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Modeling and Analysis of Metallic Particle Lift-off fields in Gas Insulated Substations

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ABSTRACT
Rapid urbanization and ever increasing electrical power demand have made it necessary to switch from Air Insulated Substations(AIS) to Gas Insulated Substation(GIS) and need for higher operating voltage levels in order to reduce or to limit the power losses in the system. Presence of free conducting particles in compressed gas insulated equipment is commonly encountered. The electrical insulation performance of Gas Insulated Substations is adversely affected by the surface roughness of electrode and conducting particle contaminants. Using electrode dielectric coatings such as polymeric films, varnishes, epoxies, paraffin wax and anodized aluminum, the operating voltage levels can be increased, space requirements can be lessened and the problems associated with the electrodes surface roughness and contaminated free conducting particles can be mitigated. The electrical insulation performance of Gas Insulated substation mainly depends on the dielectric material volume resistivity, dielectric constant and thickness of coatings are significant parameters which are affecting the insulation performance of Gas Insulated Substation. In this paper, modeling and analysis of particle lift-off fields and electrical insulation performance of dielectric coating in Gas Insulated Substations are presented.
Keywords – Dielectric Coating, Electrical insulation, Gas Insulated Substation, Liftoff Field, Metallic particle contamination, Particle Charging,

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I. INTRODUCTION

In the early 1960's Gas Insulated Substations(GIS) are introduced a solution that helps to deal with the increasing shortage of space in urban areas and the need for power transmission at higher voltage levels right into city centres. The Gas Insulated Substations concept soon gained popularity because of outstanding flexibility in switchgear arrangement, little space requirement, efficient and reliable operation, low life cycle costs and virtually maintenance-free operation for an expected life-time of more than 50 years[1,2,3]. But the electrode surface roughness and contaminated free conducted particles can create flashovers and thereby temporary or permanent faults in the Gas Insulated Substations. The effect of these flashovers in GIS can make them are worse than Air Insulated Substation(AIS) because of long term outages before repairs can be made. In Gas Insulated Substations, the deleterious effects of electrode surfaces roughness and contaminated free conducting particles will reduce the electrical insulation performance and reliability[4,5].

Great care will be taken before shipping the Gas Insulated Substation equipment to ensure that all the modules/components are free from metallic particles. In spite of this, metallic contaminants are inevitable in the installed systems mainly because of mechanical vibrations during shipment and service, thermal expansion/contraction at expansion joints, and machining imperfections. Under the applied electric field in Gas Insulated Substation, the free conducting particles acquire charge. If the electrostatic force because of this acquired charge and applied electric field is more than gravitational field, then the particle lifts into inter electrode gap, moves randomly in the inter electrode gap. If the applied electric field is sufficiently high then the particles approach the oppositely polarized electrode and causes flashovers[7,8]. These particle discharges severely reduce the dielectric strength of Gas Insulated Substation. In some studies it is observed that the reduction of dielectric strength is almost 80%. When the conducting particles are hovering in inter electrode gap near the inner conductor of Gas Insulated Substation, it severely affects the break down voltage. From laboratory investigations it is observed that the gap between particle and inner conductor breaks down first and then breakdown of particle and outer conductor gap follows. Several methods of conducting particle control and deactivation and they are i. electrostatic trapping ii. Adhesive coatings iii. Particles discharge through radiation iv. Dielectric coatings on electrodes[9,10,11].

The charge accumulation on free conducting particles can be modified greatly by using dielectric coatings on the electrodes and thereby the insulation performance and reliability of Gas Insulated Substation also can be improved. The effect of dielectric coatings on the insulation performance of compressed gas insulated electrodes has been studied by several researchers[8,10,11,12]. It is generally expected that the dielectric coatings improve the insulation performance of Gas Insulated Substations and a different types of insulating materials like polymeric films, varnishes, epoxies and paraffin wax, Teflon and anodized aluminum. All these insulating materials have different electrical properties but volume resistivity is one of the important parameters which affect the charge accumulation of the free conducting particles in Compressed Gas Insulated Systems. This paper focuses on modeling and analysis of lift-off fields of metallic particles in the Gas Insulated Substation in order to analyze the effect of metallic particle dimensions and dielectric coating thickness. It is observed from the simulation results that the lift-off field of particle increases with the increase in the thickness of dielectric coating and also observed that for particular coating thickness lift-off filed increases with the increase in particle radius whereas lift-off field remains same with particle length.

