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Effect of Voltage on Metallic Particle Movement in 3φ Pahse Gas Insulated Busduct Using Analytical Method, Fem & Csm

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ABSTRACT: This paper analyses the electric field effect on particle movement in three phase gas insulated busduct with different field calculation methods like analytical method(AM), charge simulation(CSM), and finite element methods(FEM). The presence of free metallic particles in GIB can result in loss of as much as 90% of the SF_6 gas dielectric strength and can be a problem with Gas Insulated Substations (GIS) operating at high electric fields. The main objective of this paper is to derive techniques for formulating the basic equations that will govern the movement of metallic particles in GIB. The simulation has been carried out to obtain the particle trajectories at various voltages on Aluminium and Copper particles. From the simulation results it is observed that the Al and Cu particle movements are increasing with increase of applied voltage. From the results it can also be observed that the maximum radial movements of Al and Cu particles are relatively less when calculated using charge simulation method and relatively highest when calculated using finite element method. It is found that maximum radial movements computed using analytical method is slightly more than charge simulation method.

***Key words**: Analytical method(AM),Charge simulation method(CSM), finite element methods(FEM),Gas Insulated Busduct(GIB), metallic particle and Maximum radial movement*

I.INTRODUCTION

As power consumption in urban areas is increasing, a large number of Gas Insulated Substations have been constructed. Compact and cost effective solutions are required for substations installed in areas where space availability is limited. Safety and the avoidance of fire accidents are the most important considerations for substations installed in urban areas. Today, design, development and manufacturing of GIS with 100% compatibility is possible with the existing and future needs everywhere in the world. Gas Insulated Substation (GIS) instead of Air Insulated Substation (AIS) offer the best solution for overcoming the sharp increase in electric power demand in large and mega cities. In Gas Insulated system(GIS) or Gas Insulated Busduct(GIB) is a multi-component assembly in which all live parts such as circuit breakers, disconnectors, busducts, current and potential transformers are enclosed in compressed Sulphur hexafluoride gas chambers. The live parts of GIS/GIB are supported by insulators called spacers and are made from alumina filled epoxy material. The GIS enclosure forms an electrically integrated, grounded enclosure for the entire substation.

Metallic conducting particles of different sizes and shapes are usually present on the inner surface of the GIB outer enclosure. The free conducting particles gets charged when they are in contact with GIB enclosure under the influence electric field produced by live inner conductor and once if they get sufficient charge in local electric field, these particles lift from its position and move into GIB inter electrode gap. If these moving charged particles come near to live inner conductor its distance seriously affects the breakdown voltage and may cause the flashover in GIB

For computing the charge acquired by the contaminated metallic particles resting on bare electrodes several authors [1,2-7] proposed expressions for calculation of charge for various types of particles having different sizes, shapes and orientation. All these equations are primarily based on the work of Felici et.al [8].The work reported in this paper deals with The maximum radial and axial movements of Aluminum and Copper particles in single phase isolated conductor Gas Insulated Busduct.

II.ELECTRIC FIELD CALCULATION METHODS IN GAS INSULATED BUSDUCT

Different types field calculation techniques are available for calculation electric field Gas Insulated Busducts and every technique has advantages and disadvantages. Basically analytical method gives exact value of electric field but can be applied to only simple geometric configurations. As the system geometric configuration is complex then non-analytic methods should be adopted. Different types of non-analytic methods for field calculation are graphical, experimental, analog and numerical methods. Non-analytical methods give only approximate solutions to the electric field calculation problems but these are reasonably accurate for engineering purposes. It has been observed that the non-analytical electrical field calculation methods obtained by analytical simplification of that particular problem. Experimental and graphical field calculation methods are used for some particular problems and errors involved are usually high. Some of most important non-analytical methods used for electric field calculation are 1. Charge simulation method, 2. Finite difference method and 3. Finite element method. With the advent of high speed digital computers non-analytical methods have become more prominent and attractive for electric field calculations.

III.ANALYTICAL METHOD FOR ELECTRIC FIELD CALCULATION IN THREE PHASE GAS INSULATED BUSDUCT:

A typical three phase common enclosure horizontal busduct comprising of three inner conductors A, B and C with dielectric coated outer enclosure filled with SF_6 gas as shown in fig.1 is considered.

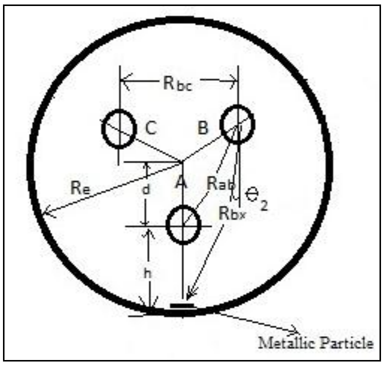

Fig.1 Typical three phase common enclosure Gas Insulated Busduct

Analytically ambient electric field 'E_y' at particle location at time 't_i' in common enclosure three phase Gas Insulted Busduct[9-11] can be calculated by using following equations,

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

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

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

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

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.

