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Study of Dynamics of Aluminium Particle Contamination in Three Phase Gas Insulated Busduct with Various Insulating Gas Mixtures

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Abstract

A conventional three phase gas insulated substation consists of all its components enclosed in sulphur hexafluoride gas. The dielectric strength of SF_6 is too high when compared to that of air and hence makes it electrically superior to conventional air insulation. But SF6 is considered to be a green house gas and hence its usage is to be limited. This can be achieved by using alternative gases like Nitrogen (N_2), Carbon dioxide (CO_2). Alternatively , for better results of obtaining both high electric properties and reducing green house effects, mixtures of these gases along with SF6 can be employed for satisfactory operation of GIS.

The major problem with the GIS is the presence of electric contaminants which generally originate from the interior parts of the GIB/GITL. The movement of these metallic particle contaminants is to be minimised to improve the efficient operation of GIS. The present work deals with study of the dynamics of commonly encountered aluminium metallic particle contaminants present in the Gas insulated Substations. The mixtures of SF_6+CO_2, SF_6+N_2 and SF_6+air have been used as alternatives for pure SF6 gas.The movements of metallic particles are analyzed for different proportions of gas mixture and at various power frequency voltages, the results of which are presented and analyzed.

Keywords: Gas insulated busduct, SF_6+N_2 , SF_6+CO_2 and SF_6+Air gas mixtures, particle contamination, Analytical Method.

INTRODUCTION

The evolution of SF_6 gas has been a revolution in the field of insulation in electrical industry. Because of its extraordinary insulation strength and electronegativity, it has been extensively used in circuit breakers and electrical substations. They are employed in various parts of substation including the busbars, conncectors and cables. In recent years, sulphur hexafluoride (SF_6) gas has been of considerable technological interest as an insulation medium in high voltage apparatus due to its greater insulating properties, good thermal and chemical stability and high dielectric strength at relatively low pressure. SF_6 exhibits many properties that make it suitable for equipment utilized in the transmission and distribution of electric power SF_6 has been found to be a greenhouse gas. It absorbs infrared radiation and is also immune to chemical and photolytic degradation. The SF_6 gas half-life time in the atmosphere is estimated as 3200 years. So the effect of it to the atmosphere is effectively cumulative and permanent. Therefore, its contribution to global warming is cumulative and virtually permanent. Over a 100 years, its global warming potential (GWP) is estimated to be 24000 times greater than that of CO_2. For this reason it is included in the six gas basket of the Kyoto Protocol. Calculations based on atmospheric measurements show that the total worldwide emissions of SF_6 contribute only about 0.1 percent of the overall anthropogenic greenhouse effect. This includes both the SF_6 emissions from the major area of use in electricity transmission and distribution systems (about 70-80 % of the global SF_6 production is used in this sector) and those from all other uses.

The searches for even better gas insulation continues in order to develop gases and gas mixtures to satisfy specific requirements for various devices, provided such gases have dielectric properties comparable or superior to each other. There are two basic reasons for carrying out such investigations. Firstly, the aims are to develop an insulating medium, which is technically as well as economically attractive. The other reason is to obtain a better understanding of the breakdown mechanisms operating in compressed gases, and their gas mixtures. Most of the published data refer to uniform or nearly uniform field gaps for SF_6, CO_2, (carbon dioxide) N_2 (nitrogen) and air [1-2].

The breakdown voltages depends upon applied voltage and its polarity, pressure, electrode spacing and the nature of the gas. It is verified that Sulphur Hexafluoride (SF_6) gas has sterling dielectric and heat transfer properties and is progressively being used in high-pressure gas insulated systems. However, in practice the electrical breakdown strength of compressed SF_6 is often governed by a local field enhancement due to the protrusions, surface roughness, and the presence of conducting particles in the system. In addition the fact that SF_6 is a strong greenhouse gas has prompted interest in substitute gases with lower or no environmental impact. Therefore, the possibility of suitable SF6 gas mixtures which have similar dielectric strength and gives reduced installation cost and to minimize the possible hazard of particle-initiated breakdown. Many researchers have experimented the behaviour of Air, N_2 and CO_2 mixed with a small percentage of SF_6 as an additive [5,6].