II. MODELING TECHNIQUE OF GAS INSULATED BUSDUCT

For analyzing the conducting particle lift-off fields, a typical single phase gas insulated busduct(GIB) comprising of a conductors with dielectric coated outer enclosure filled with SF_6 gas as shown in the following figure.1 is considered.

2.1 FREE CONDUCTING PARTICLES CONTAMINATION IN GAS INSULATED SUBSTATIONS:

A wire like metallic particle is considered to be at rest in the inside of Gas Insulated Busduct on the dielectric coating. When voltage is applied to the inner conductor of GIB, the particle resting on the dielectric coating surface acquires charge mainly due to two different particle charging mechanisms. They are 1. Conduction through dielectric coating 2. Micro discharges between the particle and dielectric coating[8,9,10,11]. An appropriate particle charge and electric field at the metallic particle location causes the particle to lift and begins to move in the direction of the electric field by overcoming the forces due to its own weight and drag[5,6,7,12]. The movement of metallic particle depends on several parameters like the macroscopic field at the location of the particle, its weight, viscosity of the gas, Reynold's number, drag coefficient and coefficient of restitution on its impact to the enclosure. Several authors [7,8,9,10,11,13] proposed expressions for calculation of charge for various types of particles having different sizes, shapes, orientation and resting on bare electrodes. All these equations are primarily based on the work of Felici et.al [6].

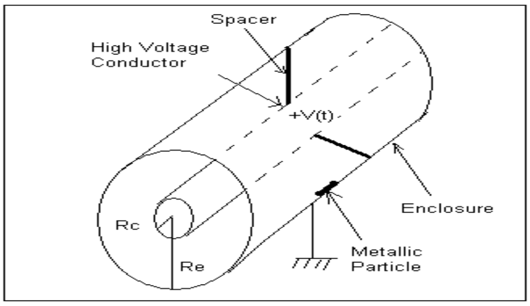

Fig.1 Typical single phase common enclosure Gas Insulated Busduct

A wire like metallic particle is considered to be at rest in the inside of Gas Insulated Busduct on the dielectric coating. When voltage is applied to the inner conductor of GIB, the particle resting on the dielectric coating surface acquires charge mainly due to two different particle charging mechanisms. They are 1. Conduction through dielectric coating 2. Micro discharges between the particle and dielectric coating[8,9,10,11]. An appropriate particle charge and electric field at the metallic particle location causes the particle to lift and begins to move in the direction of the electric field by overcoming the forces due to its own weight and drag[5,6,7,12]. The movement of metallic particle depends on several parameters like the macroscopic field at the location of the particle, its weight, viscosity of the gas, Reynold's number, drag coefficient and coefficient of restitution on its impact to the enclosure. Several authors [7,8,9,10,11,13] proposed expressions for calculation of charge for various types of particles having different sizes, shapes, orientation and resting on bare electrodes. All these equations are primarily based on the work of Felici et.al [6].

The electric field associated with the contaminated metallic particle increases, the particle resting on the bare electrode gradually gets charged. The charge acquired by the particle depends on the size, shape, orientation and local electrical field of the metallic particle. If the electrostatic force on the charged metallic particle overcomes the gravitational force magnitude then the particle lifts from its position and moves into the Gas Insulated Busduct inter-electrode gap[11,12,13]. This causes the probability of flashover.

Metallic particle lift-off field is the minimum electric field required at the particle resting location for its lift from the enclosure in to inter electrode gap and it is calculated by making some approximations for metallic particle motion equation.

