METALLIC PARTICLE CONTAMINATION IN A GAS INSULATED BUSDUCT (GIB) WITH SF_6 AND SF_6+N_2 GAS MIXTURES

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Abstract: Gas Insulated Substations (GIS) have found a broad range of applications in power systems because of their high reliability and small ground space requirement. Although, GIS have been in operation for several years, the problem of particle contamination needs full attention. In this paper a model has been proposed to determine the particle contamination in a 75kV, 100kV and 145kV Gas Insulated Busduct (GIB). Computer simulations of the motion of metallic particles were carried out on a GIB of 55mm inner diameter and 146mm outer diameter. Aluminium, Copper and Silver particles were considered to be present on enclosure surface. From the simulation it is observed that with pure SF_6 gas in Busduct and applied voltage of 100kV, the movements of Aluminium and Copper particles are 25.19mm and 5.63mm respectively. For 60% SF_6 and 40% N_2 gas mixture corresponding movements are 25.06mm and 5.68mm. For an applied voltage of 145kV with pure SF_6 gas movements of Aluminium and Copper particles are 38.97mm and 10.74mm. For the same voltage with 60%SF_6 and 40%N_2 gas mixture corresponding movements are 38.69mm and 10.26mm. It is observed from above results that with 60%SF_6 and 40%N_2 gas mixture, the GIS can be operated reliably.

1 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 upgrading 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.

Rapid urbanization and overgrowing population is making the task of expanding transmission network very difficult due to right of way problem and limited space availability. In addition, conventional air insulated substations have many problems such as pollution by salt or dust, meteorological difficulties, safety. Hence, there is a need to replace the conventional transmission lines and substations with underground cable and Gas Insulated Substation (GIS) to overcome the above problems. Due to its many advantages, most of the utilities and industrial units are opting for Gas Insulated Substation. In this context, Gas Insulated Substation (GIS) have found a broad range of applications in power systems for more than two decades because of their high reliability, easy maintenance and small ground space requirement.

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. Wire like particles made of conducting material are more harmful and their effects are more pronounced at higher gas pressures. 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 breakdown 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.

The breakdown strength of SF_6 under non-uniform electric field like metallic particle condition is extremely susceptible leading to be lower to breakdown voltage. Furthermore, from the view point of environmental protection, as SF_6 has strong greenhouse effect, the use of SF_6 should be carefully controlled. Thus, it is needed to develop the alternative dielectric gas or gas mixtures having better insulating characteristics and no greenhouse effect. In this paper particle movement with SF_6 and N_2 mixtures have been simulated and results have been presented in a single phase isolated conductor GIB.

2 MODELING TECHNIQUE

Fig. 1 shows a typical horizontal single phase Gas Insulated Busduct. The enclosure is filled with SF6 gas at high pressure. A particle is assumed to be at rest at the enclosure surface, just beneath the busbar, 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.

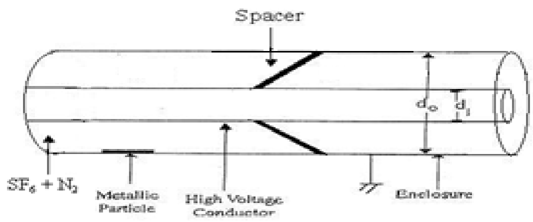

Figure 1: Typical 1-phase Gas Insulated Busduct (GIB)

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

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

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 GAS INSULATED BUSDUCT WITH AND WITHOUT GAS MIXTURES

In this paper particle movement with SF_6 and N_2 mixtures has been simulated and results have been presented in a single phase isolated conductor GIB. The viscosity of a mixture of two gasses can be approximately calculated from the equation.

$$\mu = \frac{\mu_1}{1+\dfrac{\dfrac{x_2}{x_1}\left[1+\sqrt{\dfrac{\mu_1}{\mu_2}}\left(\dfrac{m_2}{m_1}\right)^{\frac{1}{2}}\right]^2}{\dfrac{4}{\sqrt{2}}\left(1+\dfrac{m_1}{m_2}\right)^{\frac{1}{2}}}} + \frac{\mu_2}{1+\dfrac{\dfrac{x_1}{x_2}\left[1+\sqrt{\dfrac{\mu_2}{\mu_1}}\left(\dfrac{m_1}{m_2}\right)^{\frac{1}{2}}\right]^2}{\dfrac{4}{\sqrt{2}}\left(1+\dfrac{m_2}{m_1}\right)^{\frac{1}{2}}}}$$

Where, x_1 and x_2 are proportions, μ_1 and μ_2 viscosities and m_1 and m_2 are molecular weights of N_2 and SF_6 gasses respectively. m_1=28 g/mole, m_2=146 g/mole [6]. After calculating the viscosity of gas mixtures, the value can be substituted in the particle motion equation. The simulation results have been presented and analyzed.

