Analysis of Electric Field inside HV Substations using Charge simulation method in three dimensional

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***Abstract* - With the development of cities and electric power industry, the demand of electrical energy, generation, transmission, distribution and the voltage levels have increased considerably. Therefore the power frequency electric field and environmental impact assessment near / under the high voltage overhead busbars, incoming and outgoing feeders inside the high voltage substations (HVS) have caused wide public concern. Nowadays most research on electric field are concerned with calculation the electric field distribution around the transmission lines, insulators and cables but they rarely concerned with its calculation inside HVS. In this paper, a different type of calculation is achieved, the charge simulation method (CSM) is employed to analyze the three dimensional (3-D) electric field distribution near / under the busbars, incoming and outgoing feeders. At last, the effects of changing the level of operating voltage, the space between the phases, the level of calculation inside HVS is demonstrated.**

***Index Terms*- Three dimensional electric field, Charge simulation method, High voltage substation, Field distribution.**

I. INTRODUCTION

With the economic development and people's increasing environment awareness in Egypt, the electromagnetic environmental problem caused by HV overhead busbars, incoming and outgoing feeders inside HVS is paid more and more attention. Today electromagnetic environment has become the critical factor which determines the construction (size, weight and insulation thickness) of electrical equipments in order to remain competitive. Therefore, it is necessary to analyze the distribution of electric field near / under the HV overhead busbars, incoming and outgoing feeders inside HVS especially at the level of human body above the ground in the working area. How to reduce the electric field intensity produced has been a hot issue in the field of environmental protection and electromagnetic compatibility technology [1].
With the development of electric power system and increase of voltage level, it is very important to assure the reliability and stability of high voltage electrical equipment. In the insulation design and analysis of electric apparatus, one of the necessary numerical simulations involved is electric field computation [2]. CSM in 3-D is employed in this paper to assess the electric field distribution near / under HV overhead busbars, incoming and outgoing feeders inside HVS.

II. SUBSTATION DESCRIPTION AND SYSTEM MODELING

For evaluating and simulate the electric field produced by HV overhead busbars, incoming and outgoing feeders inside HVS, 500/220 kV conventional electrical power substation is chosen; located in the west of Cairo nearby the Cairo- Alexandria desert road, Egypt. This substation has a three identical power transformers are installed inside it. Each transformer has a nominal power of 500 MVA and a nominal voltage rate of 500/220 kV. The investigated substation has a simply busbars which are 300m long and 12m height above the earth for upper busbars (higher voltage busbars) and 300m long and 9m height above the earth for lower busbars (Lower voltage busbars). The considered busbar area is shown in Fig.1, which shows the arrangement of busbars, vertical connectors, incoming and outgoing feeders. Each phase from each busbar, vertical connector, incoming and outgoing feeders is divided into a small sections which are simulated as linear charges. The mirror charge as shown in Fig. 2, is considered because of the impact of ground. Fig. 3, shows the distribution of finite line charges, check points and boundary points sample on only one phase from each busbar, vertical connector, incoming and outgoing feeders.

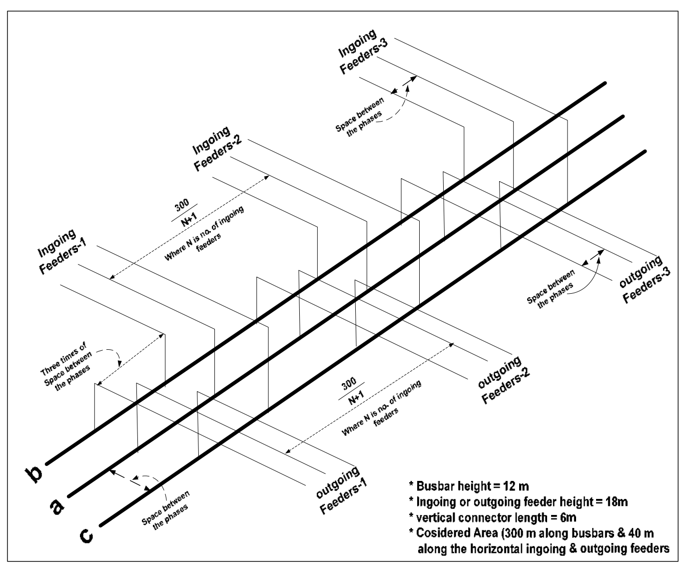

Fig. 1 the considered busbar area model for calculating the electric field.

