Affect of Height of HV Sphere above the Ground in HV Measuring Sphere Gap

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***Abstract*- Sphere gaps are the standard gaps used for measurement of peak value of high voltages. Standards specify a minimum and maximum height of the spheres above the horizontal ground plane is specified as a function of its diameter 'D'. This height 'A' of the sparking point has to be within limits according to the guidelines of these standards.**

In the present work, both simulation and experimental results to see the affect of the height 'A' on breakdown voltage is presented. These results are presented for the worst case deviation from the guidelines by placing the ground sphere on the ground plane and the upper sphere above the ground sphere with gap separation S≤D/2 units (considering commonly used vertical arrangement). The distance of the nearest grounded object is kept 'B' units away as specified in the standards. In continuation, in order to study the nearby grounded object a hemi-spherically tipped rod (needle) is brought near, radially, towards the gap axis. This needle is placed vertically on the ground plane maintained at ground potential. Experimental results are obtained with the radial distance of the needle to the gap axis as the parameter. The results are reported for both positive and negative polarity voltages.

The simulation is carried out by developing charge simulation model (CSM). Some of the results (even with out the grounded needle in the vicinity) indicate that variation in 'A' modifies the surface electric fields of both the spheres. As the height 'A' is decreased the surface field intensity of upper sphere increases and that of the lower sphere decreases. The correlation between the experimental breakdown results and the simulation results is attempted.

These results may help, the users, who have some constraints in actual practice in the laboratory to strictly follow the guidelines given in the standards.

I. INTRODUCTION

Gap configurations, which results in to uniform electric fields are of importance in voltage measurement and also in evaluating intrinsic strengths of dielectrics [1,2]. In actuality there are many different type of gaps that occur in practice [3] along with sphere gaps. Sphere gaps form one of the important gap geometries. Various national and international standards are available with disruptive discharge voltage tables for specific sphere gaps and rod gaps [4,5] The standard [4] is in complete technical agreement with IEC publication 52:1960 and is adopted in India. 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. In studying insulating materials and understanding their intrinsic strengths, much higher uniformity in electric fields is needed. For this purpose parallel plane, Rogoskwi, Bruce and Borda's profiled electrodes geometries are explored [1,6,7].

It is well known from the literature that electrode shapes have significant effects on the breakdown voltage of air gaps [3]. Particularly for measuring sphere gaps the standards [4,5] give guidelines of arranging the gaps in terms of the sphere sizes, ground vicinity, minimum distance from the near by objects. In standard [4] (clause 2.4 clearance around the spheres) states that, "at small sphere-gap spacings earthed objects of small size in the neighborhood of the gap affect the results insignificantly, but at greater spacings the presence of large areas, such as walls even at distance 'B' affect the results". It is also said that "the requirements stated relate to clearances related to approved sphere-gaps within the meaning of the standard. Sometimes, however, the test conditions render it impossible to make the values of 'A' and 'B' comply with the minimum requirements specified in relevant tables. Such sphere-gaps may also be regarded as approved, if it can be demonstrated during systematic tests in the actual testing plant under the actual test conditions that the disruptive voltages do not significantly deviate from those in this standard". Where 'A' is the clearance of the high voltage sphere above the ground plane and 'B' is the spherical radial region within which no influencing grounded objects should be present.

Present work points at looking in to these aspects of the standard, experimentally by placing the ground sphere directly on ground. The corresponding electric field calculation results obtained using the CSM [6,7] program developed are also reported. Also reported are the experimentally determined spark over voltage results with a vertical rod placed near the HV sphere placed on the ground.

CSM is the most commonly used electric field computation technique used to analyze the electric field problems with open boundaries [8,9].

II. TEST SETUP

The test setup involving sphere gaps is arranged as show in the figure 1. The spheres of 10cm diameter are arranged in vertical fashion violating the minimum clearance 'A' [4]. The worst case violation is by placing the ground sphere on the ground (see figure 1). With this sparking point of the High voltage sphere is at a height of sphere diameter 'd' plus the gap distance 'g'. The maximum gap distance allowed for this setup is 5cm as per the standard [4]. The sphere is placed on

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the ground; a perfect conducting ground plane made of aluminum sheet (16ftX8ft; 11.89m^2); firmly connected to the ground. All the components of the experimental setup are placed on this common ground plane, having connected to this ground electrically**.** This setup is so arranged that there is no near by grounded object with in 60cm from the gap axis. The spheres are made of steel and the top sphere is connected to HV terminal with the help of long vertical rod, whose length is greater than 1.5m. The gap distance is adjusted by moving the upper sphere with this rod and measuring the distance using a dial gauge (with a precision of 0.01mm with an uncertainty in measurement of 0.001mm).

