Disruptive Discharge Voltages in Sphere Gaps with Perturbed Electric Fields

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Abstract--- Quasi uniform field gaps, namely sphere gaps are quite often used in high voltage laboratories. They exhibit very little polarity effect when subjected to direct high voltages. But if their electric field is disturbed by a near by earthed object they tend to show polarity effect.

In the present work, both simulation and experimental results to see the electric stress distribution on breakdown voltage are studied. 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 polarity effect on redistribution of electric stresses, experiments have been conducted by bringing a hemi-spherically tipped rod (needle), radially, towards the gap axis (of varying rod dimensions). This rod is placed vertically on the ground plane being at ground potential. Experimental results with both positive and negative polarity dc voltages are reported.

The simulations corresponding to these experimental conditions have been reported to correlate the change in electric field distribution using charge simulation models (CSM).

The video of spark channel formation under positive and negative polarity with field perturbing rod will be shown during presentation. With rod in the vicinity, electric field gets redistributed and affects the disruptive discharge process. Under negative polarity voltage applied to the upper sphere with rod at the ground potential (along with the ground sphere), the spark is drawn towards the rod. Depending on the vicinity of the rod the spark channel is between the upper sphere and the rod. On the contrary, with the positive potential applied to the upper sphere, the spark channel is drawn towards the rod; (having got disturbed and not being along the sphere gap axis) but strikes the lower sphere and not the needle. Authors feel this research effort is likely to help better understand many aspects related to lightning rods and discharges.

INTRODUCTION

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 [1,2] The standard [1] 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 (HV). Gap configurations, which results in to uniform electric fields are of importance in voltage measurement and also in evaluating intrinsic strengths of dielectrics [3].

Present work points at looking in to the experimentally obtained disruptive discharge voltages in sphere-gaps with perturbed electric fields. Field perturbations are brought about by the influence of the rod electrode which is brought near systematically. The rod is placed vertically on the ground near the ground sphere [4].

The corresponding electric field calculation results obtained using the Charge Simulation Method (CSM) [5,6] programs developed are reported with a vertical rod placed near the sphere-gap placed on the ground. CSM is the most commonly used electric field computation technique used to analyze the electric field problems with open boundaries [7, 8].

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 [7, 8]. It makes use of mathematical linearity and expresses Laplace's equation as a summation of particular solution due to 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 at the selected number of contour points on the boundaries [8]. The unknown charges are then computed from the relation

[P] x [Q] = [V] (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).

The electric fields in the non-axis symmetric gap involving rod electrode and its influence are being presented perhaps for the first time. The vicinity effect is effectively accounted using the point charges (as the simulating charges) for simulating spheres and the rod electrode.

CSM MODEL DETAILS

The sphere-sphere gap geometry shown in figure 1 is simulated using 80 (8 point charges arranged in the form of ring; such 10 rings are used) point charges per sphere, to evaluate the electric fields, using CSM. These charges are placed inside the spheres. The rod electrode is simulated using 40 point charges placed along its length, along the axis. The gap spacing 's' is maintained at 5 cm and is equal to the sphere radius. The rod height is 10 cm and its diameter is 3 mm.

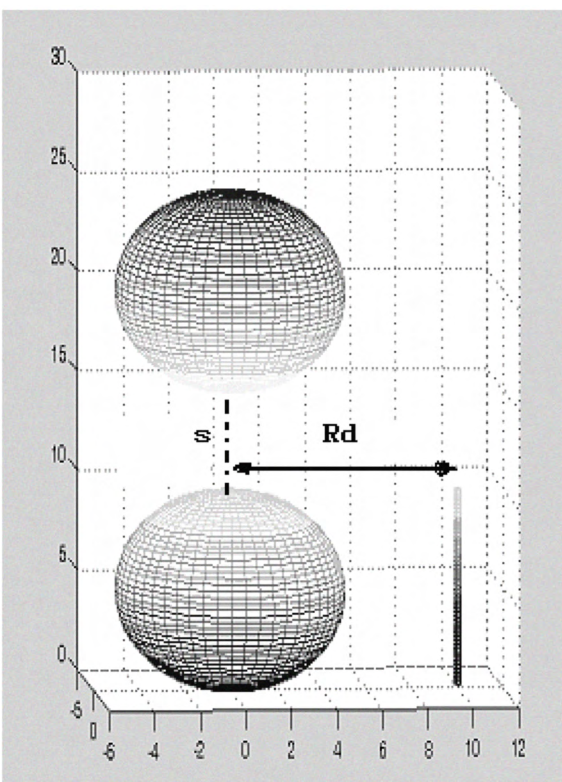

Fig. 1 Sphere-sphere gap geometry simulated using CSM, with influencing ground rod. ('Rd' is the variable).

