Optimized Charge Simulation Models of Horizontal Sphere Gaps

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Abstract: The horizontal sphere gap is modeled using six point charges per electrode as a test case. Two intuitively felt Optimized Charge Simulation Method (OCSM) models of horizontal sphere gap arrangement are set up by selectively changing degree of freedom to understand its effect on the simulation errors. The optimal location of charges is obtained using Genetic Algorithm (GA). A large number of numerical experiments are conducted by varying potential assigned to the low potential sphere, height of the spheres above the ground plane and gap separation. Lower potential sphere always shows higher error. For a typical case, the maximum surface potential error with increased freedom in locating charges reduced to 4% from its earlier value of 9.5%. The simulations with symmetrical supply show maximum surface potential error of 1.0% on both the spheres. On the other hand simulating a ground potential electrode near a high voltage electrode involves more errors and hence more effort. The Charge Simulation Method being semi analytical technique, the shape of the geometry and symmetry (if any) plays a major role and setting up accurate OCSM model still requires user experience.

Introduction

The charge Simulation method is a well known one of the boundary based methods commonly used in electric field analysis in high voltage engineering [1]. It is an appropriate method for open boundary problems and is a widely used technique [2]. The method in its simplest form computes the charge magnitudes by satisfying the boundary conditions at the selected number of contour points. The locations of the charges and the boundary conditions are predetermined and supplied based on the experience [1-2] of the researcher. The unknown charges are computed from the relation

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

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 strongly depends on the type and number of charges, locations of contour points and complexity of electrode geometry [1-2]. Hence optimization techniques have been suggested and applied to reduce the individual experience and judgment [3-6]. The OCSM methods described in [3-5] though improve accuracy, still the basic structure of the model (guidelines on charge and contour point arrangement) relies on user experience; generally guided by symmetry of the problem. These efforts can be termed as guided OCSM. In contrast to this, efforts in [6] evolve the optimal charge and contour point arrangement without relying on user experience with CSM, using GA at the expense of highly increased computational burdens. Symmetry considerations reduce the degree of freedom in optimization and hence the search space is reduced. Hence, here computational efforts drastically reduce. The CSM being semi analytical technique the shape of the geometry and symmetry (if any) play a major role [7]. Genetic algorithms use random choice to guide a highly exploitative search and hence perform better compared to purely random search [8]. Similarly, guided optimized CSM is bound to perform better is obvious. Hence, the effort here is, to carryout a systematic study and evolve general guidelines to help set up accurate models.

The paper discusses some of the numerical experimental results of optimized CSM models of horizontal sphere gap arrangement. GA has been used as the optimization tool. The search space is restricted by user planned models and the effort here is to see the effect of increased degrees of freedom on simulation accuracy of the models.

Details of the geometry simulated

The geometry chosen as a test case is a horizontal sphere gap arrangement. The schematic representation of the same is as shown in the figure 1. The parameters associated with the geometry, namely, sphere diameter is chosen as 0.125 m, being one of the standard sphere sizes [9]. Numerical experimental results reported are for equal diameter spheres with the gap spacing ‘g’ varied as 0.0625m, 0.075m and 0.125m with height of the spheres above the ground plane, ‘h’, as 7 times the diameter of the sphere. The results of effect of height of the sphere above the ground plane on simulation model accuracy are also reported for a fixed gap spacing of 0.0625 m.

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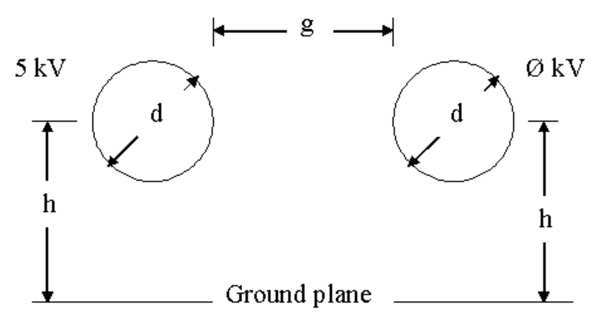

Figure 1: The schematic representation of the horizontal sphere gap simulated. The diameter of spheres is 0.125m. The simulation parameters are: potential assigned to the ground sphere 'Ø', height of spheres above the ground plane 'h' and the gap spacing 'g'.

