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PARTICLE TRAJECTORIES IN A THREE PHASE COMMON ENCLOSURE GAS INSULATED BUSDUCT WITH MONTE CARLO TECHNIQUE

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ABSTRACT

The excellent insulation properties of compressed Sulphur Hexaflouride are adversely affected by metallic particle contamination in practical gas insulated systems. The movement of such particles is random and the particles play a crucial role in determining the insulation behavior of GIS. A Three-phase enclosure-type gas insulated bus (GIB) has widely been applied to minimize the installation space of a substation. To determine the particle trajectories in a three-phase common enclosure Gas Insulated Bus duct (GIB) an outer enclosure of diameter 500 mm and inner conductors of diameters 64 mm spaced equilaterally are considered. Aluminum, copper and silver particles were considered to be present on enclosure surface. In order to determine the random behavior of moving particles, the calculation of movement in axial and radial directions was carried at every time step using rectangular random numbers. Simulation of Particle Movement with Reduced Phase Conductor is also carried out with a view to obtain optimum size of conductor for reliable operation by reducing the original diameter of the conductor from 64mm to 54mm in steps of 5 mm. At each reduced diameter the particle movement is calculated at each instant in both radial and axial directions using Monte Carlo Technique. Monte Carlo simulation is also carried out by changing the random solid angle from 1 degree to 0.5 degrees. The random solid angle is decreased to 0.5 degrees to take into account more smooth end profile of the particle. It is observed that a lower solid angle random movement yields a lower axial movement. It therefore suggests that a more smooth ended wire will have lesser axial movement than a sharp cut wire like particle.

Keywords: metallic particles, electric field, gas insulated substations, particle contamination.

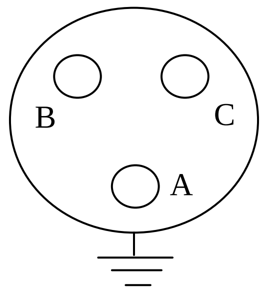
INTRODUCTION

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 SF_6 gas.

The presence of contamination can therefore be a problem with gas-insulated substations operating at high fields. If the effects of these particles could be eliminated, then this would improve the reliability of compressed gas insulated substation. It would also offer the possibility of operating at higher fields to affect a potential reduction in the GIS size with subsequent savings in the cost of manufacture and installation.

MODELING TECHNIQUE OF GIB

Figure-1 shows a typical horizontal three phase busduct. The enclosure is filled with SF_6 gas at high pressure. A particle is assumed to be rest on the enclosure surface, just beneath the bus bar A, until a voltage sufficient enough to lift the particle and move in the field is applied. After acquiring an appropriate charge in the field, the particle lifts and begins to move in the direction of field having overcome the forces due to its own weight and drag due to the viscosity of the gas.



A, B, C are the conductors
Figure-1. A typical 3-phase common enclosure GIB.

The simulation considers several parameters e.g. the macroscopic field at the surface of the particle, its weight, Reynold's number, coefficient of restitution on its impact to both enclosures and viscosity of the gas. During return flight, a new charge on the particle is assigned based on the instantaneous electric field.

THEORETICAL STUDY

Many authors [1-4] have suggested solutions for the motion of a sphere or a wire like metallic particle in an isolated busduct system. The theory of the particle charge and the electrostatic force on the particle is discussed elsewhere [5-6]. The motion equation is given by

$$m\frac{d^2y}{dt^2} = F_e - mg - F_d \qquad (1)$$

Where, y is the direction of motion and F_d is the drag force. The direction of the drag force is always opposed to the direction of motion. For laminar flow the drag force component around the hemispherical ends of the particle is due to shock and skin friction.

Very limited publication is available for the movement of particle in a three-phase busduct; however the equation of motion is considered to be same as that of an isolated phase busduct.

SIMULATION OF ELECTRIC FIELD IN 3-PHASE BUSDUCT

The charge acquired by the vertical and horizontal wire particles in contact with a bare enclosure can be expressed as given by Srivastava and Anis [3].

The electric field in 3-phase common enclosure GIB electrode system at the position of the particle can be written as

$$E(t) = E_1(t) + E_2(t) + E_3(t) \qquad (2)$$

Where, E (t) is the resultant field in vertical direction due to the field of three conductors on the surface of the particle at the enclosure.