IV.CHARGE SIMULATION METHOD FOR ELECTRIC FIELD CALCULATION IN THREE PHASE GAS INSULATED BUSDUCT

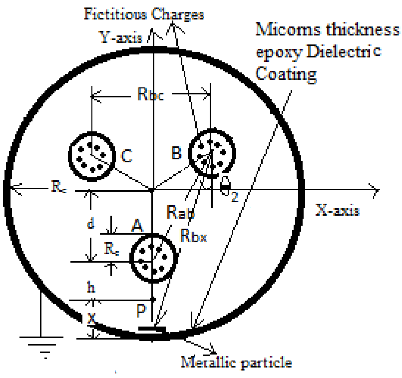

Fig. 2 Calculation of Electric Field Intensity at Point 'P' using Charge Simulation Method without image charge effect.

Fig. 2 depicts basic concept behind the calculation of ambient electric field at any time in three phase Gas Insulated Busduct using charge simulation method without image charge effect.

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

$$E_x(t) = \sum_{i=1}^{3n} \frac{\lambda_i}{2\pi\varepsilon}\left[\frac{x - x_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}}\right] \quad (5)$$

$$E_y(t) = \sum_{i=1}^{3n} \frac{\lambda_i}{2\pi\varepsilon}\left[\frac{y - y_i}{\sqrt[3]{(x-x_i)^2 + (y-y_i)^2}}\right] \quad (6)$$

Where $E_x(t)$, $E_y(t)$ are Electrostatic field components at time instant 't' 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.

V.FINITE ELEMENT METHOD FOR ELECTRIC FIELD CALCULATION IN THREE PHASE GAS INSULATED BUSDUCT

For finding solution using finite element method consist four steps and they are 1. Discretising the solution region into finite number of triangle elements, 2. Forming algebraic equations for all finite elements 3. Assembling the all elements of solution region through equations and 4. Solving system equations for finding voltages at all unknown triangle element nodes.

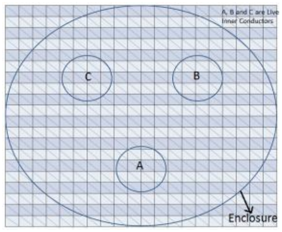

Fig3 Finite Element Method for calculating potentials at element nodes of Three Phase Gas Insulated Busduct.

Fig3 depicts basic concept for Finite Element discretisation applied three phase GIB space for calculation of ambient electric field at any using Finite Element Method [12-18].The potential V_e within an element is approximated and the potential distribution in all elements is interrelated as potential is continuous across inter element boundaries and approximate solution using finite element method is,

$$V(x,y) = \sum_{e=1}^{N} V_e(x,y) \quad (7)$$

Where N is number of elements of solution region.

Generally, triangle elements are considered in this solution region and each element is represented with approximation as,

$$V_e = a + bx + cy \quad (8)$$

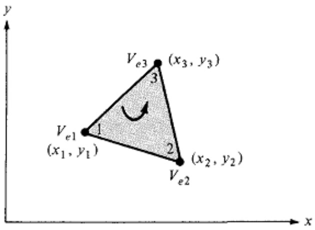

Fig 4. A typical triangle element of solution region

The potentials at the triangle element nodes are,

$$\begin{bmatrix} V_{e1} \\ V_{e2} \\ V_{e3} \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (9)$$

The element coefficients a, b and c are determined from above equation (9)as,

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{bmatrix} \begin{bmatrix} V_{e1} \\ V_{e2} \\ V_{e3} \end{bmatrix} \quad (10)$$

Substituting equation 3.30d in equation 3.30b and simplifying,

$$V_e = \sum_{i=1}^{n} \alpha_i(x,y) V_{ei} \quad (11)$$

Where α_i is element shape function, A is area of the element and there are expressed as,

$$\alpha_1 = \left(\frac{1}{2A}\right)[(x_2 y_3 - x_3 y_2)(y_2 - y_3)x - (x_3 - x_2)y] \quad (12)$$

$$\alpha_2 = \left(\frac{1}{2A}\right)[(x_3 y_1 - x_1 y_3)(y_3 - y_1)x - (x_1 - x_3)y] \quad (13)$$

$$\alpha_3 = \left(\frac{1}{2A}\right)[(x_1 y_2 - x_2 y_1)(y_1 - y_2)x - (x_2 - x_1)y] \quad (14)$$

