Study of GA Assisted CSM Models Using Optimally Located Point Charges

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***Abstract*- The Charge Simulation Method (CSM) due to its favorable characteristics is very commonly used technique for electric field analysis in High voltage engineering. In the conventional CSM location of these fictitious charges are predetermined by the programmer. In the present work charges are located optimally to increase accuracy. CSM models being case specific even while optimizing the model, the optimization parameters chosen play an important role. Here in the present work the models of high voltage sphere above the ground plane with and without another sphere below it are discussed. The study is done with optimally located symmetrically placed set of point charges. The infinite plane is simulated using image sphere(s).**

The paper compares the accuracies of the optimized CSM models and is an effort to evolve guide lines for CSM modeling which is a 'user experience specific' field computation method. The Genetic Algorithm (GA) is used as the tool for optimization.

Numerical experiments on the simulated models indicate that, even with optimized charge locations errors in simulating a ground potential (or lower potential) sphere in the vicinity of a high voltage sphere is always high. Also, if higher is the potential of the second sphere, lower is the CSM error. On reaching this limiting accuracy the options to improve the models accuracy further lie in selectively freeing the charges in optimization process (increasing the degree of freedom in optimization).

I INTRODUCTION

The CSM due to its favorable characteristics is very commonly used technique for electric field analysis in High voltage engineering [1]. 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 [2]. 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 column vector of known potentials at the contour points.

Resulting simulation accuracy depends strongly on the choice of number & type of simulating charges, their locations, contour points and complexities of electrode geometry. This conventional method has been modified by using optimization techniques in selecting simulating charge distribution in order to maximize the accuracy [3]. Relatively recently, OCSM with Genetic Algorithms as optimization tools is being explored to maximize the simulation accuracy [4,5].

This paper discusses some of selected numerical experimental results of GA assisted CSM models. The numerical experiments are designed and aimed at better understanding of CSM models to assist setting up of such models by the user. The search space in GA is restricted by user planned models (guided optimization models) in locating charges optimally. In order to improve the accuracy the freedom is selectively increased to improve the model performance. The results of the models with one sphere above the ground plane and two spheres (arranged vertically one below the other), above the ground with differing potentials is discussed from the point of view of simulation errors.

II GEOMETRIC DETAILS OF THE MODELS

Two test geometries involving spheres have been simulated. Details of these are as given below.

A. *One sphere above the ground plane*

Sphere above the infinite plane is basically a sphere plane geometry. But when an image sphere is used to simulate the infinite plane, it results in to sphere-sphere configuration with symmetrical supply. The details of geometry are as shown in the Fig. 1. In simulating, the sphere radius ‘r’ is considered as 0.1m and the gap spacing ‘g’ is a parameter expressed in meters. The potential of the sphere ‘V’ is +1 per unit. This implies, the radius of the image sphere is 0.1m, at ‘g’ units below the ground plane with its potential of -1 per unit. The numerical experiments are designed to understand the effect of height of the high voltage (HV) electrode above the ground plane on simulation error with optimally located, symmetrically placed six point charges placed inside the sphere.

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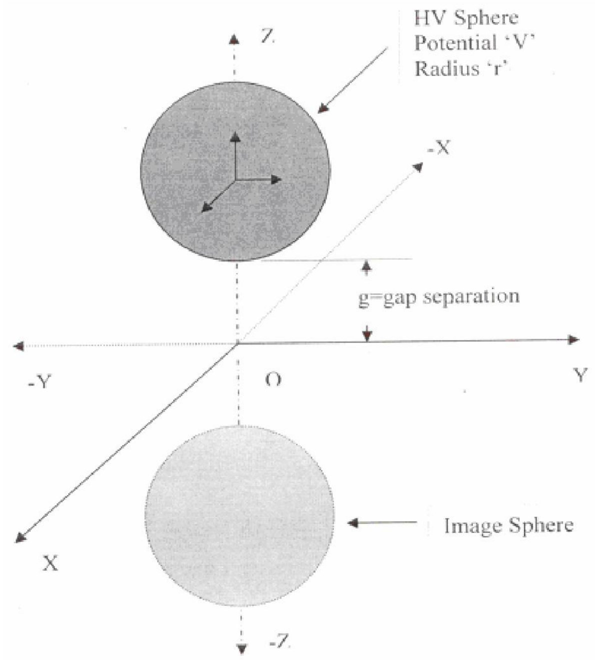

Fig. 1. Schematic of One Sphere above the ground plane.

B. *Two spheres above the ground plane*

The geometry of the test configuration is as given in Fig. 2. The geometry simulated has R1=R2=0.1m (equal sphere radius). The upper sphere forms the HV sphere with potential φ_1 and is kept at higher potential than that of the lower sphere.

