Sparkover in Sphere Gaps with Alternating Voltages and Perturbed Electric Fields

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***Abstract*- Quasi uniform field gaps, namely sphere gaps are quite often used in high voltage laboratories.**

In the present work, both simulation and experimental results to see the electric stress distribution on breakdown voltage are presented. Considering commonly used vertical arrangement of sphere gaps, disruptive discharge voltages are measured experimentally. These experiments are with one sphere grounded. In order to study the redistribution of electric stresses, experiments have been conducted by placing a hemi-spherically tipped rod (needle), near the gap axis. This rod is placed vertically on the ground plane being at ground potential. Experimental results are reported with the rod diameter of 3 mm and its height 10 cm as a function of sphere-gap separation. Experimental results reported are with power frequency alternating voltages.

The simulations corresponding to these experimental conditions are reported to correlate the change in electric field distribution obtained by charge simulation models (CSM). Interpreting the experimental breakdown results in relation with simulation results of geometric electric field is attempted. The results with rod in the vicinity of sphere gap results in to a non axi-symmetric field. These are simulated to obtain the maximum stress on the electrodes.

I. INTRODUCTION

Air is the most widely studied gaseous dielectric to understand gas discharge processes, namely, pre-discharge processes, corona and sparkover [1, 2]. No other gas is so widely used as an insulating medium as atmospheric air [3]. Since the dielectric properties of air depend on the temperature, pressure and humidity, it is customary to refer to a set of standard conditions [1,2].

Breakdown in gases depends on the electric field distribution. In studying gas breakdown processes, the geometric electric field distribution associated with the gap forms can be broadly grouped in to those with uniform (and quasi-uniform) electric fields [4] and others with non uniform electric fields [5]. Uniform and quasi-uniform field gap configurations and related studies are useful in prediction and measurement of high voltages [6,7]. They are also useful in characterizing and determining the breakdown voltages and strengths of gaseous dielectrics [8]. There are quite a few studies reporting the electric breakdown of gases under uniform field conditions [1,2]. Sphere gaps form one of the important gap geometries. Various international standards are available with disruptive discharge voltage tables for specific sphere gaps and rod gaps. The electric stress across the sphere gaps is in the near uniform region (quasi-uniform gaps). Due to relative ease of construction and setting up, sphere gaps have formed standards for measuring high voltages (HV) [6,7]. The breakdown involving uniform fields are characterized by coincident corona inception and sparkover. These gaps do not show any polarity effects with direct voltages when electrical breakdown occurs. In non uniform field gap configurations the sparkover of the gap precedes partial discharge (corona). These have practical importance in high voltage insulation problems [3] as perfect uniformity is not possible to achieve in practice. In study of gas discharges the degree of non uniformity is systematically varied using the hemi spherically tipped rod-plane gaps or sphere-plane gaps [1,2,9].

It is under static and quasi static excitations that the space charges modify the electric field distribution in the gap. With this, the sparkover voltages are altered depending on the type and polarity of excitation [1,2]. Studies with impulse voltages (non static) with sphere-rod gap have been reported and analyzed to understand the breakdown behavior of air, recently [10]. The results there have no influence of corona. Also, the study there is more confined to near uniform regions.

Hence, here in the present work, a combination of sphere-gap (quasi-uniform field gap) perturbed by a vertical rod in the vicinity (introducing non uniformity) is studied experimentally. The corresponding electric field calculation results, obtained using the Charge Simulation Method (CSM) [11,12] programs developed, are reported with a vertical rod placed near the sphere-gap. The electric fields in the non-axi-symmetric gap involving rod electrode and its influence are being presented, perhaps, for the first time. The vicinity effect of rod is accounted using the point charges (as the simulating charges) for simulating spheres and the rod electrode. CSM is the most commonly used electric field computation technique to analyze the electric field problems with open boundaries [11, 12].

The CSM is an integral equation technique. Due to its favorable characteristics, it is one of the very commonly used techniques for electric field analysis in high voltage engineering, particularly for open boundary problems [11,12]. It makes use of mathematical linearity and expresses Laplace's equation as a summation of particular solution due to a set of unknown discrete fictitious charges. In the conventional CSM, location of these fictitious charges are predetermined by the programmer, while the magnitude of these charges are found by satisfying the boundary condition

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at the selected number of contour points on the boundaries [11]. The unknown charges are then computed from the relation

$$[P] \times [Q] = [V] \quad (1)$$

Where, [P] is the potential coefficient matrix.

[Q] is the column vector of unknown charges.

[V] is the potential of the contour points (Boundary conditions).

