Simulation of Electric Fields Using Symmetrically Placed Charges

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Abstract - The electric fields associated with sphere-plane gap geometry is simulated using charge simulation method (CSM). In the present study simulation results with symmetrical placed 6 and 14 point charges are reported. The errors in Charge Simulation Method (CSM) of sphere surface potentials are analyzed by optimally placing the charges. The optimal location of point charges used in simulation are identified using Genetic Algorithm (GA). The GA makes use of maximum-potential-error on the surface of the sphere electrode as the objective function in identifying optimal charge locations.

A large number of numerical experiments are conducted and surface error plots are reported.

The effort here has been to see the effect of optimally and symmetrically placed charges on simulation error. Results indicate that percentage maximum potential errors in simulation on the surface got reduced from 3.86e-004 to 1.30e-005 when the number of charges is increased from 6 to 14, respectively (with optimal locations).

It is known from the literature that increasing the number of charges improves results of simulation in CSM. Application of GA in conjunction with CSM have been some of the recent efforts and the present work brings out the point that non optimally located increased number of charges may not yield results with improvement in accuracy.

INTRODUCTION

The charges simulation method 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 [1,2]. 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 [3]. The unknown charges are then computed from relation

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

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).

Resulting simulation accuracy depends strongly on the choice of number, type of simulating charges, their locations, contour points and complexities of electrode configuration. This conventional method has been modified by using optimization techniques in selecting simulating charge distribution in order to maximize the accuracy [1]. The method reduces the reliance on personal experience in setting up CSM and leads to improvement in simulation accuracy. Recently, OCSM with Genetic Algorithms as optimization tools is being explored to maximize the simulation accuracy [4,5] The effort also being made to reduce the dependency of users experience in setting up CSM models by GA search techniques and analyze the simulation errors[6,7].

Genetic Algorithms are a part of evolutionary computing and rely on the principle of survival of the fittest [8,9] GA's computational schemes have been successfully applied in various areas of electrical power and high voltage engineering including shape optimization of electrodes[10] and charge simulation optimization[4,5].

Present work is aimed at analyzing the errors in CSM by numerical experimentations. As a test case the electric field due to sphere gap geometry is simulated using point charges. In simulation and analysis the charge arrangements based on symmetry and the optimized locations are considered and these results are discussed from the point view of improving CSM accuracy using GA as the tool.

Sphere gap geometry is one of the most commonly used geometry in discharge studies in high voltage engineering. Sphere-plane electrode is chosen, as it forms an important test gap from the point of high voltage engineering [11]. Also, this gap is widely used to access the numerical field computation methods [2]. In the present simulation study the results are with 'free space' as the dielectric medium.

CSM MODEL DETAILS

The sphere-plane gap geometry shown in figure 1 is simulated using point charges to analyze the CSM errors. For the sake of uniformity in comparison the gap separation 'g' is maintained 10 units with sphere radius as 1 per unit. The potential of the electrode is 1 per unit. The plane electrode is simulated using image electrode and corresponding image charges.

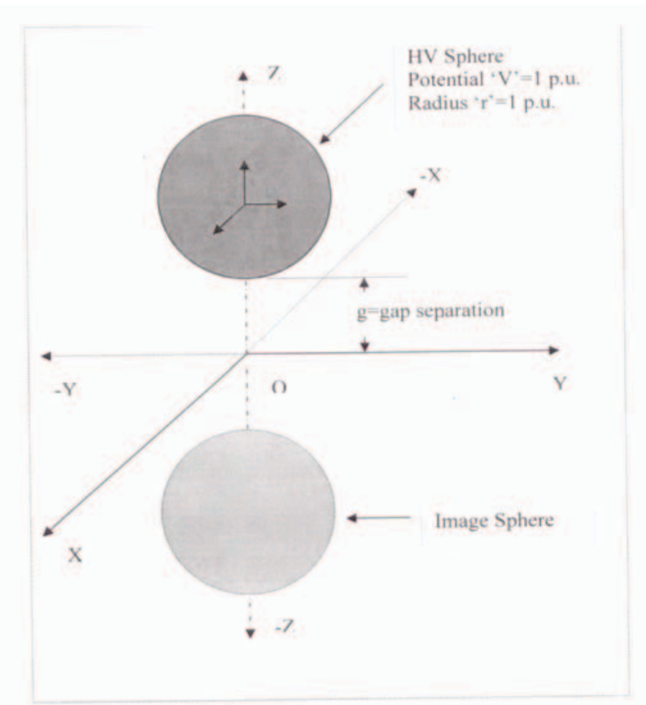

Fig 1- The Sphere-plane gap geometry simulated, shown along with the image sphere.

