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DYNAMICS OF PARTICLE CONTAMINATION IN 550 kV THREE PHASE GAS INSULATED BUSDUCT WITH VARIOUS INSULATING GAS MIXTURES

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ABSTRACT

A conventional three phase gas protected substation comprises of every one of its segments encased in sulphur hexafluoride gas. The dielectric quality of SF6 is too high when contrasted with that of air and subsequently makes it electrically better than customary air protection. In any case, SF6 is thought to be a green house gas and subsequently its use is to be constrained. This can be accomplished by utilizing selective gases like Nitrogen (N2), Carbon dioxide (CO2). On the other hand , for better after effects of getting both high dielectric properties and decreasing green house impacts, blends of these gases alongside SF6 can be utilized for agreeable activity of GIS. The significant issue with the GIS is the presence of electric contaminants which for the most part begin from the inside parts of the enclosures. The movement of these metallic contaminants is to be limited to enhance the proficient activity of GIS. The present work manages investigation of the movement of generally experienced aluminium and copper metallic particle contaminants in the Gas insulated Substations. The blends of SF6+CO2, SF6+N2 and SF6+air have been utilized as options for unadulterated SF6 gas. The developments of metallic particles are investigated for various extents of gas mixtures and 550kV power frequency ac voltage, the details of which are discussed.

Keywords: gas insulated busduct, SF_6+N_2gas mixture, SF_6+CO_2 gas mixture particle contamination, analytical method.

1. INTRODUCTION

The utilisation of SF6 gas has changed the innovation of circuit breakers as well as the design of substations. Insulating gases are utilized as a protecting medium for reduced substation parts and protected links. As of late, sulphur hexafluoride (SF6) gas has been of significant electrical utility as a protection medium in high voltage device in light of its unrivalled protecting properties, high dielectric quality at generally low weight. SF6 displays numerous properties that make it reasonable for gear used in the transmission and distribution of electric power. SF6 has been observed to be an ozone harming substance. It retains infrared radiation and is additionally invulnerable to synthetic and photolytic corruption. The SF6 gas half-life time in the environment is assessed as 3200 years. So its impact to the air is successfully aggregate and perpetual. Over 100 years, it's a dangerous atmospheric devation potential (GWP) is assessed to be 24000 times more prominent than that of CO2. Therefore it is incorporated into the six gas bin of the Kyoto Protocol. Estimations in light of environmental estimations demonstrate that the aggregate overall outflows of SF6 contribute just around 0.1 percent of the general anthropogenic nursery impact. This incorporates both the SF6 discharges from the real territory of utilization in power transmission and dispersion frameworks (around 70-80 % of the worldwide SF6 creation is utilized as a part of this segment) and those from every single other utilize.

The desire for far and away superior gas protection to create gases and gas blends to fulfil particular prerequisites for different gadgets, gave such gases have dielectric properties practically identical or better than each other. There are two essential explanations behind doing such examinations. Right off the bat, the points are to build up a protecting medium, which is in fact and monetarily appealing. The other reason is to acquire a superior comprehension of the breakdown components working in compacted gases, and their gas blends. The greater part of the distributed information allude to uniform or about uniform field holes for SF6, CO2, (carbon dioxide) N2 (nitrogen) and air [1-2].

In a commonplace modern application the non-uniform field breakdown prevails. The breakdown voltages are influenced by connected voltage, voltage extremity, anode dispersing, and nature of the gas. It is perceived that Sulphur Hexafluoride (SF6) gas has magnificent dielectric and heat transfer properties and is progressively being utilized as a part of high-pressure gas protected frameworks. Be that as it may, by and by the electrical breakdown quality of packed SF6 is regularly represented by a neighbourhood field improvement because of the projections, surface harshness, and the nearness of leading particles in the framework. Moreover the way that SF6 is a solid ozone depleting substance has provoked interest for substitute gases with lower or no natural effect. Subsequently, there is an expanding interest for the conceivable utilization of blends of SF6 and different gases to lessen protection cost and to limit the conceivable danger of particle initiated breakdown. Numerous scientists have considered air, N2 and CO2 blended with a little level of SF6 as an additive. [8, 9] The blend of SF6+N2 gases is utilized for various applications, including use as protection for high voltage equipment. From a general perspective, just SF6 blends with those

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regular gases or cushion gases (air, N2, CO2) demonstrate significance in most electrical applications [4].