II. EXRIMENTAL DETAILS

A. Test gap arrangement

The test gap arrangement used in studying the electrical breakdown characteristics with rod in the vicinity (to perturb the electric field in the sphere-gap), is as shown in the figure (1).

The upper sphere (HV sphere) is connected to a 0-100 kV, 50 mA, power frequency, high voltage ac source of MWB(India) make, through a series resistance (water column) of 200 kΩ. The input side voltmeter on the control panel is calibrated using the standard sphere-gap arrangement. This calibration of the meter is carried out adopting the procedure in [13]. Indian standard [13] is in complete agreement with international standard [6]. The calibrated meter on the LV side is used to measure the voltage with due correction applied with respect to temperature, pressure and humidity.

B. Test procedure

The vertical rod is of 3 mm diameter and height 10 cm (equal to the diameter of the spheres). The rod is placed vertically, as shown in figure 1, touching the ground sphere (LV sphere). The sphere gap separation is varied in steps staring form 0.5 cm up to 5 cm, in steps of 0.5 cm. At each position of the gap separation the breakdown voltage is measured (keeping the rod position unaltered).

Fig. 1. Sphere gap of 10 cm diameter arranged vertically with electric field perturbing rod in the vicinity. (Both ground sphere and rod are placed on a metallic ground plane).

In measuring the sparkover voltage, a mean of three readings which are within ±3 % are considered. Measurement procedure is closely matched with the procedure given in [13]. Time duration of at least 1 minute is allowed between two consecutive sparkovers.

III. SIMULATION DETAILS

The sphere-sphere gap geometry shown in figure 1 is simulated using 80 (8 point charges arranged in the form of a ring; 10 such rings are used) point charges per sphere, to evaluate the electric fields, using CSM. These charges are placed inside the spheres. The rod is simulated using 100 point charges arranged in the form of 25 rings within the rod surface. Each ring is made of 4 point charges. The axis of rings coincides with the axis of the rod axis, being placed along the length of the rod. With this total number of point charges used for the simulation are 260. The gap spacing 'S', is maintained at 5 cm and is equal to the sphere radius. The simulation errors are not consistant and high when the sphere-gap spacing is 0.5 cm and reduces as the spacing increases. The errors associated with the rod are highest. The rms potential error on the rod surface varied in the range of 0.04 % (gap spacing of 0.5 cm) to 0.02 % (gap spacing of 5 cm).

The numerical experiments (which are identical to HV laboratory experiments) are conducted, to see the influence of vicinity of the rod by varying the gap spacing between the spheres.

A. Unit potential applied to HV sphere

It is the maximum electric field intensity on the three electrodes (HV Sphere, LV Sphere and the Rod), which is of interest in understanding the disruptive discharge voltage behavior. In obtaining the geometric maximum electric fields, numerical experiments are carried out using the CSM model developed, with HV sphere given a constant potential of 1 per unit (with LV sphere and rod being at ground potential).

B. Experimentally obtained sparkover potential applied to HV sphere

Although, it is the maximum electric field intensity on the three electrodes (HV Sphere, LV Sphere and the Rod), which is of interest, it is possible to obtain these at the sparkover potentials. The sparkover potentials are not constant and depend on the sphere-gap spacing. These experimentally obtained sparkover potential is used in the CSM programs developed, to understand the critical sparkover gradients (maximum) on each surface.

IV. RESULTS AND DISCUSSION

The experimentally determined sparkover voltage (SOV) at each sphere-gap separation 'S' (for typical gap spacings) is given in table I.

Table I: Sparkover voltages (SOV) as a function of sphere-gap separation 'S'

S (cm)	0.5	1	2	3	4	5
SOV (kV) (Experimental)	17.1	27.6	43.2	44.6	55.6	58.4
SOV(kV) [12]	16.8	31.7	59.0	84.0	105	123

Comparing with the sparkover voltages listed in the tables of standards [13], it is observed that with rod in the vicinity a drastic reduction in sparkover voltage is observed. The effect is more pronounced for higher gap spacings 'S'.

The spark discharge paths are video-graphed at each gap spacing 'S'. It is observed that spark channels was not involving rod for gap spacings 0.5 cm and 1 cm. For gap spacings 1.5 cm and above the spark is always between upper sphere and the tip of the rod. Some of the stills extracted from the video will be presented during conference. These visual results may aid the prediction of sparkover paths being attempted [14].

The numerical experimental results (using CSM program developed to simulate this non-axi-symmetric gap) of maximum electric field intensity on each electrode with unit potential applied to the HV electrode is given in figure 2. The actual maximum electric field intensity with experimentally obtained spark over voltages (table I) used in CSM programs is given in figure 3. In both these graphs for the sake of comparison the average electric field in the sphere gap is also given.

