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Effect of Various Operating Parameters on Movement of Particle Contamination in Gas Insulated Substations

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Abstract— Metal encapsulated with compressed SF_6 gas insulation has reduced the size of power substations and improved their reliability over conventional air insulated substations.Compressed Gas Insulated Substations (GIS) consist basically of a conductor supported on insulators inside an enclosure which is filled with sulfur hexafluoride gas (SF_6). The voltages withstand capability of SF_6 busduct is strongly dependent on field perturbations such as those caused by conductor surface imperfections and by conducting particle contaminants. The contaminants can be produced by abrasion between components during assembly or operations. The particles can be lifted by the electric field and migrate to the conductor or insulators where they initiate breakdown at voltages significantly below the insulation characteristics of the SF6 gas. In the present work, simulation has been carried out for particle movement by using the equation of particle motion in an electric field. The effect of various parameters like radii and length of particles, coefficient of restitution, pressure in the busduct, applied voltage and inner conductor radii has been examined and presented. Different metallic contamination viz Cu, Al and Ag have been considered for the above study.

Index Terms— Bus Duct, Contamination, Drag Force, Electrostaic Force, Gravitational Force, GIS, Particle Movement, SF_6 Gas.

1 Introduction

SF_6 Gas Insulated Substations (GIS) are preferred for voltage ratings of 72.5KV to 420KV and above, particularly at locations where there are limitations of space. In such a substation, the various equipments like circuit breakers, bus bars, isolators, load break switches, current transformers, voltage transformers, earthing switches etc. are housed in the metal enclosed modules filled with SF_6 gas. The SF_6 gas provides the phase to ground insulation. As the dielectric strength of SF_6 gas is higher than air, the clearances required are smaller. Hence the overall size of each equipment and the complete substation can be reduced to as low as 10%of conventional air insulated substation.

The various modules of GIS are factory assembled and operate with SF_6 gas at pressures between 0.3 and 0.6Mpa. Such substations are compact and can be installed conveniently on any floor of a multi-storied building or in an underground substation.

As the units are factory assembled, the installation time is substantially reduced. Such installations are preferred in cosmopolitan cities, industrial townships, etc. where cost of land is very high and higher cost of SF_6 insulated switchgear is justified by saving due to reduction in floor area requirement. They are also preferred in heavily polluted areas where dust, chemical fumes and salt layers can cause frequent flashovers in conventional out door air insulated substations.

Compactness, reduced civil engineering requirements of foundations, reliable performance, total immunity against atmospheric pollution and weather conditions, modest maintenance, reduced installation time, wide choice of location etc. are the plus points of SF_6 GIS.

The usefulness of SF_6 gas is mainly due to its,

1. High dielectric strength
2. Unique arc quenching ability
3. Good thermal stability and conductivity.

In addition to excellent electrical and thermal properties; at normal temperatures, SF_6 gas is also chemically inert, non-flammable, non corrosive and non toxic.

A)The necessity of this study :

Extremely high dielectric properties of SF_6 have long been recognized. Compressed SF_6 has been used as an insulating medium as well as arc quenching medium in electrical apparatus in a wide range of voltages. Due to high reliability of the equipment, Gas Insulated Substations (GIS) can be used for longer times without any periodical inspections. Conducting contamination (i.e. aluminium, copper and silver particles) could, however, seriously reduce the dielectric strength of gas-insulated system.

B)The origin of these particles :

Metallic particles in GIS have their origin mainly from the manufacturing process or they may originate from moving parts of the system, such as breakers and disconnectors. They may also originate from mechanical vibrations during shipment and service or thermal contraction / expansion at joints.

Metallic particles can be either free to move in the GIS or they may be stuck either to an energized electrode or to an insulator surface (spacer, bushing etc.). If a metallic particle crosses the gap and comes into contact with the inner electrode or if a metallic particle adheres to the inner conductor, the particle will act as protrusion on the surface of the electrode, and the voltage required for breakdown of the GIS will be dramatically decreased. A metallic particle stuck on an insulator surface in a GIS will also cause a significant reduction of the breakdown voltage.

