# Electric Fields in the Transition Region of Sphere-Gaps to Parallel-Plane Gaps

G. S. Punekar, Vivek Mishra, N.K.Kishore and H S Y Shastry

***Abstract*-The electrode gaps which results in to uniform electric fields are the most widely used gap configurations in assessing dielectric strength. In the present study simulation results of parallel plane electrode gap configurations with symmetrical and unsymmetrical supply are reported. When plane radius of plane electrode is reduced the plane electrode at its extreme case forms a sphere resulting in to sphere gap arrangement. Results in this transition region are reported. The Charge Simulation Method (CSM) is used to compute electric fields; with errors in simulation being less than 0.06% (in potential).**

**Simulation results indicate that as the plane radius increases the field uniformity increases. Non uniformity for a given plane radius depends on the gap spacing. For given gap spacing when the plane radius of the electrode is more than the gap spacing, improvement in uniformity are not significant. The unsymmetrical supply results in higher field non-uniformity in the gap. The height of high voltage (H.V.) electrode above the ground plane (designated as parameter "A" in IS 1876-1961 for sphere gaps with vertical electrode arrangement) has shown negligible influence on the electric field distribution in the gap.**

## INTRODUCTION

The uniform field electrode configurations are of significance in basic research, testing, and characterization of insulating materials. Theoretically, the uniform field intensity is produced within the space limited between the two parallel plane electrodes of infinite dimensions. In practice since the electrode dimension cannot be infinite, carefully designed electrodes are necessary to produce uniform fields in the region of interest and to assure lower field intensities at all other points in the test gaps. Different electrode configurations like simple plane profile, Rogowski and Bruce profiles have been used in producing uniform fields [1]. Rapid developments in digital computation techniques however have made assessing and designing newer configurations possible. Such an earlier effort using finite difference technique is by Harrison [2]. Harrison in his work placed emphasis on the uniformity of field along the gap axis. In many a situations like stressed volume theory and related studies of insulating materials, electrode area, volume of the sample stressed become important. Hence uniformity of the field along the electrode surface has also become significant. In light of this newer designs have been attempted [3]. A relatively newer profile, namely, Borda's profile and field optimizations by CSM are attempted and reported by H Okubo et al [4].

The CSM [5,6] being one of the most widely used method for numerical field computation for open geometry fields are suitable for studying electrode configurations of this kind. In the present work CSM is used to simulate and evaluate electric fields in the electrode configurations. Some of the results available in the literature for the geometry's studied are examined to ascertain the correctness of the simulation model.

Though it is possible to compute numerically the profiles suitable to yield uniform fields, it takes effort to fabricate these complicated profiles and realize its application in experimentation. The simple geometry like parallel plane geometry compare well with that of profiled electrodes if one is not so much concerned about field distortions at the edges[7]. This is true if the region of interest is that of gap axis. As a compromise sphere gaps form the standard for H. V. measurements [8,9]. Here the effort has been is to compare the sphere gaps with the simplest form of more uniform stress yielding gaps namely parallel plane electrode.

## SIMULATION METHOD

The charge simulation method [5,6] is an integral equation technique which makes use of mathematical linearity and expresses the Laplaces equation as a summation of particular solution due to set of known discrete fictitious charges. In effect, the field formed by a number of charges (equivalent) simulates the actual E-field due to the charges present on the electrode, which are placed outside the region where the field solution is desired.

If several discrete charges of any type (point, line or ring) are present in a region, the electrostatic potential at any point $c_i$ can be found by summation of the potentials resulting from the individual charges as long as the point $c_i$ does not reside on any one of the charges. Let $Q_j$ be the $j^{th}$ charge of n number of individual charges and $\phi_i$ be the potential at any point $c_i$ within the space. Then according to the superposition principle,

$$\phi_i = \sum_{j=1}^{n} P_{ij} Q_j \qquad \text{......(1)}$$

Where $P_{ij}$ are the 'potential' coefficients, which have been evaluated analytically for many types of charges; for example point, line and ring charges [5].

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By properly locating the charges, their magnitudes are found by satisfying the boundary condition at the selected number of counter points on the boundaries. On knowing these charges, the potential and electric field intensity at any point can be determined from the combined effect of these charges. The resulting simulation accuracy depends strongly on the choices concerning type of simulating charges, the location of charges and counter points. It has been suggested that potential error values below 0.1% are reasonably acceptable [5].