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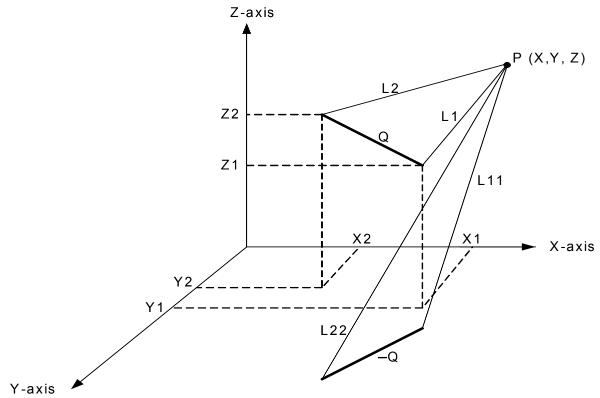

Fig.2 Linear charge calculation diagram in three-dimensional spaces.

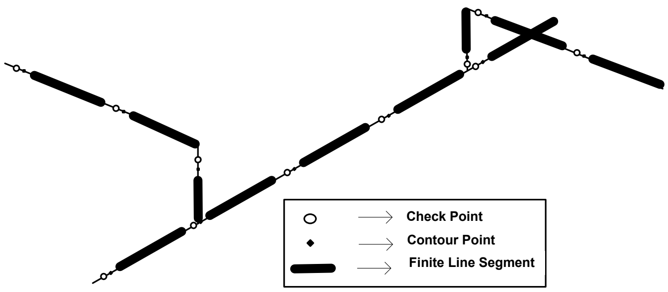

Fig.3 The distribution of finite line charges, check points and boundary points on one phase only of our model.

III. Electric Field Calculation

The basic physics of quasi-static fields allow separate discussion of power frequency electric fields. The solution methodology for the electric fields is highlighted in this section [1, 3]. The electric field can be simulated by either analytical or numerical methods. In many circumstances, the situation is so complex that analytical solutions are difficult or impossible, and hence numerical methods are commonly used for engineering applications. The electric field is usually calculated with the use of several numerical methods through a computer, *such as*:

1) Finite differences methods (FDM)
2) Finite elements method (FEM)
3) Boundary element method (BEM)
4) Charge simulation method (CSM)

These methods are highly dependent on the human experience and on trial and error. The charge simulation method is one of them which is commonly used for engineering applications to compute successfully and accurately the electric field. This method is the most understandable one and it is relatively simple to Program and accurate [4]. The charge simulation method gets approximate solution and has a little difference from actual situation. The way to improve the accuracy of calculation is choosing suitable type, number and position of simulated charges. The key to solve the electric field distribution near / under HV overhead busbars, incoming and outgoing feeders inside HVS is how to deal with them, and impact of ground [1]. We use this method in our research to simulate the 3-D electric field distribution near / under the busbars, incoming and outgoing feeders inside HVS.

A. *The Principle of using CSM for the Calculation of Electric Field*

The solution methodology for electric field is based on three dimensional charge simulation method. This commonly used approach consists essentially of *two stages:*

1) Calculation of the equivalent charges.
2) Calculation of the electric field produced by these charges.

The general relationship used to calculate the charges on a considered system is presented in matrix form as shown in (l).

$$[Q] = [P]^{-1}\,[V] \qquad \ldots\ldots (1)$$

$$[V] = [P]\,[Q] \qquad \ldots\ldots (2)$$

Where: [Q] is a column vector of the fictitious simulation charges; [V] is a column vector of the potential given by the boundary conditions; $[P]^{-1}$ is the inverted matrix of the Maxwell potential coefficients [3, 4].