5 SIMULATION OF PARTICLE MOTION

Computer simulations of the motion of metallic particles were carried out on GIB of 55mm inner diameter for each enclosure and 146mm outer diameter with 75 kV, 100kV and 145kV applied to inner conductor. A conducting particle motion, in an external electric field will be subjected to a collective influence of several forces [7-9]. 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

From table1 it is observed that for an applied voltage of 75kV for pure SF_6 i.e. 0% N_2 the maximum movement was recorded as 13.43371 mm, 2.397945 mm and 2.332016 mm for Aluminium, Copper and Silver particles respectively. For 40% N_2 and 60% SF_6 mixture it was observed that the maximum movement for Aluminium, Copper and Silver particles for the same voltage are 13.21965, 2.378525 and 2.324747 respectively. From table2 it is observed that for an applied voltage of 100kV for pure SF_6 i.e. 0% N_2 maximum movement was recorded as 25.19753 mm, 5.638526 mm and 4.15983 mm for Aluminium, Copper and Silver particles respectively. In case of 40% N_2 and 60% SF_6 mixture the corresponding values are recorded as 25.06408 mm, 5.688031 mm and 3.959907 mm respectively. From table3 it is observed that for an applied voltage of 145kV for pure SF_6 i.e. 0% N_2 maximum movement was recorded as 38.97122 mm, 10.74789 mm and 13.12459 mm for Aluminium, Copper and Silver particles respectively. In case of 40% N_2 and 60% SF_6 mixture the corresponding values are recorded as 38.69516 mm, 10.26797 mm and 12.79488 mm respectively. As the percentage of N_2 in the gas mixture changes the maximum radial movement also changes as given in table 1, table2 and table3. Figure 2 shows the movement of Aluminium particle in radial direction for an applied voltage of 75kV rms for pure SF_6 i.e. 0% N_2. The highest displacement in radial direction during its upward journey is simulated to be 13.43371 mm. Figure 3 shows the movement of Aluminium particle in radial direction for an applied voltage of 75kV rms for 60% SF_6 + 40% N_2. The highest displacement in radial direction during its upward journey is simulated to be 13.21965 mm. Graphical representation of radial movements are shown from Figure 2 to Figure 9. The movement patterns for Aluminium, Copper and Silver for 75kV for 100% SF_6+0% N_2 and 60% SF_6+40% N_2 mixtures are shown from Figure 2 to Figure 7 respectively. The movement pattern for 100kV, Aluminium particle for 100% SF_6+0% N_2 and 60% SF_6+40% N_2 mixtures are shown in Figure 8 and Figure 9 respectively.

From the above results it is observed that 40% N_2 and 60% SF_6 mixture gives good reduction in the particle movement so that at this condition the GIS can be reliably operated.

Table 1: variation of maximum movement (mm) of aluminum, copper and silver particles (l=10mm, r=0.25mm) in single phase gib(55mm/146mm) with gas mixtures for 75kv . simulation time: 1.5 sec.

N2%	75 kV		
	Y_{max}(Al)	Y_{max}(Cu)	Y_{max}(Ag)
0	13.43371	2.397945	2.332016
10	14.35965	2.341988	2.244033
20	13.64411	2.435466	2.319936
30	14.26962	2.436809	2.333487
40	13.21965	2.378525	2.324747
50	14.39368	2.162968	2.352014
60	14.56331	2.573016	2.33057
70	14.07969	2.447626	2.288737
80	13.69276	2.292708	2.217682
90	13.13895	2.680149	2.292418
100	13.27175	4.667543	2.198654

Table 2: variation of maximum movement (mm) of aluminum, copper and silver particles (l=10mm, r=0.25mm) in single phase gib(55mm/146mm) with gas mixtures for 100kV . simulation time: 1.5 sec.