Charge arrangement of models

In the model with six charges, with a set of two charges on each line parallel to the coordinate axis placed on the either side of the center of the spherical electrode (within the sphere), are such that they all are equidistant from the centre of the sphere. And this radial distance is chosen as the only variable. Thus optimal locations of all the charges are obtained by obtaining this radial distance from the sphere centre coupling CSM with GA as optimization tool. That is r' (=Xq1=Xq2=Yq3=Yq4=Zq5=Zq6) is the only variable with 0<r'<r. With this arrangement six point charges lay on a sphere surface concentric to sphere electrode at a radial distance r'.

In the model with 14 charges also the charges lie on a sphere surface concentric to sphere electrode at a radial distance r', as in the case of six charge arrangement. The position of 6 charges is the same as described in earlier 6-charge model, but remaining 8 charges are placed on the sphere radius of r' at the locations equidistant from the adjacent three charges; these three charges being placed on the Cartesian coordinate axis forming the quadrant. These additional 8 charges will lie along the axis intersecting the 8 quadrants at 45° with respect to the Cartesian coordinate axis, when placed taking in to account symmetry.

DETAILS OF GA AND OBJECTIVE FUNCTION

The MATLAB tool box of GA[11] is used along with the CSM implemented for the models with 6 and 14 charges described above. The general algorithm of these models for the application program is as given below.

Algorithm for application program:

1. Decided on population size, number of generation for the GA routine. (Population size is chosen to 40 and the number of generation is 50.)
2. Specify bounds on the variables (Charge locations). In the present study bounds on charges are such that they lie within the sphere (radius<1 per unit) and are symmetrically placed.
3. Basic call to GA function: Specifying bounds and file containing the function to be optimized.
4. CSM program as function:
    - Gets initial population (or new population in subsequent generations) as charge locations.
    - Specify Geometric details in CSM program including contour points.
    - Compute charge magnitudes.
    - Compute potential error on the surface at 'n' number of points on the surface along a particular angle 'phi' (Ø) for differing 'theta' (θ) values. (See figure 3). In the present study this done with n=100 and phi=45° (for 6-charge- model) and phi=22.5°(for 14-charge-model).
    - Obtain maximum potential error 'maxerr'.

- Evaluate objective function value =1/(1+maxerr); which is to be maximized. It is supplied back to GA routine.

5. GA routine goes through Reproduction process to arrive at new population.
6. Check for generation number. If specified number of generations is completed then declare best population; else repeat steps 4 to 6.
7. The fitness function used to maximize the accuracy is of the type

$$\text{Fitness function}=1/(1+U) \qquad (2)$$

Where U is the maximum potential error and its value is obtained by CSM routine. The float genetic algorithms perform better [11] and hence this is adopted in the present work. The matlab toolbox [11] is used with the number of generations which as 50 and the population size of 40.

N UMERICAL EXPERIMENTS AND RESULTS

For model with 6 charges the results of surface potential error plot with charges placed at the radius 0.5 p.u (r'=0.5p.u. with radius of sphere r=1p.u.) is shown in figure 2. In order to determine the optimal location of the charge (that is optimal r') the GA- CSM program is run for 10 test run and the typical results with optimized location are given in figure 3. The optimal r' obtained is 0.0377 p.u..

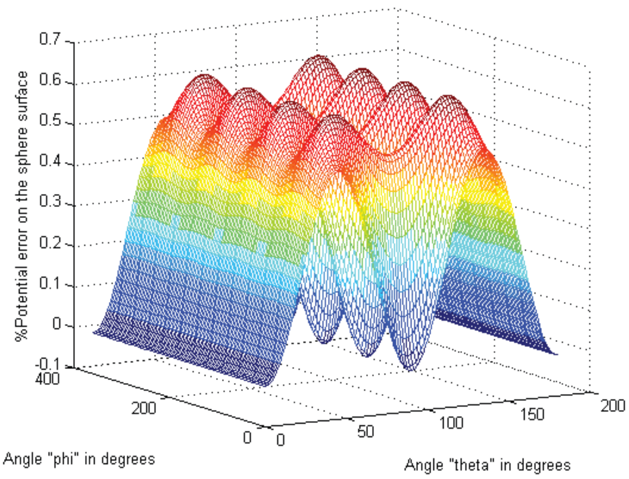

Fig 2- Variation in % potential error on the sphere electrode surface for 6-charge model.
With 'theta' € [0, 180°] and 'phi' € [0, 360°].The charges are placed at a distance 0.5 units away from the center of the sphere deviating from the optimal value; radius of spherical electrode is unity, gap separation is 10 units; potential of the electrode is unity.