L.G. Christophorou *et al.*, [3] expressed that expansion of little measure of SF6 to N2 gas can extensively enhance the breakdown quality relying upon the gas weight and decreases protection cost of the framework at higher gas weights. This sort of behaviour is more articulated when the field arrangement is very non-uniform as well as gas weight is high.

2. MODELING TECHNIQUE

A typical three phase common enclosure gas insulated busduct comprising of three inner conductors filled with SF_6 mixed with Nitrogen, Carbon dioxide and Dry Air gases as an insulating medium is shown in Figure-1 is considered.

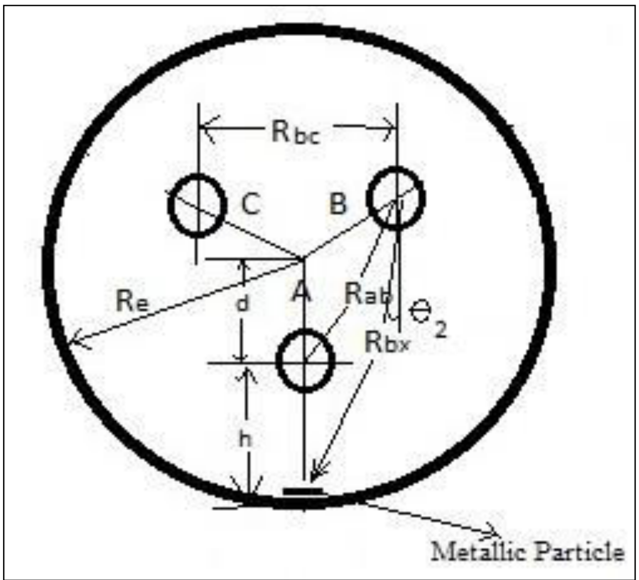

Figure-1. Typical representation of three phase Gas Insulated Busduct.

Analytically ambient electric field 'E_y' at particle location at time 't_i'in common enclosure three phase Gas Insulted Busduct [68-70] can be calculated by using following equations,

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

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

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

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

Where E_{ay}, E_{by} and E_{cy} are electric field intensities due to A, B and C Conductors respectively, V_{max} maximum voltage of any phase conductor, R_c is the high voltage conductor radius, R_{bx} is distance between B phase conductor, 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 inner side 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

$$\mathrm{m}\frac{\mathrm{d}^2\mathrm{y}}{\mathrm{dt}^2} = \mathrm{F}_{\mathrm{electrostatic}} - \mathrm{F}_{\mathrm{gravitational}} - \mathrm{F}_{\mathrm{drag}} \quad \text{........... (5)}$$

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 charge acquired by a vertical wire particle in contact with naked enclosure can be expressed as:

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

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

'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:

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

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:

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

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 (1) are given as:

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

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 and copper 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 outer Gas Insulated Busduct between bounces of metallic particle.

The work reported in this paper deals with the movement of metallic particle in 3-phase common enclosure Gas Insulated Busduct with SF_6 gas and different blends. The specific work reported deals with the charge acquired by the particle due to macroscopic field at the tip of the particle, the force exerted by the field on the particle, drag due to viscosity of the gas and random behaviour during the movement. Wire like particles of aluminium and copper of a fixed geometry in a 3-phase busduct have been considered.

3. SIMULATION OF ELECTRIC FIELD IN GAS INSULATEDBUSDUCT WITH AND WITHOUT GAS MIXTURES

After few approximations in kinetic theory of diffusion, Wilke have built up the expression for finding the 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 viscosity equation is independent of the diffusivity and density of the gas content. Where, $\mu_i$and $\mu_j$are individual gas viscosities and x_i and x_j are proportions of individual gases, and $M_i$and $M_j$are molecular weights of two individual gasses respectively in the binary gas mixture.

