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RESEARCH ARTICLE OPEN ACCESS

Effect of particle contamination in a 1- Phase Gas Insulated Bus duct under Lightning impulse voltage

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ABSTRACT
Gas Insulated Substations have to withstand for lightning surges without breakdown of Insulation. In this paper a single Phase Gas Insulated Bus duct with inner diameter conductor 55mm and diameter of enclosure 150 mm is considered. Three particle of different sizes assumed to be rest at a position. Lightning Impulse Voltage of 1050 kV is superimposed on Power frequency voltages of 100 kV, 132 kV ,145 and 200 kV are applied to one Phase GIS bus.

The motion of the three particles are simulated for different voltages using MATLAB. Effect of the three particles for Lightning Impulse Voltage super imposed on power frequency on particle movement are analyzed and time of collisions of the particle at first time is determined for various voltages. And also the horizontal and vertical distances at which the particles collide are determined for 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 radii. The results show that the three particle collide at different points depending on the particles position , the velocity and direction of the particle changes after collisions . The max displacement of the particles without collision are compared with the max radial displacements by considering the collisions. The results show that the max displacement of particles is higher as compared with without collisions.

Keywords – Multiple particles , collision ,Gas Insulated Substations, Particle Contamination, MATLAB.

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I. INTRODUCTION

Compressed Gas Insulated Substations (GIS) consists basically of a conductor supported by insulator inside an enclosure, 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 a position, and using the basic equations for the movement of these metallic particles. Lightning Impulse Voltage of 1050 kV is superimposed on Power frequency voltages of 245 kV, 300 kV ,400 and 450 kV are applied to singlePhase GIS bus.

In this paper a 1- Phase Gas Insulated Bus duct with diameter of conductor 55 mm and enclose diameter of 150 mm is considered for analysis . copper particles 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

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II.MODELING OF GAS INSULATED BUS DUCT

A typical horizontal single-phase bus duct shown in Figure 1 has been considered for the analysis. It consists of a conductor spaced in a metal enclosure, filled with SF6 gas. Particles are assumed to be 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 begin 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].

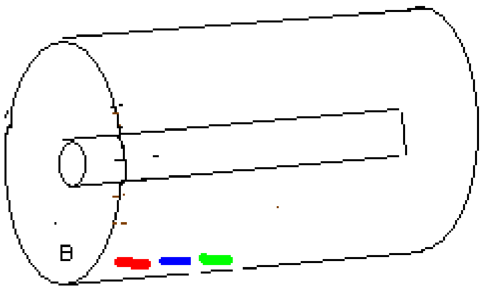


Figure. 1 Typical single phase gas insulated bus

Conducting particles in motion in an external electric field will be subjected to a collective influence of several forces. The forces are : -
-Electrostatic force (Fe)
- Gravitational force (mg)
- Drag force (Fd)

The motion equations for the three particles are given by [6][7]

$$m_1 \frac{d^2 y_1}{dt^2} = F_{e1} - m_1 g - Fd_1 \quad ----(1a)$$

$$m_2 \frac{d^2 y_2}{dt^2} = F_{e2} - m_2 g - Fd_2 \quad ----(1b)$$

$$m_3 \frac{d^2 y_3}{dt^2} = F_{e3} - m_3 g - Fd_3 \quad ----(1c)$$

where m1,m2,m3 = mass of the particles
y = displacement in vertical direction
Fe = Electrostatic force
g = gravitational constant

Lightning Impulse voltage is superimposed on power frequency voltage and is given by
(1) Lightning impulse of 1.2/50 micro sec

$$V = V_0 (e^{-at} - e^{-Bt}) \text{.........} \text{..........} (A)$$

Where V_0=1050 KV

$$a = 0.1477X10^5$$
$$b = 0.1933X10^7$$

(2) Super imposed Lightning impulse on power frequency

$$V = (Vm.\sin w(t - t_0) + V_0 (e^{-at} - e^{-Bt}) \text{.....} (B)$$

Where t_0=time at which it is superimposed

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

$$Q_1 = \frac{\pi \epsilon_0 l_1^{\,2} E(t0)}{\left(\ln(\frac{2l_1}{r_1}) - 1 \right)} \text{............} 2(a)$$

$$Q_2 = \frac{\pi \epsilon_0 l_2^{\,2} E(t0)}{\left(\ln(\frac{2l_2}{r_2}) - 1 \right)} \text{............} 2(b)$$

$$Q_3 = \frac{\pi \epsilon_0 l_3^{\,2} E(t0)}{\left(\ln(\frac{2l_3}{r_3}) - 1 \right)} \text{............} 2(c)$$

