J. Univ. Kuwait (Sci.) **13**, 1986

Computation techniques for evaluating the electric field effects of single and double circuit HVAC overhead lines

M. H. SALAMA, Y. SAFAR AND M. SAIED

Department of Electrical and Computer Engineering, University of Kuwait, P.O. Box 5969, Kuwait

ABSTRACT

The description of two techniques for the digital computation of the environmental effects on the electric field of single- and double-circuit high voltage alternating current (HVAC) overhead lines is given. The towers can carry up to two 3-phase systems which differ in voltage levels, relative phase angles, number of subconductors in a bundle, tower dimensions and conductor radii. The results include computation of the voltage gradients at the ground surface as well as the surface of all conductors, including ground wires. Potential distribution, as function of time and location can also be obtained.

The first technique is based on replacing each energized subconductor by an equivalent line charge. From geometrical data, the potential coefficient matrix can be determined, which is then inverted to obtain the capacitance coefficient matrix, which if multiplied by the known voltages, results in the equivalent charges for all conductors. After that, voltage gradients as well as the spatial potential distribution can be obtained.

The second approach utilizes the charge simulation technique. For each energized subconductor, a number of line charges is assumed; these have to satisfy different boundary conditions such as zero tangential field component at the conducting surfaces. By solving the corresponding system of linear equations, the equivalent charges for all conductors can be found.

The two computer programmes using the methods outlined above have flexible features. They are applicable to cases including different numbers of circuits, bundles or voltage levels. They are tested for different cases, and the results for the surface voltage gradients of the conductors in some specific cases of single circuit and symmetrical double-circuit towers are found to be in good agreement with the available standard charts such as those included in various EPRI research reports and other publications.

INTRODUCTION

The electric field and potential distribution in the vicinity of HVAC overhead power lines are of great importance for the design and operation of these lines (EPRI 1982; Grant & Stewart 1984). In the design phase, for example, they enable the designer to check for the possibility of corona discharges over the conductor surfaces. These discharges can lead to some technical problems such as excessive corona power losses. radio and T.V. interference and audible noise. Preventive measures are available and they include conductor bundling or the use of hollow conductors. The additional expenses are usually overcompensated by the savings achieved by reducing the corona losses (Chang & Zinn 1976). Also, the study of the line fields yields significant information for special applications such as the design of systems based on the principle of capacitive tapping-off of power via parallel antenna wires or even through the already existing ground (Maruvada & Harbec 1978; Saied 1982). Also, due to the increasing concern about the environmental effects on overhead power lines, the electric field distribution at the ground level in the vicinity of the overhead lines can be of decisive significance for assessing the possibility of power frequency hazards to humans, animals and moving objects (Grant & Stewart 1984).

It is impossible to find analytical solutions for the two-dimensional Laplace equation describing the electric field of high voltage lines. This is due to the large number of variables considered and the complexity of the geometrical arrangement of the line and ground conductors. For this reason, this study investigates the applicability of numerical techniques. The aim is, therefore, to describe two methods for solving the transmission line problem. Both methods have been implemented, using two computer programmes, and the results of their application will be given. The flexibility of the programmes to solve problems of general type is emphasized. Typical problems of practical importance are line circuits of different voltage levels, asymmetrical tower configurations, as well as non-horizontal ground surfaces.

METHODS OF ANALYSIS

METHOD I: IMAGING AND EQUIVALENT RADIUS

In this method, the electric field for a double-circuit system, or two physically separate single-circuit systems, can be computed. Fig. 1 shows the basic tower configuration and conductor arrangement. The two circuits can generally have operating voltages which differ in magnitude and/or phase. Moreover, they can have different phase conductor sizes. The two ground wires are also considered, but it is also possible to represent towers with a single ground wire. There are no restrictions related to tower

