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EFFECT OF LIGHTNING IMPULSE VOLTAGE ON THE PERFORMANCE OF 1-PHASE GAS INSULATED BUSDUCT IN THE PRESENCE OF METALLIC PARTICLE CONTAMINATION WITH SF_6/N_2 GAS MIXTURES

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ABSTRACT

SF_6 is the main mode of insulation in a GIS. However, in recent years, the future use of SF_6 has been debated throughout the world in spite of it having all the desirable properties of a good insulating and arc quenching medium. Sulfur hexafluoride (SF_6) has been used as a gaseous dielectric (insulator) in high voltage equipment since the 1950s. It is now known that SF_6 is a potent greenhouse warming gas with one of the highest global warming potentials (GWP) known. In the presence of metallic contamination can seriously reduce the insulation performance of a GIS. Particularly the influence of free metallic particles has been regarded as an important issue for many years, since free particles are considered to be hazardous because of the possibility of initiating a voltage breakdown. Transient over voltages due to lightning voltages cause steep build up of voltage on transmission lines and other electrical apparatus. Therefore GIS must be able to withstand such voltages without breakdown of insulation. As GIS operates under power frequency voltages. Lightning impulse voltage of 1050kV superimposed on power frequency voltages of 75kV,120kV and 132kV are applied to 1-Φ GIB and the maximum movement of Cu, Al and Silver contaminants are obtained with and without Monte-Carlo technique for SF_6 gas SF_6/N_2 gas mixtures as dielectric medium.

Keywords: *Electric Field, Gas Insulated Substations, Metallic Particles.*

1. INTRODUCTION

Demand for electrical power has become one of the major challenges faced by the developing countries. Considering the relative low per capita power consumption, there is a constant need for power capacity addition and technological up gradation 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. Power needed a creative solution to its urbanization problem, a compact design on a smaller site with improved aesthetics to lessen the impact on the neighborhood. In this context of changing and challenging market requirements, Gas Insulated Substation has 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 etc SF_6 is the main mode of insulation in a GIS[1-5]. However, in recent years, the future use of SF_6 has been debated throughout the world in spite of it having all the desirable properties of a good insulating and arc quenching medium. Sulfur hexafluoride (SF_6) has been used as a gaseous dielectric (insulator) in high voltage equipment since the 1950s. It is now known that SF_6 is a potent greenhouse warming gas with one of the highest global warming potentials (GWP) known. Because of its high GWP, it is being phased out of all frivolous applications.SF6 is an efficient absorber of infrared radiation, particularly at wavelengths near 10.5 µm. Among the environmentally benign insulating gases alternative to SF6 gas, SF_6/N_2 gas mixtures (at different percentages of SF_6) is regarded as one of the most attractive gases because of the synergistic effect in electrical insulation performance. By using SF_6/N_2 gas mixture [3], we will be able to reduce SF_6 gas amount for power apparatus and this enables us to suppress the global warming effect. SF_6-N_2 mixtures are the most thoroughly investigated among all known gas mixtures. Based on the research conducted worldwide, the optimum composition of SF_6- N_2 mixture for practical applications is considered to be 40% SF_6 - 60% N_2 mixtures.

A particle is assumed to be at rest at the enclosure surface, until a voltage sufficient enough to lift the particle (lift-off field, 'E_{lo} ') 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 drag [5].

The main objective of this paper is to simulate particle movement in a 1-phase GIB of inner electrode diameter of 55mm and outer enclosure diameter of 152mm filled with SF_6 /N2 gas mixtures as dielectric medium and to compare the movement of wire like metallic particulate of Al, Cu and Ag with radius 0.25mm and length 10mm by considering its presence on the enclosure with application of lightning impulse voltage superimposed on power frequency voltage. The simulation of which is carried out for a time period of 1.5 seconds by solving the motion equation which is non linear differential equation solved with and without Monte-Carlo technique for typical 1-phase bus voltages of 75kv,120kv and 132kv.

2. MODELLING TECHNIQUE

Figure 1 shows a typical horizontal bus duct comprising of an inner conductor and an outer enclosure, filled with SF_6 gas is considered for the study. A particle is assumed to be at rest at the enclosure surface, 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 the field after overcoming the forces due to its own weight and drag.