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(t0) 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:

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

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

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

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

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

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:

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

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

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

where y is the velocity of the particle, μ is the viscosity of the fluid (SF6 : 15.5_10−6kg/m_s at 200C), r1 r2 r3 are the particle radius, ρg is the gas density, l1 l2 l3 are the particle lengths, Kd(y) is a drag coefficient.
The influence of gas pressure on the drag force is given by empirical formula.

$$\rho_g = 7.118 + 6.332P + 0.2032P^2 \text{..............} (6)$$

where ρ_g= density p = Pressure of the gas and 0.1 < p < 1mboxMPa.
The restitution coefficient for copper 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

$$m\ddot{y}(t) = \frac{\pi \epsilon_0\, l^2\, E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \text{ x } 48.64 \text{ x}10^3 \left[\left(\frac{1}{0.125 - x} \right) + \left(\frac{\cos\theta_2}{R_1} \right) \right] \sin \omega t - mg$$
$$- \dot{y}(t)\, \pi r\, (6\mu K_d\, (\dot{y}) + 2.656\, (\mu r_g\, ly\, (t)^{0.5})$$

In the above equation, the parameters m,l,r can be replaced by m1,l1,r1 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

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 φ/2 is half of the solid angle subtended with the vertical axis.

III. RESULTS AND DISCUSSIONS

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.

Table 1 shows the radial movement of the particles in a 1- Phase Gas Insulated Bus duct in Electric Field for switching impulse voltage superimposed on voltages of 100KV ,132 kV ,145 KV and 200 KV respectively.

Table 2 shows the time at which particle collide for first time Tc and Vertical height of the particle at collisions in mm . velocity of the particle at just before the collision (mm /sec) .

In Table 3 the velocity of the particles at just before the collision and after collision are shown determined by the equation of collision given in appendix at Tc by MATLAB . Figure 2 to Figure 5 shows the movement patterns of copper particles in Electric Field for lightning impulse voltage superimposed on voltages applied voltages of 100KV ,132 kV ,145 KV and 200 KV respectively.

Figure 6 to Figure 9 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 6 to 9. 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 height and time of collision also shown in Table 2. At this point of collisions (from fig 6 to 9) the particle moves randomly and its direction and velocity also changes. It gives the actual maximum radial displacement more than the maximum radial displacement when no collision takes place.

The axial movements of particles and collision points are shown in figures 10 to 13 for the applied voltages of 245 KV,300 KV,400 KV and 450 KV respectively.

The vertical velocity and angle of collision of the particles are calculated by simulation results for different voltages 100KV ,132 kV ,145 KV and 200 KV respectively by the equation given in appendix , the velocity of the particles 1, 2 and 3 after collisions are calculated as given in Appendix

In the table 3 ,the velocity of the particles just the instant after collision for different voltages is given. It is seen from the table 3 that for 100 KV the particles 1 and 3 are collide and their velocities are (Blue and red colours in the plot) abruptly changes after collision.

For 132 KV,145 KV and 200 KV voltages, the particles 1 and 2 are collide and their velocities are (Green and red colours in the plot) abruptly changes after collision.

Sample calculation for a voltage of 200 KV

The velocity before collision at Tc for particle 1 (blue) $V_{NO.Col}$ =5284 mm/sec.
the velocity after collision at T_C for particle 1 (blue) V_{Col}=23045 mm/sec.
ratio of the velocities = V_{Col} / $V_{NO.Col}$ =23045/5284 =4.36
height of particle-1 at collision = 31.5 mm
first peak of particle -1 without collision = 35 mm
difference in displacement = 35-31.5 = 3.5 mm
Net displacement particle 1 with collision =3.5*4.36=15.26 mm
Total radial displacement with collision =
height of particle at collision+ Net displacement particle with collision.
Total radial displacement with collision =31.5+15.26=46.76 mm.