The horizontal metallic particle resting on a bare electrode gets charged when external electric field 'E' is applied and the charge acquired by it is given by[5,7,8,11,13]:

$$Q_{hw} = 2\,\pi\, r\, l\, \in_o E \quad --- \quad (1)$$

where '$\in_0$' is the permitivity of free space or vacuum, 'r' is the radius of particle and 'E' is the Electric Filed Intensity. The lift-off field is obtained by equating electrostatic force to gravitational force on the particle.

$$K\,[(2\,\pi\,\epsilon_o\, r\, l\, E_{lo})E_{lo}] = \pi r^2\, l\, \rho\, g \quad --- \quad (2)$$

Where 'K' is the correction factor and for horizontal conducting particle its value is 0.715 [58] and by using equation (2) the lift-off field 'E_{lo}' of horizontal particle is,

$$E_{lo} = 0.84\sqrt{\frac{\rho\, g\, r}{\epsilon_o}} \quad --- \quad (3)$$

Where 'ρ' is particle material density and 'g' is acceleration due to gravity.

2.2 METALLIC PARTICLE CHARGING IN THE PRESENCE OF DIELECTRIC COATING:

Coating with thin layer of epoxy type dielectric material on the inner surface of Gas Insulated Busduct enclosure increases the breakdown voltage of Gas Insulated System. The high resistivity of dielectric coating obstructs charge acquisition of the particle and the lift-off field is increased. The equivalent circuit model of particle charging through the dielectric coating is as shown in the Fig.2[9,10,11,12].

In the circuit model of fig.2 'C_g' represents capacitance between the phase conductor and the particle whereas 'Cc' represents capacitance between the particle and the enclosure. The conductance 'G' represents the part of the dielectric coating where the Charging current is flowing.

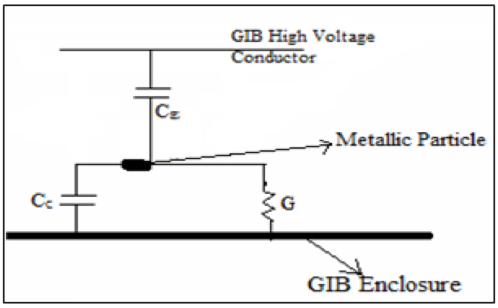

Fig. **2 Circuit model of particle charging through the** dielectric coating.

The charging current flowing through the conductance circuit model represented in fig.2 is:

$$I_c(t) = I_c \sin(\omega\, t + \emptyset) \quad (4)$$

Where angle '$\emptyset$' is Phase difference between applied voltage and charging current.

The applied voltage is:

$$V(t) = V \sin\omega\, t \quad (4.9)$$

So, the charging current through metallic particle can be written as:

$$I_c = \frac{V}{\left[R^2\left(1+\frac{C_c}{C_g}\right)^2 + \frac{1}{\omega^2\, C_g{}^2}\right]^{0.5}} = \frac{V}{\left[\frac{1}{G^2}\left(1+\frac{C_c}{C_g}\right)^2 + \frac{1}{\omega^2\, C_g{}^2}\right]^{0.5}} \quad --- \quad (5)$$

The charge acquired by particle is obtained by integrating equation (5),

$$Q(t) = \int_o^t I_c \sin(\omega\, t + \emptyset)\, dt \quad --- \quad (6)$$

Total charge of metallic particle can be obtained by simplifying the above equation (6),

$$Q(t) = \frac{\left(\frac{V}{\omega}\right)}{\left[\frac{1}{G^2}\left(1+\frac{C_c}{C_g}\right)^2 + \frac{1}{\omega^2\, C_g{}^2}\right]^{0.5}}\,[\cos\emptyset - \cos(\omega\, t + \emptyset)] \quad --- \quad (7)$$

The electrostatic force acting on charged metallic particle resting on inner surface of dielectric coated Gas Insulated Busduct is:

$$F_e(t) = K\;\; E(t)\; Q(t) \quad --- \quad (8)$$

Where 'K' is constant, $Q(t)$ is total charge of metallic particle and $E(t)$ is electric field intensity.

Substituting equation (7) in equation (8) and If the phase difference ' ' between applied voltage and charging current is assumed to be small, then electrostatic force becomes maximum when $\omega\, t \cong \frac{2\pi}{n}$. The lift-off field '$E_{lo}$' can be obtained as,

$$E_{lo} = K\left[\left(1+\frac{C_c}{C_g}\right)^2 + \frac{1}{R^2\,\omega^2\, C_g{}^2}\right]^{0.25}\left(\frac{\rho_c\;\; T}{S}\right)^{0.5} \quad --- \quad (9)$$

Where 'K' is a constant. 'C_g' is effective capacitance between three phase conductors and metallic particle. 'ω' is angular velocity, 'T' is thickness of dielectric coating, 'S' is contact area between particle and dielectric coating, 'ρ_c' is resistivity of dielectric material, 'R' is resistance between particle and GIB enclosure and 'C_c' is capacitance between particle and GIB enclosure.