There are two essential features concerning an effective application of the CSM for calculation the three dimensional electric field. The first relates to the proper selection of the types of simulation charges, and the second to a suitable arrangement of the charges and contour points [1-4].

B. *Potential and field coefficients of substitute charges*

The charge simulation method was adopted here to simulate three dimensional electric field distribution inside HVS, so the busbars, vertical connectors, incoming and outgoing feeders are dissected into certain number of finite straight-line charges extending parallel to their axes and separated by very small spaces.

Consider a finite line charge Q_i of length d with both ends at (X_1, Y_1, Z_1) as end point and (X_2, Y_2, Z_2) as start point. The potential coefficient P_{iJ} at the point P_J (X, Y, Z) due to this charge and its image charge - Q_i with respect to the plane, fig. 2, is given as [5]:

$$P_{ij} = \frac{1}{4\pi\varepsilon d}\ln\left\{\frac{(L_1 + L_2 + d)(L_{11} + L_{22} - d)}{(L_1 + L_2 - d)(L_{11} + L_{22} + d)}\right\} \qquad \ldots. (3)$$

The X, Y, Z components of the field coefficients (F_x, F_y, F_z) at any point P_J are given by:

$$F_x = \frac{1}{4\pi\varepsilon d}\left\{\left(\frac{X - X_1}{L_1} + \frac{X - X_2}{L_2}\right)\Gamma 1 - \left(\frac{X - X_1}{L_{11}} + \frac{X - X_2}{L_{22}}\right)\Gamma 2\right\} \qquad \ldots.. (4)$$

$$F_y = \frac{1}{4\pi\varepsilon d}\left\{\left(\frac{Y - Y_1}{L_1} + \frac{Y - Y_2}{L_2}\right)\Gamma 1 - \left(\frac{Y - Y_1}{L_{11}} + \frac{Y - Y_2}{L_{22}}\right)\Gamma 2\right\} \qquad \ldots.. (5)$$

$$F_z = \frac{1}{4\pi\varepsilon d}\left\{\left(\frac{Z - Z_1}{L_1} + \frac{Z - Z_2}{L_2}\right)\Gamma 1 - \left(\frac{Z + Z_1}{L_{11}} + \frac{Z + Z_2}{L_{22}}\right)\Gamma 2\right\} \qquad \ldots. (6)$$

Where

$$L_1 = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z - Z_1)^2}$$

$$L_2 = \sqrt{(X - X_2)^2 + (Y - Y_2)^2 + (Z - Z_2)^2}$$

$$L_{11} = \sqrt{(X - X_1)^2 + (Y - Y_1)^2 + (Z + Z_1)^2}$$

$$L_{22} = \sqrt{(X - X_2)^2 + (Y - Y_2)^2 + (Z + Z_2)^2}$$

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$$

$$\Gamma 1 = \frac{1}{(L_1 + L_2 - d)} - \frac{1}{(L_1 + L_2 + d)}$$

$$\Gamma 2 = \frac{1}{(L_{11} + L_{22} - d)} - \frac{1}{(L_{11} + L_{22} + d)}$$

So the X, Y, Z components of the electric field (E_x, E_y, E_z) at any point P_J are given by:

$$E_x = \sum_{j=1}^{n} (F_{ij})_x * Q_i \quad \text{........ (7)}$$

$$E_y = \sum_{j=1}^{n} (F_{ij})_y * Q_i \quad \text{........ (8)}$$

$$E_z = \sum_{j=1}^{n} (F_{ij})_z * Q_i \quad \text{........ (9)}$$

So the net field E_{ti} at any point P_J is given by:

$$E_{ti} = E_x * a_x + E_y * a_y + E_z * a_z \quad \text{....... (10)}$$

$$E_{ti} = \sum_{j=1}^{n} (F_{ij})_x * Q_i * a_x + \sum_{j=1}^{n} (F_{ij})_y * Q_i * a_y + \sum_{j=1}^{n} (F_{ij})_z * Q_i * a_z \quad \text{........ (11)}$$

Where a_x, a_y and a_z are unit vectors in the x, y and z directions, respectively [5].

