

Effect of simultaneous movement of multiple particles under electric field in a Single Phase Gas Insulated Bus duct

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ABSTRACT

20% of failures in Gas Insulated Substations are due to the existence of various metallic contaminations in the form of loose particles. These particles may be free to move in the electric field or may be fixed on the conductors, thus enhancing local surface fields. In this paper a Single Phase Gas Insulated Bus duct with inner and outer diameter to 55mm and 152 mm is considered. In this paper multiple particles i.e three particles of different sizes are considered. These three particles are assumed to be rest at a position. Basic equations for the movement of three metallic particles are formulated. The motion of the three particles are simulated for different voltages using MATLAB. Effect of multiple particles for various electric fields on particle movement are analyzed and time of collisions of the particle at first time is determined for various voltages. Particles of copper of 10 mm in length and 0.25 mm radius, 10 mm length and 0.15 mm radius and 7 mm and 0.25 radius are considered. The results show that the three particles collide at different points depending on the particles positions. The simulation results have been presented and analyzed.

Keywords – multiple particles , Gas Insulated Substations, Particle Contamination, MATLAB.

I. INTRODUCTION

Sulphur hexafluoride is the electric power industry's preferred gas for electrical insulation and, especially for arc quenching current interruption equipment used in the transmission and distribution of electrical energy. Compressed Gas Insulated Substations (GIS) and Transmission Lines (CGIT) consist basically of a conductor supported on insulator inside an enclosure, which is filled with SF₆ gas. Basic components of the GIS bay are circuit breakers, disconnectors, earthing switches, bus ducts, current and voltage transformers, etc. The inner live parts of GIS are supported by insulators called spacers, which are made of alumina filled epoxy material. The GIS enclosure forms an electrically integrated, rounded enclosure for the entire substation. Even though SF₆ exhibits very high dielectric strength, the withstand voltage of SF₆ within the GIS is drastically reduced due to the presence of particles or defects like free particles on the inner surface of the enclosure, protrusion on the high voltage (HV) bus, protrusion on the inner surface of the enclosure and narrow gaps between the spacer and the electrode are due to imperfect casting and imperfect mechanical strength. The presence of contamination can therefore be a problem with gas-insulated substations operating at high fields [1]-[2].

Free conducting particles are most dangerous to GIS. These free conducting particles may have any shape or size,

may be spherical or filamentary (wire like) or in the form of fine dust. Particles may be free to move or may be fixed on to the surfaces. Wire like particles made of conducting material are more harmful and their effects are more pronounced at higher gas pressures. As given by the authors [2-5], the presence of atmospheric dust containing conducting particles, especially on the cathode, reduces the breakdown voltage.

The present work deals with considering three different particles on the inner surface of the bus duct at different positions, and formulating the basic equations for

the movement of these metallic particles.

In this paper a Single Phase of Gas Insulated Bus duct with diameter of 55mm and enclosure diameter of 152mm is considered for analysis. Particles of copper of 10 mm in length and 0.25 mm radius, 10 mm length and 0.15 mm radius and 7 mm and 0.25 radius are considered for simulation with MATLAB.

II. II.MODELING OF GAS INSULATED BUS DUCT

A typical horizontal single-phase bus duct shown in Figure (a) has been considered for the analysis. It consists of an inner conductor and an outer enclosure, filled with SF₆ gas. Particles are assumed to be at rest at some position on the

enclosure surface, until a voltage sufficient enough to lift the particles and move in the field is applied. After acquiring an appropriate charge in the field, the particles lift and begins to move in the direction of the field after overcoming the forces due to its own weight and drag. For particles on bare electrodes, several authors have suggested expressions for the estimation of charge on both vertical/horizontal wires and spherical particles. The equations are primarily based on the work of Felici[5].

Understanding the dynamics of a metallic particle is of vital importance for determining the effect of metallic contamination in a Gas Insulated System (GIS). If the motion patterns of a metallic particles are known, the probability of particle colliding in coaxial gap and causing a flash over can be estimated. The lift-off field for the particles on the surface of an electrode can be estimated by solving the motion equation. Conducting particles in motion in an external electric field will be subjected to a collective influence of several forces.