If the particles continue to move with its new velocity the maximum height of the particle would be more than that when particles are considered individually without collision as given in Table 4.

Table:1 Radial movement of aluminum particles with Monte-Carlo technique for various voltages assuming no collisions

Voltage KV	Max. Radial Movement of particle 1 (mm)	Max. Radial Movement of particle 2 (mm)	Max. Radial Movement of particle 3 (mm)
100	28.8395	52.3147	19.0344
132	34.7383	54.1098	24.5201
145	36.0814	54.3394	26.5471
200	41.4718	57.8648	33.1313

Table.2 height and time of particle collisions for various voltages.

Voltage KV	Time at which particle collide first time Tc (sec)	Vertical height of the particle at collisions (mm)		
		Particle1 (blue)	Particle2 (green)	Particle3 (Red)
100	0.15	2.1	NC	2.1
132	0.065	29.5	29.5	NC
145	0.05	31	31	NC
200	0.06	32.5	32.5	NC

Table.3 height and time of particle collisions and velocities of the particles after the collision for various voltages.

Voltag e KV	Time at which particle collide first time Tc (sec)	Velocity of the particle at just before the collision (mm /sec)			Velocity of the particle after the collision (mm /sec)		
		Particle 1 (blue)	Particle2 (green)	Particle3 (Red)	Particle1 (blue)	Particle2 (green)	Particle3 (Red)

100	0.15	**1572.4**	4800	**1268**	1170.4	**NC**	**1474.8**
132	0.065	**-1490**	**1105.7**	-733.8	1938.3	**-657.4083**	NC
145	0.05	**458.5**	**6275.4**	1769	3538.0	**-2278.9**	NC
200	0.025	**-5284**	**48226.5**	--2572.6	23045	**-30465**	NC

Table. 4 Max Radial displacements with and without collision

s.no	Max Radial displacements without considering collisions			Max Radial displacements with collisions		
Voltage KV	Max. Radial Movement of particle 1 (mm)	Max. Radial Movement of particle 2 (mm)	Max. Radial Movement of particle 3 (mm)	Radial Movement of particle 1 (mm)	Radial Movement of particle 2 (mm)	Radial Movement of particle 3 (mm)
100	28.8395	52.3147	19.0344	28.8395	52.3147	19.0344
132	34.7383	54.1098	24.5201	34.7383	54.1098	24.5201
145	36.0814	54.3394	26.5471	36.0814	54.3394	26.5471
200	41.4718	57.8648	33.1313	**46.76**	57.8648	33.1313

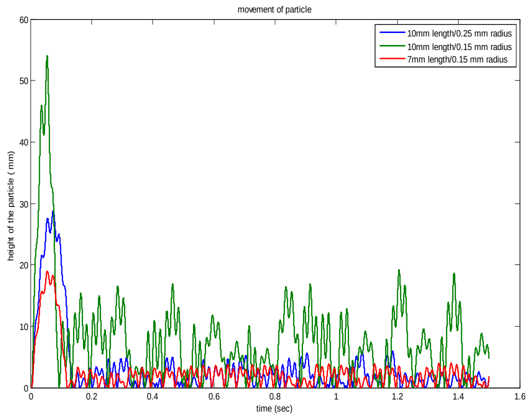


Figure. 2 Radial Movement Cu/ 100KV superimposed of 1050 KV / 55mm - 150mm Enclosure

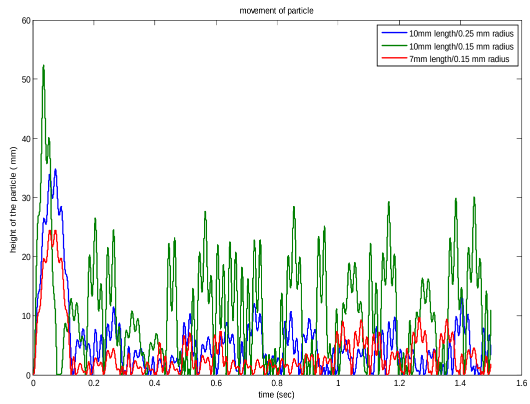


Figure. 3 Radial Movement for Cu/ 132KV superimposed of 1050 KV / 55mm - 150mm Enclosure