The mixture of SF_6+N_2 gases is used for numerous applications, including use as insulation for high voltage equipment. From a practical point of view, only SF_6 mixtures with those common gases or buffer gases (air, N_2, CO_2) show an importance in most industrial applications [4].

The inclusion of little amount of SF_6 to Nitrigen gas can considerably improve the breakdown strength depending on the gas pressure, which reduces insulation cost of the system at higher gas pressures. This type of behaviour is more definite when the field configuration is highly non-uniform and/or at high gas pressure.

MODELING TECHNIQUE

A symbolic three phase gas insulated busduct comprising of three inner conductors filled with SF_6 gas mixtures as an insulating medium is shown in fig.1 is considered.

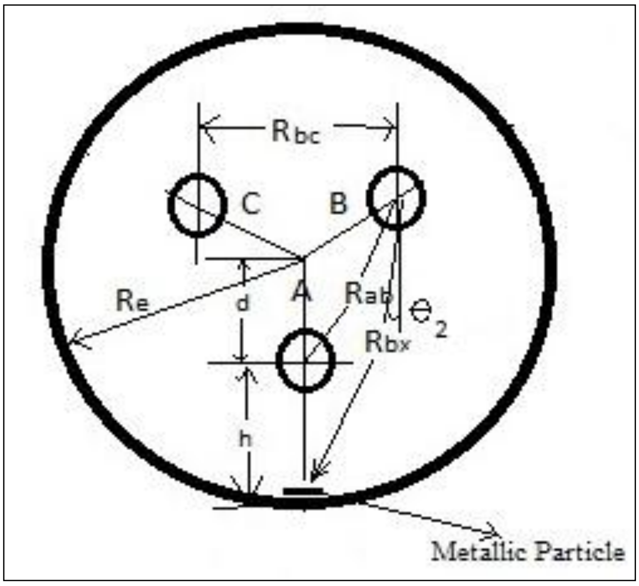

Figure 1. Typical representation of three phase Gas Insulated Busduct

The electric field 'E_y' at the surroundings of the particle location in time 't_i' inside three phase GIB/GITL can be estimated by following equations.

$$E_{ay} = \frac{V_{max}}{\log\left(\frac{h}{R_c}\right)}\left[\sin(\omega t_i)\frac{\cos(\pi)}{(h-x)}\right] \qquad \text{............ (1)}$$

$$E_{by} = \frac{V_{max}}{\log\left(\frac{h}{R_c}\right)}\left[\sin\left(\omega t_i - (2\pi/3)\right)\frac{\cos(\theta_2)}{R_{bx}}\right] \qquad \text{.................. (2)}$$

$$E_{cy} = \frac{V_{max}}{\log\left(\frac{h}{R_c}\right)}\left[\sin\left(\omega t_i - (4\pi/3)\right)\frac{\cos(\theta_2)}{R_{cx}}\right] \qquad \text{.................. (3)}$$

$$E_y = E_{ay} + E_{by} + E_{cy} \qquad \text{................ (4)}$$

Where E_{ay}, E_{by} and E_{cy} are electric field intensities due to A, B and C Conductors respectively. V_{max} is maximum voltage of any phase conductor.R_c is the high voltage conductor radius. R_{bx} is distance between B phase conductor to location of particle. R_{cx} is distance between C phase conductor and particle location. 'Θ_2' is the angle between R_{bx} and vertical axis at B or C phase conductor and 'x' is the distance from enclosure inner surface to the position of the particle which is moving upwards.

Contaminated metallic particle trajectory simulation in a three phase Gas Insulated Busduct is shown in figure (1).The wire like particle is assumed initially at rest on the innerside of the outer enclosure. Various forces experienced by a conducting particle which is in motion under external electrical field are 1. Electrostatic force (F_e) 2. Gravitational force (F_g) 3. Drag force (F_d) 4.Forces formed due to space charges near the particle and finally force due to coronal windage effect.