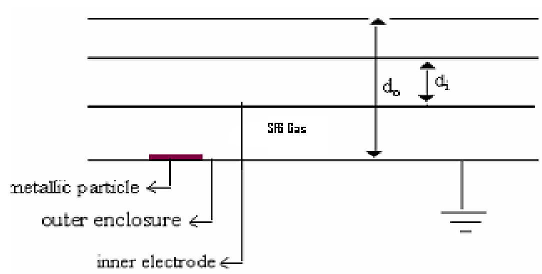

Figure 1: Typical 1-phase Gas insulated bus duct

In order to study the particle trajectory, the expressions for charge and thus the liftoff field acquired by conducting contaminants of different shapes are studied, primarily based on the work of Felici [5]. When the electric field around a particle is increased, an uncharged contaminant resting on bare electrode will gradually acquire a net charge which is function of local electric field, orientation, shape and size of the particle. The particle lifts-off from its position, when the electrostatic force (F_e) exceeds the gravitational force (F_g).

2.1 Charge acquired by particle (Q):

Metallic particles that move randomly in the electrode gap may be of different shapes, sizes and orientations. The charge acquired by horizontal shape is given below

For Horizontal wire**:**

$$Q_{hw} = 2\pi\varepsilon_0 rlE \qquad \textbf{(1)}$$

Where r → radius of the particle in meters
l → length of the particle in meters

Effect of electric field on contaminant at any position 'y' from the outer enclosure [4]

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

(2)

Where V→ supply voltage to the inner electrode in volts

r_o→ radius of the outer enclosure in meters

r_i → radius of the inner conductor in meters

y → position of particle which is moving upwards from surface enclosure towards inner electrode in meters

2.1 Lift off field:

For horizontal wire particle:

$$\Rightarrow E_{LO} = 0.84\sqrt{\frac{r\, g\, \rho}{\varepsilon_0}} \qquad (3)$$

2.2 Drag Force (F_d):

$$F_d = \dot{y}\, \pi\, r\left(6\, \mu\, K_d(\dot{y}) + 2.656\, \left[\mu\, \rho_g\, l\, \dot{y}\right]^{0.5}\right)$$

(4)

$K_d(y)$ → dimensionless drag coefficient and is given by:

$$K_d(y) = e^{\left[0.1142 + 0.0543 \ln(R_e) + 0.0516 (\ln(R_e))^2\right]}$$

(5)

An empirical relationship between gas pressure P and density ρ_g is given by

$\rho_g = 7.118 + 6.332\, P + 0.2031\, P^2 \quad 0.1<P<1$ Mpa

(6)

2.3 Reynolds number (R_e):

Reynolds number Re is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and is given by

$$R_e = \frac{2\, r \rho_g\, \dot{y}}{\mu}$$

(7)

Where ρ_g → the gas density in Kg/m^3

μ → the viscosity of the gas in Kg/ms(for SF_6=15.5 x 10^{-6} Kg/ms at 20^0C)

r → radius of the particle in m

$\dot{y}$ → Velocity of the particle in m/s

2.4 Gravitational force (F_g):

The gravitational pull experienced by the particle is given by

$$F_g = mg = (\pi\, r^2 l) * \rho * g \qquad (8)$$

2.5 Electrostatic force (F_e):

Electrostatic force is given by

$$\mathbf{F_e = KQE} \qquad (9)$$

Thus Electrostatic force can be expressed as

$$F_e = \left[\left(\frac{\pi \varepsilon_0 l^2 E}{\left(\ln\left(\frac{2l}{r}\right) - 1\right)}\right) * \left(\frac{V \sin \omega t}{\left[\ln\left(\frac{r_o}{r_i}\right)\right]\left[r_o - y(t)\right]}\right)\right]$$

(10)

2.6 Motion equation:

Thus, considering the effects of all the forces, the motion equation can be expressed as

$$m\ddot{y}(t) = \left[\frac{\pi\varepsilon_0 l^2 E(t_0)}{\left(\ln\left(\frac{2l}{r}\right) - 1\right)} \times \frac{V \sin \omega t}{(r_0 - y(t)) \ln\left(\frac{r_0}{r_i}\right)}\right] - \pi\, r^2 l\, \rho\, g \sin\theta - \dot{y}\, \pi\, r\left(6\, \mu\, K_d(y) + 2.656\, \left[\mu\, \rho_g\, l\, \dot{y} \sin\theta\right]^{0.5}\right)$$

(11)

2.7 Calculation of viscosity and Reynolds number of SF_6 and N_2 Gas mixtures:

The viscosity of a mixture of two gasses can be approximately calculated from the following equation.