CSM Model details

Two CSM models of the geometry described are studied and reported. Both the CSM models use six point charges per sphere to simulate. The charges inside each sphere are placed along the co-ordinate axes as shown in the figure 2. For a given geometry, based on intuition a number of Optimized Charge Simulation Method (OCSM) models are possible, even for a fixed number of charges. In model-I all the six charges for both spheres are tied together, independently and their optimal location from the center of the spheres is determined by GA-CSM routine. The potential error associated with sphere with lower potential is always higher. Hence, in model-II freedom to charges is increased in the low potential sphere. Here, inside the low potential sphere, the distances of the charges placed along the gap axis (those of q3 and q4) and those placed parallel to 'h' axis (those of q5 and q6) formed four additional variables and are determined independently. The program makes use of six contour points per sphere whose locations are fixed and are pre-decided. The infinite ground plane is simulated using image spheres.

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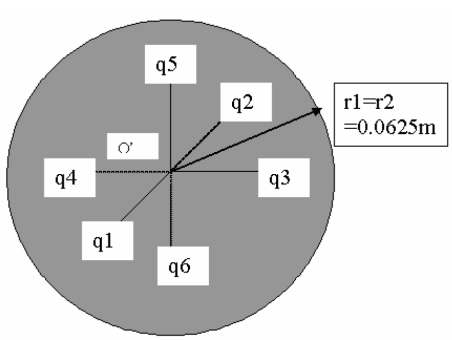

Figure 2: General charge arrangement within the spherical electrodes. (O' is the center of the sphere. Charges q1, q2, q3, q4, q5 and q6 are the six charges placed on the axis within the sphere.)

GA-CSM details

The MATLAB tool box of GA [10] is used along with CSM models for the study. The locations of charges are treated as variables with freedom for the charges to move along the Cartesian co-ordinate axes within the spherical electrode surface. The program flow chart for the application program is as given in the figure 3.

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

$$f = 1/(1+U) \tag{2}$$

Where U is the maximum surface potential error and its value is determined by CSM routine. The float genetic algorithm is adopted in the present work with number of generations as 50 and the population size of 40 using the tool box [10]. A number of test runs for each case are carried out as the results differ slightly, due to initial random seed not being identical. The best case optimal results for both the models are reported and discussed.

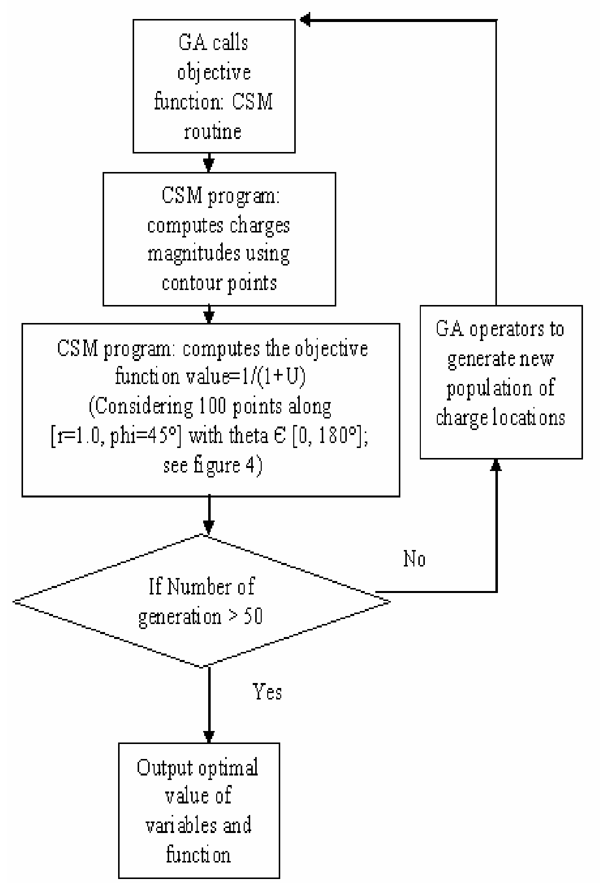

Figure 3: General flow of the application program for GA-CSM routine.