In the present work the electrodes are simulated using ring charges. The infinite ground plane electrode is simulated using image electrode with image charges on it.

## ELECTRODE CONFIGRATIONS & SIMULATION DETAILS

The figure 1 is the simulated parallel plane electrode with symmetrical supply. Each electrode is simulated using 151 ring charges and correspondingly same number of contour points. Among the contour points corresponding to these charges, 50 contour points are placed on the flat-bottom surface of the plane electrode, 51 contour points are placed on the semi-circular surface and 50 contour points are placed on the flat-top portion of the plane electrode.

In order to assess the uniformity in electric field in the gap, numerical experiments are conducted by varying parameters like gap spacing, plane radius. Computed electric fields on the surface of the electrode and those along the gap-axis help in comparing non-uniformity in electric fields for parallel plane electrode with that of sphere gap configurations. In case of study with unsymmetrical supply the effect of height of H.V. electrode above the ground plane is also studied. The schematic of electrode configuration simulated with the unsymmetrical supply is as given in figure 2. Figure1 & 2 indicate the typical value of plane radius. It is to be observed that as plane radius is shrunk to smaller value (0.1cm) the gap almost assumes the form of sphere gap.

The gap separation (h), radius of plane portion of the electrode ($R_p$), height of the H V electrode above the ground plane (A) and overall radius (R) formed the parameters of numerical experimentation. The overall radius R of the plane profile electrode is $R = R_p + R_e$ and its thickness $T=2R_e$. For the unsymmetrical supply system (figure2) the height $A=h + 2R_e$ + Distance between the ground plane to ground electrode. In the present study the results have been reported for $R_e=12.5$ cm which form one of the standard radius mentioned in IS standard [9].

Results with symmetrical supply become comparable with those of unsymmetrical if the applied potential difference between the electrodes is the same and the gap separation (electrode to electrode distance) remains the same. In order to maintain the potential difference same in case of symmetrical supply (the potential difference being 2V,) a potential of 2V is applied to H.V. electrode in unsymmetrical supply with the other electrode being at the ground potential.

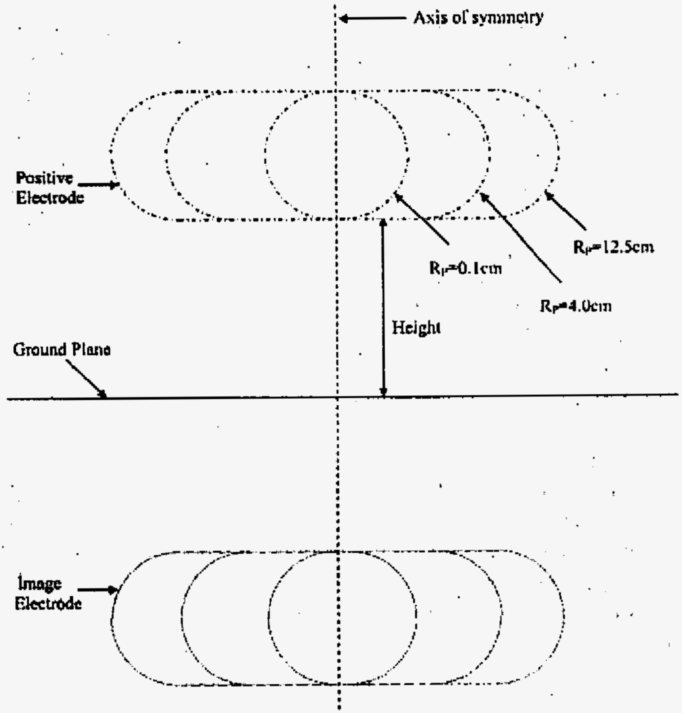

Fig. 1 Schematic of parallel plane electrode with shrinking plane radii with symmetrical supply. ( Typical values of $R_p$ have been shownd.)