The numerical experiments (which are identical to HV laboratory experiments) are conducted, to see the influence of vicinity of the rod by varying the axial position of the rod 'Rd', shown in the figure (1). The potential of the high voltage electrode is 1 per unit in the numerical experiments. The plane earth electrode is simulated using image electrodes and corresponding image charges.

The CSM model is implemented in the Matlab. The figure (1) is the Matlab generated model which is formed by the points generated on the electrode surfaces to compute the CSM errors in potential calculation.

Simulation accuracy

Each sphere is simulated using point charges arranged in the form of a ring. Ten such rings are formed in each sphere with 8 point charges per ring. The point charges forming the ring are placed equidistant. Rings are so positioned that the assignment factor 'fa' used is 1.5. Assignment factor is defined as the ratio of the distance between a contour point and the corresponding charge 'a2' to the distance between two successive contour points 'a1', as given in relation (2).

fa= a2/a1 (2)

With this arrangement the number of charges per sphere is 80. The rod is simulated using 40 point charges arranged along the length of the rod, placed on its axis. With this total number of point charges used for the simulation are 200.

Here, the conventional CSM (in which charges are not located using optimization) is being adopted. It is observed that the accuracy varies with the position of the rod. When the rod is almost touching the lower sphere the (Rd=5cm), as expected the accuracy is least. Even under that situation, for the present model the maximum potential error on lower sphere is 8.53%. The maximum potential error for this situation associated with the upper sphere and rod electrode are 0.20% and 3.43% respectively. As the rod is moved away from the lower sphere the simulation accuracies drastically improve for the lower sphere and the rod (which show higher errors compared to errors associated with the upper sphere). The simulation error associated with the upper sphere remains unaffected with variation in 'Rd'.

Hence, the simulation accuracies are better than 0.4% (accounting for maximum potential errors associated with all the electrodes) for all the simulation runs except when the rod touches the lower sphere (the error being 8.53%).

EXPERIMENTAL SETUP & PROCEDURE

The laboratory experiments (identical to simulation runs) to determine the disruptive discharge voltage with positive and negative polarity voltages with varying 'Rd' (identical to that shown in figure (1)) are conducted using a HV source [4]. The HV source is of MWB (India) make, having high voltage ac source of 100 kV, 50 mA. The rectifier of 140 kV, 20 mA and a filter capacitance of 25 nF are used to produce high direct voltages for the test applications. Half wave rectification is adopted; which is the accepted norm in HV testing, as the currents associated are small. The DC voltage is measured using the bleeder resistance method with 280 MΩ 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 500 kΩ.

The DC voltage source and the test setup described above, is used to apply direct voltages of both the polarities. The disruptive discharge voltage is measured for fixed gaps separation 's' of 5 cm The gap is irradiated using the quartz tube mercury vapor lamp as specified in the standard [1]. 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. A large number of breakdown tests are conducted till consistency is achieved and results are within ±3%. The breakdown voltages determined experimentally are corrected to standard temperature and pressure.

For each gap separation of the sphere gaps a vertical rod of 3 mm diameter and 10 cm 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 5 mm (touching the ground sphere) to the 60 cm, always placed on the ground vertically. The disruptive discharge voltages measured and reported to indicate the influence of this near by ground rod, placed near the ground sphere. The CSM based field calculation program developed is used to obtain the maximum field on all the three electrodes (two spheres and the rod) to find out the maximum electric field intensity with varying rod position, similar to experimental conditions.

N UMERICAL EXPERIMENTS AND RESULTS

It is the maximum electric field intensity on the three electrodes, which is of interest in understanding the disruptive discharge voltage behavior. Hence, the numerical experimental results (with upper sphere potential as unity) are given in figure 2.

