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Effect of Different Field Calculation Techniques on Determination of Particle Maximum Movement in Single Phase Gas Insulated Busduct

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Abstract - Present paper analyses the effect of various electric field calculation techniques on the determination maximum movement of contaminated metallic particles inside a single phase Gas Insulated Busduct(GIB). The charge acquired by the particle and its liftoff field depends on geometrical configuration, size, shape, type of the particles and electric field at the particle location. The electric field at the particle location which is considered as resting on the inner surface of GIB can be computed by using analytical or simulation or numerical methods. In this paper computer software simulation programs have been developed for computing electric fields at the contaminated particle location using different field calculation methods, thereby maximum movements of free conducting particles are calculated and compared. From the results it is observed that the particle maximum movements with FEM calculated electric fields are slightly more than the movements obtained with analytical method and charge simulation methods. The results have been analyzed and presented in this paper.

Keywords— Particle Contamination, Gas Insulated Busduct, Particle charge, liftoff field, Charge Simulation Method, Finite Element Method.

I. INTRODUCTION

All live parts are enclosed in compressed Sulphur Hexa Fluoride(SF_6) gas chambers in a Gas Insulated Busduct(GIB). Even though SF_6 exhibits very high dielectric strength, practical Gas Insulated Systems operate well below the theoretical insulation strength of SF_6 gas due to the deleterious effects of metallic particle contaminants, conductor surface roughness and the presence of support insulators. Investigations revealed that 20% of failures in GIS are due to the existence of various metallic particle contaminations in the form of loose particles[1][2] and the electrical insulation performance of GIB is adversely affected by these free metallic particle contaminants. The electrostatic force can cause the particle to move into the high field region near the high voltage conductor[3][4]. Though great care has been taken at the time of manufacturing of GIS equipment metallic particle contaminants are inevitable in installed systems.

The specific work reported deals with the effect of electric field calculated with different methods on determination of the maximum particle movement in a single phase Gas Insulated Busduct. In this paper Analytical, Charge Simulation and Finite Element Methods are used for calculating electric field independently at the particle location and thereby electric field calculation techniques effect on computing maximum movements are analyzed.

II. MODELING TECHNIQUE OF GAS INSULATED BUSDUCT

For this study a typical single phase gas insulated busduct comprising of a conductor and outer enclosure filled with SF_6 gas as shown in figure.1 is considered. A wire like particle is assumed to be at resting on the inner surface of Gas Insulated Busduct enclosure. When a voltage is applied to single phase GIB inner conductor, the particle resting on inner surface of enclosure acquires charge in the presence of high electric fields due to particle charging mechanisms[5-7]. An appropriate particle charge and electric field causes the particle to lift and begins to move in the direction of the electric field after overcoming the forces due to its own weight and drag[4],[5]. This simulation considers several parameters affecting the charge acquired by the particle and its liftoff field.

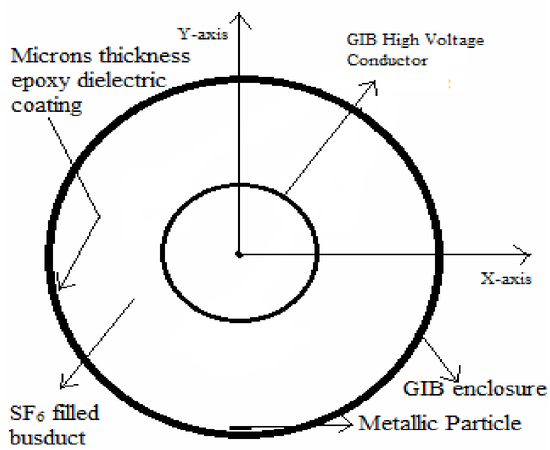

Fig.1 Typical single phase Gas Insulated Busduct

A. Charge acquired and Liftoff field of Metallic particle in Gas Insulated Busduct

The charge acquired by a horizontal wire particle resting on a bare electrode gets charged(Q_{hw}) in the presence of external electric field 'E' and is given by[4-6]:

$$Q_{hw} = 2\ 1 \quad \text{Coulombs - (1)}$$

Where '*r*' is the radius of the horizontal particle, '*l*' is the length of the horizontal particle, 'ε_o' is permittivity of free space or vacuum and '*E*' is Electric Field Intensity.