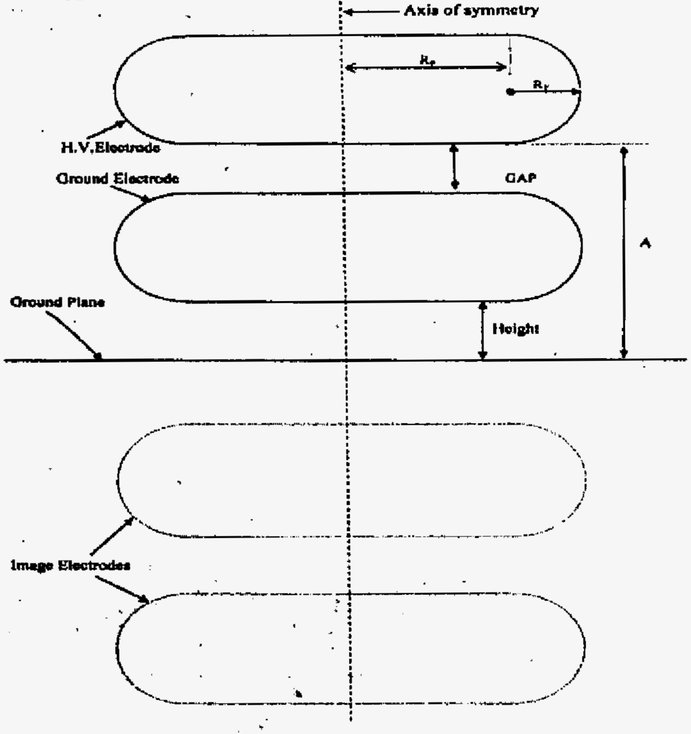

Fig. 2 Schematic of parallel plane electrode with unsymmetrical supply.

## NONUNIFORMITY FACTOR

Non uniformity factor (f) is defined as the ratio of "maximum-field" in the gap to the "average-field" in the gap. This factor is widely referred to, and used in the literature to quantify the nonuniformity of various gaps [1,10]. For a perfectly uniform field this factor will be unity. The sphere gaps are the near uniform field gaps and hence are termed quasi uniform gaps. Uniformity in electric field distribution can be further improved if a plane portion is added to form a parallel plane electrode system.

## RESULTS AND DISCUSSION

### *Electric field along the gap axis*

By conducting systematic numerical experiments, variations in axial field (along the gap axis) as a function of plane radii have been studied. For the unsymmetrical case the variation is as given in figure 3. The results are with a fixed gap separation of 12.5cm and height of H V electrode A=175cm. The average electric field for this condition works out is 0.166V/cm. From the figure it is observed that as Rp is increased the electric field along the axis approaches the average value. It is to be note that as expected, the maximum electric field occurs on the H. V. electrode which is farther away from the ground plane.

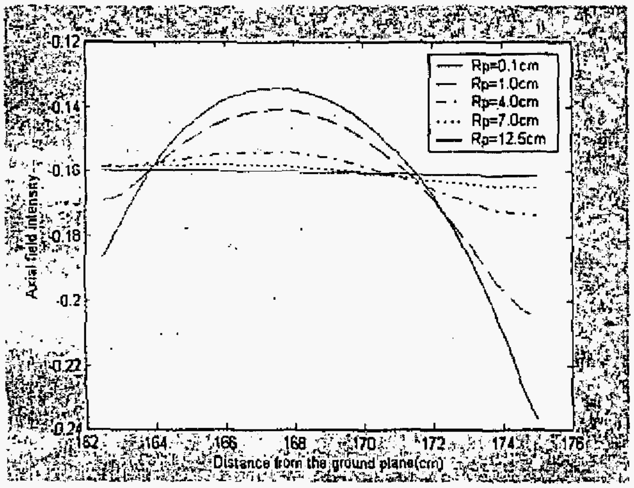

Fig. 3 Electric field intensity along the axis of symmetry with unsymmetrical supply. ($R_e$=12.5cm; Gap=12.5cm; A=137.5cm)

Unlike symmetrical supply case, the electric field along the axis at the H.V. and ground electrode is not same and this difference is more pronounced for smaller values of $R_p$.

### *Surface electric fields*

Results of numerical experiments (with identical conditions of the gap configuration as stated above) to observe the variation in surface electric field yielded the results as shown in figure 4. The plots are for the H.V. electrode surface with unsymmetrical supply. The line joining both vertical and horizontal axis of symmetry of the H.V. electrode on the lower surface is divided in to 500 equiv-spaced points and forms the abscissa (figure 4).