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

This formula can be used to find the viscosity of n number of gases.

4. RESULTS AND DISCUSSIONS

The simulation study has been done to assess the movement of aluminium and copper metallic particles in a three phase gas insulated busduct operated on 550kV power frequency voltage. The enclosure measurements are 165mm/ 51mm, the former being the inner radius of the enclosure and the later being the outer radius of the conductor. The electric field is evaluated using the formulae mentioned in the previous sections and it is used for calculation of the maximum movements of the wire type aluminium and copper metallic particles which are assumed to be present on the inner surface of the outer enclosure.

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Table-1. Maximum radial movements of Al metallic particles at 550 kV (l=9mm, r=0.2mm) for various proportions of gas mixtures.

% of SF6 Gas	% of other gas	Maximum radial movement (Ymax) of aluminium(Al) particle at 550KV		
		SF_6+N_2	SF_6+CO_2	SF_6+AIR
100	0	32.69641	32.69641	32.69641
90	10	32.47299	32.69579	32.81619
80	20	32.54396	32.43214	32.45430
70	30	32.71049	32.30650	32.67825
60	40	32.20027	32.45987	32.58115
50	50	32.35330	32.50754	32.46527
40	60	32.42760	32.27462	32.44180
30	70	32.49680	32.29100	32.59565
20	80	32.52826	32.45308	32.36894
10	90	32.50858	32.64838	32.49746
0	100	32.15553	32.75539	32.66689

Table-2. Maximum radial movements of Cu metallic particles at 550 kV (l=9mm, r=0.2mm) for various proportions of gas mixtures.

% of SF_6 Gas	% of other gas	Maximum radial movement (Ymax) of copper(Cu) particle at 550KV		
		SF_6+N_2	SF_6+CO_2	SF_6+AIR
100	0	11.88079	11.88079	11.51275
90	10	11.67162	11.64025	11.86734
80	20	11.87700	11.69545	11.63885
70	30	11.72618	11.57420	11.68341
60	40	11.80279	11.82208	11.77246
50	50	11.47607	11.79725	11.65766
40	60	11.42441	3.68548	11.64013
30	70	11.45810	11.82309	11.63268
20	80	11.69352	11.77535	11.82378
10	90	11.23264	11.74941	11.78340
0	100	11.60812	11.77376	11.82959

Table-1 shows the maximum radial movements of the aluminium particles at 550 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 shows the maximum radial movements of the copper particles for the same gas proportions when the conductor is energized at 550 kV. The data which is presented in the tables, as shown above, has been analyzed in detail. Figures 2 & 3 indicate the variation of the maximum movements of the particle contaminants at various proportions of gas mixtures.

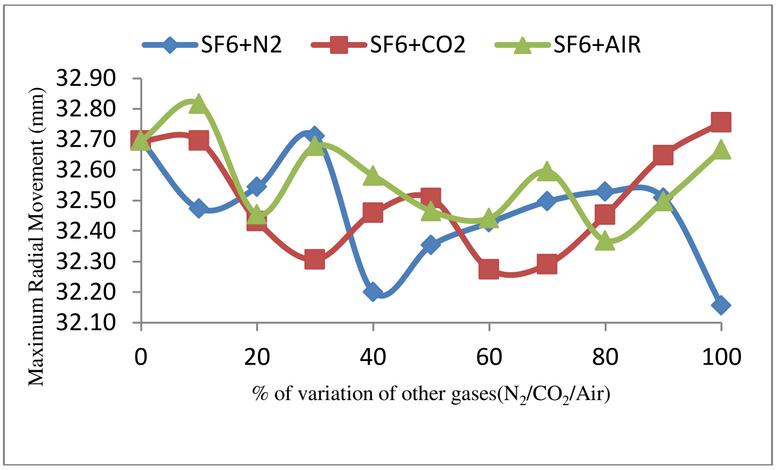

Figure-2. Maximum Radial Movement of Al particle(l=9mm, r=0.2mm) for different gas mixtures (SF_6 +N_2/CO_2/Air) at 550kVvoltage.