N2%	100 kV		
	Y_{max}(Al)	Y_{max}(Cu)	Y_{max}(Ag)
0	25.19753	5.638526	4.15983
10	24.89139	5.799206	4.157463
20	24.09657	5.72516	3.809912
30	24.91585	5.724181	4.318901
40	25.06408	5.688031	3.959907
50	23.73021	4.555839	3.970885
60	23.33101	5.416516	3.66922
70	24.46316	5.159186	4.299564
80	22.6621	5.250872	3.692593
90	24.24554	4.2057	3.996439
100	24.52871	4.37779	4.220316

Table 3: variation of maximum movement (mm) of aluminum, copper and silver particles (l=10mm, r=0.25mm) in single phase gib(55mm/146mm) with gas mixtures for 145kV . simulation time: 1.5 sec.

N2%	145 kV		
	Y_{max}(Al)	Y_{max}(Cu)	Y_{max}(Ag)
0	38.97122	10.74789	13.12459
10	38.19901	15.9454	12.29578
20	38.07091	10.74463	11.44178
30	38.37261	15.46362	11.29156
40	38.69516	10.26797	12.79488
50	38.39528	10.73835	13.6786
60	37.47791	16.3259	13.7119
70	38.22276	13.65682	12.64914
80	37.6651	15.72616	12.2193
90	38.15562	17.65819	13.34112
100	38.25146	17.84144	13.24392

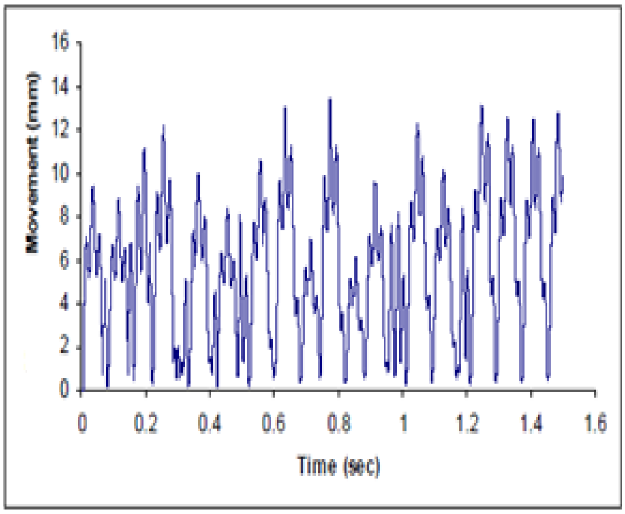

Figure 2: Particle Movement in 1-phase GIB (75KV/Al/ 0.25mm / 10mm) for 100% SF_6 + 0% N_2.

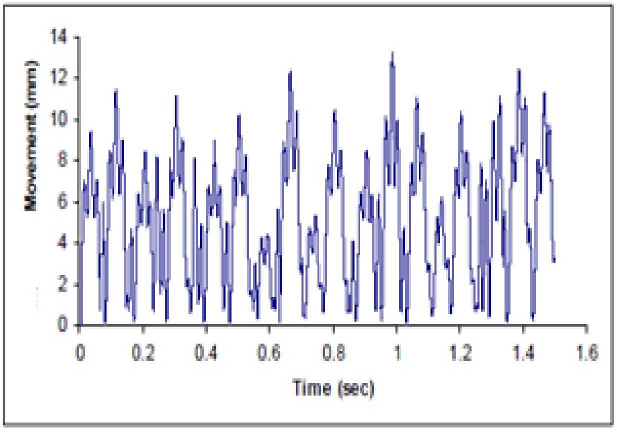

Figure 3: Particle Movement in 1-phase GIB (75KV/Al / 0.25mm / 10mm) for 60% SF_6 + 40% N_2.

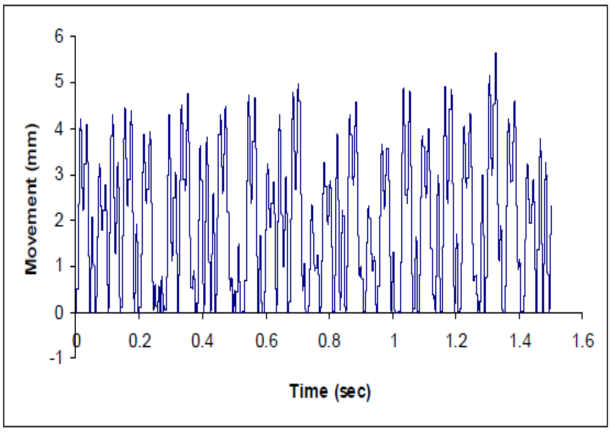

Figure 4: Particle Movement in 1-phase GIB (75KV/Cu / 0.25mm / 10mm) for 100% SF6 + 0%N2