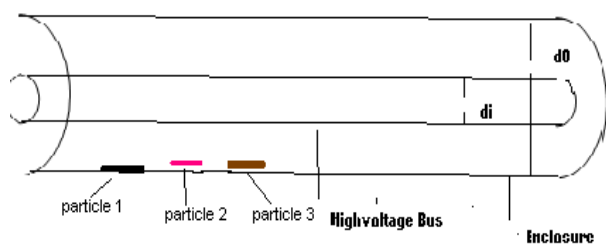


Fig. (a). Typical single phase gas insulated bus

The forces are :-

- Electrostatic force (Fe)
- Gravitational force (mg)
- Drag force (Fd)

The motion equations for the three particles are given by

$$m_1 \frac{d^2 y_1}{dt^2} = F_{e1} - m_1 g - F_{d1} \quad \text{---(1a)}$$

$$m_2 \frac{d^2 y_2}{dt^2} = F_{e2} - m_2 g - F_{d2} \quad \text{---(1b)}$$

$$m_3 \frac{d^2 y_3}{dt^2} = F_{e3} - m_3 g - F_{d3} \quad \text{---(1c)}$$

where m1,m2,m3 = mass of the particles

y = displacement in vertical direction

Fe = Electrostatic force

g = gravitational constant

The charges acquired by a vertical wire particles respectively in contact with a naked enclosure can be expressed as:

$$Q_1 = \frac{\pi \epsilon_0 l_1^2 E(t)}{\left(\ln\left(\frac{2l_1}{r_1}\right) - 1 \right)} \quad \text{---(2a)}$$

$$Q_2 = \frac{\pi \epsilon_0 l_2^2 E(t)}{\left(\ln\left(\frac{2l_2}{r_2}\right) - 1 \right)} \quad \text{---(2b)}$$

$$Q_3 = \frac{\pi \epsilon_0 l_3^2 E(t)}{\left(\ln\left(\frac{2l_3}{r_3}\right) - 1 \right)} \quad \text{---(2c)}$$

where Q1 Q2 Q3 are the charges on the particles until the next impact with the enclosure, l1 l2 l3 are the particle length, r1 r2 r3 are the particle radii respectively, E(t) is the ambient electrical field at t = t0. The charge carried by the particle between two impacts has been considered constant in the simulations.

The electric field in a coaxial electrode system at position of the particles can be written as:

$$E(t) = \frac{\hat{V}_m \text{Sin } \omega t}{[r_0 - y(t)] I_n \left[\frac{r_0}{r_i} \right]} \quad \text{---(3)}$$

where Vm Sin wt is the supply voltage on the inner electrode, r0 is the enclosure radius, ri is the inner conductor radius y(t) is the position of the particle which is the vertical distance from the surface of the enclosure towards the inner electrode.

The electrostatic force on each particle is given by

$$F_{e1} = K Q_1 E(t) \quad \text{---(4a)}$$

$$F_{e2} = K Q_2 E(t) \quad \text{---(4b)}$$

$$F_{e3} = K Q_3 E(t) \quad \text{---(4c)}$$

Where K is a corrector and is a factor less than unity. However, for length-to-radius ratios greater than 20 the correction factor, K, is close to unity

The drag forces are given by:

$$F_{d1} = \dot{y} \pi r_1 \left(6\mu K_d (\dot{y}) + 2.656 \left[\mu \rho_g l_1 \dot{y} \right]^{0.5} \right) \quad \text{---(5a)}$$

$$F_{d2} = \dot{y} \pi r_2 \left(6\mu K_d (\dot{y}) + 2.656 \left[\mu \rho_g l_2 \dot{y} \right]^{0.5} \right) \quad \text{---(5b)}$$

$$F_{d2} = \dot{y} \pi r_3 \left(6\mu K_d (\dot{y}) + 2.656 \left[\mu \rho_g l_2 \dot{y} \right]^{0.5} \right) \dots\dots\dots(5c)$$

where y is the velocity of the particle, μ is the viscosity of the fluid (SF6 : 15.5_10⁻⁶kg/m_s at 200C), r_1 r_2 r_3 are the particle radius, ρ_g is the gas density, l_1 l_2 l_3 are the particle lengths, $K_d(y)$ is a drag coefficient.

The influence of gas pressure on the drag force is given by empirical formula.

$$\rho_g = 7.118 + 6.332P + 0.2032P^2 \dots\dots\dots(6)$$

where ρ_g = density p = Pressure of the gas and $0.1 < p < 1$ mboxMPa.