Figure 2 gives the maximum geometric electric field on each electrode. It is observed that at all the sphere-gap spacing(s) the electric field (V/cm in this case; HV electrode potential being 1 p.u.) is highest on the rod and is much higher than the average electric field in the sphere-gap, as expected.

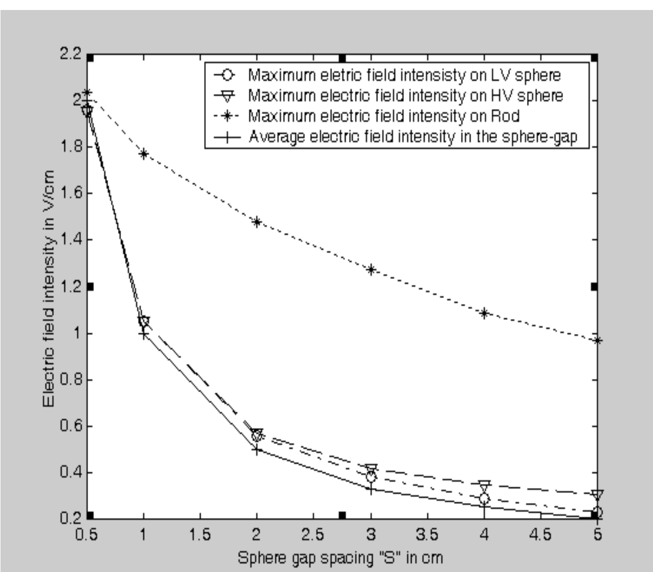

Fig. 2. Maximum electric field intensity on the electrode surface as a function of sphere gap spacing compared with the average electric field intensity in the gap. (Geometric field magnitudes with potential of HV electrode being assigned 1 p.u.; constant).

Figure 3 gives the CSM computed, geometric maximum electric field intensity at each electrode, but at a voltage equal to sparkover voltages. Although, these are also the geometric fields (as CSM program developed did not account for space charges) with the sparkover voltages used in the simulation indirectly account for the space charges to some extent. This is because the sparkover voltages are not constant and are varying not only with the geometry but also with the space charge modified electric fields.

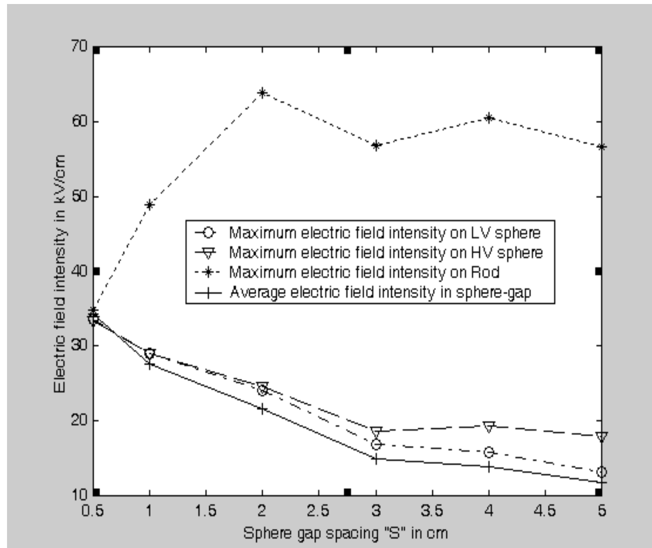

Fig.3. Maximum electric field intensity on the electrode surface as a function of sphere gap spacing compared with the average electric field intensity in the gap. (Geometric field magnitudes with potential of HV electrode being assigned 1 p.u.; constant).

Comparing the trends in the figures 2 and 3, it is observed that the actual maximum electric field on the rod is much higher than the maximum electric field occurring on the HV and LV electrodes. It is also to be noted that the maximum electric field intensity on HV-sphere and LV-sphere electrodes are comparable with average electric field in the gap.

Inspite of the higher electric fields associated with the rod electrode, the observed sparkover was between spheres only up to a gap spacing 'S' of 1 cm. As the maximum stress on the sphere electrodes up to 1 cm is almost nearly equal to 30 kV/cm and hence, in spite of the rod in the vicinity, the spark was not drawn to the rod electrode and occurred between the spheres. Although, highest electric field intensity is there on the rod tip.

V. CONCLUSONS

Sparkover voltages in the sphere-gaps with the perturbed electric field has been studied experimentally over the useful range of sphere-gap spacings (where the fields are uniform; for 10 cm diameter sphere, S is 5 cm). The geometric electric fields are computed using the CSM programs developed. The program is used to observe the geometric electric field at the time of sparkover, using the experimentally determined sparkover voltages.

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