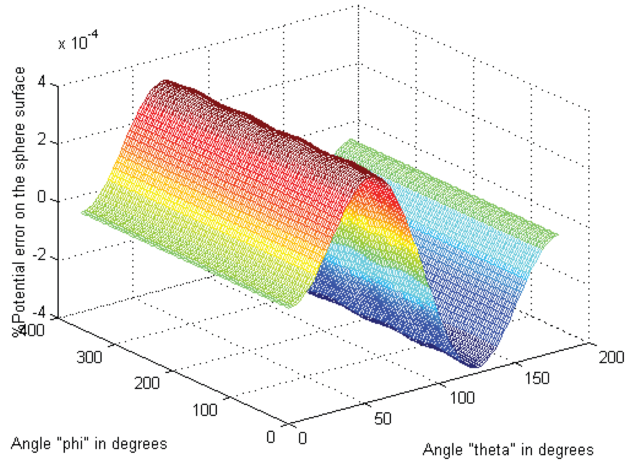

Fig 3- Variation in % potential error on the sphere electrode surface for 6-charge model.
With 'theta' € [0, 180°] and 'phi' € [0, 360°].The charges are placed at a distance 0.0364 units away from the center of the sphere (optimal value); radius of spherical electrode is unity, gap separation is 10 units; potential of the electrode is unity.

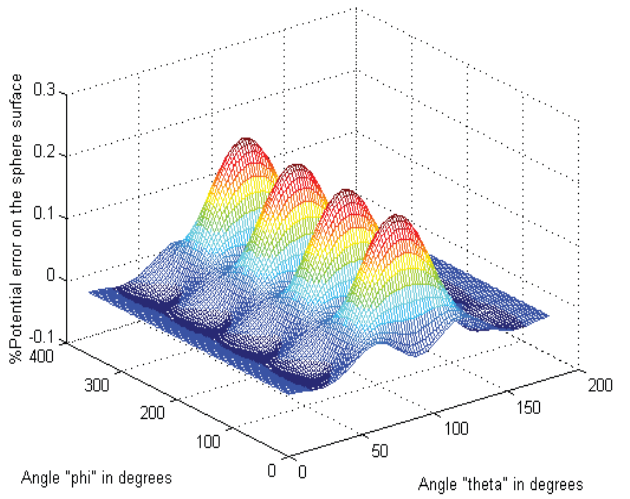

Fig.4 Variation in % potential error on the sphere electrode surface for 14-charge model.
With 'theta' € [0, 180°] and 'phi' € [0, 360°].The charges are placed at a distance 0.5 units away from the center of the sphere deviating from the optimal value; radius of spherical electrode is unity, gap separation is 10 units; potential of the electrode is unity.

For model with 14 charges the numerical experiments are carried out similar to that of 6 charge model. The potential surface error plot results with r'=0.5 p.u. is presented in figure 4. The typical results with optimized location r' for this model is given in figure 5. The optimal r' obtained for 14-charge model is 0.0346 p.u..

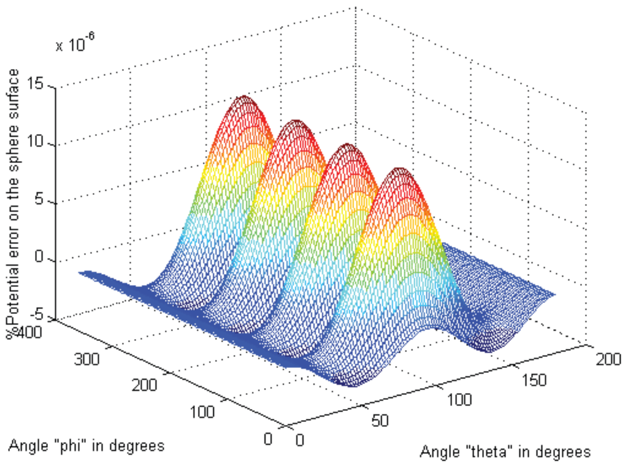

Fig.5 Variation in % potential error on the sphere electrode surface for 14-charge model.

With 'theta' € [0, 180°] and 'phi' € [0, 360°].The charges are placed at a distance 0.0377 units away from the center of the sphere (optimal value); radius of spherical electrode is unity, gap separation is 10 units; potential of the electrode is unity.

Results indicate that percentage maximum potential errors in simulation on the surface got reduced from 3.86e-004 to 1.30e-005 when the number of charges is increased from 6 to 14, respectively (with optimal locations). The computational time for 6-charge model is in order of 1 second where that for 14 charge model is 10 seconds. Comparing figures 3 and 4 it is can be concluded that increased number of charges (from 6 to 14) does not reduce give better results if they are not located optimally. As see from figures 2 and 4 with out optimized locations the maximum potential errors are in the order 0.3 to 0.7 percent. Conversely, optimally locating charges improves accuracy immensely.

CONCLUSIONS

CSM errors using point charges placed with due consideration to symmetry have been reported with differing charge numbers and optimally located arrangement. Though results are specific to sphere plane geometry following important conclusions have evolved:

- Increasing number of charges can give results with increased accuracy of simulation but this gain is not appreciable (if at all it is observed).
- Increase in number of charges without consideration to optimal locations may not yield better results in terms of accuracy.
- Simulations with symmetrically placed optimally located charges results in high degree of accuracy.
- With symmetrically placed optimally located charges if the number of charges are increased there will further improvement in the results, which is appreciable.

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