Nagbhushan, J. Amarnath, D. Subbarayudu / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue 5, September- October 2012, pp.1756-17160

Analysis of Electric Field Intensity in Gas Insulated Busduct

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ABSTRACT

Gas insulated substations (GIS) have received great interest in the recent years. One of the advantages of GIS over conventional substations is their compactness which makes them a favourite for service in urban residential areas. These consists conductors supported on insulator inside on enclosure filled with sulphur hexafluoride (SF_6) gas. The voltage withstands capability of SF_6 bus duct is strongly dependent on field perturbations such as those caused by conductor surface imperfections and by conducting particle contaminants. These acquire charge due to the electric field intensity. Nearly 50% of GIS failures are due to metallic conducting particles lifted by electric field and migrate to conductor or insulator initiating breakdown at voltages significantly below the insulation characteristics. This paper analyses the electric field intensity for different dimensional conductor and enclosures at various applied voltages in a three phase Gas Insulated Bus duct. Electric field intensity decreases with increase in diameter of enclosure.

Keywords - Bus duct, Image charge, Field intensity.

1. INTRODUCTION

The Electric power industry worldwide has some 35 years of manufacturing and field experience with Gas Insulated Substations (GIS). The advantages of GIS over conventional substations are their compactness, reliable and maintenance free operations. Basic components of 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 up of alumina filled epoxy material [1]. The GIS enclosure forms an electrically integrated, ground enclosure for the entire substation. The enclosure is filled with sulphur hexafluoride (SF_6) gas. It has excellent dielectric and heat transfer properties. Sulphur Hexafluoride (SF_6) gas is the electric power industry's preferred gas or electric insulation and especially for arc quenching current interruption equipment used in transmission and distribution of electrical energy. The usefulness of SF_6 gas is mainly due to its high dielectric strength, good thermal stability, economically inert, non-flammable, non-corrosive and non-toxic. Even though SF_6 exhibits very high dielectric strength, the withstand voltage of SF_6 within GIS is drastically reduced due to the presence of metallic particles on the inner surface of the enclosure. The origin of these particles may be from the manufacturing process, from mechanical vibrations or from moving parts of the system like breakers or disconnectors etc. Aluminium, copper and silver are the types of metal particles. GIS also suffer from certain drawbacks. One of them is outage due to conducting particles which accounts or nearly 50% of GIS failures. 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. These particles move randomly in a horizontally mounted Gas Insulated Bus duct (GIB) system due to the electric field, and this movement plays a crucial role in determining the behaviour of GIS [2]. Under 50 Hz AC voltages, the particle motion is complex, and under appropriate conditions, the particle may cross the gaseous gap from the low field region near the outer enclosure to the high field region near the central electrode. In order to know behaviour of particles analysis of the electric field intensity was made for different dimensional conductors, enclosures at various applied voltages.

2. GIB MODELLING TECHNIQUE

The Fig.1 shows the cross sectional view of typical horizontal three phase bus duct. The enclosure is filled with SF_6 gas at high pressure. A particle is assumed to be at rest on the enclosure inner surface, just beneath the bus bar until a voltage sufficient enough to lift the particle and move it in the direction of 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 [3]. The particle motion largely depends on applied voltage. Under AC voltages, for a wire particle of given radius, the activity increases with particle length since the particle charge-to-mass ratio at lifting increases with length.

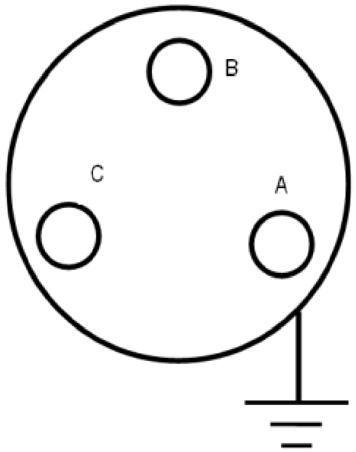

Fig.1 Three Phase Bus Duct

A conducting particle motion is an electric field will be subjected to a collective influence of several forces. These forces may be divided into electrostatic force (F_e), gravitational force (mg) and drag force (F_d).

The motion equation is given by

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

Where m = mass of particle, y = displacement in vertical direction, g = gravitational constant.

