CHARGE SIMULATION METHOD ERRORS, FIELD FACTORS AND OPTIMAL ASSIGNMENT FACTORS

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Abstract: The optimal assignment factors 'f_a' and the errors associated with Charge Simulation Method (CSM) for typical values chosen over the entire range (from near uniform to highly non uniform field) of electric field non uniformity factors '*f*' (also termed as field factors) are computed for the sphere-plane geometry and are reported. The data generated using GA as the optimization tool is thought to be useful in setting up accurate CSM programs, which ~~are~~ generally bank on users understanding CSM.

1 INTRODUCTION

The charge simulation method (CSM) is one of the widely used numeric field computation technique ideally suited for simulating open boundary problems [1-2]. The high voltage engineering makes use of this technique extensively [3].

The method in its simplest form (conventional CSM) 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 chosen based on the experience [1] of the researcher. The unknown charges are computed from the relation (1) by setting up simultaneous equations

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

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.

CSM accuracy depends on the choice of type of simulating charges, their number, location of these charges and the contour points. Hence, the CSM programs for a particular application become case specific and depend on the programmer. Setting up an accurate CSM model, calls for familiarity and understanding of the programmer with the CSM. In order to help, the empirical relations relating location of charges with the contour points become useful. One such parameter is the assignment factor 'f_a' [1]. The attempts are made to locate the charges using optimized charge simulation methods (OCSM) [4-8] instead of 'f_a' as the guiding parameter. With GA as a tool, with number of charges pre-decided (by the programmer) using point charges (also pre-decided) automatic allocation of these charges and contour points is attempted, relatively recently [9]. All these efforts are to reduce the need of user's experience. Even with all these efforts, the CSM programs have remained user and case specific as regards to the choice of type and number of charges. The CSM being a semi analytical technique makes use of potential and field coefficients of simulating charge configurations [1-2], user interference and knowledge can be an advantage. Based on the symmetries of the simulating charges and those of the geometry simulated, user through experience can guide the charge arrangement in relation with the contour point locations. Hence, it is felt that empirical guiding parameter like 'f_a' and its impact on the simulation errors needs further understanding. The present work reports, optimal assignment factors (and corresponding errors) for selected non uniformity factors over entire range.

The earlier investigations [1, 10] give guidelines with ring charges as the fictitious charges and indicate that 'f_a's in the region of 1 to 2 can achieve acceptable accuracies. Where as the range of values, 'f_a' can assume depends on the type and number of charges.

The effort in this work has been to relate 'f_a' with '*f*' [11]. This has been attempted with, sphere-plane gap and ring charge models (with 3, 5 and 10 ring charges). Using GA as a tool best 'f_a's at which errors are minima have been computed for select set of '*f*'s, covering the wide range (near uniform to highly non uniform fields) of non uniformities. These results are believed to be unique and are being reported, perhaps, for the first time. They should help the CSM programmers, in furthering the understanding of CSM errors and aid in setting up accurate CSM programs.

2 PARAMETERS OF STUDY AND MODEL

2.1 Assignment Factor ' f_a'

It 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). The schematic

showing the charges and the contour points given in Fig. 1 depicts distances 'a1' and 'a2'.

$$f_a = \frac{a2}{a1} \qquad (2)$$

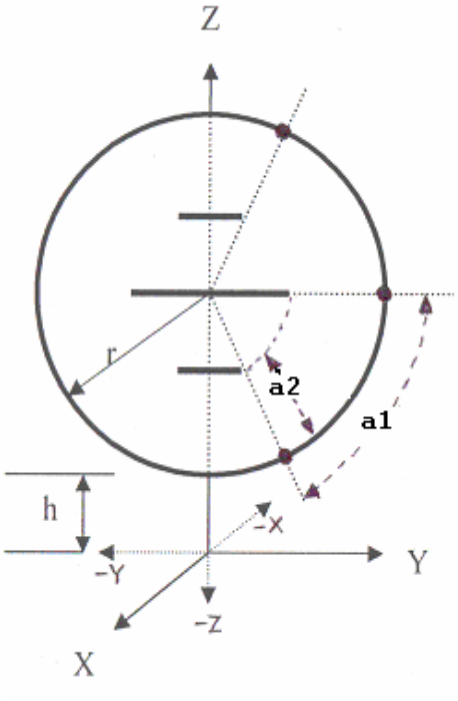

Figure 1: The sphere-plane model showing three ring charge arrangement inside the sphere. The parameters related to assignment factors (a1 and a2) are also depicted.

Type of simulating charges is chosen based on the profile of the geometry. One also decides the number and general arrangement taking in to account the accuracy requirements and symmetry. Further, it is the exact location of these charges in relation with the contour points that needs to be decided, to maximize the accuracy. This aspect is quantified by the parameter, 'assignment factor'. Literature, states that it should be in the region of 1 to 2 for a low error [1, 10]. This is being analyzed by numerical experiments for differing electric field uniformities.