The restitution coefficient for copper and aluminum particles seem to be in the range of 0.7 to 0.95: $R = 0.8$ implies that 80% of the incoming impulse of the particle is preserved when it leaves the enclosure.

The motion equation (1a) ,(1b),(1c) using all forces can therefore be expressed as

$$m\ddot{y}(t) = \left[\frac{\pi \epsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \times \frac{V \sin \omega t}{[r_0 - y(t)] \ln\left(\frac{r_0}{r_i}\right)} \right] - mg - \dot{y}(t) \pi r \left(6\mu K_d (\dot{y}) + 2.656 \left[\mu \rho_g l \dot{y}(t) \right]^{0.5} \right)$$

In the above equation, the parameters m, l, r can be replaced by m_1, l_1, r_1 and motion of the particle 1 can be obtained . similarly for particles 2 and 3 motions can be obtained. The above equation is a second order non-linear differential equation and in this paper, the equation are solved using MATLAB by Runge- Kutta 4th Order Method.

III. SIMULATION OF PARTICLE MOTION

In order to determine the random behavior of moving particles, the calculation of movements in axial and radial directions was carried at every time step using rectangular random numbers. The above simulation yields the particle movement in the radial and axial directions. The random movement can be adequately simulated by Monte-Carlo method. In order to determine the randomness, it is assumed that the particle emanates from its original site at any angle less than ϕ , where $\phi/2$ is half of the solid angle subtended with the vertical axis. At every step of movement, a new rectangular random number is generated between 0 and 1 and modified to ϕ . The angle thus assigned, fixes the position of particle at the end of every time step, and in turn

determines the axial and radial positions. The position in the next step is computed on the basis of equation of motion with new random angles as described above.

Three different particles on the inner surface of the bus duct are considered ,Particles of copper of 10 mm in length and 0.25 mm radius, 10 mm length and 0.15 mm radius and 7 mm and 0.25 radius are considered for simulation.

IV. RESULTS AND DISCUSSIONS

Table 1 shows the radial movement of the particles in a 1- Phase Gas Insulated Bus duct. Figure 1 to Figure 4 shows the movement patterns of copper particles in Electric Field and with Monte Carlo Technique for applied voltages of 100 kV ,132 KV,145 KV and 200 kV respectively.

The particle 1 has 10 mm in length and 0.25 mm radius ,particle 2 has 10 mm length and 0.15 mm radius and particle 3 has 7 mm and 0.25 radius.

Figure 5 to Figure 8 shows the collision of particles in the bus ducts. It is observed that the three particle are started at same position and probability of collision at different points also shown in figures 5 to 8. It is seen that as the voltage varies from 100 kv to 200 Kv maximum radial movement also varies as shown in Table1 and also the particles collide at different intervals. The collisions of the particles for the first time both time and height of collision also shown in Table 2.

At this point of collisions (from fig 5 to 8) the particle moves randomly and its velocity and direction also changes which gives the actual maximum radial displacement would be more than the maximum radial displacement when no collision takes place.

The axial movements of particles and collision points are shown in figures 9 to 12 for the applied voltages of 100 KV,132 KV,145 KV,200 KV respectively

Table:1 Radial movement of copper particles with Monte-Carlo technique for various voltages.

Voltage KV	Max. Radial Movement of particle 1 (mm)	Max. Radial Movement of particle 2 (mm)	Max. Radial Movement of particle 3 (mm)
100	4.4906	14.0571	10.7879
132	13.1	21.4638	16.0967
145	13.7259	24.0725	18.3780
200	17.8027	32.2358	26.7390

Table:2 height and time of particle collisions with Monte-Carlo technique for various voltages.

Voltage KV	Time of particle collision at first time (sec)	Height of the particle collisions at first time (mm)
100	0.067	0.72
132	0.08	3.5
145	0.065	8.82
200	0.0425	18.65