The understanding of the dynamics of a metallic particle in a coaxial electrode system is of vital importance for improving the voltage withstand capacity of a Gas Insulated System. If the motion pattern of a metallic particle is generally known, the probability of a particle crossing a coaxial gap, causing a flashover, can be estimated.

Depending on the shape of the particles, as well as the geometry and voltage levels of the system, the particles get more or less influenced by the electric field which, in turn, makes them hazardous to the electrical system, in terms of partial discharges and breakdown.

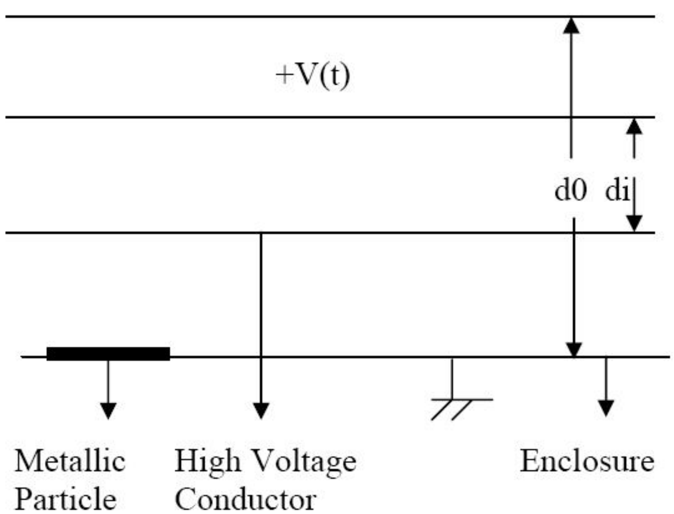

Fig. 1 Schematic diagram of a typical gas insulated busduct

In the present simulation work for the motion of metallic particles (Al, Cu and Ag wires) busduct of 102mm / 292mm inner and outer diameter is considered.In the present work the particle is on the surface of the enclosure and the enclosure is earthed. The schematic diagram of a typical compressed Gas insulated busduct is shown in Fig. (1).

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2. Metallic Particles In Contact With Bare Electrodes

When the electrical field surrounding the particle is increased, an uncharged metallic particle resting on a bare electrode will gradually acquire a net charge. The charge on the particle is a function of the local electrical field and shape, orientation and size of the particle. When the electrostatic force exceeds the gravitational force the particle will lift [1-5].

2.1 Lift-off field for a particle can be estimated as

In order to lift a particle from its position of rest the electrostatic force on the particle should balance its weight[6-8].

Hence,

$$F_e = mg \qquad (1)$$

Where F_e = electrostatical force

g = gravitational force

Charge acquired on a horizontal wire particle :

$$Q_{hw} = 2\pi \in_0 r\, l\, E \qquad (2)$$

Where l is the wire particle length

2.2 Lift-off field is given by

$$0.715\left((2\pi \in_0 rl\, E_{L0})E_{L0}\right) = \pi r^2 \rho l g \qquad (3)$$

which gives

$$E_{L0} = 0.84\sqrt{\frac{\rho g r}{\in_0}} \qquad (4)$$

Once the particle has lifted from a horizontal to a vertical position the charge will increase significantly. The sudden increase of charge will most likely lift the particle from the electrode.

For vertical wire particles the charge-to-mass ratio increases with increasing length. i.e. a longer particle moves higher from electrode than shorter one. For ac voltages critical length of the wire particle is of the order of few millimeters.

3 Simulation Of The Wire Particle Motion

The primary goal of this work is to compare the results of several authors [5-7] with simulated results to create a satisfactory model of the particle motion in the GIS bus which will enable future simulations of the motion of particles with arbitrary shapes.

3.1 Theory of Particle motion

A conducting particle in motion in an external electrical field will be subjected to a collective influence of several forces. The

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forces may be divided into :

- Electrostatic force (Fe)
- Gravitational force (mg)
- Drag force (Fd)
- Forces due to space charges formed near the particle and forces due to local ionization near the particle surface (coronal windage effect).