C. Three Dimensional Electric Field simulation inside HVS using CSM.

Each phase of busbars, vertical connectors, incoming feeders and outgoing feeders is simulated by a number of finite straight-line charges extending parallel to their axes and separated by very small spaces. To determine the unknown charges of assumed segments of total number N_t, a number of N_t boundary points are selected on the surface of each phase along the radial direction at the middle of the spacing between finite line charges as shown in Fig. 3. At each boundary point, the calculated potential due to all the fictitious charges is equal to the applied voltage. Applying (2) at all the boundary points results in a set of simultaneous equations whose solution determines the unknown simulation charges. The charges are complex because the applied phase voltages are also complex:

$$V_a = V \cos(wt)$$
$$V_b = V \cos(wt - 120^0) \quad \text{......................(12)}$$
$$V_c = V \cos(wt + 120^0)$$

To check the accuracy of the calculated unknown charges, a number of N_t check points are selected midway between the boundary points and the starting of each fictitious charge segment as shown in Fig. 3. Applying (2) at all check point's results in a set of simultaneous equations whose solution determines the calculated potential at the check points. The deviation of the calculated potential at the check points from the applied voltage measure the accuracy of simulation [1-5].

IV. Results And Discussion

The height of a typical worker (human body) is assumed to be 1.75 m. Therefore the computation for electric field is conducted at 1m height from the ground. After computation of field's values at these points along the human body, the maximum value of the electric field intensity is recorded.

For the investigated model, assume different number of finite-line charge segments, n_1, n_2, n_3 for each phase of busbars, vertical connectors, incoming and outgoing feeders. The simulation charges were determined and the potential was calculated at the check points. The three dimensional components of electric field intensity were calculated.

By applying a different number of finite line charge segments on our system, we found the minimum value of calculation error results in the calculated potential at the check points is obtained when n_1=8, n_2=2 and n_3=4. So we assume this case is the base case of our study.

A. Analysis of electric field due to changing the operating voltage.

Table 1 show the effect of changing the operating voltage on the electric field intensity, from the data in this table we deduced that as the operating voltage increased the electric field intensity at the same height level increased. and the location of this maximum field Point is not displaced as shown in Fig. 4, Fig. 5 and Fig. 6.

B. Analysis of electric field due to changing the height level of calculation under operating voltage of 500KV.

Table 2 show the effect of changing the height level of calculation increased on the electric field intensity, from the data in this table we deduced that as the height level of calculation increased, the maximum value of calculated field intensity is increased due to the near from the live system.

C. Analysis of electric field due to changing the spacing between the phases under operating voltage of 500KV.

Table 3 show the effect of changing the spacing between the phases on the electric field intensity, from the data in this table we deduced that as the phase spacing increased the maximum value of calculated field intensity is increased due to decreasing the cancellation factor.

TABLE 1
The Field Calculation Due to Changing the level Of Operating Voltage

The Operating Voltage	Total no. of Charge Segments	The height level of Calculation (m)	The spacing between the phases (m)	Maximum Field Value (KV/m)	Average Field Value (KV/m)	Position of maximum field (x,y) in meter
500 KV	132	1	6	13.45	4.91	(19, 21)
220 KV				5.92	2.16	(19, 21)
66 KV				1.77	0.64	(19 , 21)

TABLE 2
The Field Calculation Due to Changing the Height Level of Calculation

The Operating Voltage	Total no. of Charge Segments	The height level of Calculation (m)	The spacing between the phases (m)	Maximum Field Value (KV/m)	Average Field Value (KV/m)	Position of maximum field P(x,y) in meter	% error with respect to base case
500 KV	132	1	6	13.45	4.91	(19, 21)	Base Case
		2		13.95	5.05	(19, 21)	3.69
		3		14.83	5.38	(19 , 22)	10.23
		4		16.54	5.84	(19, 22)	22.96