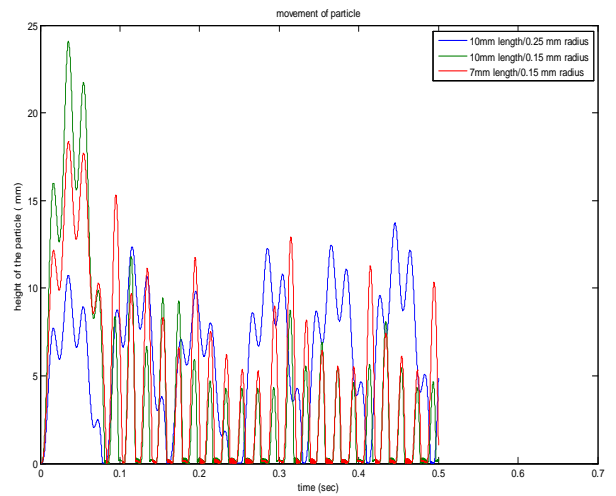


Figure:3 RadialMovement for Cu/ 145 KV / 76mm - 25mm Enclosure

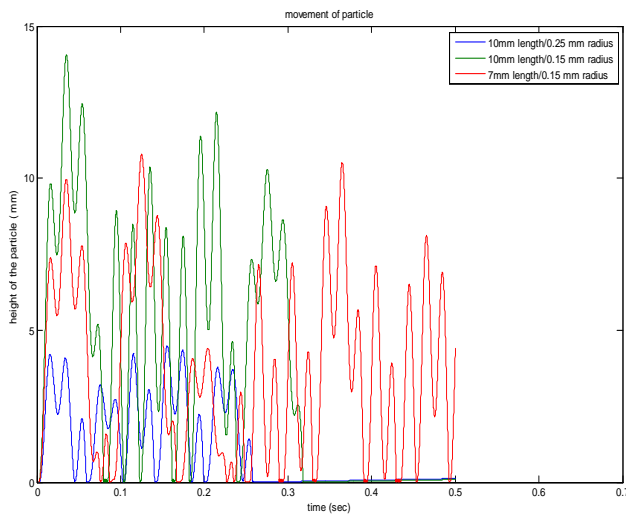


Figure:1 Radial Movement for Cu/ 100 KV / 76mm - 25mm Enclosure

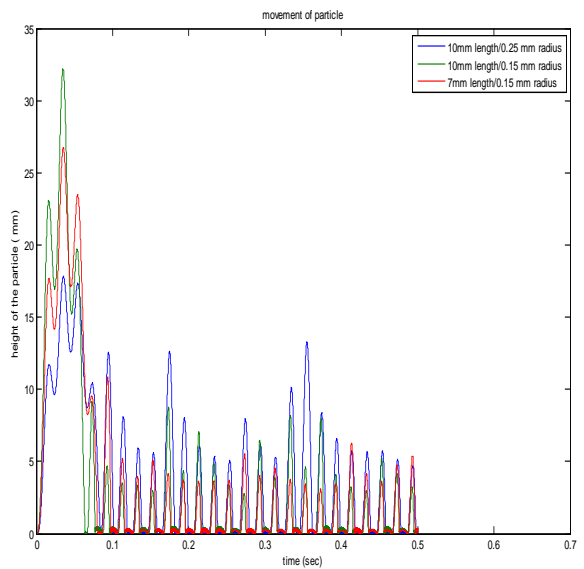


Figure:4 RadialMovement for Cu/ 200 KV / 76mm - 25mm Enclosure

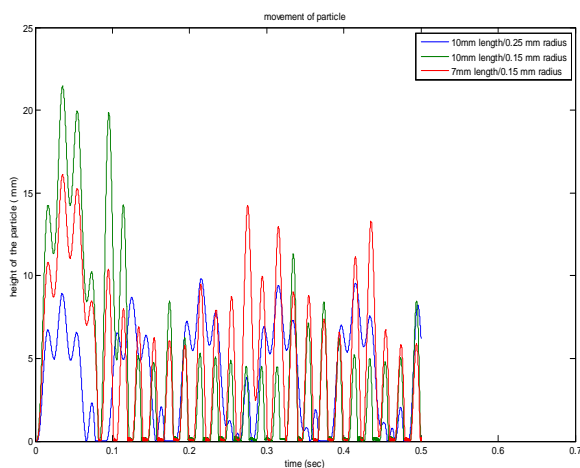


Figure:2 Radial Movement for Cu/ 132 KV / 76mm - 25mm Enclosure

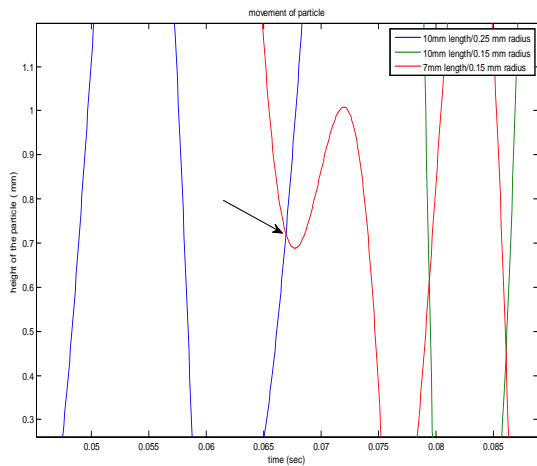


Figure:5 Particles collision for Cu/ 100 KV / 76mm - 25mm Enclosure

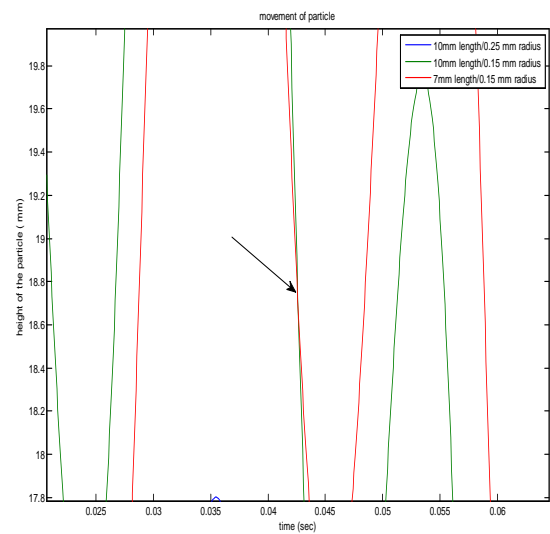


Figure:8 Particles collision for Cu/ 200KV / 76mm - 25mm Enclosure

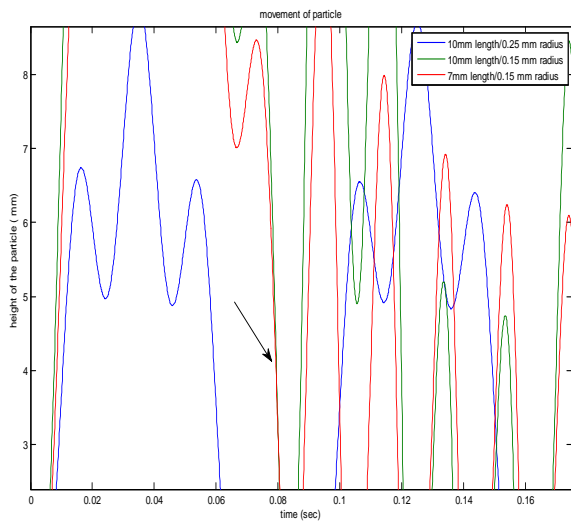