III. SIMULATION OF PARTICLE LIFT-OFF FIELDS

For analyzing the effect of various parameters on metallic particle lift-off field, Gas Insulated Busduct of dimensions 27.5mm/76mm is considered. Dielectric coating on inside surface of GIB enclosure reduces the charge acquired by the metallic particles and thereby increases the lift-off fields. By using dielectric coating in Gas Insulated Busduct of particular size, can be operated at higher voltages when compared with uncoated Gas Insulated Busduct thereby cost can be reduced. The increase of dielectric coating thickness decreases the charge acquired by the metallic particle and increases the particle lift-off field. Dielectric materials of different types like Resins, epoxy and Al_2O_3 etc., are available. But, epoxy dielectric material is used for the present analysis of particle lift-off fields in the Gas Insulated Busduct through computer simulations. The metallic particle lift-off fields, charges acquired and respective conductor potentials for different metallic particle dimensions are analyzed and results are presented in this paper.

IV. RESULTS AND DISCUSSIONS

The metallic particle lift-off fields of Aluminum and Copper particles at different dimensions and for different dielectric coating thicknesses have been simulated for single phase Gas Insulated Busduct. The dimensions of single phase GIB are 27.5mm/76mm (27.5mm radius of the inner conductor and 76mm radius of the enclosure) is considered for the analysis of all metallic particles for all the cases.

4.1 Metallic particle lift-off field in uncoated Gas Insulated Busduct:

Table 4.1 represents the charges acquired, lift-off fields and voltages by the Aluminum and copper metallic particles of length 2.5mm with different radii. From the results it has been observed that with 0.05mm radius Aluminum particle the charge acquired is 2.26E-12 Coulombs, lift-off field and voltages are 324.87kV/m and 17.75kV respectively. For Copper particles of radius 0.05mm the charge acquired is 4.10E-12 Coulombs and lift-off field and voltages are 589.83kV/m and 32.22kV respectively. With the increase of radius of metallic particles the charge acquired, lift-off filed and voltages are also increasing. For Aluminum and Copper particles of 0.75mm radius the charge acquired is 1.31E-10 Coulombs and 2.38E-10 Coulombs respectively. The lift-off fields and voltages are 1258.23kV/m, 2284.41kV/m and 68.74kV,124.80kV for Aluminum and Copper particles respectively. Table 4.2 shows the particle acquired charges, lift-off fields and voltages of Aluminum and Copper metallic particles of length 5mm with different radii varying from 0.05mm to 0.75mm. For Aluminum particle the charge acquired, lift-off field and voltages are 4.52E-12 Coulombs, 324.87 kV/m and 17.75kV respectively and the same for Copper particle are 8.20E-11, 589.83kV/m and 32.22kV respectively. With the increase of particle radius the charge acquired, lift-off field and voltages are increased and for 0.75mm Aluminum particle, the charge acquired, lift-off field and voltages are 1.31E-10 Coulombs, 1258.23kV/m and 68.74kV respectively and for Copper particle the values are 2.38E-10 Coulombs, 2284.41kV/m and 124.80kV respectively.

Table 4.1 Al and Cu particle charges, lift-off fields and voltages for the Length of 2.5 mm with varying radius from 0.05mm to 0.75mm

Sl.No.	Particle Radius (mm)	Aluminum			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	0.05	2.26E-12	324.87	17.75	4.10E-12	589.83	32.22
2	0.1	6.39E-12	459.44	25.10	1.16E-11	834.15	45.57
3	0.15	1.17E-11	562.70	30.74	2.13E-11	1021.62	55.81
4	0.2	1.81E-11	649.75	35.49	3.28E-11	1179.67	64.44
5	0.25	2.53E-11	726.44	39.68	4.59E-11	1318.91	72.05
6	0.3	3.32E-11	795.78	43.47	6.03E-11	1444.79	78.93
7	0.35	4.18E-11	859.54	46.96	7.60E-11	1560.55	85.25
8	0.4	5.11E-11	918.88	50.20	9.28E-11	1668.30	91.14
9	0.45	6.10E-11	974.62	53.24	1.11E-10	1769.50	96.67
10	0.5	7.14E-11	1027.34	56.12	1.30E-10	1865.22	101.90