$E_1(t)$, $E_2(t)$ and $E_3(t)$ are the components of the electrical field in vertical direction. The gravitational force and drag forces are considered as described by several authors.

MONTE-CARLO TECHNIQUE

The above simulation yields the particle movement in the radial direction only. However, the configuration at the tip of the particle is generally not sufficiently smooth enough to enable the movement unidirectional. This decides the movement of particle in axial direction. The randomness of 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 thanϕ, 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. The results have been presented and analyzed.

RESULTS AND DISCUSSIONS

Tables 1 and 2 show the peak movement in radial and axial movement for Al, Cu and Ag particles for applied voltages of 300 KV, 400 KV, 500 KV, 600 KV and 700 KV, respectively. The tip of the particle is not smooth enough to move the particle in one direction. Due to cross sectional irregularities of the particle it moves, randomly.

The random movement of the particle is adequately simulated by using Monte Carlo technique with different solid angles. The results have been simulated using Monte Carlo technique presented in Tables 1 and 2 with various inner conductor diameters. The radial movement of the aluminium particle is higher than that of copper and silver. This behavior is expected due to heavy weight of copper and silver particles than those of aluminium of the same size. It is also observed that for a given particle and given voltage condition, the radial movement is the same whether or not the particle is influenced by random behavior. However, the axial movement depends on the mass, size of the particle and the solid angle considered for every time step. The maximum movement for aluminium particle for an applied voltage of 300 kV rms in axial direction for a simulation time of 1.5 seconds and Monte Carlo Solid angle of 1 Degree is 535.61 mm, the same value for copper particle is 115.62 mm and for silver particle it is No movement (N.M). From this it can be inferred that the axial movement is strongly dependent on the random behavior of the particle and a given solid angle. When the solid angle is decreased the movement is also decreases. This is very much justified since the bus duct length is few meters. Therefore lesser the solid angle actual movement is less. This was shown in Table-2 for 0.5 deg. Solid angle gives correct result. It is also observed that inner conductor diameter reduces the cost of GIS also reduced since the decrease in Gas volume.

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Table-1. Radial and axial movement for Al, Cu, Ag particles of various voltages using Monte-Carlo technique for 1 degree solid angle.

Voltage (kV)	Type	Monte Carlo Technique (1 Deg)					
		64 mm		59 mm		54 mm	
		Axial	**Radial**	**Axial**	**Radial**	**Axial**	**Radial**
300	Al	535.61	34.54	426.41	33.56	563.14	33.11
	Cu	115.62	6.95	129.96	6.69	88.44	6.58
	Ag	N.M.	N.M.	N.M.	N.M.	N.M.	N.M.
400	Al	615.46	64.04	738.09	63.09	663.91	62.15
	Cu	311.05	17.68	155.66	15.07	328.12	14.93
	Ag	261.76	12.58	244.18	12.37	226.25	13.79
450	Al	626.92	81.84	627.18	81.00	755.64	80.95
	Cu	511.00	26.63	419.71	26.27	390.56	24.48
	Ag	325.11	20.79	384.24	20.27	360.26	20.00
500	Al	784.77	100.07	809.37	99.13	794.34	98.69
	Cu	488.65	28.68	461.81	28.89	555.17	28.79
	Ag	406.27	25.39	492.24	24.57	400.70	23.06
600	Al	2319.62	140.41	1825.34	139.72	1260.25	139.77
	Cu	691.71	45.56	651.71	44.63	629.95	44.20
	Ag	641.28	39.88	609.47	37.22	542.43	37.28
700	Al	4440.91	325.67	6225.36	324.94	7359.95	324.88
	Cu	856.81	65.16	737.85	64.73	892.97	64.30
	Ag	751.44	54.26	677.60	53.83	769.92	53.39

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Table-2. Radial and axial movement for a Al, Cu, Ag particles of various voltages using Monte-Carlo technique for 0.5 degree solid angle.