3.2 Electrostatic Force

The charge acquired by a vertical wire particle in contact with nacked enclosure can be expressed as :

$$Qnet = \frac{\pi \in_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - 1} \quad (5)$$

Where l is the particle length, r is the particle radius, $E(t_0)$ is the ambient electrical field at $t = t_0$.

Disregarding the effect of charges on the particle, the electric field in a coaxial electrode system at position of the particle can be written as :

$$E(t) = \frac{V \operatorname{Sin}\omega t}{[r_0 - y(t)]\ln\left[\frac{r_0}{r_i}\right]} \quad (6)$$

Where is the supply voltage on the inner electrode

ro is the enclosure radius,

ri is the inner conductor radius

y(t) is the position of the particle which is the vertical distance form the surface of the enclosure towards the inner electrode.

The electrostatic force relating charge and electric field E(t) is given by :

$$F_e = K\, Q_{net}\, E(t) \quad (7)$$

Where

K is a correction factor smaller than unity.

3.3 Gravitational Force

The gravitational force is given by

$$mg = \pi r^2 l \rho g \quad (8)$$

3.4 Drag force

Drag is a result of energy dissipation in the shock wave near the particle and skin friction along the surface of the particle. In spherical particles shock wave energy dissipation and in wire particles skin friction is more significant.

The direction of the drag force is always opposed to the direction of motion of particle.

By considering all the forces the equation of motion can be written as

$$m\frac{d^2y}{dt^2} = F_e - mg - F_d \quad (9)$$

Where

Fd is drag force.

The above equation is solved by Runge-Kutta method to obtain radial movement with time, for various values of parameters.

4. Results and Discussions

The Maximum movement for aluminium, copper and silver with variation of radius of the particle is shown in Fig. 2. As the radius increases maximum movement for any type of particle decreases. This nature is expected since the charge acquired is proportional to the logarithmic value of radius, where as mass is proportional to the square of the radius. Hence, the moving force is a function of radius and the retarding force is proportional to the square of the radius. The effect of variation is more predominant for aluminium particles compared to silver and copper. Fig. 3 shows the movement pattern with increase in the length of the particle. An entirely opposite pattern of movement is seen for the increasing length of particle. This is also expected , since the charge which influences movement of particle, is proportional to the square of the particle length where as the retarding force is proportional to the length.

Fig. 4 shows the movement pattern with the increase in the voltage. The movement for all particles increases with increase in voltage, since the field acquired by the particle and hence the force is increased. Fig. 5 shows the movement with increase in the radius of the busbar conductor. The movement of all particles increases with increased radii, since the field acquired by the particle is increased with the increase in radius.

Fig. 6 and Fig. 7 show the movement with increase in pressure and co-efficient of restitution. As the pressure increases there is marginal decrease in maximum movement with regard to silver and copper, There is a substantial reduction in case of aluminium. This reduction may be justified because the maximum movement is a function of product of velocity and density of gas. The maximum movement in the interelectrode gap is seen to increase with the increase in co-efficient of restitution. It is expected since higher rebound velocities are retained with higher co-efficient of restitution.

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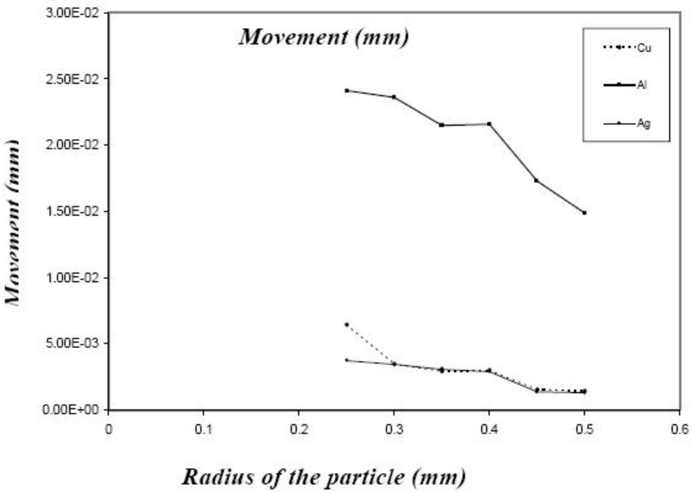