TABLE 3
The Field Calculation Due to Changing the Space between the phases

The Operating Voltage	Total no. of Charge Segments	The spacing between the phases (m)	The height level of Calculation (m)	Maximum Field Value (KV/m)	Average Field Value (KV/m)	Position of maximum field P(x,y) in meter	% error with respect to base case
500 KV	132	6	1	13.45	4.91	(19, 21)	Base Case
		4		11.85	3.85	(57, 22)	-11.95
		8		14.65	5.48	(19, 21)	8.85

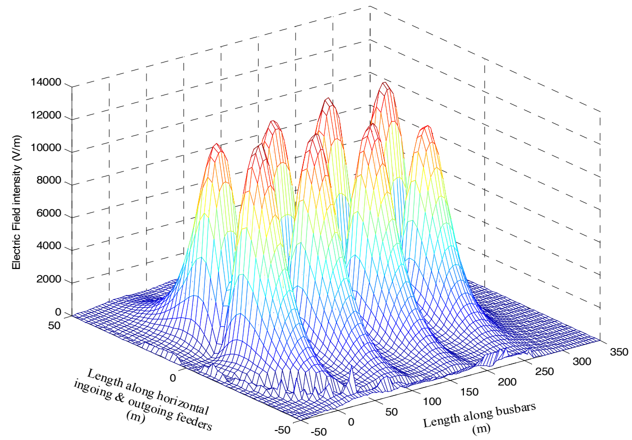

Fig. 4 Electric field distribution at 1m height for the base case under a 500 KV

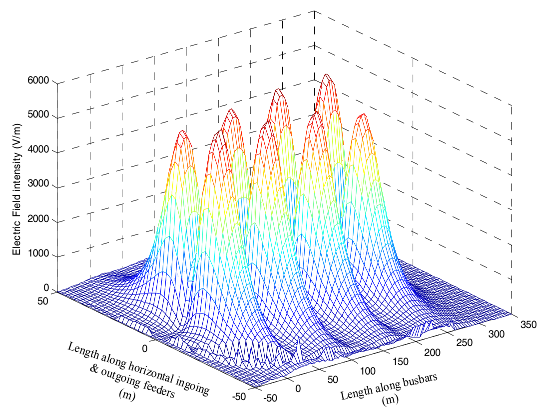

Fig. 5 Electric field distribution at 1m height for the base case under a 220 KV

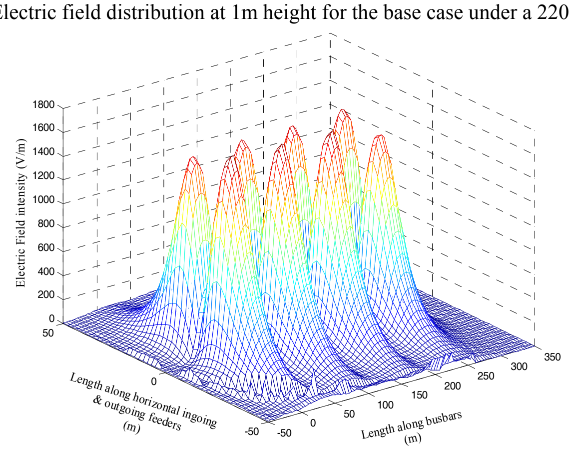

Fig. 6 Electric field distribution at 1m height for the base case under a 66 KV

V. Conclusion

The present paper is concerned with the calculation of three-dimensional electric field inside HVS using CSM. *The following conclusions can be drawn:*

1) The calculated electric field values in three dimensional inside HVS is depend on the number of segments, the spacing between the phases, level of operating voltage and the height level of calculation.
2) As the height level of calculation increased, the field intensity is increased.
3) As the phase spacing increased, the field intensity is increased.
4) As the operating voltage increased, the field intensity at, but the location of this maximum field point is not displaced.

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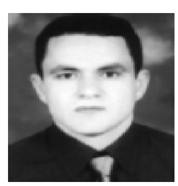

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