11	0.55	8.24E-11	1077.49	58.86	1.50E-10	1956.25	106.87
12	0.6	9.39E-11	1125.39	61.48	1.71E-10	2043.24	111.62
13	0.65	1.06E-10	1171.35	63.99	1.92E-10	2126.67	116.18
14	0.7	1.18E-10	1215.57	66.40	2.15E-10	2206.95	120.56
15	0.75	1.31E-10	1258.23	68.74	2.38E-10	2284.41	124.80

Table 4.2 Al and Cu particle charges, lift-off fields and voltages for the Length of 5.0 mm with varying radius from 0.05mm to 0.75mm

Sl. No.	Particle Radius (mm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	0.05	4.52E-12	324.87	17.75	8.20E-11	589.83	32.22
2	0.1	1.28E-11	459.44	25.10	2.32E-10	834.15	45.57
3	0.15	2.35E-11	562.70	30.74	4.26E-10	1021.62	55.81
4	0.2	3.61E-11	649.75	35.49	6.56E-10	1179.67	64.44
5	0.25	5.05E-11	726.44	39.68	9.17E-10	1318.91	72.05
6	0.3	6.64E-11	795.78	43.47	1.21E-09	1444.79	78.93
7	0.35	8.37E-11	859.54	46.96	1.52E-09	1560.55	85.25
8	0.4	1.02E-10	918.88	50.20	1.86E-09	1668.30	91.14
9	0.45	1.22E-10	974.62	53.24	2.21E-09	1769.50	96.67
10	0.5	1.43E-10	1027.34	56.12	2.59E-09	1865.22	101.90
11	0.55	1.65E-10	1077.49	58.86	2.99E-09	1956.25	106.87
12	0.6	1.88E-10	1125.40	61.48	3.41E-09	2043.24	111.62
13	0.65	2.12E-10	1171.35	63.99	3.85E-09	2126.67	116.18
14	0.7	2.37E-10	1215.57	66.41	4.30E-09	2206.95	120.56
15	0.75	2.62E-10	1258.23	68.74	4.77E-09	2284.41	124.80

Table 4.3 Al and Cu particle charges, lift-off fields and voltages for the Radius of 0.1 mm with varying length from 1.0mm to 10mm

Sl.No.	Particle Length (mm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	1	2.56E-09	459.44	25.10	4.64E-09	834.15	45.57
2	2	5.11E-09			9.28E-09		
3	3	7.67E-09			1.39E-08		
4	4	1.02E-08			1.86E-08		
5	5	1.28E-08			2.32E-08		
6	6	1.53E-08			2.78E-08		
7	7	1.79E-08			3.25E-08		
8	8	2.04E-08			3.71E-08		
9	9	2.30E-08			4.18E-08		
10	10	2.56E-08			4.64E-08		

Table 4.4 Al and Cu particle charges, lift-off fields and voltages for the Radius of 0.25 mm with varying length from 1.0mm to 10mm

Sl.No.	Particle Length (mm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	1	1.01E-08	726.44	39.68	1.83E-08	1318.91	72.05
2	2	2.02E-08			3.67E-08		
3	3	3.03E-08			5.50E-08		
4	4	4.04E-08			7.34E-08		
5	5	5.05E-08			9.17E-08		
6	6	6.06E-08			1.10E-07		
7	7	7.07E-08			1.28E-07		
8	8	8.08E-08			1.47E-07		
9	9	9.09E-08			1.65E-07		
10	10	1.01E-07			1.83E-07		