An advanced model is developed by observing the drag force, the influence of gas pressure and gas properties. So, improved model of particle motion equation is given as

$$m\frac{d^2y}{dt^2} = F_{electrostatic} - F_{gravitational} - F_{drag} \qquad \text{........... (5)}$$

Where 'm' is mass of the particle and y is the radial movement of the particle towards the conductor inside the three phase gas insulated busduct.

A. Electrostatic Force:

The electrostatic force experienced by vertical wire like metallic particle resting on inner surface of bare outer enclosure is given by

$$F_e = K\left(\frac{\pi\epsilon_o l^2 E(t_o)}{\ln\left(\frac{2l}{r}\right) - 1}\right)E(t) \qquad \text{........... (6)}$$

'K' is correction factor which depends on length-to-radius ratio of particle. 'E (t)' is Electric Field intensity at time instant 't'. 'ε_o' is permittivity of free air or vacuum, 'l' is length of the particle, $E(t_o)$ is Electric Field Intensity at time 't_o', 'r' is radius of the particle.

B. Gravitational Force:

The gravitational force acting on metallic particle having mass 'm', length 'l', radius 'r', and particle material density 'ρ' is:

$$mg = \pi r^2 l\rho g \qquad \text{........... (7)}$$

Where r is the radius of the particle
l is the length of the particle
g is the acceleration due to gravity
ρ is the density of the particle

C. Drag force:

The drag force plays important role in particle movement at higher gas pressures and at higher velocities of the particle in gas insulated busduct.The drag force acts in opposite direction to particle motion and causes the loss of energy due to shockwaves and skin friction of metallic particle.

In compressed gas insulated systems energy dissipation due to shock waves for **spherical particles** more and for greater length to radius ratio particles skin friction energy loss is more.

The total drag force is given as:

$$F_d = \dot{y}\pi r(\quad 6\,\mu K_d(\dot{y}) + 2.656 \quad (\mu\rho_g l \quad \dot{y})^{0.5}) \qquad \text{...........} (8)$$

For simulating the particle trajectory in gas insulated busduct using computer programs, it has been assumed that particle is resting on inner surface of outer enclosure and initial velocity of particle is zero. So, two initial conditions required for solving above equation (5) are given as:

$$\boldsymbol{m\dot{y}(t=0_+) = -Rm\dot{y}(t=0)}$$

$$\text{and } \boldsymbol{y(t=0_+) = 0}$$

where 'R' is the restitution coefficient, 'y(t=0_+)' is initial distance or distance from the surface of outer enclosure and $\dot{y}$(t=0_+)is the initial velocity or velocity of the particle just before lift-off from the inner surface of GIB enclosure. The value of restitution coefficient for Aluminium particles are usually in the range of 0.7 to 0.95 and R is equal to 0.9 means that 90% of the particle energy is preserved when bouncing on inner surface of outer gas insulated busduct between bounces of metallic particle.

The equation is a second order differential equation and can be solved by Runge-Kutta4th order method to obtain radial movement with time, for various values of parameters.

The work presented in this paper deals with different movement patterns of aluminium particle in a 3-phase GIB with the mixture of SF_6 gas and other mixtures. The charge acquired by the particle due to macroscopic electrostatic field at the tip of the particle is estimated. The force exerted by the field on the particle, effect of drag due to viscosity of the gas and its effect in reducing the net force exerted on the particle are estimated.