The lift-off field of an ideal cylindrical horizontal wire particles with the correction factor 'K'[4],[6] as 0.715 is given by,

$$0.715[(2\pi \epsilon_o r l E_{LO}) E_{LO}] = \pi r^2 l \rho g \quad 2)$$

Where 'E_{LO}' is lift-off Electric Field Intensity, 'ρ' is particle material density, '*g*' is acceleration due to gravity.

From Equation (2), the particle lift off field(E_{LO}) is,

$$E_{LO} = 0.84\sqrt{\frac{\rho g r}{\epsilon_o}} \quad \text{V/m} \qquad (3)$$

When horizontally lying particle rises to vertical position then the charge acquired by vertically standing particle increases significantly and increased charge is usually sufficient to lift the particle from electrode surface. The charge acquired and lift-off field (E_{LO}) of vertical wire particle resting on a bare electrode surface are [3-6]:

$$Q_{VW} = \frac{\pi \epsilon_0 l^2 E_{LO}}{\left[\log\left(\frac{2l}{r}\right) - 1\right]} \quad \text{Coulombs} \qquad (4)$$

$$E_{LO} = \left[\log\left(\frac{2l}{r}\right) - 1\right]\sqrt{\frac{r^2 \rho}{\epsilon_0 l \ [\log(}} \quad \text{V/m} \quad (5)$$

Where '*r*' is the radius of the vertical particle, '*l*' is the length of the vertical particle, 'ε_o' is permittivity of free space or vacuum, 'E_{LO}' is lift-off Electric Field Intensity, 'ρ' is particle material density, '*g*' is acceleration due to gravity.

When horizontally lying particle rises to vertical position then the charge acquired by vertically standing particle increases significantly and increased charge is usually sufficient to lift the particle from electrode surface.

Many methods are available for more accurate calculation of charge of conducting particle such as charge simulation algorithms which consider the particle size, shape and orientation. For larger value of l/r ratios the above equations are sufficient to calculate charge and lift-off field values with acceptable approximations.

The Correction Factor 'K' for vertical wire particles depends on particle length to radius ratio(*l*/r) and for values of *l*/r larger than 20, K value is usually near to unity.

It can be observed that from equations (3) and (4),

(6)

So, it can be realized from equation (5) that particle charge-to-mass ratio for Vertical particles increases with length and it causes longer particles move higher distance from the electrode surface than a shorter particles. Research studies are revealing that critical length of wire particles is of the order of few millimeters with ac voltage to occur flashover in GIS.

B. electric field calculation Methods

The study of charge acquired, lift-off field and maximum movement of metallic particles in GIB requires magnitude of electrostatic field present at the metallic particle location. The electric field in GIB is calculated using analytical method[8], charge simulation method[9] and Finite Element Method[11]-[13] separately.

Analytical Method:

In analytical method ambient electric field at any time in single phase Gas Insulated Busduct can be calculated by using following equation [10],

$$E(t) = \quad \text{V/m} \quad (7)$$

Where V Sin ωt is the supply voltage on the inner electrode, R_e is the enclosure radius, R_c is the inner conductor radius, y(t) is the position of the particle which is moving upwards, the distance from the surface of the enclosure towards the inner electrode.

Charge Simulation Method:

The following figure.2 shows the basic concept of Charge Simulation Method with image charges for calculating electric field intensity at the point 'P':

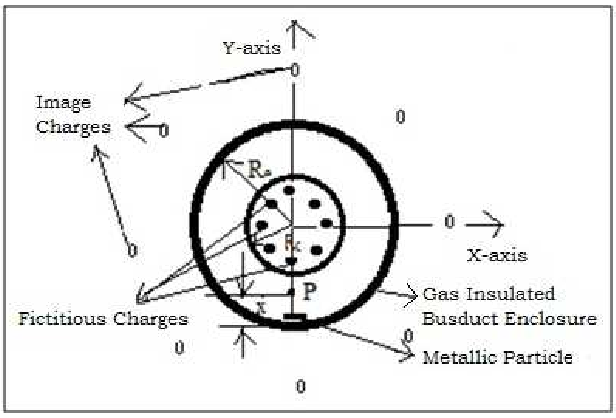

Figure.2 Basic Concept of Charge Simulation Method with image charges

The Electrostatic field at point 'P(*x,y*)' without image charge is calculated by using the following equations[7,10]:

$$E_x = \sum_{i=j=1}^{n} \frac{\lambda_i}{2\pi\epsilon} \left[\frac{x-x_i}{\sqrt[2]{(x-x_i)^2+(y-y_i)^2}} - \frac{(R_g/d)(x-x_j)}{\sqrt[2]{(x-x_i)^2+(y-y_i)^2}} \right] \quad (8a)$$

$$E_y = \sum_{i=j=1}^{n} \frac{\lambda_i}{2\pi\epsilon} \left[\frac{y-y_i}{\sqrt[2]{(x-x_i)^2+(y-y_i)^2}} - \frac{(R_g/d)(y-y_j)}{\sqrt[2]{(x-x_i)^2+(y-y_i)^2}} \right] \quad (8b)$$

Where E_x, E_y are Electrostatic field components along X(Horizontal) and Y(Vertical)-axes respectively, x, y are coordinates of point 'P' where Electric field is to be calculated, x_i, y_i are coordinates of i^{th} fictitious charge, 'n' is the total number of fictitious charges, λ_i is line charge density of i^{th} fictitious charge. x_i, y_i are coordinates of i^{th} fictitious charge, x_j, y_j are coordinates of j^{th} image charge and 'd' is distance from conductor center to fictitious charge.

Finite Element Method:

Figure.3 depicts basic concept for discretisition of Gas Insulated Busduct space for calculation of ambient electric field at any time in single phase Gas Insulated Busduct using Finite Element Method[8-10].

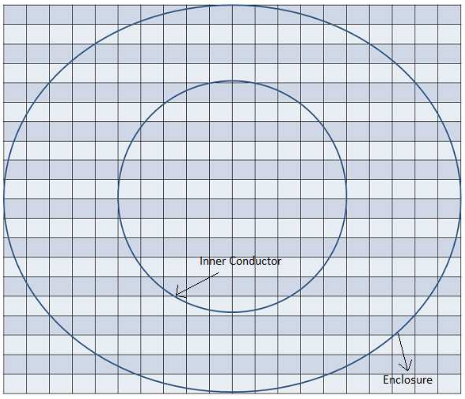

Fig. 3: Finite element mesh for calculating potentials at finite element nodes.

The Total Energy(W) associated with the assemblage of all elements in Gas Insulated Busduct is,

$$W = \sum_{e=1}^{N} W_e = \frac{1}{2} \quad \epsilon[V]^T \quad [C] \quad (9)$$

Where 'N' is number of elements, 'V' is node voltage matrix of 'n' nodes and 'C' is overall or global coefficient matrix.

In Finite Element Method, the solution region has minimum total energy satisfying the laplace's or poission's equation. So, partial derivatives of 'W' with respect to each nodal value of potential must be zero.

$$\frac{\partial W}{\partial V_1} = \frac{\partial W}{\partial V_2} = \cdots \cdots \frac{\partial}{\partial} \quad (10)$$

In general, simplifying the finite element mesh,

$$\sum_{i}^{i} \quad (11)$$

Where i is number of nodes and k=1,2,3,………n. So, a set of 'n' simultaneous equations are obtained and solving the above simultaneous equations using band matrix method for unknown node voltages(V_f),

$$[V_f] = [C_{ff}]^{-1} \quad (-[C \quad (12)$$

Where V_f is free node voltage matrix, V_p prescribed or fixed node voltage matrix, C_{ff} free node global coefficient matrix and C_{fp} is free to prescribed nodes global coefficient matrix.

Electric Field intensity at any point in Gas Insulated Busduct is calculated by using following equation,

(13)

III. SIMULATION OF PARTICLE MAXIMUM MOVEMENTS

The maximum movements of aluminum and copper metallic particles with different field calculation methods are obtained by using computer simulations. Computer simulations were carried out using advanced C Language programs for GIB inner conductor diameter 55mm and enclosure diameter of 152mm for 75kV, 100kV, 132kV, 145kV and 175kV applied voltages.