Table 4.3 and Table 4.4 shows the charge acquired, lift-off field and voltages for Aluminum and Copper particles with radius of 0.1mm and 0.25mm with varying particle lengths from 1mm to 10mm. For 1mm Aluminum particle length the acquired charge is 2.56E-9 Coulombs and for Copper particle is 4.64E-9 Coulombs. As the Aluminum/Copper particle length increases the charge acquired also increased and for 10mm length aluminum particle the charge acquired is 2.56E-8 Coulombs and the same for Copper particle is 4.64E-8 Coulombs. From the table 4.4 it can be observed that the charge acquired by Aluminum particles are increased from 1.01E-08 Coulombs to 1.01E-7 Coulombs and for Copper particle the charge acquired increased from 1.83E-8 Coulombs to 1.83E-7 Coulombs. But from the tables 4.3 and Table 4.4 the lift-off field and voltages are same for all the particle lengths as 459.44 kV/m, 25.10kV for aluminum and 834.15kV/m, 45.57kV for Copper.

Table 4.5 Al and Cu particle charges, lift-off fields and voltages for the particle length of 2.5 mm and radius of 0.1mm with varying dielectric thickness from 10μm to 100μm

Sl.No.	Dielectric Coating Thickness (μm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	10	6.78E-18	626.83	34.24	6.78E-18	1138.05	62.17
2	20	6.67E-18	630.56	34.45	6.67E-18	1144.82	62.54
3	30	6.57E-18	634.49	34.66	6.57E-18	1151.97	62.93
4	40	6.47E-18	638.60	34.89	6.47E-18	1159.42	63.34
5	50	6.36E-18	642.85	35.12	6.36E-18	1167.15	63.76
6	60	6.26E-18	647.24	35.36	6.26E-18	1175.11	64.19
7	70	6.16E-18	651.73	35.60	6.16E-18	1183.26	64.64
8	80	6.06E-18	656.32	35.85	6.06E-18	1191.59	65.10
9	90	5.96E-18	660.98	36.11	5.96E-18	1200.06	65.56
10	100	5.86E-18	665.71	36.37	5.86E-18	1208.65	66.03

Table 4. Al and Cu particle charges, lift-off fields and voltages for the particle length of 2.5 mm and radius of 0.25mm with varying dielectric thickness from 10μm to 100μm

Sl.No.	Dielectric Coating Thickness (μm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	10	1.69E-17	991.10	54.14	1.69E-17	1799.41	98.30
2	20	1.67E-17	997.00	54.47	1.67E-17	1810.12	98.89
3	30	1.64E-17	1003.22	54.80	1.64E-17	1821.42	99.50
4	40	1.62E-17	1009.71	55.16	1.62E-17	1833.21	100.15
5	50	1.59E-17	1016.44	55.53	1.59E-17	1845.42	100.81
6	60	1.56E-17	1023.37	55.91	1.56E-17	1858.01	101.50
7	70	1.54E-17	1030.48	56.29	1.54E-17	1870.90	102.21
8	80	1.51E-17	1037.73	56.69	1.51E-17	1884.07	102.92
9	90	1.49E-17	1045.10	57.09	1.49E-17	1897.46	103.66
10	100	1.47E-17	1052.59	57.50	1.47E-17	1911.05	104.40

4.2 Metallic particle lift-off field in coated Gas Insulated Busduct:

Table 4.5 shows the particle charge, lift-off field and voltages of Aluminum and Copper particles of length 2.5mm and radius of 0.1mm with varying dielectric coating thickness from 10 micrometer to 100 micrometer. For Aluminum particle, the charge acquired, lift-off field and lift-off voltage are 6.78E-18 Coulombs, 626.83 kV/m and 34.24 kV respectively and for Copper particle these values are 6.78E-18 Coulombs, 1138.05kV/m and 62.17 kV respectively. With increase of dielectric coating thickness the charge acquired by the particles are reduced and thereby the lift-off field and voltages increasing. When dielectric coating thickness coating is increased to 100micrometer, the charge acquired is reduced to 5.86E-18 Coulombs for Aluminum and Copper particles. But lift-off field and voltages are increased to 665.71 kV/m, 36.37kV for Aluminum and 1208.65 kV/m, 65.56 kV for Copper particle.