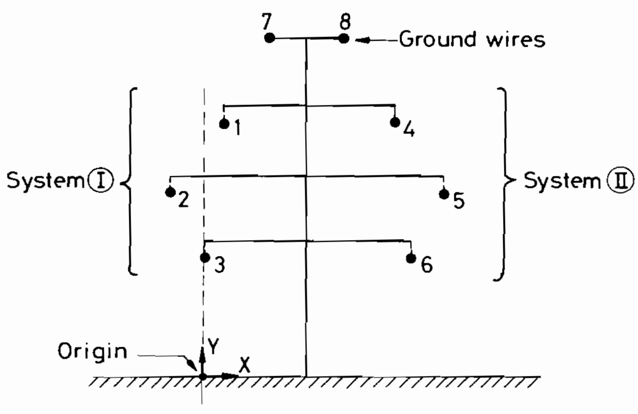


Fig. 1. Tower geometrical data.

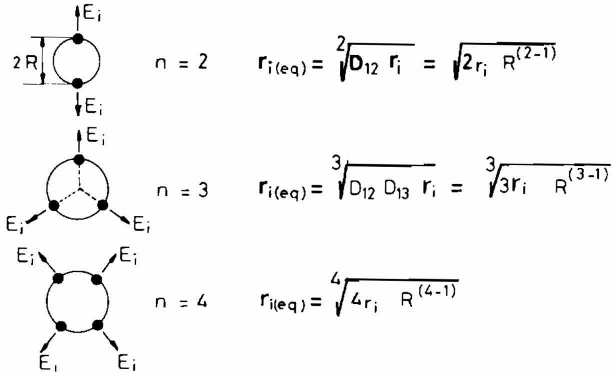


Fig. 2. Equivalent radii and maximum voltage gradients for bundled conductors.

dimensions, since the input data of the computer programmes is the *x–y* coordinates of line and ground conductors. Therefore, the programme can handle any conductor configuration on both sides of the tower. The tower data includes:

(i) The *x–y* coordinates of all line conductors given in the order shown in Fig. 1. Conductors 1–3 belong to the first system, while conductors 4–6 belong to the second system. The origin of the *x–y* system of coordinates was arbitrarily chosen on the ground plane right under conductor 3. As stated above, the two systems might as well be two different single-circuit towers.

(ii) The *x–y* coordinates of the two ground wires whose notations are 7 and 8.

(iii) The radii of the line and ground conductors.

(iv) In the case of bundled conductors, the number of conductors per bundle and the spacings between subconductors are needed. The equivalent conductor radius of a bundle, $r_{i(eq)}$, can be calculated as follows (Denzel 1966):

$$r_{i(eq)} = [n \cdot r_i \cdot R^{n-1}]^{1/n} \tag{1}$$

where

n = number of subconductors
r_i = radius of subconductor
R = bundle radius (Fig. 2).

Using this method in entering the tower data gives the flexibility to describe special cases for the programme. For example, single-circuit systems can be treated in the same manner as double-circuit systems except that the coordinates of one of the two systems are set at infinity. As for towers with only one ground wire, the same concept can be applied, i.e. the coordinates of one of the ground wires are set at a very large distance. In the case of no ground wires, however, the coordinates of both wires are set at infinity. The radii of the conductors of system I can be different from those of system II. This allows the use of this method to find electric field distribution for two different systems on one common tower, or two different systems on two different single-circuit towers.

Then, the required electrical data for the programme is the rated voltage of system I, the rated voltage of system II and the phase shift between the corresponding conductor potentials (which is generally due to transformers in substations and is

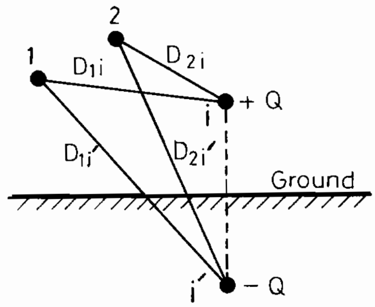


Fig. 3. Determination of potential coefficients.

generally multiples of 30°). For double-circuit lines, the two voltage levels are equal and there is no phase shift between system I and system II.