Fig 2. Movement of particle with variation of particle radius

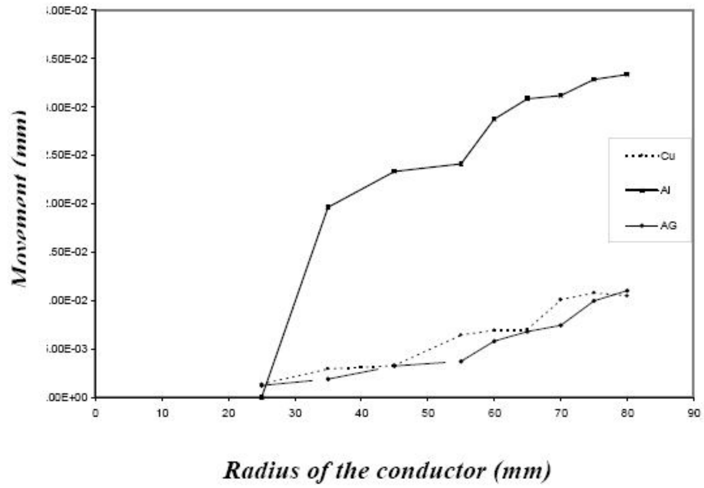

Fig 5. Movement of particle with variation of conductor radius

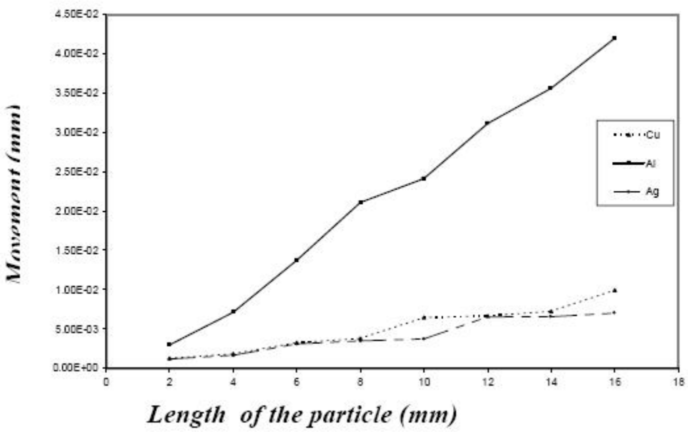

Fig 3. Movement of particle with variation of particle length

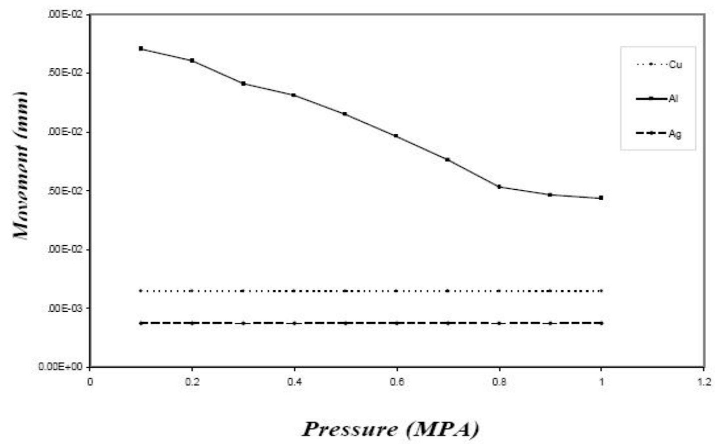

Fig 6. Movement of particle with variation of pressure

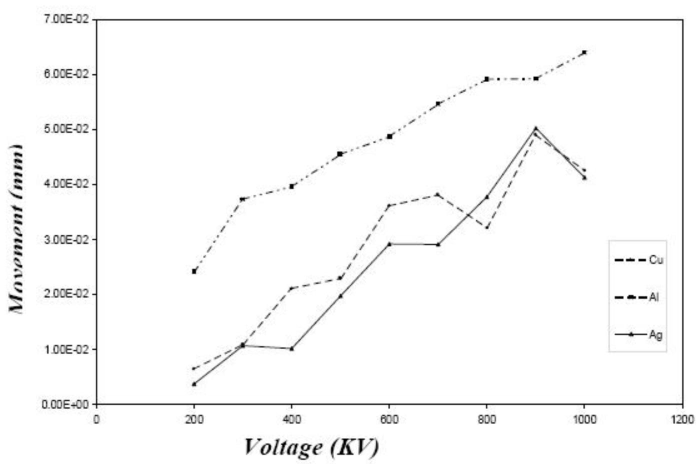

Fig 4. Movement of particle with increase in voltage

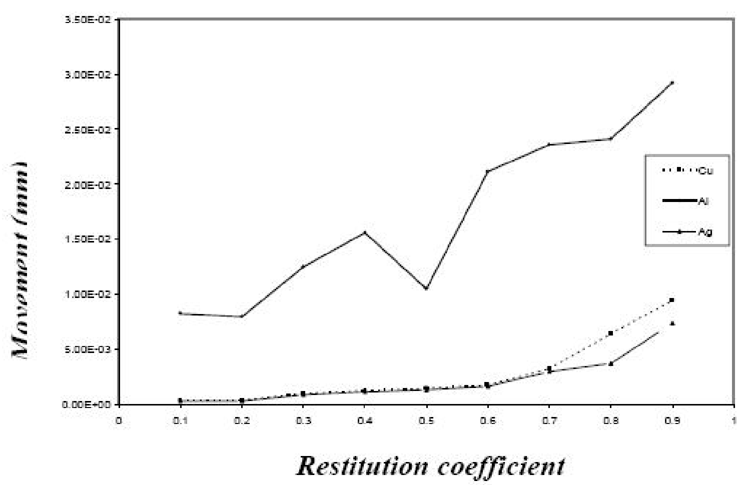

Fig 7. Movement of particle with variation of restitution coefficient

5. ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Anis and K.D. Srivastava; "Movement of charged conducting particles under Impulse Voltages in Compressed Gases" ; *IEEE Int. Conf. On industrial Applications ;* 1980

[2] J. Amarnath, B.P. Singh, S. Kamakshaiah and C. Radhakrishna : "Determination of Particle Trajectory in Gas Insulated Busduct by Monte-carlo technique" : CEIDP-99 (IEEE) during Oct. 17-21, 1999, Austin, Texas, U.S.A

[3] J. Amarnath, B.P. Singh, S. Kamakshaiah and C. Radhakrishna : "Monte-Carlo Simulation of Particle movement in a coated gas insulated substation for power frequency and switching transients" : International High Voltage Workshop (IEEE) during April 10-12, 2000, California, USA