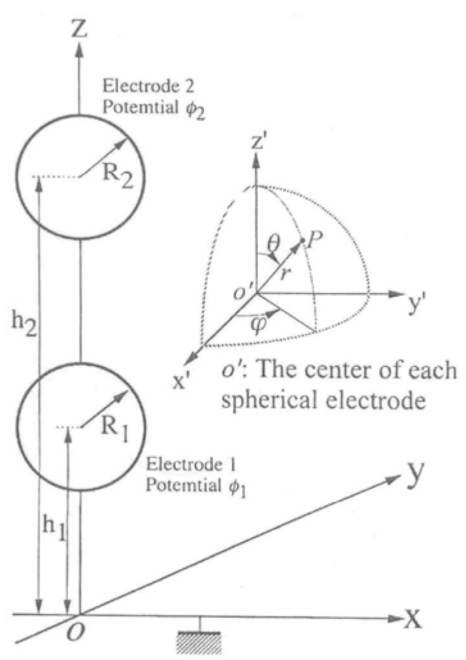

Fig. 2. Schematic of two Spheres above the ground plane. (Ground plane simulated using two more image spheres; not shown in the figure).

In the numerical experiments to understand the simulation errors, height h1 (keeping h2 constant), height h2 (keeping gap separation between spheres constant) and potential φ_1 (keeping potential difference between spheres constant) are varied systematically (with optimally located charges).

III CSM MODEL DETAILS

The CSM models use six point charges per sphere which are placed inside the sphere symmetrically over a concentric sphere of radius R_c (less than r, R_1 and R_2). It has been shown that symmetry plays an important role in CSM [6]. Two charges are placed on either side of the sphere center along the co-ordinate axis at distance R_c from the sphere center. The distance R_c is the optimal distance at which the simulation errors are minimum, determined by GA-CSM routine. The program used the six contour points whose locations are fixed and are pre-decided.

IV GA-CSM ALGORITHM

In GA-CSM algorithm, it is the location of charges which are treated as variables with freedom to move along the Cartesian coordinate axis within the spherical electrode surface. The MATLAB tool box of GA [7] is used along with the CSM models implemented. The general algorithm of these models for the application program is as given below:

Algorithm for application program:

1. Decides on population size, number of generation for the GA routine. (Population size is chosen to be 40 and the number of generation is 50.)
2. Specifies bounds on the variables (Charge locations). In the present study bounds on charges are such that they lie within the sphere (radius<0.1m) 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.
    - Specifies Geometric details in CSM program including contour points.
    - Computes charge magnitudes.
    - Computes 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°.
    - Obtains maximum potential error 'maxerr'.

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

5. GA routine goes through Reproduction process to arrive at new population.

6. Checks for generation number. If specified number of generations is completed then declares best population; else repeats steps 4 to 6.

The fitness function used to maximize the accuracy is of the type:

Fitness function=1/(1+U) (2)

Where U is the maximum potential error and its value is obtained by CSM routine. For the cases with two spherical electrodes maximum error (per unit) among the two is considered as the objective function value. The float genetic algorithm is adopted in the present work. The MATLAB toolbox [7] is used with the number of generations as 50 with the population size of 40.

It is to be noted that due to initial random seed differing from one another, there will be spread in the optimal value obtained and hence a number of test runs for each case are carried out (optimal values are not identical; differ slightly). Hence, in general, the worst case optimal results are used for the discussion.

V RESULTS AND DISCUSSION

One Sphere above the ground plane case with the gap separation (between sphere and its image) equal to the radius of the sphere (0.1m) is ±4.9%. The typical surface error plot of potential is as shown in the Fig. 3. But when the gap separation is doubled keeping the sphere radius same the errors reduced to 0.63%. It has been the observation that as the gap separation increases the simulation errors decrease rapidly and then the optimization may not be required.

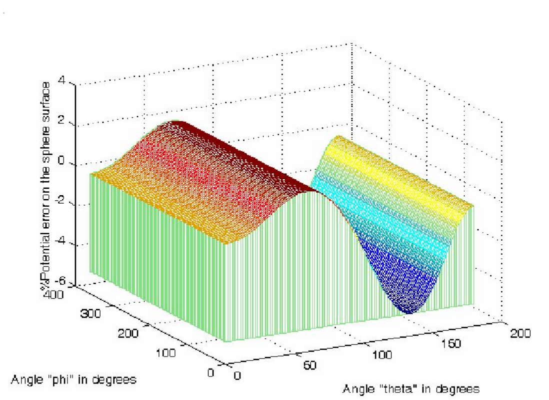

Fig. 3 Surface error plot with sphere height above the ground being 0.05m. (with sphere radius of 0.1m)

For the two spheres above the ground plane (Fig. 2.) the effort is to see the effect of lower sphere potential on the simulation error, keeping the potential difference between spheres almost equal. The results obtained are tabulated in Table-I. As the potential of the lower sphere approaches that of the ground, maximum errors in simulation are observed. These maximum errors always occur on lower (low voltage) sphere. These results are for a gap separation of 0.1m. This configuration corresponds to maximum gap separation condition for sphere gaps of diameter 0.2 m before they loose uniformity in their electric field according to the standards [8,9].

