% failures are due to contamination of particles. It may be due to manufacturing defects or due to transportation [1].

At atmospheric pressure, SF₆ dielectric strength is about 2 to 3 times that of the air. So, the phase to phase, and phase to earth clearances are very much reduced. Today SF6 gas was popularly used
worldwide because of outstanding dielectric and arc-quenching properties. SF6 gas was non-flammable, colourless, non-toxic, and chemically inert. According to the survey, about 70 to 80% of SF6 gas produced is used only for GIS.

In this paper, the free conducting particle radial peak movement was found in 1-Φ GIB using CSM technique.

2. Mathematical modelling
For the work based in this paper, a wire like particle is assumed to be resting on the surface of the outer enclosure, and the particle may move upwards from its original position provided the voltage is high enough, and at the same time, acquires charge in the presence of field [3]. All the given equations are based on Feliciet.al[2]

\[ E(t) = \frac{V}{[R_0 - y(t)]} \ln \left( \frac{R_0}{R_i} \right) \sin \omega t \]

Where, \( V \sin \omega t \) - is the inner conductor GIB supply voltage
\( R_0 \) – outer enclosure inner radius
\( R_i \) – radius of inner conductor
\( y(t) \) - the inner enclosure surface to upward moving metallic particle.
Finally, the motion of the particle equation can be shown as second order differential equation given below [5]

\[
m \ddot{y}(t) = \left[ \frac{\pi \varepsilon_i I^2 E(t_0)}{\ln \left( \frac{2l}{r_e} \right) - l} \right] \left[ \frac{V S \sin \alpha}{r_e - y(t)} \right] - mg \\
- \dot{y}(t) \pi r \left( 6 \mu K_d \dot{y} + 2.656 \left[ \mu \rho \dot{y} \right]^{0.5} \right)
\]

3. Motion of particle simulation
The electric field calculations using CSM are done based on the work of Malik et.al[3] and H.Singer[4] and is with analytical method compared.

![Figure 3. Basic CSM Concept.](image)

The field computation at point ‘p’ shown is computed as:

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

In which \(E_x\), \(E_y\) are field components on axes X and Y, ‘and P’ are coordinates \(x, y\) where field is to be found [8].

4. Result analysis
The results of simulation are obtained with length= Twelve mm, radius= 0.25mm, SF\(_6\) gas Pressure= 0.5 Mega Pascal and R=0.9, restitution Coefficient for voltage levels 75KV, 100KV, 132KV and 145KV with calculation of field for analytical and CSM methods and are differentiated. Simulation is carried out for many voltage levels for 1-Φ GIB using advanced C language program [13-21].
Looking at a glance of simulation results from Table 1, it is observed that Al particles exhibit higher mobility in the direction of radial as against Cu particles due to lighter weight\cite{6}. As the voltage rises, movement also increases especially for particles of Aluminium. Also, it can be inferred that movement peak radially is high in analytical field compared to CSM. Figures 4 to 19 show the Peak radial movements of CSM and analytical methods.

**Table 1. Particles peak movement**

| Sl.No. | Voltage (kV) | Particle type | Max. Movement with Analytical Field (mm) | Max. Movement Without Charge(mm) With CSM |
|--------|--------------|---------------|-----------------------------------------|------------------------------------------|
| 1      | 75           | Al            | 14.2                                    | 13.1                                     |
|        |              | Cu            | 2.5                                     | 2.6                                      |
|        |              | Al            | 23.14                                   | 23.09                                    |
| 2      | 100          | Cu            | 5.5                                     | 5.47                                     |
|        |              | Al            | 32.2                                    | 31.20                                    |
| 3      | 132          | Cu            | 12.64                                   | 12.43                                    |
| 4      | 145          | Al            | 37.73                                   | 37.60                                    |
|        |              | Cu            | 15.76                                   | 14.83                                    |

**Figure 4.** Particle of Al mobility for analytical method for 75KV.

**Figure 5.** Particle of Al mobility for CSM method for 75KV.
Figure 6. Particle of Cu mobility using analytical field for 75KV.

Figure 7. Particle of Cu mobility using CSM field for 75KV.

Figure 8. Particle of Al mobility for analytical field for 100KV.

Figure 9. Particle of Al mobility for CSM for 100KV.
Figure 10. Particle of Cu mobility using analytical method for 100KV.

Figure 11. Particle of Cu mobility using CSM for 100KV.

Figure 12. Particle of Al mobility using analytical method for 132KV.

Figure 13. Particle of Al mobility using CSM for 132KV.
Figure 14. Particle of Cu mobility using analytical method for 132KV.

Figure 15. Particle of Cu mobility using CSM for 132KV.

Figure 16. Particle of Al mobility using analytical method for 145KV.
5. Conclusion
A Mathematical model has been developed and the radial peak movement was found using CSM. In this work, radial peak movement was found at the particle locations instantaneously using CSM in 1-phase GIB. An advanced C program language is used for simulation. It is observed that Al particles have higher movement than Cu particles. Due to lighter in weight, it is also observed that particles of Al are highly affected by the voltage than copper particles. The results of simulation is done for 75KV, 100KV, 132KV, 145KV, and are analysed and presented.

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