After several approximations in kinetic theory of diffusion Wilke have developed the expression for calculating the viscosity of gases.This viscosity of gas mixture based on the quantitative evaluation of inter molecular forces and the use of collision integrals, which reproduce the experimental data for non-polar gases with high precision for n number of gases is given in equation (9).This equation of viscosity is independent of the diffusivity and density of the gas content. Where, x_i and x_j are proportions of individual gases,$\mu_i$and $\mu_j$areindividual gas viscosities and M_i and M_j are molecular weights of two individual gasses respectively in the binary gas mixture.The viscosity of n number of gases can be estimated by using this equation.

$$\mu = \sum_{i=1}^{n} \frac{\mu_i}{1 + \frac{1}{x_i}\sum_{\substack{j=1 \\ j\neq i}}^{j=n} \left\{ \frac{x_j\left[1+\left(\frac{\mu_i}{\mu_j}\right)^{\frac{1}{2}}\left(\frac{M_j}{M_i}\right)^{\frac{1}{4}}\right]^2}{2\sqrt{2}\left[1+\left(\frac{M_i}{M_j}\right)\right]^{\frac{1}{2}}} \right\}} \qquad \text{..........} (9)$$

Table I: Maximum radial movements of Al metallic particles (l=9mm, r = 0.2mm) at 362 kV for various proportions of gas mixtures.

% of SF6 Gas	% of other gas	Maximum radial movement		
		SF6+N2	SF6+CO2	SF6+Air
100	0	14.90	14.90	14.90
90	10	14.41	14.40	15.97
80	20	15.33	14.69	15.57
70	30	15.45	15.35	15.34
60	40	15.70	14.39	15.28
50	50	15.00	15.33	15.53
40	60	15.21	15.21	15.23
30	70	14.87	14.84	15.07
20	80	14.48	15.11	14.56
10	90	14.39	15.20	14.38
0	100	15.48	14.84	15.28

Table II: Maximum radial movements of Al metallic particles (l=9mm, r = 0.2mm) at 420 kV for various proportions of gas mixtures

% of SF6 Gas	% of other gas	Maximum radial movement		
		SF6+N2	SF6+CO2	SF6+Air
100	0	19.36	19.35	19.36
90	10	19.32	19.33	19.38
80	20	19.34	19.37	19.09
70	30	19.41	19.35	19.29
60	40	19.22	19.26	19.25
50	50	19.34	19.40	19.36
40	60	19.25	19.19	19.28
30	70	19.87	19.23	19.13
20	80	19.29	19.31	19.18
10	90	18.99	19.37	19.24
0	100	19.30	19.30	19.38

RESULTS AND DISCUSSIONS

The simulation study has been carried out on the movement of Al metallic particles in a three phase GIB. Three different power frequency voltages of 362kV, 420kV and 550kV have been employed as the line voltages in the three phase busduct. The enclosure dimensions are 250mm/32mm, the former being the inner radius of the enclosure and the later being the outer radius of the conductor. The electric field is calculated using the formulae mentioned in the previous sections and it is used for calculation of the maximum movements of the wire type aluminium metallic particle which is assumed to be present on the inner surface of the enclosure.

Table III: Maximum radial movements of Al metallic particles (l=9mm, r = 0.2mm) at 550 kV for various proportions of gas mixtures

% of SF6 Gas	% of other gas	Maximum radial movement		
		SF6+N2	SF6+CO2	SF6+Air
100	0	32.70	32.70	32.70
90	10	32.47	32.70	32.82
80	20	32.54	32.43	32.45
70	30	32.71	32.31	32.68
60	40	32.20	32.46	32.58
50	50	32.35	32.51	32.47
40	60	32.43	32.27	32.44
30	70	32.50	32.29	32.60
20	80	32.53	32.45	32.37
10	90	32.51	32.65	32.50
0	100	32.16	32.76	32.67