Voltage (kV)	Type	Monte Carlo Technique (0.5 Deg)					
		64 mm		59 mm		54 mm	
		Axial	Radial	Axial	Radial	Axial	Radial
300	Al	267.80	34.54	231.20	33.56	281.57	33.11
	Cu	57.81	6.95	64.98	6.69	44.22	6.58
	Ag	N.M	N.M	N.M	N.M	N.M	N.M
400	Al	307.73	64.04	369.04	63.09	331.95	62.15
	Cu	155.52	17.68	77.83	15.07	164.06	14.93
	Ag	130.88	12.58	122.09	12.37	113.12	13.79
450	Al	313.46	81.84	313.59	81.00	377.82	80.95
	Cu	255.50	26.63	209.85	26.27	195.28	24.48
	Ag	162.55	20.79	192.12	20.27	180.13	20.00
500	Al	392.38	100.07	404.68	99.13	397.17	98.69
	Cu	244.32	28.68	230.90	28.89	277.58	28.79
	Ag	203.13	25.39	246.12	24.57	200.35	23.06
600	Al	1159.81	140.41	912.67	139.72	630.12	139.77
	Cu	345.85	45.56	325.85	44.63	314.97	44.20
	Ag	320.64	39.88	304.74	37.22	271.21	37.28
700	Al	2220.45	325.67	3112.68	324.91	3679.97	324.88
	Cu	428.40	65.16	368.92	64.73	446.48	64.30

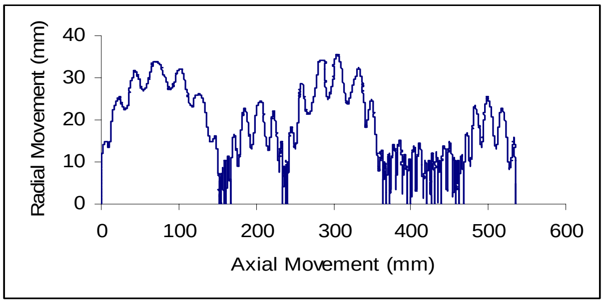

Figure-2. Axial and radial movement in a 3-phase 500/64mm GIB for 300kV / AL/ 10mm / 0.1 mm radius (1 deg).

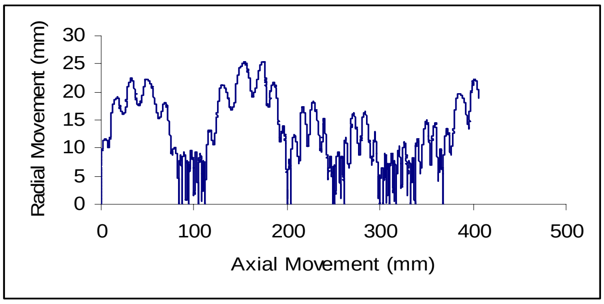

Figure-4. Axial and radial movement in a 3-phase 500/64mmGIB for 500kV /AG/10mm/0.1mm radius (1 deg).

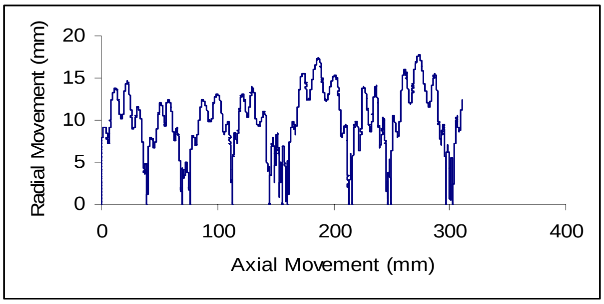

Figure-3. Axial and radial movement in a 3-phase 500/64mm GIB for 400kV / CU/ 10mm / 0.1 mm radius (1 deg).

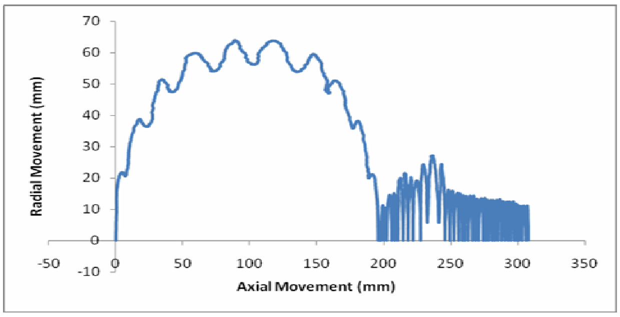

Figure-5. Axial and radial movement in a 3-phase 500/64mm GIB for 400kV /AL/10mm/0.1 mm radius (0.5 deg).