2.2 Field non uniformity factor '*f*"

The electric field non uniformity factor is defined as the maximum electric field intensity (Emax) in the gap (occurring at the tip of the high voltage electrode) to the average electric field intensity (Eav=U/h; where 'U' is applied potential and 'h' the gap separation) as given in equation (3).

$$f = \frac{E\ \max}{Eav} \qquad (3)$$

The reciprocal of this, field non uniformity factor, is called the electric field utilization factor '*η*'(equation (4)).

$$\eta = \frac{1}{f} \qquad (4)$$

The *'η'* can assume a value any where from 0 to 100% and is used to interpret how best the insulation in the gap is being utilized. These gap factors have been extensively used in the literature in interpreting the electric field dependency, breakdown and corona inception behaviors of electrical insulation. For this purpose, these factors are also computed and reported in the literature for the simple geometric forms [11, 12]. The '*η*' & '*f*' which depend on the gap spacing 'h' and the sphere radius 'r' are reported for the sphere-plane gap in reference [11]. This data is used to compute the corresponding CSM errors by successive simulations in this systematic study.

2.3 Model details

2.3.1 Geometric details of sphere-plane model

The sphere electrode radius, 'r', is considered as 1 per unit (Fig. 1). And with respect to this, the gap separation is, 'h' per unit. It is the dimension 'h' in relation with 'r' that decides the electric field non uniformity of the geometry [11]. Image sphere ~~is~~ used simulates the infinite ground plane (Not shown in Fig. 1).

2.3.2 CSM Model details and range of 'fa'

The sphere-plane geometry is simulated using ring charges (3, 5 or 10 in the present study). The charges are placed inside the sphere symmetrically and spaced equally. The range of values, the *'fa'* can assume, is specific to the model depending on the type of charges and their number. The range of *'fa'* for the models under study are given in table-I. The range of '*fa*' also depends on the type of charges; for six-point-charge model of sphere-plane gap the range varies from 0 to 0.637 [14].

Table 1: Range of assignment factors for the sphere-plane models

Model description	'a1'(=πr/n) (r=1 p.u.; n=no. of charges)	Range of assignment factor 'f_a'(= a2/a1)
3-ring charges	1.047	0 to 0.955
5-ring charges	0.628	0 to 1.591
10-ring charges	0.314	0 to 3.183

2.3.3 Optimal 'fa' using Genetic Algorithm (GA)

The optimal value of the '*fa*' is obtained for few typical values of the '*η*'s chosen from its entire

range (listed in [11]), using GA as the optimization tool [13]. The root mean square (rms) potential error on the surface formed the objective function in error minimization. The rms value is obtained by evaluating errors at 100 regularly spaced points on the surface of sphere. The GA, as the optimization, tool used randomly generated initial population of size 40 with 25 numbers of generations as the termination criteria. The bound for *'fa'* were chosen based on its range, appropriately. In arriving at the optimal value a minimum of 5 test runs are carried out, as the initial population is generated randomly.

3 RESULTS

The evaluated optimal values of the *'fa'*s for the corresponding *'f'*s can be seen in Fig. 2. Using these optimal values of *'fa'*s (obtained using GA-CSM program), the maximum potential error, maximum deviation angle error, rms potential error and rms deviation angle error are calculated for different *'f'*s. Only the rms potential errors are plotted in Fig. 3, as similar trends are observed with other error criteria.

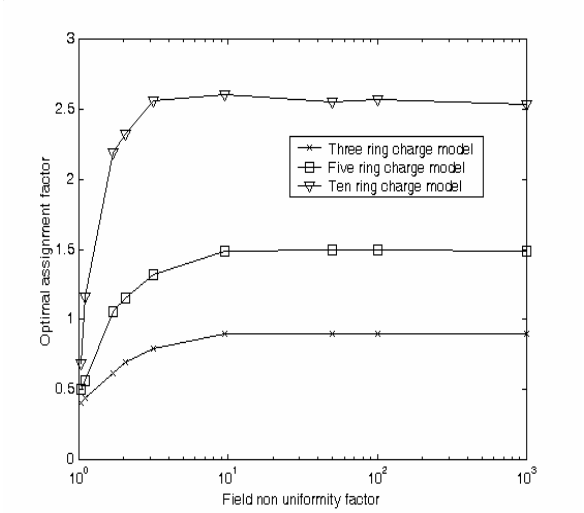

Figure 2: Optimal assignment factors 'fa' as function of field non uniformity factors 'f' for the sphere-plane gap.

4 CONCLUSION

The best value of the assignment factor for a CSM model is unique. Higher the non uniformity factor higher will be the assignment factor for the model, within its applicable range (range depending on the type and number of charges; being model specific). Hence, the CSM programs remain user specific. Errors associated with the CSM models are inherently higher, when field utilization factor is higher (near uniform field configuration). CSM errors are analysed in the light of field non uniformity factors probably for the first time and should help the CSM users.

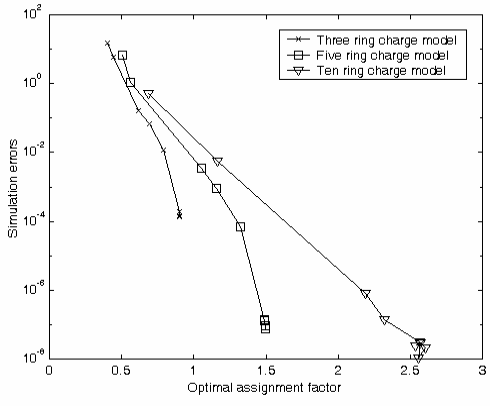

Figure 3: rms potential errors as a function of optimal assignment factors 'fa' (corresponding to 'f' in Fig. 2) for the sphere-plane gap.

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