Results and discussion

Some of the typical results related to surface error plots, effect of variation in potential ‘φ’ assigned to the low voltage electrode on simulation accuracy, error variation with geometric parameters like gap separation ‘g’ and height of the spheres above the ground plane ‘h’ are discussed below.

Surface error plots: The typical surface error plots for Model-I (with 2 variables) and Model-II (with 6 variables) are shown in figures 4, 5 and figures 6, 7 respectively, under identical conditions except for the charge locations. Figures 4 and 6 are for the high voltage (HV) sphere (5kV) and figures 5 and 7 are for the low voltage (LV) sphere with an assigned potential of -100V. The x & y axes in these figures (angle “phi” and angle “theta”) correspond to spherical co-ordinates.

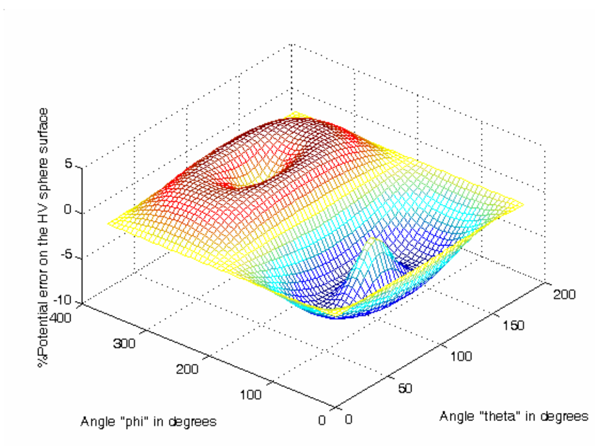

Figure 4: Typical error surface plot of the HV sphere for model-I. (d=0.125 m; g=d/2=0.0625 m; h=7d)

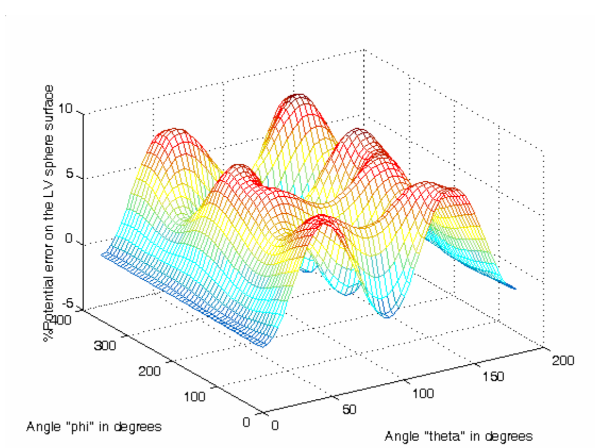

Figure 5: Typical error surface plot of the LV sphere for model-I. (d=0.125 m; g=d/2=0.0625 m; h=7d)

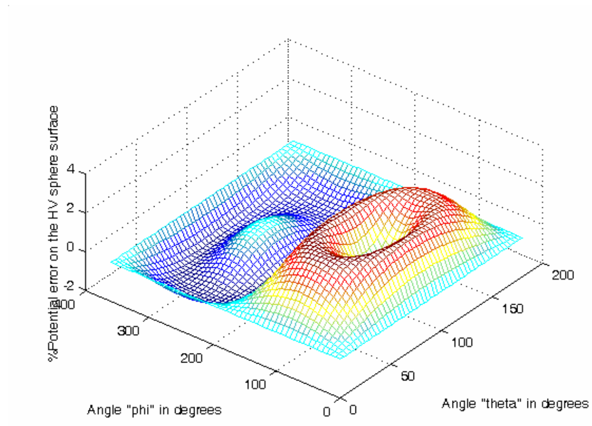

Figure 6: Typical error surface plot of the HV sphere for model-II. (d=0.125 m; g=d/2=0.0625 m; h=7d)