$$\mu = \frac{\mu_1}{1+\frac{\frac{x_2}{x_1}\left[1+\sqrt{\frac{\mu_1}{\mu_2}}\left(\frac{m_2}{m_1}\right)^{\frac{1}{2}}\right]^2}{\frac{4}{\sqrt{2}}\left(1+\frac{m_1}{m_2}\right)^{\frac{1}{2}}}} + \frac{\mu_2}{1+\frac{\frac{x_1}{x_2}\left[1+\sqrt{\frac{\mu_2}{\mu_1}}\left(\frac{m_1}{m_2}\right)^{\frac{1}{2}}\right]^2}{\frac{4}{\sqrt{2}}\left(1+\frac{m_2}{m_1}\right)^{\frac{1}{2}}}} \quad \textbf{(12)}$$

Where: x_1 and x_2 are proportion of N_2 and SF_6 gasses respectively.
μ_1 and μ_2 are viscosities of N_2 and SF_6 gasses respectively.
m_1 and m_2 are molecular weights of N_2 and SF_6 gasses respectively.
m_1=28 gm/mole, m_2=146 gm/mole.

After calculating the viscosity of gas mixtures from equation (12), the Reynolds's number can be calculated using (7) and its value can be substituted in the particle motion equation.

3. RESULTS AND DISCUSSIONS:

Table: 1 shows the maximum radial movements of Al, Cu, Ag obtained by solving the motion equation using iterative techniques and also shows the axial and radial movements obtained by solving motion equation using Monte – Carlo technique corresponding to solid angle1^0 for 75kV, 120kV and 132kV power frequency voltages superimposed on lightning impulse voltage at 90^o with pure SF_6 gas as dielectric medium. Fig (1) shows the input voltage corresponding to impulse voltage superimposed on power frequency voltage at 90^0. Fig (3) and Fig (5) depicts the maximum movement pattern of Aluminium particle for 75Kv and Copper particle for 132Kv respectively. Fig (4) shows axial and radial movements of silver particle for 132Kv.Fig (6) to Fig (8) Shows the maximum movement patterns of Al, Cu and Ag Particles for different concentrations of N_2 in SF_6/N_2 Gas mixtures for superimposed voltages corresponding to 75Kv, 120Kv and 132Kv respectively. As the applied voltage increases the maximum movement also increases in all the three cases. The movement pattern obtained for Al, Cu and Ag is same but, the movement for Al is very high when compared to Cu and Ag because of its light weight. Further from the above results we can observe that the Movement of particles is less corresponding to mixture of gases between 40% and 60% of N_2 in SF_6/N_2 gas mixtures.

Table: 1 Maximum Movement of Aluminium, copper and silver particles of 0.3mm radius and length 10mm in 152/55mm 1-Φ GIS with lightning impulse voltage superimposed on the power frequency voltage.

Voltage (kv)	Type	Maximum Radial Movement (mm)	Monte- Carlo (1deg)	
			Axial (mm)	Radial (mm)
75	Al	59.08154	183.0091	59.0793
	Cu	0.331653	6.4587	0.3316
	Ag	0.234282	2.5439	0.2343
120	Al	61.06657	168.2337	61.066
	Cu	15.9318	105.1447	15.9316
	Ag	11.28481	68.6911	11.2848
132	Al	63.59171	209.0911	63.5897
	Cu	19.0232	152.3332	19.0229

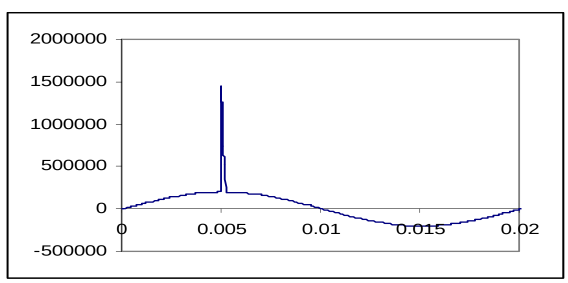

Figure 2: Lightning impulse voltage superimposed on Power Frequency voltage (90^0)

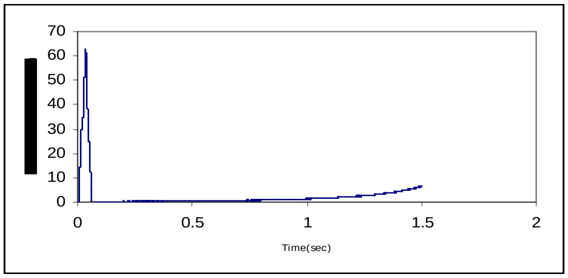

Figure 3: Movement pattern for superimposed under lightning impulse (90^0) Al/75kV/10mm/0.3/152mm-55mm enclosure.