If the ground is to be considered as an infinitely conductive plane, then conductor images with respect to the ground should be included for the field calculations. To find the potential coefficients between conductors 1 and 2, and a third conductor i, with its image i' (Fig. 3), it is required to determine the contribution of the charge Q_i and its image $-Q_i$ to the potential difference between conductors 1 and 2. It can be shown that this contribution is

$$\begin{aligned}(\Delta V_{1\text{-}2}) &= \frac{Q_i}{2\pi\varepsilon_0}\ln\left(\frac{D_{2i}}{D_{1i}}\right) + \frac{-Q_i}{2\pi\varepsilon_0}\ln\left(\frac{D_{2i'}}{D_{1i'}}\right)\\ &= (V_1 - V_2) \quad \text{due to } -Q_i \text{ and } +Q_i\\ &= \frac{Q_i}{2\pi\varepsilon_0}\ln\frac{D_{2i}D_{1i'}}{D_{1i}D_{2i'}} \quad , \quad \varepsilon_0 = \frac{10^{-9}}{36\pi\varepsilon}\ \text{F/m} \quad .\end{aligned} \tag{2}$$

The term

$$\frac{1}{2\pi\varepsilon_0}\ln\frac{D_{2i}D_{1i'}}{D_{1i}D_{2i'}} \tag{3}$$

is the potential coefficient between the charge on conductor i and the potential difference between conductors 1 and 2. Consequently, for a double-circuit line with two ground wires, the complete expression for the total electric potential between any two of the eight conductors, say 1 and 2, is given by

$$V_{1\text{-}2} = \sum_{i=1}^{8}(\Delta V_{1\text{-}2})_i = \sum_{i=1}^{8}\frac{Q_i}{2\pi\varepsilon_0}\ln\frac{D_{2i}D_{1i'}}{D_{1i}D_{2i'}}$$

or

$$V_{1\text{-}2} = \frac{1}{2\pi\varepsilon_0}\sum_{i=1}^{8}Q_i\ln\frac{D_{2i}D_{1i'}}{D_{1i}D_{2i'}} \quad . \tag{4}$$

Usually, all the relative potentials between the 8 different conductors are known. The corresponding 8 line charges $[Q_1, Q_2, \ldots, Q_8]$ are the unknowns in the problem. Assuming that vector $[V]$ represents the known voltages to ground in complex form, and $[Q]$ is the vector representing the complex line charges, then

$$\underset{8\times 1}{[V]} = \underset{8\times 8}{[P]} \cdot \underset{8\times 1}{[Q]} \quad . \tag{5}$$

Since there are 8 unknowns, then eight independent potential equations are needed. Eq. 5 can be written as

$$\underset{8\times 1}{[Q]} = [C]\cdot[V] = \underset{8\times 8}{[P]^{-1}}\ \underset{8\times 1}{[V]} \quad . \tag{6}$$

The square matrix $[C]$ is called the capacitance coefficient matrix, and is obtained by inverting the potential coefficient matrix $[P]$ defined by Eq. 6. In this equation, the multiplication of $[C]$ by the independent voltage vector $[V]$ yields the line charge vector $[Q]$. It is easy then to calculate the conductor surface voltage gradients as follows:

$$\mathbf{E}_i = \frac{Q_i}{2\pi\varepsilon_0 r_i} \quad . \tag{7}$$

For bundled conductors, Eq. 7 should be modified to give the maximum voltage gradients at the subconductor surfaces. Assuming that the total phase charge, Q_i, is equally distributed on the subconductors, it will then be easy to prove that the maximum local field on each subconductor has a radial direction (with respect to the bundle centre point) and its magnitude is given by

$$E_i = \frac{Q_i}{2\pi\varepsilon_0}\left[\frac{1}{n}\left\{\frac{1}{r_i} + \frac{n-1}{2R}\right\}\right] \tag{8}$$

where r_i, n and R are defined in Eq. 1. This is illustrated schematically in Fig. 2. Since the ground is an equipotential surface, the electric field will have only a normal component. The total ground surface voltage gradient at a general point of x-coordinate x_g is given by

$$\mathbf{E}_{n_{x_g}} = \sum_{i=1}^{8} \mathbf{E}_{n_{x_{g_i}}} = \sum_{i=1}^{8} 2\,|E_{Q_i}|\cos\theta_i = \frac{2\mathbf{Q}_i}{2\pi\varepsilon_0\sqrt{(X_i - X_g)^2 + y_i^2}}\cos\theta$$

$$\mathbf{E}_{n_{x_g}} = \sum_{i=1}^{8} \frac{\mathbf{Q}_i y_i}{\pi\varepsilon_0[(X_i - X_g)^2 + y_i^2]^{3/2}} \quad . \tag{9}$$