[4] J. Amarnath, B.P. Singh, S. Kamakshaiah, C. Radhakrishna and K. Raghunath; "movement of metallic particles in gas insulated substations under the influence of various types of voltages" : National Power System Conference (NPSC-2000) IISc, Bangalore 20th - 22nd Dec., 2000.

[5] M.M. Morcos, K.D. Srivastava and H. Anis : "Dynamies of Metallic Contaminants in Compressed Gas Insulated Power Apparatus"; *Fourth Int. Symposium on High Voltage Engineering :* Athens, 1983.

[6] H. Anis and K.D. Srivastava : "Breakdown Characteristics of Dielectric coated electrodes in Sulphur Hexafluoride Gas with Particle Contamination" ; Sixth International Symposium on High Voltage Engineering , No. 32. 06, New Orleans, LA, USA, 1989

[7] H.Anis and K.D. Srivastava : "Free Conducting particles in Compressed Gas Insulation" : *IEEE Trans on Electrical Insulation,* Vol EI-16, pp. 327-338, August, 1981

[8] H. Parekh, K.D. Srivastava and R.G. Van Heeswijk; "Lifting Field of Free Conducting Particles in Compressed SF6 with Dielectric Coated Electrodes"; *IEEE Transactions on Power Apparatus and Systems,* Vol. PAS-98, No. 3, May / June 1979.

[9] A.H. Cookson and R.E.Wotton; "Movement of Filamentary Conducting Particles Under AC Voltages in High Pressure Gases" : *International Symposium Hochspannungstechnik;* Zurich, 1975