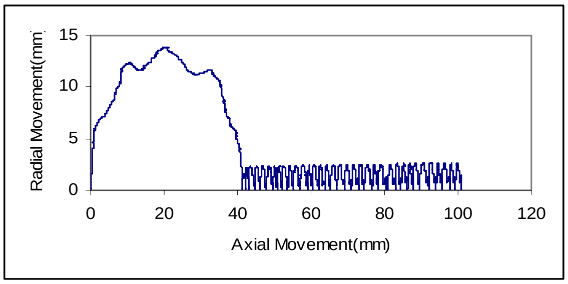

Figure 4: Axial and Radial movement in a 1-phase GIB for superimposed lightning impulse (90^0) Ag/132kV/10mm/0.3/152mm-55mm enclosure

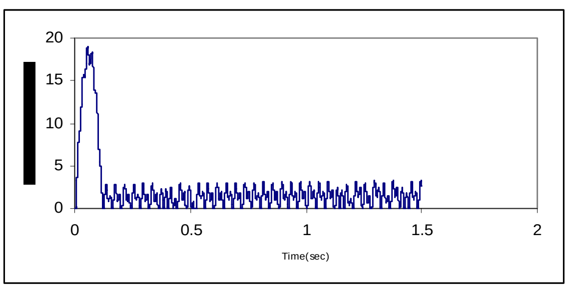

Figure 5: Movement pattern for superimposed lightning Impulse (90^0) Cu /132kV/ 10mm/0.3/152mm-55mm enclosure.

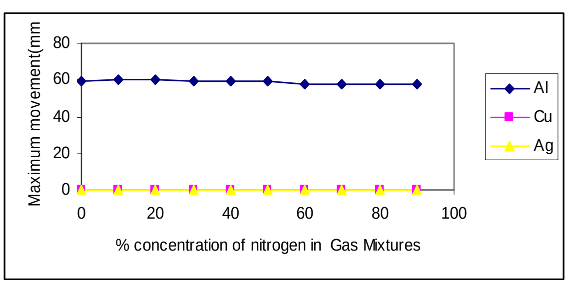

Figure 6: Maximum Movement of metallic particle in SF_6/N_2 Gas Mixtures for lightning voltage superimposed on power frequency voltage 75Kv (rms)

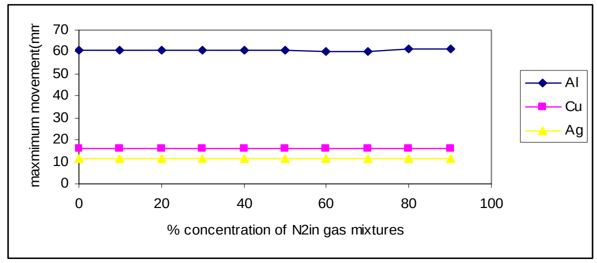

Figure 7: Maximum Movement of metallic particle in SF_6/N_2 Gas Mixtures for lightning voltage superimposed on power frequency voltage 120Kv (rms)

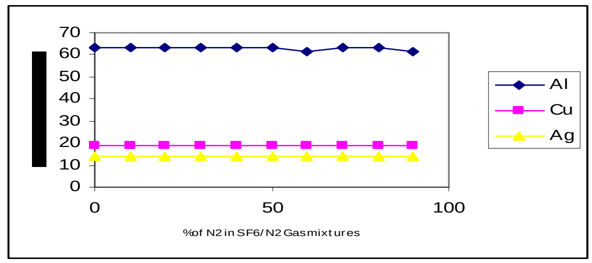

Figure 8: Maximum Movement of metallic particle in SF_6/N_2 Gas Mixtures for lightning impulse voltage superimposed on power frequency voltage 132Kv (rms)

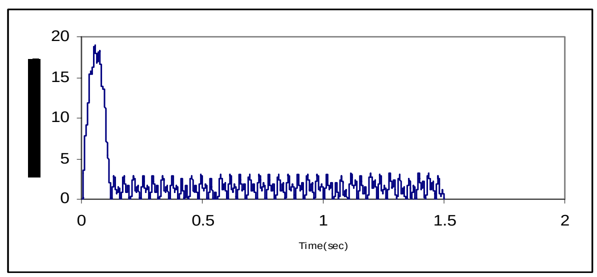

Figure 9: Maximum Movement pattern of copper particle with 40% N2 in SF_6/N_2 Gas Mixtures for with lightning impulse superimposed on power frequency voltage132Kv (rms)

4. CONCLUSIONS

A model has been formulated to simulate the movement of metallic particle in SF_6 / N_2 Gas mixtures environment on single phase GIS with application of 75kV,120kV and 132kV power frequency voltages superimposed on lightning impulse voltage. The movement is lower for all the particles for 40%to 60% concentration of N_2 in SF_6/N_2 gas mixtures and the results are in agreement with the published work of pure SF_6 gas.

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