Here,

(i) $F_e = K.q.E(t)$ (2)

K = Correction factor <1, and charge q is,

$$q = \frac{\pi\varepsilon_0 l^2 E(t_0)}{\ln\left(\frac{2l}{r}\right) - l} \qquad (3)$$

$E(t_0)$ is ambient electric field at t=t_0

Electric field $E(t) = \dfrac{V_m \sin\omega t}{R_0 - y(t)\ln\left(\frac{R_0}{R_i}\right)}$ (4)

Where R_0 are Enclosure radices and R_i is conductor radius. y(t) = position of particle which is vertical distance from the surface of enclosure towards inner electrode.

$$mg = \pi r^2 l\rho g \qquad (5)$$

where, $\rho = 1.68x10^{-8}$ for C_u.

(iii) F_d = Drag force=

$$\dot{y}.\pi.r[6\mu K_d(\dot{y}) + 2.6560[\mu\rho_g.l.\dot{y}]^{0.5} \qquad (6)$$

Where $\dot{y}$ is velocity, μ is viscosity, r is particle radius. ρ_g is gas density, l is length of particle, $K_d(\dot{y})$ is drag coefficient.

2.1 Electric Field Intensity in 3-phase GIB (including image charges):

Fig.2 shows three phase GIB with image charge conductors.

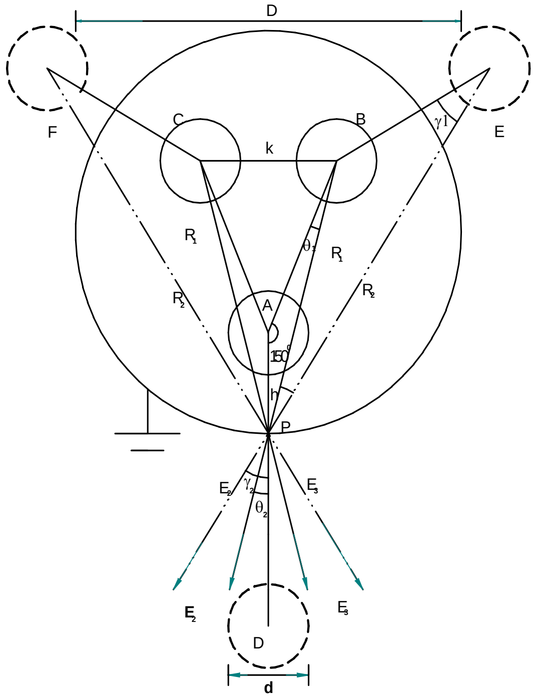

Fig.2 Three phase GIB with image charge conductors

Let the particle moves to a distance x from the inner surface of the enclosure at point P, then from Fig. 2.

From triangle PAB

$$R_1^2 = (h-x)^2 + K^2 - 2(h-x)K.\cos(150^0) \qquad (7)$$

The electric field intensities for different conductors A, B, C taking into account their image charge effect, are E_1, E_2 and E_3 respectively [4,5].

$$E_1 = \frac{V_1\left[\frac{1}{h-x} + \frac{1}{h+x}\right]}{2\ln\left(\frac{2h}{r}\right)} \text{ V/mm} \qquad (8)$$

$$E_2 = \frac{V_2\left[\frac{\cos\theta_2}{R_1} - \frac{Cos\gamma_2}{R_2}\right]}{2\ln\left(\frac{2h}{r}\right)} \text{ V/mm and} \qquad (9)$$

$$E_3 = \frac{V_3\left[\frac{\cos\theta_2}{R_1} - \frac{Cos\gamma_2}{R_2}\right]}{2\ln\left(\frac{2h}{r}\right)} \text{ V/mm.} \qquad (10)$$

The total electric field intensity E at point P is

$$E = E_1 + E_2 + E_3 \qquad (11)$$

$$E = \frac{1}{2\ln\left(\frac{2h}{r}\right)}\left[V_1\left(\frac{1}{h-x}+\frac{1}{h+x}\right)+\left(\frac{\cos\theta_2}{R_1}-\frac{\cos\gamma_2}{R_2}\right)(V_2+V_3)\right] \qquad (12)$$

volts per mm, where,

$V_1 = Vm\sin\omega t$, $V_2 = Vm\,\mathrm{Sin}\,(\omega t+120^\circ)$, and

$V_3 = Vm\sin\,(\omega t+240^\circ)$.