Table 4.6 and Table 4.7 show the particle charge, lift-off field and voltages for Aluminum and Copper particles with varying dielectric coating thickness from 10 micrometers to 100 micrometers with particle lengths of 2.5mm, 5mm and radii of 0.25mm and 0.1mm.

From Table 4.6 it can be observed that for varying dielectric thickness from 10 micrometer to 100 micrometer the charge acquired reduced from 1.69E-17 Coulombs to 1.47E-17 Coulombs for both Aluminum and Copper particles. At the same conditions the lift-off field and voltages are increased from 991.10kV/m, 54.14kV to 1052.59 kV/m, 57.50 kV for Aluminum particle and from 1799.41 kV/m, 98.30 kV to 1911.05 kV/m, 104.40 kV for Copper particle respectively. Similarly from Table 4.7 it is observed that the increase in dielectric coating thickness from 10 micrometer to 100 micrometer, the charge acquired by Aluminium and Copper particle decreased from 1.36E-17 Coulombs to 1.17E-17 Coulombs and lift-off field and voltages are increased from 626.83 kV/m, 34.24 kV to 665.71 kV/m, 36.37 kV respectively for Aluminium particle and from 1138.05 kV/m, 62.17 kV to 1208.65 kV/m, 66.03 kV respectively for Copper particle.

Table 4.7 Al and Cu particle charges, lift-off fields and voltages for the particle length of 5 mm and radius of 0.1mm with varying dielectric thickness from 10μm to 100μm.

Sl.No.	Dielectric Coating Thickness (μm)	Aluminium			Copper		
		Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)	Particle Charge (Coulombs)	Lift-off Field (kV/m)	Lift-off Voltage (kV)
1	10	1.36E-17	626.83	34.24	1.36E-17	1138.05	62.17
2	20	1.33E-17	630.56	34.45	1.33E-17	1144.82	62.54
3	30	1.31E-17	634.49	34.66	1.31E-17	1151.97	62.93
4	40	1.29E-17	638.60	34.89	1.29E-17	1159.42	63.34
5	50	1.27E-17	642.85	35.12	1.27E-17	1167.15	63.76

6	60	1.25E-17	647.24	35.36	1.25E-17	1175.11	64.19
7	70	1.23E-17	651.73	35.60	1.23E-17	1183.26	64.64
8	80	1.21E-17	656.32	35.85	1.21E-17	1191.59	65.10
9	90	1.19E-17	660.98	36.11	1.19E-17	1200.06	65.56
10	100	1.17E-17	665.71	36.37	1.17E-17	1208.65	66.03

V. CONCLUSIONS

A mathematical model has been formulated for simulating the lift-off fields of Aluminum and Copper wire like particles resting on the enclosure surface under the influence of electric field by considering with and without dielectric coating on the inner surface of GIB enclosure. When a voltage is applied to the inner conductor of Gas Insulated busduct, the electrostatic force at the metallic particle location causes the particle to acquire charge and further increase in the applied voltage increases the charge magnitude of the metallic particle. At some particular voltage(lift-off voltage) the electrostatic force on the metallic particle and its gravitational force are same then the particle lifts from its position. If voltage is further increased then the metallic particle moves in to the inter electrode gap of Gas Insulated Busduct in the direction of the electric field. It is observed from the results that the lift-off field of Aluminum particle is less than that of Copper particle for the same dimensions and dielectric coating thickness due to the specific weight of specific weight of Aluminum is less than that of Copper. For the dielectric coated Gas insulated busduct the lift-off of field of metallic particle is greater than that of uncoated Gas Insulated Busduct because the dielectric coating reduces the charge acquired by the particles. From the results it is also observed that the lift-off field of metallic particle increased with the increase of metallic particle radius because the gravitational force increases more than that of electrostatic force with increase in radius. With the increase of length of the particle the lift-off field remains as the same because the increase in the gravitational force with length of the particle and the increase in the electrostatic force both are same. With the increase of dielectric coating thickness the lift-off field of metallic particle is reduced because the charge acquired by the metallic particle is decreasing with the increase of dielectric coating thickness. The lift-off field of metallic particle depends on its dimensions, specific weight and thickness of the dielectric coating. The results obtained are presented and analyzed for various metallic particle dimensions and Gas Insulated Busduct with and without dielectric coating.

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