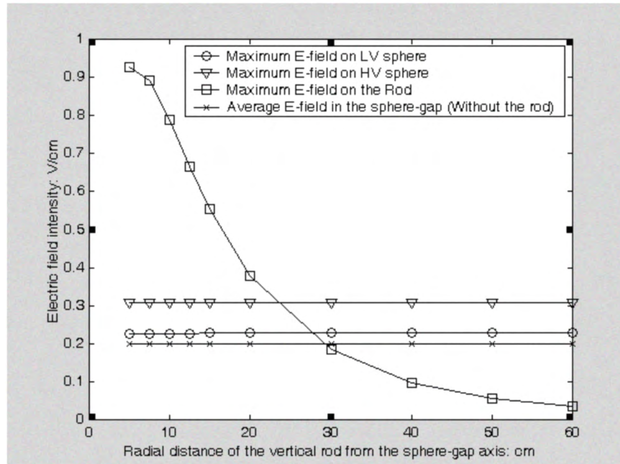

Fig 2. Maximum electric field intensity on the spheres and the rod surface computed using CSM program, compared with the average electric field in the gap. (HV electrode potential 1 p.u.; Sphere diameter 10 cm; Gap spacing 5 cm; Rod height 10 cm; Rod diameter 3 mm).

It is observed from figure 2 that the maximum field on the spheres has almost remained same, where as that near the tip of the rod near to the HV sphere (where the electric field intensity is maximum) reduces as the rod is moved away from the sphere-gap axis. Beyond 30 cm (Rd>30 cm) the field at the tip of the rod is lower than the average field in the gap. Hence, it can be said that the rod influence, is negligible beyond this distance, as no corona is likely to occur, before the field in the main gap exceeds the breakdown strength. Sphere gaps being near uniform field gaps, the average field is lower than the maximum field observed on either upper or lower sphere, although they almost approach the average field magnitude.

Experimental results

Laboratory experiments with sphere gap and rod in the vicinity showed, that the disruptive discharge voltages are influenced with lowering of disruptive discharge voltages. As seen from figure 3 the disruptive discharge voltages are affected up to Rd ≤ 20 cm. As the experiments are with direct voltages the spark channel are affected by the polarity. The videos of spark development process will form part of the paper presentation, during the conference.

The observations made are, spark is drawn towards the needle for negative polarity (applied to upper sphere) voltages. With positive polarity voltages the breakdown is still between the spheres (and not to the rod), although, the spark channel is disturbed. Also, the breakdown voltage magnitudes are lower for negative polarity, than the positive polarity. This is likely to kindle interest in the research associated with lightning rods, which predominately experience negative discharges due to negatively charges clouds.

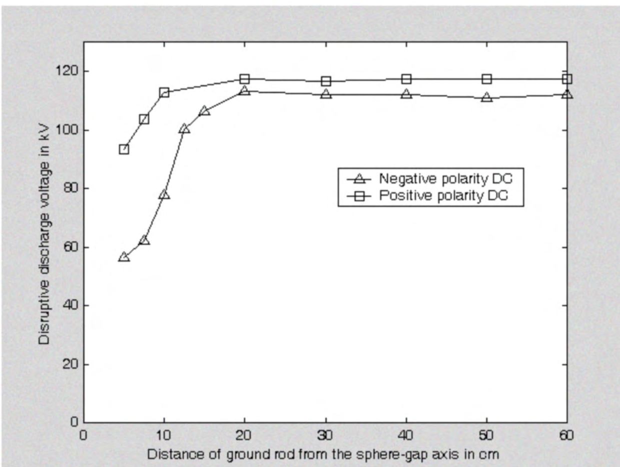

Fig3. Effect of rod distance on disruptive discharge voltages with gap separation of 5 cm for both (+ve & –ve) polarity voltages.

CONCLUSIONS

Electric field computation program using CSM has been developed to study the influence of the perturbed electric fields of the sphere gap due to a vertically placed needle. Maximum electric stress on the rod surface reduces below the average field in the sphere gap for distance of 3 times the diameter 'D' of the sphere (3D). The high voltage laboratory experiments substantiate the results. The disruptive discharge voltages are affecting up to 2 times D for the negative polarity voltages. Discharges show the polarity effect and in case of negative polarity the spark is drawn towards the needle.

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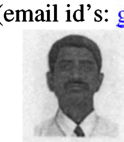

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