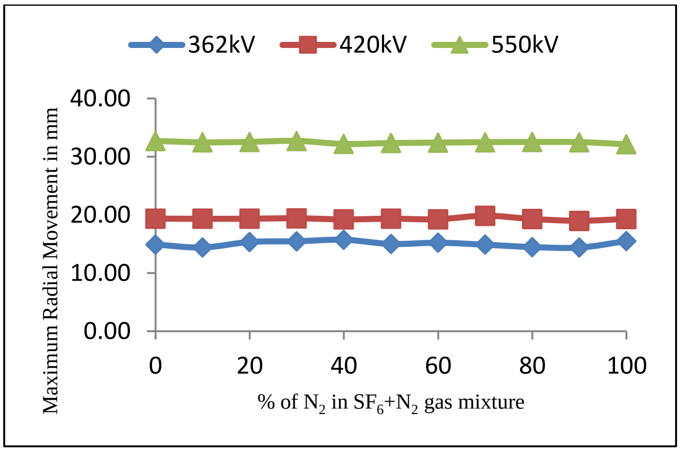

Figure 2: Maximum Radial Movement of Al particle (l=9mm, r=0.2mm) for different voltages for different compositions of SF_6 +N_2 gas mixture.

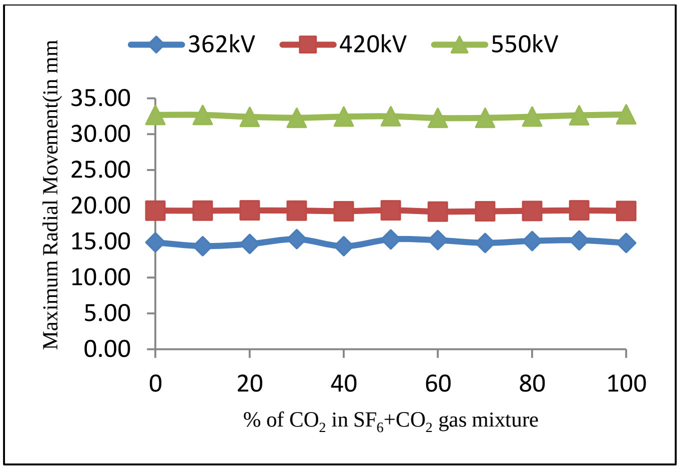

Figure 3: Maximum Radial Movement of Al particle (l=9mm, r=0.2mm) for different voltages for different compositions of SF_6 +CO_2 gas mixture.

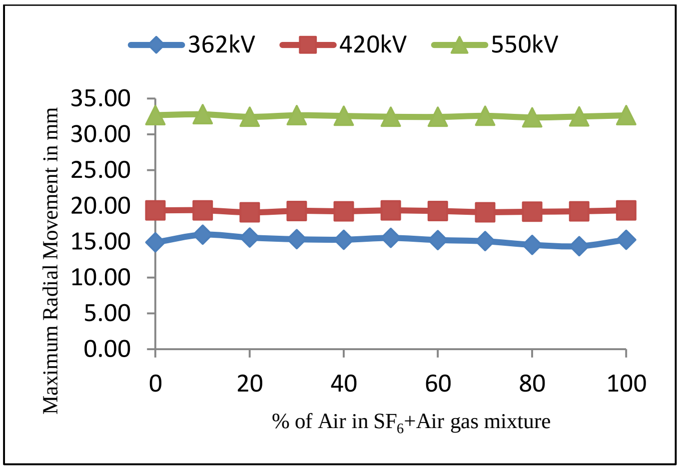

Figure 4: Maximum Radial Movement of Al particle(l=9mm, r=0.2mm) for different voltages for different compositions of SF_6 +Air gas mixture.

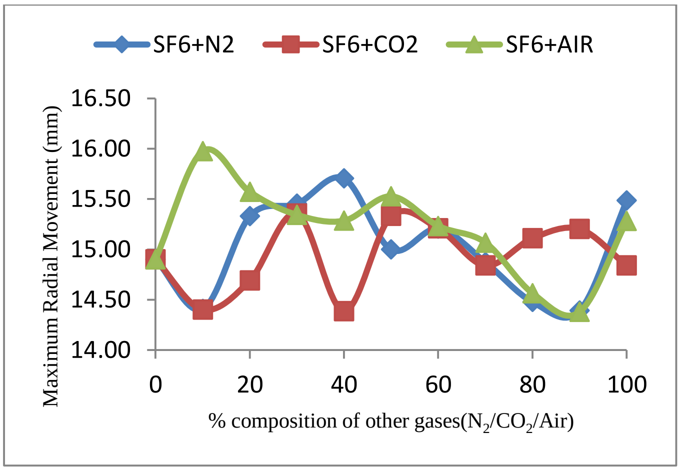

Figure 5: Maximum Radial Movement of Al particle(l=9mm, r=0.2mm) for different gas mixtures(SF_6 +N_2/CO_2/Air) at 362kVvoltage