3. RESULTS AND DISCUSSION.

Simulation has been carried out for electric field intensity at different level of voltages and for different dimension of enclosure and conductor. The distance between the conductor is taken as K=215mm. Table 1 shows the variation of field intensity for different values of dimeter of enclosure and diameter of conductor at various values of maximum voltages and fixed values of x=1mm.as shown in figure 2. A conducting particle moving in an external electric field will be subjected to a collective influence of electrostatic force, Gravitational force and Drag force

4. CONCLUSION

An attempt has been made to simulate the electric field intensity in a 3-phase isolated GIB on bare electrodes system considering the effect of field due to image charge.. It is seen that the field intensity is a function of dimensions of enclosure and conductor. The electric field intensity is in linear relation with diameter of conductor and it decreases with an increase in the diameter of enclosure resulting in reduction of rate of motion of particle.

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Table 1 shows, the variation of Field intensity for different values of diameter of enclosure (D) and diameter of conductor (d) for Vm 300KV, 400 KV, 600 KV, 800 KV and 1000KV .

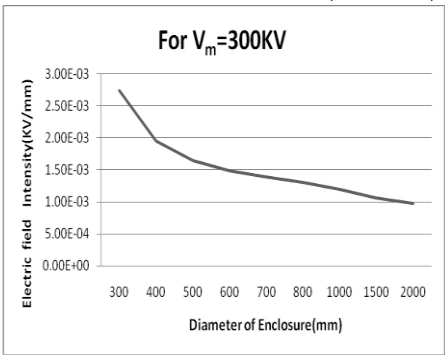
V_m=300KV			
K=215mm,x=1mm h=1mm,d=100mm		K=215mm,x=1mm h=125mm	
D (mm)	E(KV/mm)	d (mm)	E(KV/mm)
300	2.74E-03	10	1.07E-03
400	1.95E-03	20	1.30E-03
500	1.65E-03	30	1.49E-03
600	1.49E-03	40	1.66E-03
700	1.39E-03	50	1.82E-03
800	1.31E-03	60	1.98E-03
1000	1.20E-03	70	2.13E-03
1500	1.06E-03	80	2.29E-03
2000	9.78E-04	90	2.45E-03

V_m=400KV			
K=215mm,x=1mm h=1mm,d=100mm		K=215mm,x=1mm h=125mm	
D (mm)	E(KV/mm)	d (mm)	E(KV/m m)
300	3.66E-03	10	1.43E-03
400	2.60E-03	20	1.99E-03
500	2.21E-03	30	1.99E-03
600	1.99E-03	40	2.21E-03
700	1.85E-03	50	2.43E-03
800	1.75E-03	60	2.64E-03
1000	1.75E-03	70	2.84E-03
1500	1.41E-03	80	3.05E-03
2000	1.41E-03	90	3.26E-03

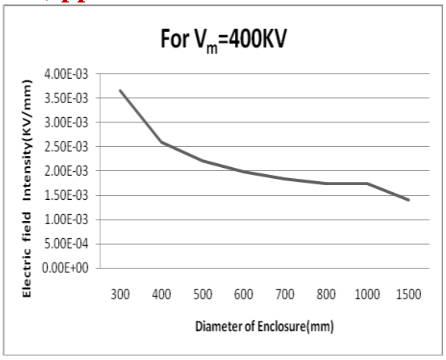
V_m=600KV			
K=215mm,x=1mm h=1mm,d=100mm		K=215mm,x=1mm h=125mm	
D(mm)	E(KV/mm)	d(mm)	E(KV/mm)
300	5.48E-03	10	2.14E-03
400	3.89E-03	20	2.61E-03
500	3.31E-03	30	2.98E-03
600	2.98E-03	40	3.32E-03
700	2.77E-03	50	3.64E-03
800	2.62E-03	60	3.95E-03
1000	2.41E-03	70	4.26E-03
1500	2.12E-03	80	4.58E-03
2000	1.96E-03	90	4.89E-03

V_m=800KV			
K=215mm,x=1mm h=1mm,d=100mm		K=215mm,x=1mm h=125mm	
D(mm)	E(KV/mm)	d (mm)	E (KV/mm)
300	7.31E-03	10	2.85E-03
400	5.19E-03	20	3.47E-03
500	4.41E-03	30	4.43E-03
600	3.98E-03	40	4.00E0-3
700	3.69E-03	50	4.86E-03
800	3.49E-03	60	5.27E-03
1000	3.21E-03	70	5.69E-03
1500	2.82E-03	80	6.10E-03
2000	2.61E-03	90	6.52E-03