IV. RESULTS AND DISCUSSION

The results are obtained by using computer simulations for different aluminum and copper particle sizes. The Electric fields are determined by using Analytical Method as given by equation (7), Charge Simulation Method(8a&8b) and Finite Element Method by using equations(12) and (13).

Table I and Table II are showing the movement patterns of aluminum and copper particles for power frequency voltages. 512 simulated charges are considered for charge simulation method for electric field calculation. 289 finite element nodes are considered in Gas Insulated Busduct space for calculating node potentials using Finite Element Method. The radius of Aluminum and copper particles in all cases are considered as 0.25mm, lengths of the particle as 8mm and 12mm, restitution coefficient is 0.9 and SF_6 gas pressure is 0.4MPa.

Table.I Particle Maximum Radial Movements at different Voltages(l=8mm, r=0.25mm)

Sl. No.	Voltage (kV)	Particle type	Max. Movement with Analytical Field(mm)	Max. Movement with CSM Field(mm)		Max. Movement with FEM Field(mm)
				Without Image Charge	With Image Charge	
1	75	Al	10.59	10.49	19.96	10.57
		Cu	1.03	1.03	3.97	1.14
2	100	Al	19.60	17.42	27.54	19.90
		Cu	3.80	3.77	8.90	3.89

3	132	Al	28.80	29.54	43.33	29.07
		Cu	8.87	8.47	5.74	9.08
4	145	Al	30.45	29.54	48.50	31.22
		Cu	9.54	10.98	20.84	11.78
5	175	Al	43.02	42.05	48.50	42.11
		Cu	17.51	16.91	25.81	17.81

During the application of power frequency voltages, the moving metallic particle makes several impacts with the enclosure and the maximum radial movement increases with increase of applied voltage. Table I shows the maximum radial movements for aluminum and copper particles of length 8mm and radius 0.25mm for different voltages with analytical, charge simulation and FEM calculated electric fields. For Aluminum metallic particles with analytically calculated electric field, the maximum radial movement is 10.59mm, 10.49mm with charge simulation method and with Finite Element Method is 10.57mm for 75kV and these radial movements increase with increase of applied voltage. The maximum radial movement is reaching 43.02mm,42.05mm and 42.11mm with analytical, charge simulation and FEM calculated electric fields respectively at 175kV. For Copper particles, the radial movement is 1.07mm with analytically and charge simulation calculated fields and 1.14mm with FEM calculated electric field at 75kV and this radial movement is increasing with increase of applied voltage and reaching maximum value of 17.51mm,16.91 and 17.81mm with analytical, charge simulation and FEM calculated electric fields respectively for 175kV. From table I it is also observed that Aluminum and Copper particles maximum radial movement is relatively higher if image charges are considered with charge simulation method and the aluminum particle crosses the electrode gap for 145kV whereas Copper particle is reaching maximum radial movement of 25.81mm at 175kv.

Table.II Particle Maximum Radial Movements at different Voltages(l=12mm, r=0.25mm)

Sl. No.	Voltage (kV)	Particle type	Max. Movement with Analytical Field(mm)	Max. Movement with CSM Field(mm)		Max. Movement with FEM Field(mm)
				Without Image Charge	With Image Charge	
1	75	Al	14.67	14.53	24.38	15.03
		Cu	2.67	2.68	6.24	2.77
2	100	Al	23.86	23.80	34.41	25.32
		Cu	5.64	5.47	13.42	6.07
3	132	Al	32.52	31.33	48.50	33.61
		Cu	12.93	12.59	21.94	13.03
4	145	Al	37.85	37.69	48.50	40.23
		Cu	15.94	14.98	26.70	15.67
5	175	Al	48.50	48.50	48.50	48.50
		Cu	22.84	22.02	31.76	23.14