Figure:6 Particle collision for Cu/ 132KV / 76mm - 25mm Enclosure

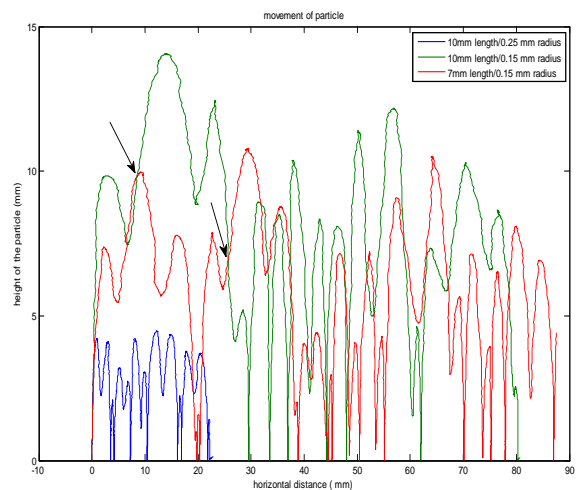


Figure:9 Axial Movement for Cu/ 100 KV / 76mm - 25mm Enclosure

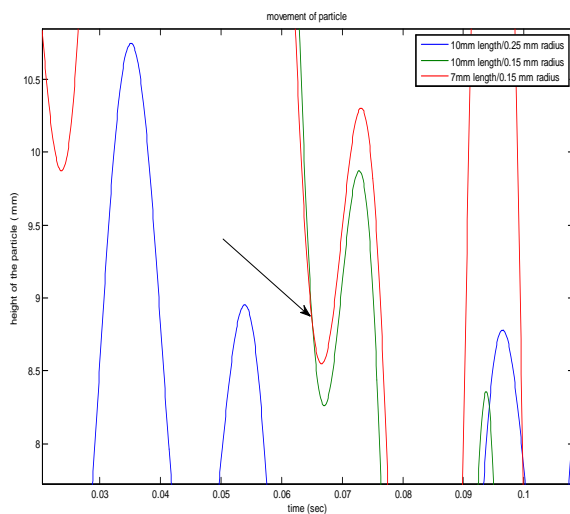


Figure:7 Particle collision for Cu/ 145KV / 76mm - 25mm Enclosure

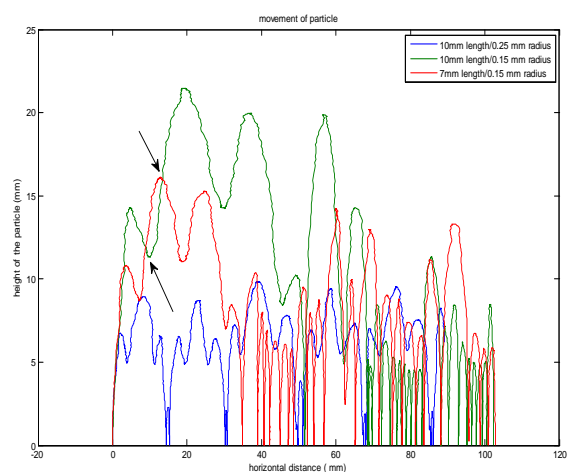


Figure:10 Axial Movement for Cu/ 132 KV / 76mm - 25mm Enclosure

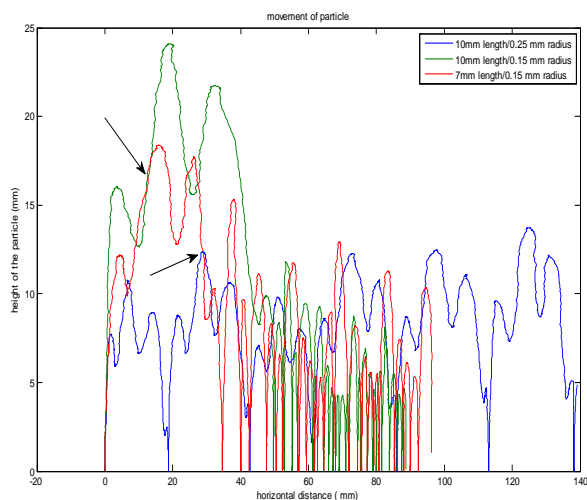


Figure:11 Axial Movement for Cu/ 145 KV / 76mm - 25mm Enclosure

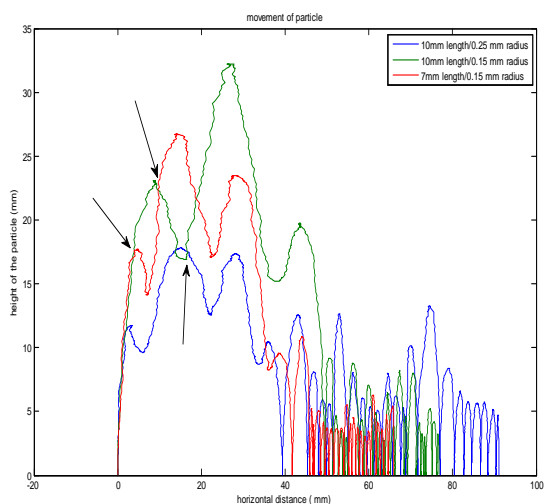


Figure:12 Axial Movement for Cu/ 200 KV / 76mm - 25mm Enclosure

V. CONCLUSION

It is shown that the probability of a flashover occurs at smaller size of the particle and at higher voltages but due to the particle collisions particles move randomly and its velocity and direction also changes which leads to flash over even at low voltages. If the calculations, as described above, are performed at a different voltage levels by considering a single particle at a time as no collisions takes place, max height of the particle and chances of flash over would be low. The results obtained from the calculations show that additional information about the particles collision and time at which first time collision takes place should be considered to estimate the flash over chances.

VI. ACKNOWLEDGMENT

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