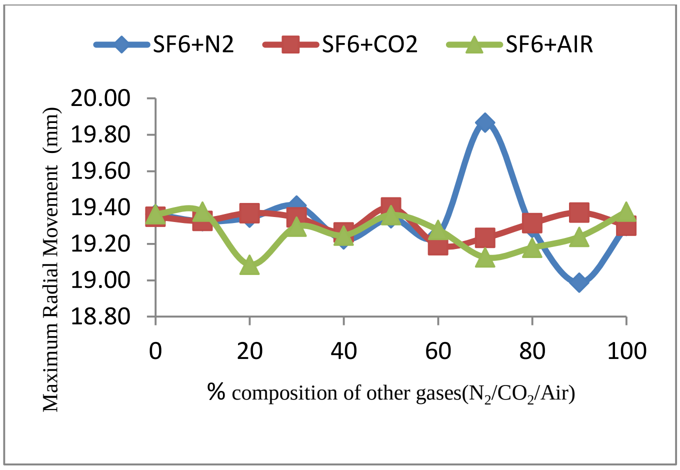

Figure 6: Maximum Radial Movement of Al particle(l=9mm, r=0.2mm) for different gas mixtures(SF_6 +N_2/CO_2/Air) at 420kVvoltage

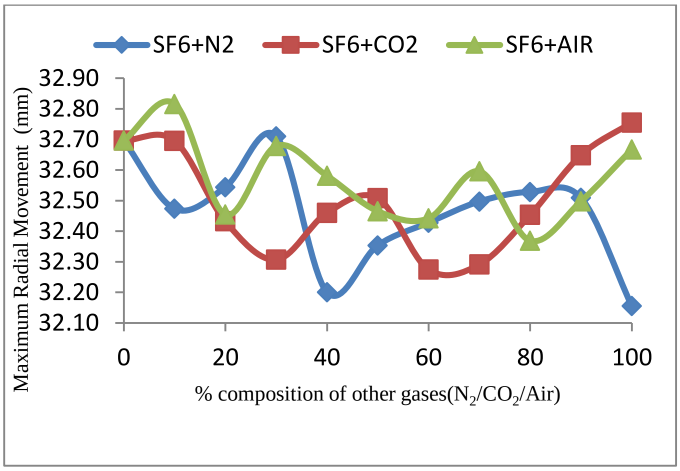

Figure 7: Maximum Radial Movement of Al particle(l=9mm, r=0.2mm) for different gas mixtures(SF_6 +N_2/CO_2/Air) at 550kVvoltage

Table 1 shows the maximum radial movements of the aluminium particle contaminants at 362 kV for various proportions of the gas mixtures of ***SF_6+CO_2*, *SF_6+N_2* and *SF_6+air***. It can be observed that the particle movement does not vary much due to change in the dilution of the SF_6 gas. But the proportion of 60-40 to 40-60 of the gas mixtures can be treated ideal as the insulation medium. Table 2 and Table 3 show the maximum radial movements of the same particles when the conductor is energized with 420kV and 550 kV respectively.

The data which is presented in the tables, as shown above, has been analyzed in detail. Figures 2-7 indicate the variation of the maximum movements of the particle contaminants at various conditions.

CONCLUSIONS

A model has been formulated to simulate the movement of wire like particle in a three phase common enclosure GIB in the presence of SF_6 gas mixed with Nitrogen, Dry Air,CO_2 gases. The results have been presented and analyzed in this paper. Distance travelled in the radial direction is found to be reduced when small amounts of gases are mixed with SF_6. This reduces the effect of green house gases.

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