The circuit schematic of the high voltage dc source used for conducting spark over tests is as shown in the figure 2. The HV source is of MWB (India) make, having high voltage ac source of 100kV, 50mA. The rectifier of 140kV, 20mA and a filter capacitance of 25nF are used to produce high direct voltage for the test applications. The DC voltage is measured using the bleeder resistance method with 280MΩ high voltage measuring resistance and a calibrated, control panel mounted, micro ammeter, forming the measuring system. The error associated with this measuring system is better than 2%. The DC voltage is applied through a series protective resistance (water resistance) of 300 to 500kΩ.

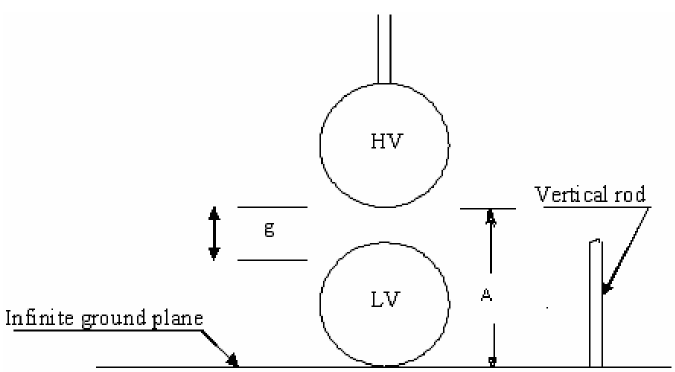

Fig. 1. Sphere gap assembly used for experimentation with ground sphere (LV) directly place on ground. HV sphere is the high voltage sphere placed above ground sphere (LV sphere) with a gap separation 'g'. The vertical rod is a 3mm diameter rod of 10cm height placed in the vicinity of sphere gap assembly. Spheres are of10cm diameter.

III. Test Procedure

The DC voltage source and the test setup described above is used to apply direct voltage of both the polarities. The disruptive discharge voltage is measured by varying the gap distance 'g' in steps starting from 5mm to 5cm for the gap distances listed in the standard [4]. The gap is irradiated using the quartz tube mercury vapor lamp [4]. A large number of breakdown voltage readings are taken and the mean of three successive readings agreeing within 3 percent are reported as the final result. A minimum of 1 minute is allowed between two disruptive discharges. As the experiments are with direct voltages the entire area (especially the aluminum flooring) is repeatedly cleaned using the vacuum cleaner to minimize spurious breakdowns. It is to be noted, that in spite of this exercise, some spurious breakdowns are observed at abnormally low voltages as reported in reference [10] particularly after a long resting period. To give a particular instant, while conducting experiment with 4cm gap separation and positive DC, in the beginning (this was in the beginning of that days experimentation;) at least first 12 applications showed values as low as 15 to 25%. This is taken care by conducting a large number of breakdown tests till consistency is achieved and results are within ±3%.

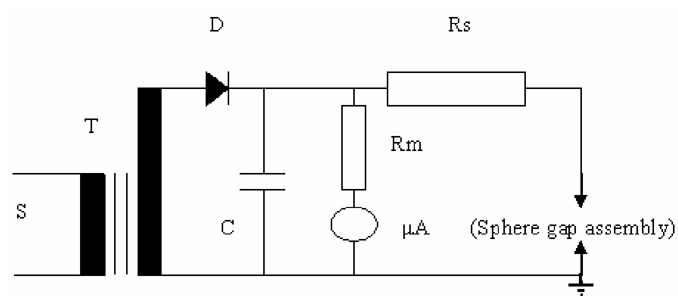

Fig. 2. Circuit schematic showing the source and high voltage dc measuring unit. (S is the ac power frequency source of 50 Hz; T is the high voltage transformer of 100kV, 50mA; D is the high voltage rectifier unit 140kV PIV, 20mA; C is the high voltage filter capacitance 25nF; Rm is the 280MΩ measuring resistance; Rs is the protective series resistance).

The breakdown voltages determined experimentally are corrected to standard temperature and pressure. The experiments are conducted at the high voltage laboratory of National Institute of Technology, Karnataka India which is very nearly at the sea level. Hence, only the temperature correction factors need to be applied to the results.

In the second part of the experimentation, for each gap separation of the sphere gaps a vertical rod of 3mm diameter and 10cm height is placed on the ground as shown in the figure 1. This is moved systematically, in steps, radially perpendicular to the gap axis starting from 5mm (touching the ground sphere) to the 60cm, always placed on the ground vertically. This rod of 3mm diameter is hemi-spherically capped towards its upper end. The disruptive discharge voltages measured and reported to indicate the influence of this near by ground rod, placed near the ground sphere.