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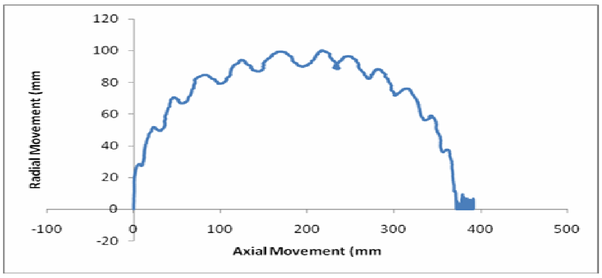

Figure-6. Axial and radial movement in a 3-phase 500/64 mm GIB for 500kV / AL/ 10mm / 0.1 mm radius (0.5 deg).

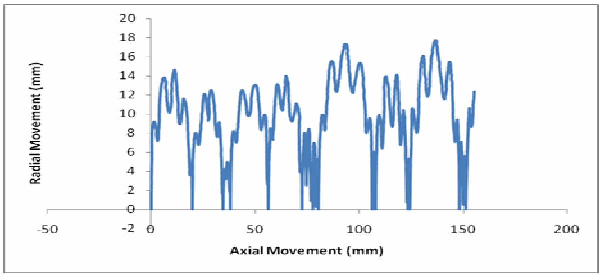

Figure-7. Axial and radial movement in a 3-phase 500/64 mmGIB for 400kV / CU/ 10mm / 0.1 mm radius (0.5 deg).

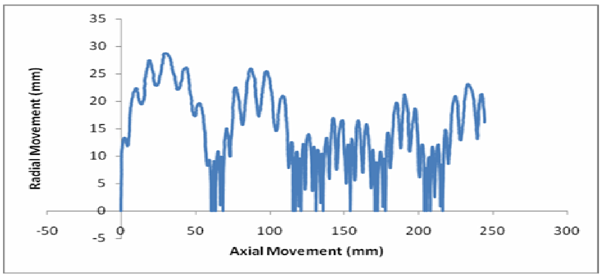

Figure-8. Axial and radial movement in a 3-phase 500/64mm GIB for 500kV / CU/ 10mm / 0.1 mm radius (0.5 deg).

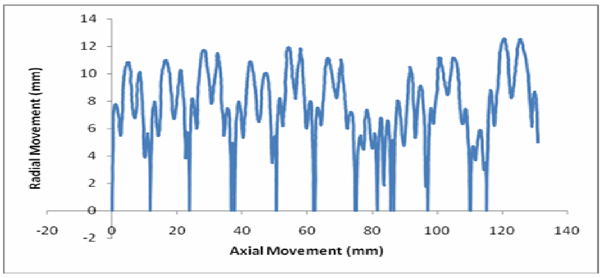

Figure-9. Axial and radial movement in a 3-phase 500/64mm GIB for 400kV / AG/ 10mm / 0.1 mm radius (0.5 deg).

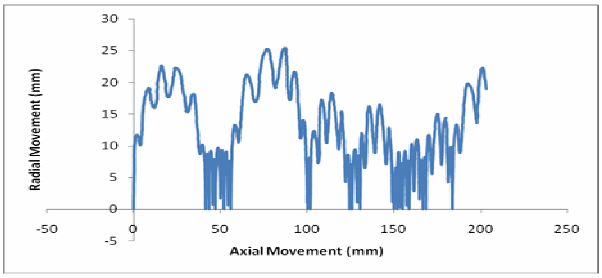

Figure-10. Axial and radial movement in a 3-phase 500 / 64 mm GIB for 500kV /AG/10mm/0.1 mm radius (0.5 deg).

CONCLUSIONS

The model has been developed for a 3-phase common enclosure GIB. The above simulation yields the particle movement in the radial direction only. However, the configuration at the tip of the particle is generally not sufficiently smooth enough to enable the movement unidirectional. This decides the movement of particle in axial direction.

The randomness of 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 thanϕ, 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. The results have been presented and analyzed.

The results show that when the solid angle is increased the axial movement is also increased and solid angle decreases the axial movement is decreased. It shows that for lower solid angle gives correct results since the bus duct length is a few meters, this is justified.

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