TABLE I

Potential error variation with changes in potential φ_1 (keeping potential difference between spheres constant) with optimally located symmetrically placed, six point charges per sphere.
(h_1=0.3m; h_2=0.6; gap separation=0.1m)

φ_1 (Volts)	φ_2 (Volts)	% potential error seen in simulating lower sphere
-1500	+3500	±0.5
-500	+4500	±2.1
-250	+4750	±3.7
-100	+4900	±8.2
-75	+4925	±11
-50	+4950	±15
-30	+4970	±30
-1	+5000	±820
+1	+5000	±880
+100	+5000	±7.7

With the height of HV sphere above the ground plane (h_2) being 1.8m and lower sphere being at near ground potential of 30V when moved from 1.5m to 1m the simulation errors reduced drastically. The details are as given in the Table II.

TABLE II

Potential error variation with changing the vicinity (h_1 varied) of the lower sphere from the HV sphere (keeping potential difference between spheres constant and keeping h_2 constant) with optimally located symmetrically placed, six point charges per sphere.
(φ_1=+30V; φ_2=+5kV h_2=1.8m)

h_1 (m)	Distance between spheres (m)	% potential error seen in simulating lower sphere
1.5	0.1	±30
1.4	0.2	±5.4
1.3	0.3	±1.8
1.2	0.4	±1.3
1.1	0.5	±1.0
1.0	0.6	±0.6

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This implies, simulating low potential sphere in the vicinity of a HV sphere is difficult and will have more errors as seen from tables I and II.

In order to increases the simulation accuracy one possibility is to increase the number of simulating charges on low voltage sphere. Or selectively increase the degree of freedom in obtaining optimal charge locations. In the earlier models discussed so far, all the six charges (simulating a sphere) were tied together and their optimal distance from the center of sphere was identified. Now for the lower sphere the charges along the gap axis were made free and their locations are identified independently. Though, it leads to increase in search space with GA, it yields better results. With this maximum error comes down to 11% from 30%. The typical results of surface error plots are as shown in the Fig.4 and Fig.5 for HV and low voltage spheres, respectively.

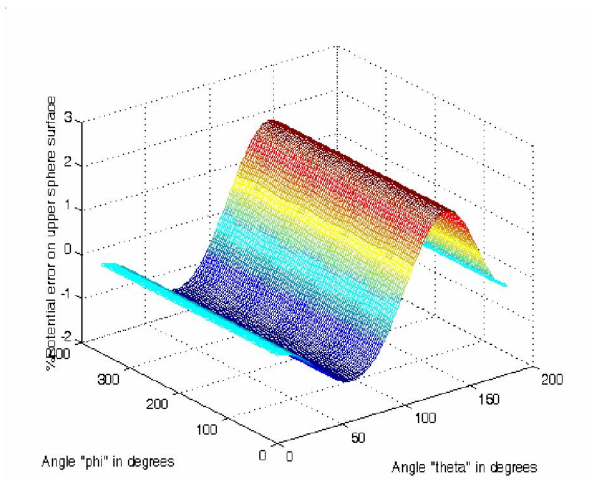

Fig. 4 Surface error plot on HV sphere with increased degree of freedom for charges in it, placed along the gap axis. (R1=R2=0.1m; h1=1.5m; h2=1.8m; φ_1=+30V; φ_1=+5kV)

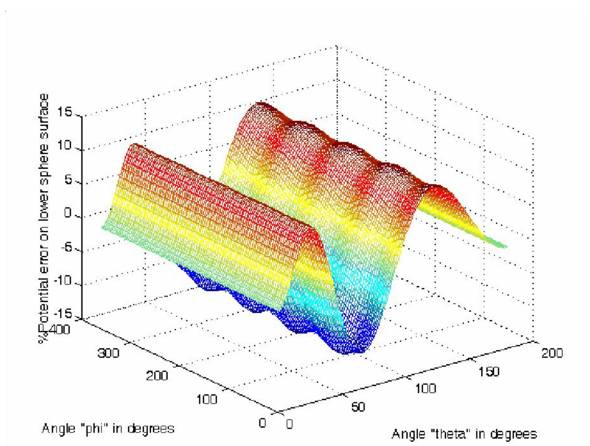

Fig. 5 Surface error plot on lower (low voltage) here with increased degree of freedom for charges in it, placed along the gap axis. (R1=R2=0.1m; h1=1.5m; h2=1.8m; φ_1=+30V; φ_1=+5kV)

VI CONCLUSIONS

Dependency of CSM accuracy on various parameters with optimally located point charges involving sphere geometry has been reported. Though the CSM programs are case specific some general observation have been made after conducting number of numerical experiments. Some of the important observations are:

- Simulating a low voltage sphere near an HV sphere involves more errors and the errors associated with low voltage sphere are higher.
- Higher the potential of the low voltage sphere (with respect to ground; polarity independent) higher will be the simulation accuracy.
- To further increase the accuracy one need to selectively increase the freedom for charges on the low voltage sphere (on which errors are more). Though, this has great advantage of reduced search space but still remains to be programmer specific.

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