Similarly Table II shows the maximum radial movements for aluminum and copper particles of length 12mm and radius 0.25mm for different voltages with analytical, charge simulation and FEM calculated electric fields. For Aluminum particles the maximum axial movement with analytical calculated electric field is 14.67mm, 14.53mm with charge simulation method and with FEM calculated electric field is 15.03mm for 75kV. The maximum radial movements of Aluminum particles are increasing with increase of voltage up to 175kV. For 175kV maximum radial movements are crossing the electrode gap for electric fields calculated with Analytical, charge simulation and FEM calculated electric fields for Aluminum particles. For Copper particles at 75kV, the maximum axial movement is 2.67mm,2.68mm and 2.77mm with analytical, charge simulation and FEM calculated electric fields respectively. The maximum radial movements of Copper particles are increasing with increase of voltage for up to 175kV and reaching maximum radial movements of 22.84, 22.02mm and 23.14mm respectively for analytical, charge simulation and FEM calculated electric fields respectively. From table II the Aluminum and Copper particles maximum movement is relatively higher if image charges are considered with charge simulation method and Aluminum particle is crossing the electrode gap at 132kV whereas Copper particle is reaching maximum radial movement of 31.76mm at 175kV.

V. CONCLUSION

A reasonable second order differential equation has been formulated to simulate the wire like particle maximum radial movements under the influence of electric fields calculated using Analytical, Charge Simulation and Finite Element Methods in single phase Gas Insulated Busduct. When an electrostatic force on the metallic particle due to applied voltage exceeds the gravitational and drags forces, the particle lifts from its position and moves into the inter electrode gap. From the results it is observed that particle movements with the electric fields calculated using Finite Element Method are slightly more than the particle movements obtained using analytical method and charge simulation methods of electric field computions. Also, it is noted that aluminum particles are more influenced by the voltage than copper particles due to their lighter mass and this causes the aluminum particle to have greater charge-to-mass ratio. Also it is noted that the particle maximum movements are slightly less with charge simulation method when compared other two analytical and Finite Element methods. It is had been also observed that the maximum radial movement is very high if electric fields are calculated with image charges with charge simulation method. All the above investigations have been carried out for various voltages under power frequency. The results obtained are analyzed and presented.

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REFERENCES

[1] A.Diessner, CAPIEL draft paper on “The Influence of Switchgear on the Greenhouse Effect”, private communication, 1996.

[2] J. R. Laghari and A.H. Qureshi, “A Review of Particle Contaminated Gas Breakdown”, IEEE Transactions on Electrical Insulation. Vol. EI-16 No.5, pp. 388-398, 1981.

[3] Hiroshi Kuwahara, Shoichi Inamura, Tsugio Watanabe and Yoshikuni Arahat, Effect of Solid Impurities on Breakdown in Compressed SF_6 Gas”, IEEE PES Winter Meeting, New York, N.., January 27-February 1, 1974.

[4] H.Anis and K.D.Srivastava “Free conducting particles in compressed gas insulation”, IEEE Tranctions on electrical insulation, Vol. EI-16, pp.327-338, August 1995.

[5] M. M. Morcos, S. Zhang, K. D. Srivastava and S. M.Gubanski,“Dynamics of Metallic Particle Contaminants in GIS with Dielectric-Coated Electrodes”, IEEE Trans. on Power Delivery,Vol.15, No. 2, Apr 2000, pp. 455-460.

[6] J. Amarnath, S. Kamakshaiah, C. Radhakrishna, B.P. Singh and K.D.Srivastava. 2001 “Particle Trajectory in a Common Enclosure Three phase SF6 Busduct”, 12th Intern. Sympos. High Voltage Eng., IISc, Bangalore, India, Vol. 2, pp. 441-444.

[7] H.Singer, H.Steinbigler and P. Weiss, “A charge simulation method for the calculation of high voltage fields”, IEEE Trans. PAS, Vol. 93, 1974, pp. 1660-1668

[8] O.W.Andersen, “Laplacian Electrostatic Field Calculations by Finite Elements with Automatic Grid Generation”, IEEE PES Winter Meeting, New York, N.Y., January 28-February 2, 1973.

[9] James F.Hoburg and James L. Davis, “A Student-Oriented Finite Element Program for Electrostatic Potential Problems”, IEEE Transactions on Education, Vol. E-26, No.4, November 1983.

[10] Sadiku Matthew, “Elements of Electromagnetics”, 4th Edition, Oxford Publishers, pp 694-711, 2007