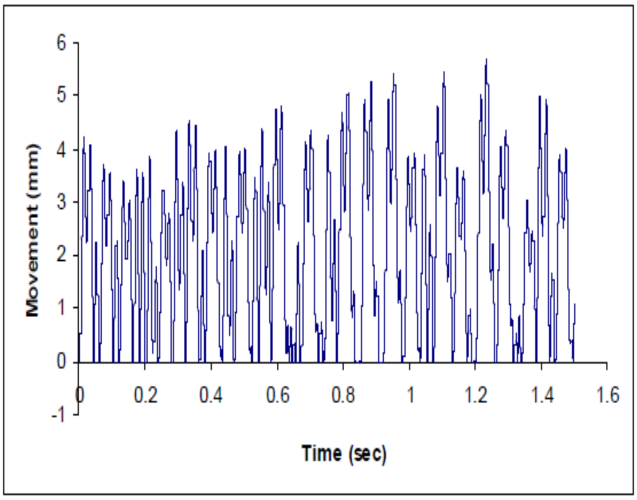

Figure 5: Particle Movement in 1-phase GIB (75KV/Cu/0.25mm/10mm) for 60% SF_6+40% N_2.

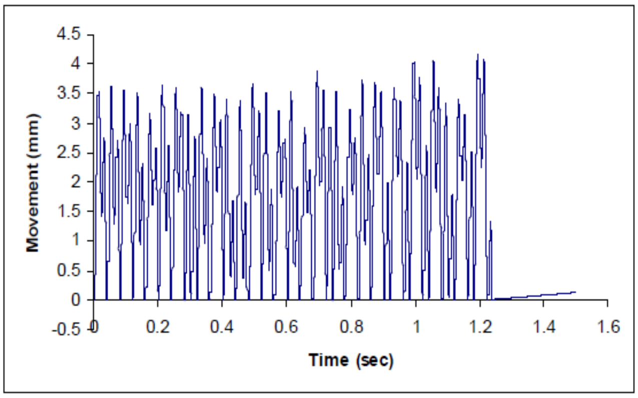

Figure 6: Particle Movement in 1-phase GIB (75KV/Ag/0.25mm/10mm) for 100% SF_6 + 0%N_2

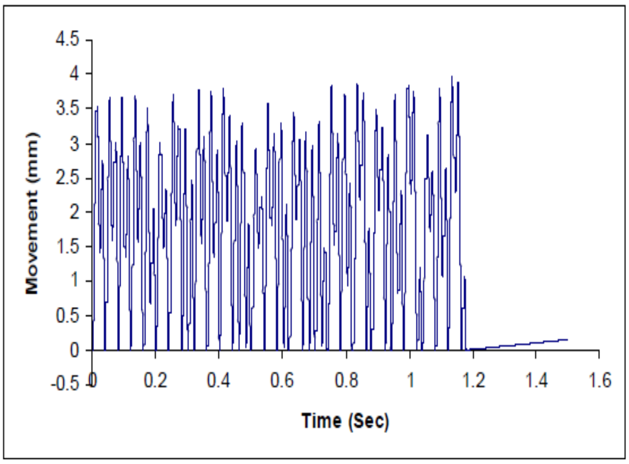

Figure 7: Particle Movement in 1-phase GIB (75KV/Ag / 0.25mm / 10mm) for 60% SF_6 + 40% N_2.

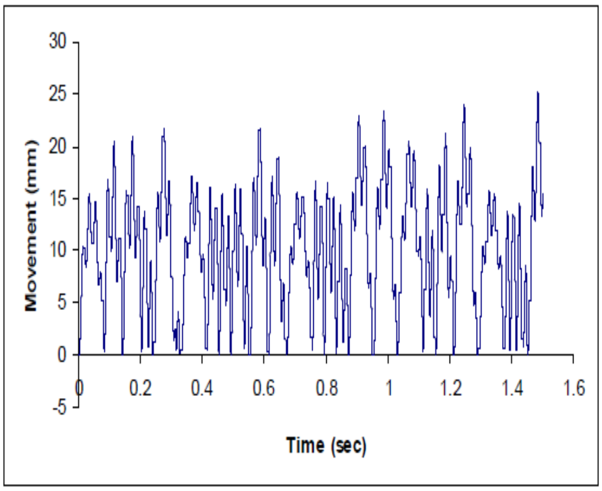

Figure 8: Particle Movement in 1-phase GIB (100KV/Al / 0.25mm / 10mm) for 100% SF_6 + 0% N_2.