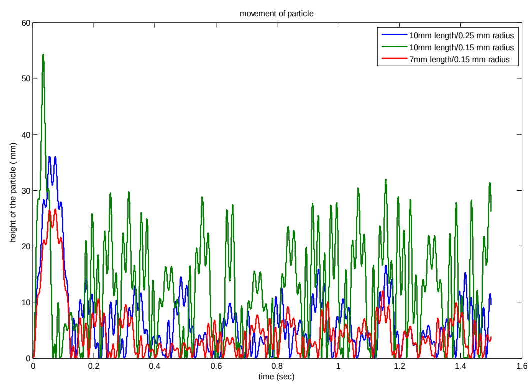


Figure. 4 Radial Movement for Cu/ 145KV superimposed of 1050 KV / 55mm - 150mm Enclosure

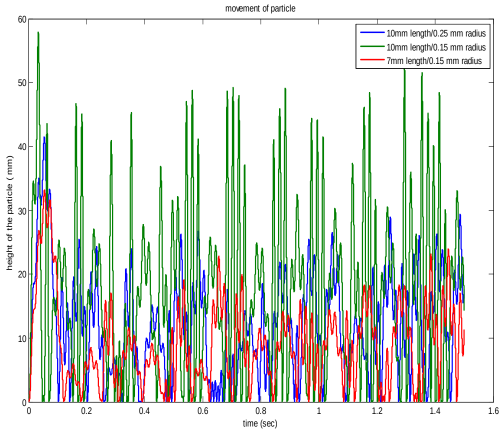


Figure. 5 Radial Movement for Cu/ 200KV superimposed of 1050 KV / 55mm - 150mm Enclosure

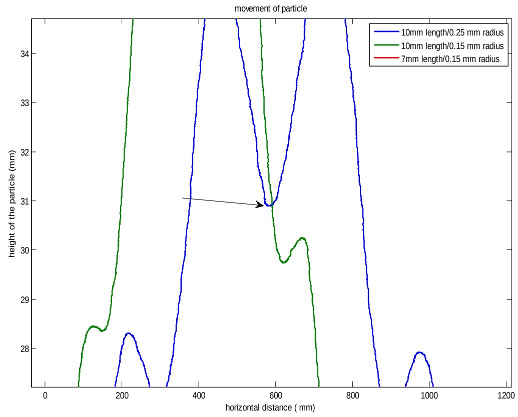


Figure.8 Particle collisiont for Cu/ 145 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

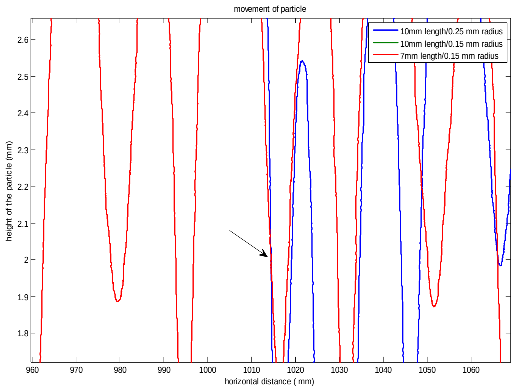


Figure.6 Particles collision for Cu/ 100 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

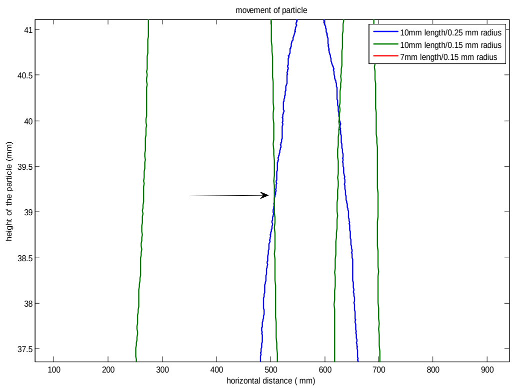


Figure.9 Particle collisiont for Cu/ 200 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