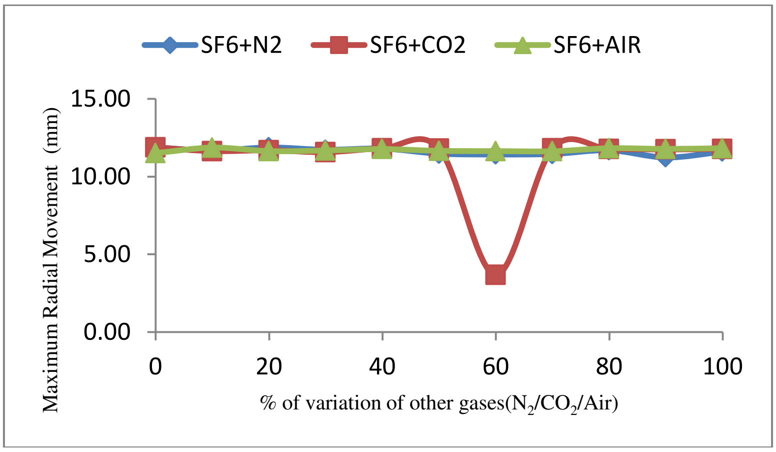

Figure-3. Maximum Radial Movement of Cu particle(l=9mm, r=0.2mm) for different gas mixtures(SF_6 +N_2/CO_2/Air) at 550kVvoltage.

5. CONCLUSIONS

A model has been formulated to simulate the movement of wire like particle in a single phase common enclosure GIB in the presence of gas mixtures. 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 diminishes the impact of green house gases.

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REFERENCES

[1] Kevork Mardikyan, Orhan Ersen, Ergun Canarsian. 1966. Ac Breakdown Strength of N_2, SF_6 and a Mixture of N_2+SF_6 containing a small amount of SF6. IEEE conference on Electrical Insulation, Canada.

[2] Emel Önal. 2004. Breakdown Characteristics of Gases in Non Uniform Fields. Journal of Electrical and Electronics Engg-Istanbul University. 4: 1177-1182.

[3] NIST Technical note-1425: Gases for Electrical Insulation and arc interruption: Possible present and future alternatives to pure SF6 by L.G. Christophorou, J. K. Olthoff and D. S. Green.

[4] L. G. Christophorou, J. K. Olthoff, R. J. Van Brunt. 1995. SF_6 /N_2 mixtures, basic and HV Insulation properties. IEEE Transactions, Dielectrics and Electrical Insulation. 2(5): 952-1002.

[5] Y. Hoshina *et al*. 2000. Dielectric properties of SF6/N2 gas mixtures on full scale model of the gas insulated bus bar. IEEE Transactions, Dielectrics and Insulation 2000 IEEE pp-2129-2134.

[6] N. H. Mallik and A. H. Qureshi. 1980. Breakdown gradients in SF6-N2, SF6-AIR and SF6-Co2

Mixtures. IEEE Transactions on Electrical Insulation. EI-15(5).

[7] N. J. Felici. 1966. Forces et charges de petits objects en contact avec une electrode affectee d'un champ electrique. Revue generale de I'electricite. pp. 1145-1160.

[8] H. E. Nechmi, A. Beroual, A. Girodet. 2016. Fluoronitriles/CO2 gas mixture as promising substitute to SF6 for insulation in high voltage applications. IEEE Transactions on Dielectrics and Electrical Insulation. 23(5).

[9] Y. Qiu, Y. F. Liu, A. Sun and E. Kuffel. Dielectric strengths of SF_6/N_2 and SF_6/CO_2 gas mixtures at low pressure-gap separation values. Journal of Physics: Applied Physics. 21(1).