IV. Experimental Results

The experimentally determined disruptive discharge voltages for sphere gap separation for both positive and negative polarities with ground sphere placed on the ground plane are given in figure 3. For the sake of comparison the corresponding values specified in the standard [4] are also given. It is to be noted that values specified in the standard correspond to the high voltage sphere spark over point placed sufficiently above the ground (in the region 6 to 8 times D;

where D is the diameter of the sphere; in this case 10cm). These experimental results obtained here are without any near by earth object in the vicinity with in 60 cm.

The experimentally determined disruptive discharge voltages for sphere gap with gap separation ‘g’ of 3.5 cm (a typical result) with influencing ground rod, for positive and negative polarity are as shown in the figure 4. Similar plots are obtained for different gap separations ranging from 0.5cm to 5cm and will be presented in the conference.

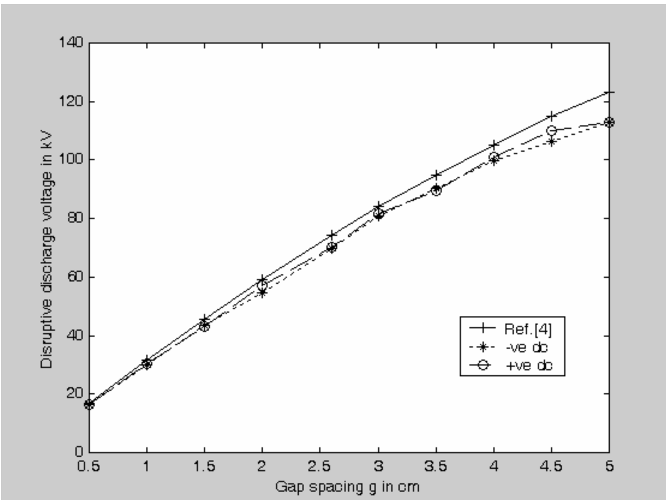

Fig. 3. Disruptive discharge voltages as the function of gap spacing ‘g’. (Values tabulated in ref.[4] are compared with the experimentally determined values for the LV sphere placed on the ground; for both the polarities; these results are without the vertical rod.)

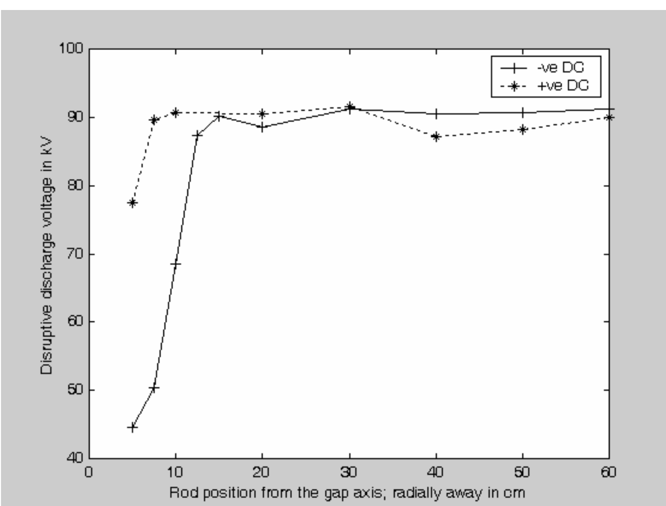

Fig. 4. Disruptive discharge voltages as function of rod position from the gap axis. (rod is moved radially away from the gap axis having placed on the ground plane vertically; with sphere-gap separation of 3.5cm)

V. Surface Electric Fields

The electric field corresponding to variable height of the sphere assembly (with HV and LV spheres moved together) above the ground sphere is obtained by charge simulation models developed for a 25 cm diameter spheres with vertical arrangement of the sphere-gap. The parameter ‘A’ shown in the figure 1 is specified in the standard [4]. For the 25 cm diameter sphere this can be maximum of 175cm and a minimum of 125 cm [4]. The simulations are conducted outside this range by reducing the ‘A” such that in the worst case LV sphere almost touches the ground. As the height decreases the ground influence should increase. This can be seen by plotting the surface electric fields for the two spheres under study. With ‘A’ as the parameter the surface electric field variation for HV sphere is shown in figure 5. The corresponding surface electric variation for the LV sphere (ground sphere) is shown in the figure 6. From these figures it is observed that the increase in the electric stress with parameter ‘A’ decreasing for the HV sphere is not very high; although a slight increase is observed. The sparking point (lowest point on the HV sphere) has slightly increased electric field intensity when the LV sphere is placed on the ground. These results are with the gaps separation ‘g’ of 12.5cm for a 25 cm diameter spheres. A similar trend is expected for 10cm diameters spheres with a gap separation of 5cm. The simulation using CSM models is with ring charges. It is to be noted that the maximum potential error in simulation is less than 0.05%. These simulation results are without the influencing ground rod shown in figure 1. The simulation results help in analyzing the experimental results given in figure 3, which are also without the influencing ground rod.