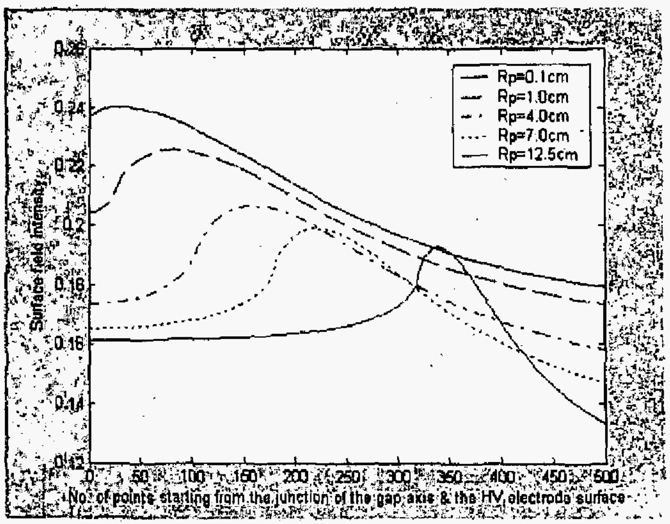

Fig. 4 Electric field intensity on electrode surface with unsymmetrical supply. ($R_e$=12.5cm; Gap=12.5cm; A=137.5cm)

It is observed that as the plane radius increases the point of maximum stress moves away from the gap axis. Maximum stress occurs at the edge of the plane portion. Also, the magnitude of the maximum stress comes down with increase in $R_p$. The ground electrode surface electric field plots are similar to these but with less pronounced edge effects for unsymmetrical supply situation.

The symmetrical and unsymmetrical supply cases when compared with nonuniformity factor as the basis indicate that for the typical gap separation of 12.5cm and the Re=12.5cm, increase in $R_p$ beyond 12.5cm shows negligible improvement in uniformity of the gap.

### *Effect of parameter "A"*

The height of the H.V. electrode above the ground plane has been designated as parameter "A' in IS-1876 on sphere gaps used for measurement of H.V. [9]. In order to check its influence on the electric field in the gap the simulations are carried out with "A" as the parameter. In these simulation runs all other aspects of the gap namely $R_e$, $R_p$ and gap separation h are maintained constant. The typical result of such an experiment is shown in figure 5. The result indicate that even for A=37.6cm, with $R_e$=12.5cm and gap separation of 12.5cm negligible change in electric field is observed. This implies even if the ground electrode is placed at 0.1cm above the ground for this typical setup no much change in electric field distribution is observed. Hence it is concluded that parameter "A' has no much significance as far as ground plane influence on variation of electric field and uniformity in the gap is concerned.

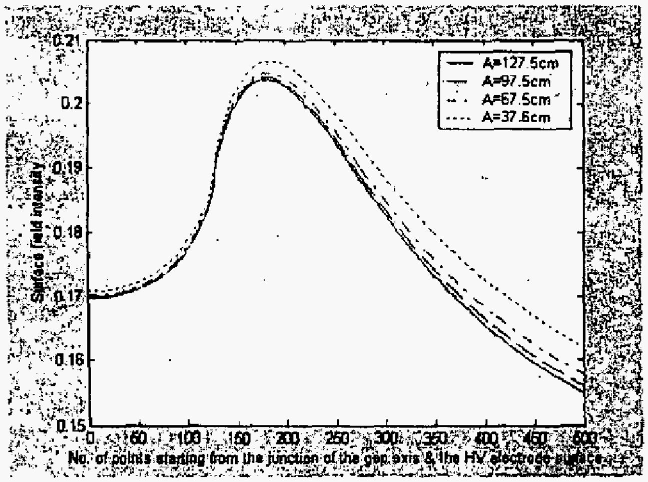

Fig. 5 Electric field intensity on electrode surface with unsymmetrical supply with "A" as parameter. ($R_c$=12.5cm; Gap=12.5cm; $R_p$=137.5cm)

## CONCLUSIONS

- In case of parallel plane electrode large plane radii of the plane electrode results in to uniform fields. But plane radius greater than the gap separation further give less improvement in uniformity.
- The nonuniformity factors are higher with the unsymmetrical supply compared to the symmetrical supply system. Also, stress distribution at the H.V. and L.V. electrode are not identical.
- The height of the H.V. electrode above the ground plane seems to have no influence on the electric field distribution in the gap.

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