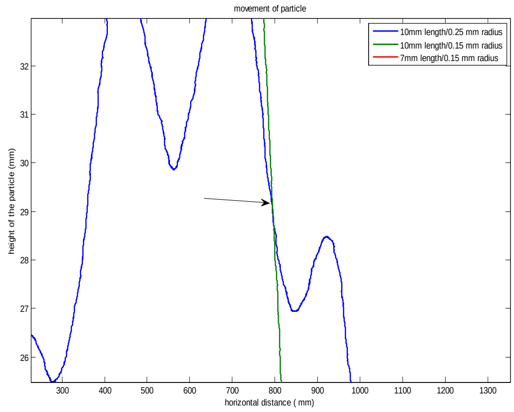
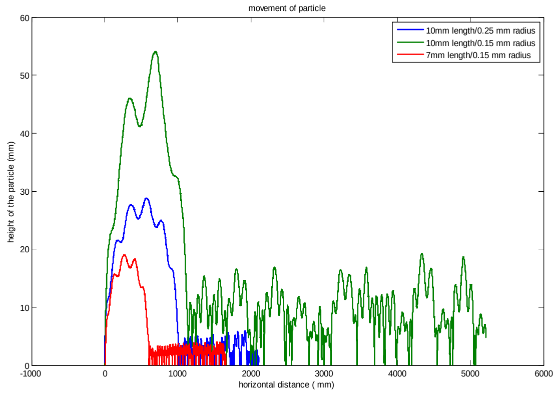


Figure.7 Particles collision for Cu/ 132 KV superimposed of 1050 KV / 55mm - 150mm Enclosure



. Figure.10 Axial Movement for Cu/ 100 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

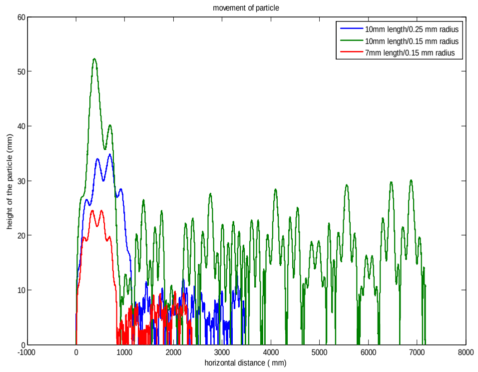


Figure.11 Axial Movement for Cu/ 132 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

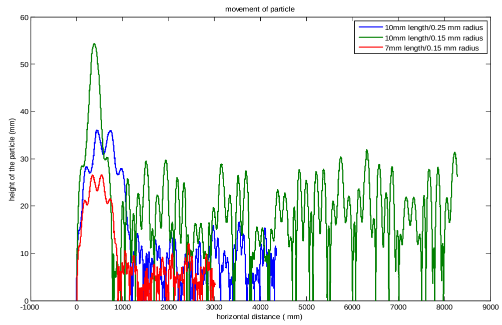


Figure.12Axial Movement for Cu/ 145 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

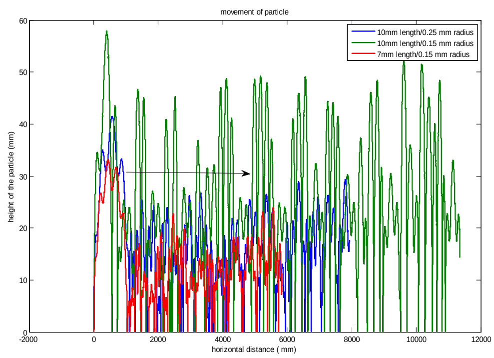


Figure.13 Axial Movement for Cu/ 200 KV superimposed of 1050 KV / 55mm - 150mm Enclosure

V. CONCLUSION

For the superimposed voltages of 100 KV 132 KVand 145 KV the collision of particles take place just at retarding edge of the the lightning impulse ,where as the for the superimposed voltages of 200 KV the collision takes place in the rising edge of the lightning impulse. So due to particles collision in first case there is NO change in the maximum radial displace ments of the particles when single particle at a time is considered as no collisions takes place. But for a voltage of 200 KV as particles collide at rising edge of the impulse wave the maximum height of the particle 1 increases due to collision.