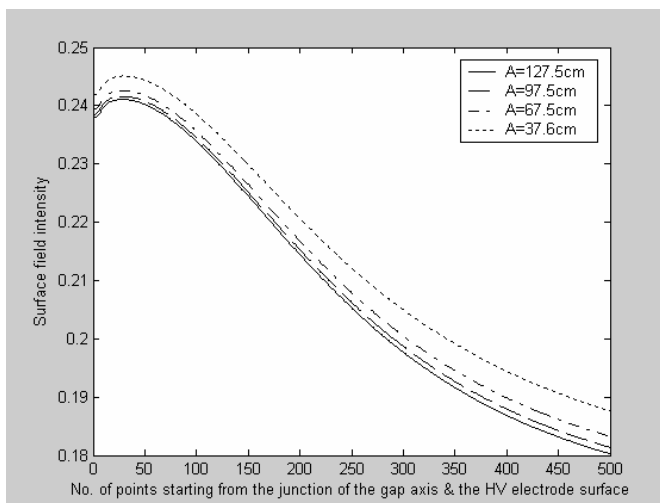

Fig. 5. Variation of surface electric field intensity on the electrode surface (upper sphere) with an unsymmetrical supply (One sphere grounded) with A as the parameter with sphere radii of 12.5 cm and gap separation of 12.5cm and a potential difference of 2V between spheres. [7]

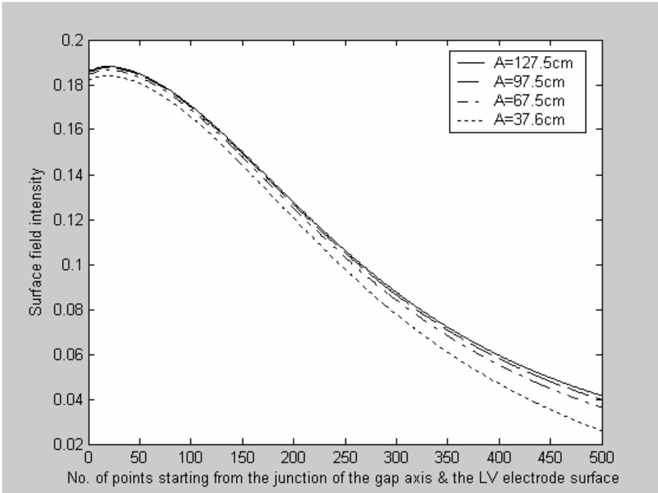

Fig. 6. Variation of surface electric field intensity on the electrode surface (lower sphere) with an unsymmetrical supply (One sphere grounded) with A as the parameter with sphere radii of 12.5 cm and gap separation of 12.5cm and a potential difference of 2V between spheres.

VI. Discussion

From figure 3 it is observed that in the worst case violation of height of HV sphere above the ground (by placing the LV sphere directly on the ground) the disruptive discharge voltages do not differ much from those specified in the standard [4]. As expected under this condition when gap spacing is increased the disruptive discharge magnitudes are lower than those specified in the table (for both the polarities). This may be attributed to the increased surface electric field intensity at the sparking point of the HV sphere by a small amount as seen from the simulation results (figure 5).

The rod in the vicinity showed a large influence on the negative polarity voltages. The disruptive discharge voltages are affected by the rod up to 10cm of radial distance from the gap axis for negative dc (figure 4); where as with positive dc the disruptive discharge voltages are lowered only up to a radial distance of 7.5cm. These results are true for 3.5cm of sphere gap separation. But for higher sphere gap separations the region of influence for both positive and negative dc voltages increased. But among these, negative disruptive discharge voltages showed much higher influence. It was also noticed that the discharges were between upper sphere and the rod rather than lower sphere for negative polarity in this region. But for positive dc applications, the discharges still have a tendency to disrupt between upper and lower spheres (with the occasional disruptive discharges to the rod). With rod influence the magnitudes of disruptive discharge voltages are lower for negative polarity than those of positive disruptive voltages (up to 10cm). Beyond a certain distance away (12.5cm in this case of g=3.5cm) the influence of the rod is not very much apparent.

VII. Conclusions

The experimental results with high voltage DC indicate that the parameter 'A' specified in the sphere-gap related standard seems to have relatively little influence on the breakdown voltage and also this influence increases as the gap separation increases; meaning lower gaps have relatively less influence. This has been substantiated by the simulations results of surface electric fields for the two spheres. The polarity of applied voltages under these conditions also seems to have no much significance.

The vertical influencing rod near the LV sphere showed some interesting results with negative disruptive discharges greatly influenced by the rod. Also, the spark is drawn towards the rod for negative polities voltages applied to the HV upper sphere.

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