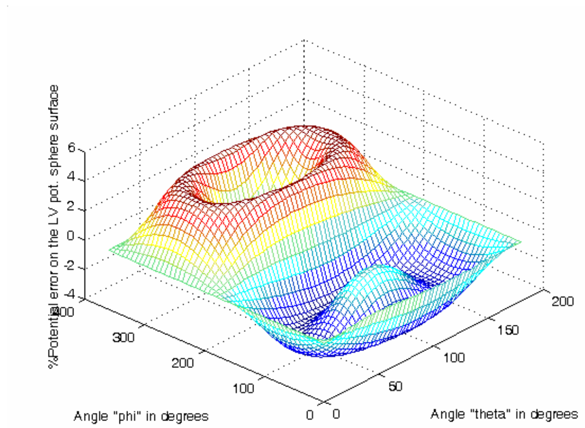

Figure 7: Typical error surface plot of the LV sphere for model-II. (d=0.125 m; g=d/2=0.0625 m; h=7d)

It is to be noted that error on the HV sphere is less than that of LV sphere. Also, due to increase in the freedom of locating charges, the maximum surface potential error for LV sphere for model-II is less than ±4%, where as under identical conditions this error for model-I is 9.5%. The interesting thing to be observed by comparing Figures 5 and 7 is that the surface error profile has lost the irregularities and has become more systematic; having allowed the charges to locate independently, probably exploiting up to its limit of accuracy for model-II. Also, LV electrode error profile has assumed the shape similar to that of HV electrode, which dominates the simulation process.

Effect of potential assigned to LV electrode: The ground electrode in the vicinity of HV electrode is assigned different potential systematically and its effect on error variation of OCSM models is reported. The potential assigned is of both polarities and it is varied in steps starting form ±1 V to ±5kV. Figure 8

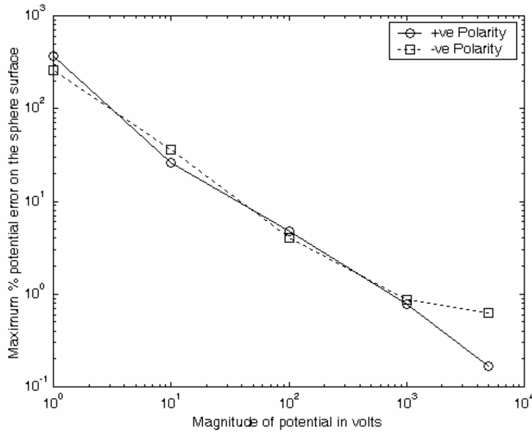

Figure 8: Maximum surface potential error as a function of potential 'φ' for Model-II. (Potential of HV sphere held at 5 kV; g=d/2; h=7d).

compares the variation of errors for model-II with polarity as the parameter. Polarity seems to have less effect. But simulating a sphere of low potential (implying near-ground potential) sphere in the vicinity of a HV sphere encounters more simulation error. Figure 9 compares the performance of two models studied and model-II in general, is seen to perform better.

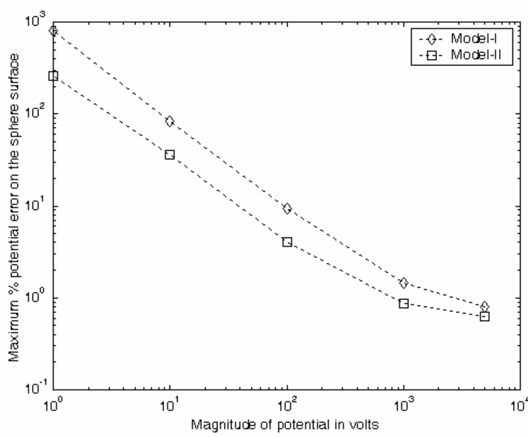

Figure 8: Maximum surface potential error as a function of potential 'φ' of LV sphere (Potential of HV sphere held at 5 kV; g=d/2; h=7d).

Effect of variation in 'h' and 'g': In general as height of the spheres above the ground 'h' and gap separation 'g' increase, the simulation errors for both the models studied decrease. But in all the cases the model-II shows better accuracy than model-I.

Conclusions

A number of optimized CSM models can be designed for a given problem and hence setting up of the OCSM models also relies on the personal experience of the user. Based on symmetry, selectively freeing the charges in optimization, one can expect better results. This has been shown with a specific example in which error got halved just by changing OCSM model by selectively freeing charges, keeping number of charges same. Simulating an electrode which is near-ground potential involves more error. A ten times increase in potential (near around ground potential; 1V to 10V) resulted in more than ten fold increase in simulation error. The surface error plots can be more educative and help understand OCSM errors better.

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