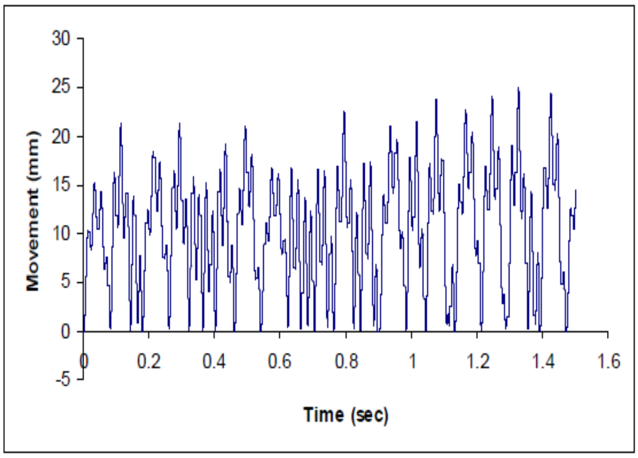

Figure 9: Particle Movement in 1-phase GIB (100KV/Al / 0.25mm / 10mm) for 60% SF_6 + 40% N_2.

7 CONCLUSIONS

A model has been formulated to simulate the movement of wire like particle in single phase GIB with and without gas mixtures. The results have been presented and analyzed in this paper. Distance travelled in the radial direction is found to be reduced with SF_6, N_2 gas mixture. From the above results 40% N_2 and 60% SF_6 gas mixture is highly reliable to the operation of GIS. At this condition the green house effect can be reduced.

8 ACKNOWLEDGMENTS

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9 REFERENCES

[1] H. Cookson, P.C. Bolin, H.C. Doepken, R.E. Wootton, C.M. Cooke and J.G. Trump, "Recent research in the United States on the effect of particle contamination reducing the breakdown voltage in compressed gas insulated system," Int.Conf. on large high voltage system: Paris, 1976.

[2] H. Anis and K.D. Srivastava, "Breakdown characteristics of Dielectric coated Electrodes in Sulphur Hexafluoride Gas with particle contamination," Sixth International Symposium on High Voltage Engineering No. 32.06, New Orleans, LA, USA. 1989.

[3] M.M. Morcos, S. Zhang, K.D. Srivastava and S.M. Gubanski, "Dynamics of Metallic particle contamination in GIS with Dielectric coating electrodes," IEEE Transactions on Power Delivery Vol. 15, No. 2, April 2000 pp.455-460.

[4] J. Amarnath, B.P. Singh, C. Radhakrishna and S. Kamakshaiah, "Determination of Metallic particle trajectory in a Gas insulated Busduct predicted by Monte-Carlo technique," CEIDP, October 17-21, 1999, Texas, Austin, USA.

[5] N.J. Felici, "Forces et charges de petits objects en contact avec une electrode affectee d'un champ electrique," Reveue generale de l' electricite, October 1966, pp.1145-1160.

[6] C.R. Wilke, "Viscosity Equation for gas mixtures," Jour.Chem.Phys., vol.18, 1950, pp.517-519.

[7] K. Mardikyam, O. Kalenderli, O. Ersen and E. Canarslan, "AC breakdown strength of N_2, SF_6 and a mixture of N_2+SF_6 containing a small amount of SF_6," IEEE International symposium on Electrical Insulation, Montreal, Quebec, Canada, June 16-19, 1996, pp.763-765.

[8] H. Ismailoglu, O. Kalenderli, M. Ozakaya and I. Gonenc, "Breakdown in compressed N_2 under Impulse voltages," CEIDP, October 19-22, 1997, Minneapolis, USA, pp.604-607.

[9] S.A. Ward, "Assessment of optimum SF_6-Air, SF_6-N_2, SF_6-CO_2 according to particle contamination sensitivity," CEIDP, October 17-21, 1999, Texas, Austin, USA, pp.415-418.