Hence 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 simulation show that due to collision of particle the maximum radial displacements would be more and additional information about the particles collision and time at which first time collision takes place should be considered to estimate the flash over chances. However the collision of the particles in the gap will increase the chances of flashover.

Appendix

Two- dimensional Collision of particles

Consider two particles, denoted by subscripts 1 and 2. Let m_1 and m_2 be the masses, v_1 and v_2 the velocities before collision. For the case of two colliding bodies in two dimensions, the overall velocity of each body must be split into two perpendicular velocities: one tangent to the common normal surfaces of the colliding bodies at the point of contact, the other along the line of collision.

In a center of momentum frame at any time the velocities of the two bodies are in opposite directions, with magnitudes inversely proportional to the masses. In an elastic collision these magnitudes do not change. The directions may change depending on the shapes of the bodies and the point of impact. Assuming that the second particle is at rest before the collision, the angles of deflection of the two particles, ϑ_1 and ϑ_2, are related to the angle of deflection θ in the system of the center of mass by

$$\tan \nu_1 = \frac{m_2 \sin\theta}{m_1 + m_2 \cos\theta}$$

$$\nu_2 = \frac{\pi - \theta}{2}$$

The velocities of the particles after the collision are:

$$\nu_1{}' = \nu_1 \frac{\sqrt{m_1{}^2 + m_2{}^2 + 2m_1 m_2 \cos\theta}}{m_1 + m_2}$$

$$\nu_2{}' = \nu_1 \frac{2m_1}{m_1 + m_2} \sin\frac{\theta}{2}$$

where v_1 and v_2 are the scalar sizes of the two original speeds of the objects, m_1 and m_2 are their masses, θ *is the* movement angle.

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REFERENCES

[1]. L. G. Christophorou, J. K. Olthoff, R. J. Van Brunt, "SF6 and theElectric Power Industry", IEEE Electrical Insulation Magazine,DEIS, 1997, pp. 20

[2]. A.H. Cookson, P.C. Bolin, H.C. Doepken, R.E. Wootton, C.M. Cooke and J.G. Trump, "Recent Research in the United States on the Effect of Particle Contamination Reducing the Breakdown Voltage in Compressed Gas Insulated System", Int. Conf. On Large High Voltage System; Paris, 1976.

[3]. H.Anis and K.D. Srivastava, "Breakdown Characteristics of Dielectric Coated Electrodes in Sulphur Hexafluoride Gas with Particle contamination", Sixth Intern. Sympos High Voltage Engineering, Paper No. 32.06, New Orleans, LA, USA. 1989.

[4]. J. Amarnath, B. P. Singh, C. Radhakrishna and S. Kamakshiah, "Determination of particle trajectory in a Gas Insulated Busduct predicted by Monte-Carlo technique", IEEE Conf. Electr. Insul.Dielectr. Phenomena (CEIDP), Texas, Austin, USA, 1991 Vol. 1, pp. 399-402,1991.

[5]. N. Felic. Forces et charges de petits objects en contact avec une electrode affectee d'un champ electrique. Revue generale de I' electricite, 1996, 1145–1160.

[6]. Ranuva Nageswara Rao,Dr S S tulasi Ram , "Effect of simultaneous movement of multiple particles under electric field in a Single Phase Gas Insulated Bus duct" Int. Journal of Engineering Research and Applications ISSN : 2248-9622, Vol. 4, Issue 10(Part - 3), October 2014,

[7]. Ranuva Nageswara Rao,Dr S S tulasi Ram ," Effect of movement of multiple particles and collisions in a 3- Phase Gas Insulated Bus duct " "International conference on High Voltage Engineering & Technology" (ICHVET2015), during January 29-30, 2015 at Hyderabad,

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