$$A = \frac{1}{2}[(x_2 - x_1)(y_3 - y_1) - (x_3 - x_1)(y_2 - y_1)] \quad (15)$$

A is positive if element nodes are numbered in counter clockwise direction and element shape function has the following properties:

$$\alpha_i(x_i \quad y_j) = \begin{bmatrix} 1 \\ 0 \end{bmatrix} \begin{bmatrix} i = & j \\ i \neq & j \end{bmatrix} \quad (16)$$

$$V_e = \sum_{i=1}^{3} \alpha_i(x,y) = 1 \quad (17)$$

The energy associated with each element is,

$$W_e = \frac{1}{2}\,\varepsilon\,[V_e]^T [C^e]\,[V_e] \quad (18)$$

Where V^e is element node voltage matrix and is given by,

$$V_e = \begin{bmatrix} V_{e1} \\ V_{e2} \\ V_{e3} \end{bmatrix} \quad (19)$$

C^e is element coefficient matrix and is given by,

$$C^e = \begin{bmatrix} C^e_{11} & C^e_{12} & C^e_{13} \\ C^e_{21} & C^e_{22} & C^e_{23} \\ C^e_{31} & C^e_{32} & C^e_{33} \end{bmatrix} \quad (20)$$

$$C^e_{11} = \frac{1}{4A}[(y_2 - \quad y_3)^2 - (x_2 - \quad x_3)^2] \quad (21)$$

$$C^e_{12} = \frac{1}{4A}[(y_2 - \quad y_3)(y_3 - \quad y_1) - (x_3 - \quad x_2)(x_1 - \quad x_3)] \quad (22)$$

$$C^e_{13} = \frac{1}{4A}[(y_2 - \quad y_3)(y_1 - \quad y_2) - (x_3 - \quad x_2)(x_2 - \quad x_1)] \quad (23)$$

$$C^e_{22} = \frac{1}{4A}[(y_3 - \quad y_1)^2 - (x_3 - \quad x_1)^2] \quad (24)$$

$$C^e_{23} = \frac{1}{4A}[(y_3 - \quad y_1)(y_1 - \quad y_2) - (x_1 - \quad x_3)(x_2 - \quad x_1)] \quad (25)$$

$$C^e_{33} = \frac{1}{4A}[(y_1 - \quad y_2)^2 - (x_2 - \quad x_1)^2] \quad (26)$$

$$C^{(e)}_{21} = C^{(e)}_{12}, \quad C^{(e)}_{31} = C^{(e)}_{13}, \quad C^{(e)}_{32} = C^{(e)}_{23} \quad (27)$$

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

$$W = \sum_{e=1}^{N} W_e = \frac{1}{2}\,\varepsilon\,[V]^T [C][V] \quad (28)$$

VI.RESULTS AND DISSCUSSIONS

Tables I and II are presenting the radial and axial movements of Aluminum and Copper particles for voltages ranging from 220kV to 1600kV obtained with different field calculation methods like analytical, charge simulation, and finite element methods. Fig 5 to 8 are showing the variation of Al and Cu particles maximum radial movements with voltage obtained for different field calculation methods. The particle sizes of length 8mm and 12mm and radius 0.25mm and 0.35mm are considered to be present in three phase uncoated Gas Insulated Busduct for these simulations. From the simulation results it is observed that the Al and Cu particle movements are increasing with increase of applied voltage

Table1: Movement of Al particle (l=8mm, r=.25mm) at various power frequency voltages

Sl. No.	Voltage Applied (kV)	Particle movement using analytical method		Particle movement using CSM		Particle movement using FEM	
		Radial (mm)	Axial (mm)	Radial (mm)	Axial (mm)	Radial (mm)	Axial (mm)
1	220.00	0.00	187.34	0.00	153.59	13.43	432.89
2	300.00	8.75	260.04	6.81	247.38	22.58	911.06
3	400.00	13.05	412.55	10.65	286.80	37.88	1131.48
4	500.00	18.29	457.56	14.29	412.52	49.21	1360.95
5	600.00	23.31	659.26	18.45	574.16	60.27	1581.33
6	800.00	31.32	794.66	25.72	630.32	70.75	1623.99
7	1000.00	35.96	885.45	30.61	761.12	73.47	1384.62
8	1200.00	39.98	852.32	34.42	712.12	76.20	134.26
9	1600.00	44.46	187.34	41.30	153.59	93.00	432.89

Table2: Movement of Cu particle (l=8mm, r=.25mm) at various power frequency voltages