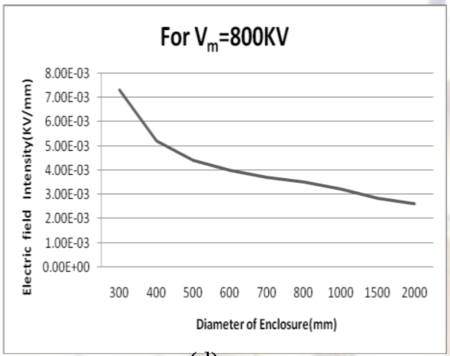
V_m=1000KV			
K=215mm,x=1mm h=1mm,d=100mm		K=215mm,x=1mm h=125mm	
D(mm)	E(KV/mm)	d (mm)	E(KV/mm)
300	9.14E-03	10	3.57E-03
400	6.59E-03	20	4.34E-03
500	5.5133E-03	30	4.96E-03
600	4.97E-03	40	5.53E-03
700	4.62E-03	50	6.07E-03
800	4.36E-03	60	6.59E-03
1000	4.01E-03	70	7.11E-03
1500	3.53E-03	80	7.63E-03
2000	3.26E-03	90	8.15E-03



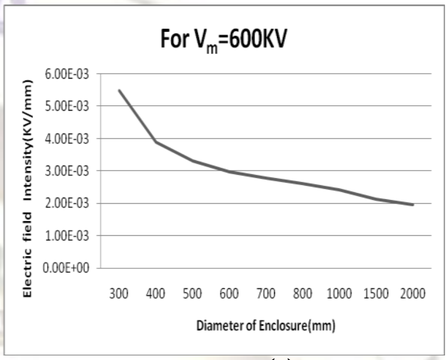
(a)



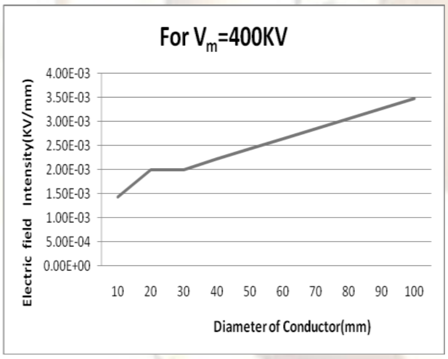
(b)



(d)



(c)



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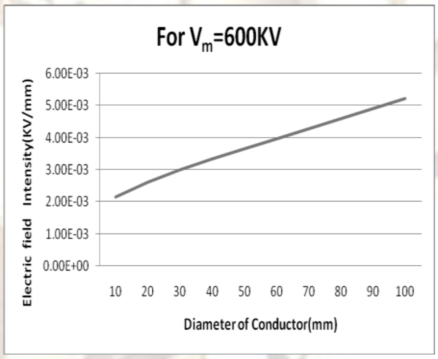
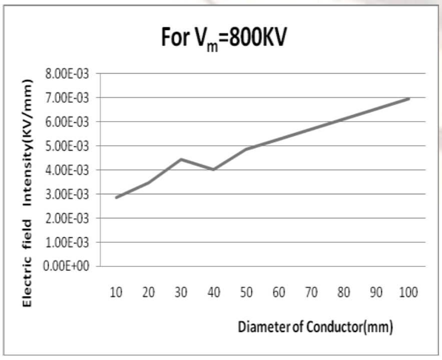
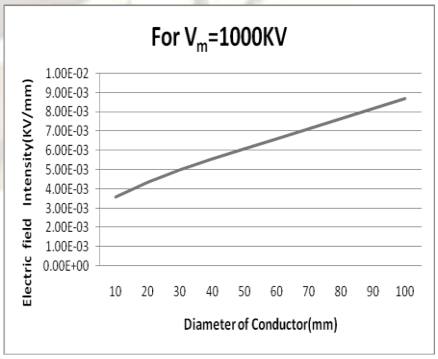


(e)



(h)



(g)

Fig 3. (a) to (h) Shows, the variation of Field intensity for different values of diameter of enclosure (D) and diameter of conductor (d)