Sl. No.	Voltage Applied (kV)	Particle movement using analytical method		Particle movement using CSM		Particle movement using FEM	
		Radial (mm)	Axial (mm)	Radial (mm)	Axial (mm)	Radial (mm)	Axial (mm)
1	220.00	0.00	0.00	0.00	0.00	0.00	0.00
2	300.00	0.00	0.00	0.00	0.00	7.59	157.33
3	400.00	0.00	0.00	0.00	0.00	12.82	301.46
4	500.00	6.78	122.83	5.04	108.77	18.09	266.41
5	600.00	9.27	192.97	7.23	120.91	25.42	443.72
6	800.00	14.19	277.57	11.31	218.87	42.01	557.66
7	1000.00	20.06	317.12	15.68	288.68	33.26	470.91
8	1200.00	25.47	343.96	19.65	327.12	49.35	535.45
9	1600.00	33.31	444.84	25.37	334.88	58.99	501.13

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From the results it can also be observed that the maximum radial movements of Al and Cu particles are relatively less when calculated using charge simulation method and relatively highest when calculated using finite element method. It is found that maximum radial movements computed using analytical method is slightly more than charge simulation method. It is inferred from the results that the particle maximum radial movements with image charge effect are more than that of without image charge effect.The maximum axial movements of Al and Cu particles are increasing usually with increase of applied voltage. But sometimes the axial movements are decreasing with increase of voltage and this is because of random behavior of particle movement and dependency on the solid angle considered for every time step.

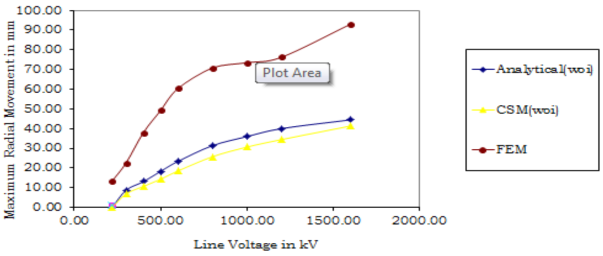

Fig:5 Radial Movement of Al particle at voltages ranging from (220- 1600)kV using AM,CSM and FEM

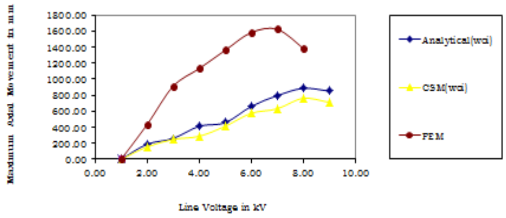

Fig:6 Axial Movement of Al particle at voltages ranging from (220- 1600)kV using AM,CSM and FEM

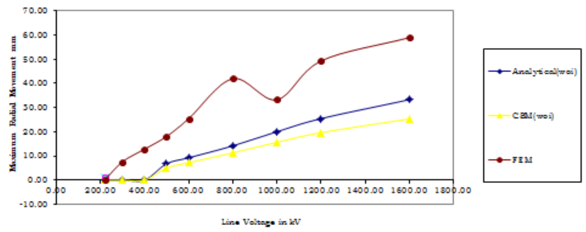

Fig:7 Radial Movement of Al particle at voltages ranging from (220- 1600)kV using AM,CSM and FEM

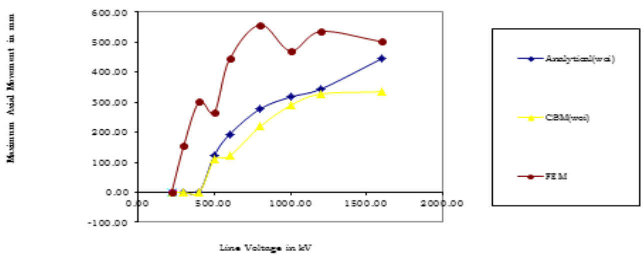

Fig:8 Axial Movement of Al particle at voltages ranging from (220- 1600)kV using AM,CSM and FEM

From the simulation results it is observed that the Al and Cu particle movements are increasing with increase of applied voltage. From the results it can also be observed that the maximum radial movements of Al and Cu particles are relatively less when calculated using charge simulation method and relatively highest when calculated using finite element method. It is found that maximum radial movements computed using analytical method is slightly more than charge simulation method. It is inferred from the results that the particle maximum radial movements with image charge effect are more than that of without image charge effect.

VII.CONCLUSION

When electrostatic force exceeds the drag and gravitation forces the particle lifts up which is resting on the enclosure surface. A three phase mathematical model has been proposed to determine the movement of particle, When the particle is subjected to electric field by applying voltages ranging from(220-1600)Kv. The Movement of aluminum particle is more than that of copper and the maximum axial movements of Al and Cu particles are increasing usually with increase of applied voltage. But sometimes the axial movements are decreasing with increase of voltage and this is because of random behavior of particle movement and dependency on the solid angle considered for every time step. Movement of metallic particle is greater than that of FEM and CSM. Movement of particle using CSM is less than among three methods

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