$\mathbf{E}_{n_{x_g}}$ is a phasor quantity and defined as positive in the downward direction, as shown in Fig. 4.

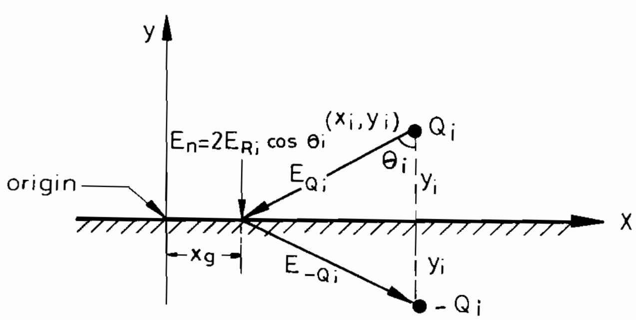


Fig. 4. Determination of the voltage gradient at ground level.

As a check of the results, the tangential component of the total electric field at the ground surface is given by

$$\mathbf{E}_{t_{x_g}} = \sum_{i=1}^{8} \frac{Q_i(X_i - X_g)}{[(X_i - X_g)^2 + y_i^2]^{3/2}} \quad . \tag{10}$$

When calculated, it is found to be zero, as expected.

METHOD II: CHARGE SIMULATION TECHNIQUE

The charge per unit length of a transmission line is computed by choosing a boundary point on the surface of each conductor. The potential, V_i, at these boundary points is computed by the superposition principle. This leads to a system of n simultaneous equations in n unknown charges. Therefore

$$V_i = \sum_{j=1}^{8} P_{ij} Q_j \quad \text{for} \quad i = 1, 2, \ldots, n \tag{11}$$

where V_i is the complex potential at the ith boundary point, P_{ij} the potential coefficient at the ith boundary point due to a unit charge per unit length at (X_j, Y_i) and Q_j is the complex charge per unit length assumed to be located at (X_j, Y_j). Consider a system consisting of n conductors of which one is shown in Fig. 5. This conductor is simulated by one infinite line charge, Q_j, perpendicular to the x–y plane and located at (x_j, y_j) and has an image at point $(x_j, -y_j)$. To solve for Q_j, a boundary point at the surface of the conductor is selected. This point is located at (X_i, Y_i) and hence its potential will be

$$V_i = P_{ij} \cdot Q_j \tag{12}$$

where

$$P_{ij} = \frac{1}{2\pi\varepsilon_0} \ln \frac{(y_i + y_j)^2 + (x_i - x_j)^2}{(y_i - y_j)^2 + (x_i - x_j)^2} \quad .$$

Thus

$$Q_j = \frac{V_i}{P_{ij}} \text{ C/m} \quad .$$

The voltage gradient on the surface of the conductor can be calculated by applying the following equations (Singer *et al.* 1974):

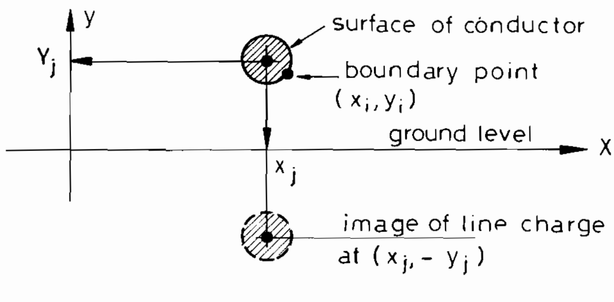


Fig. 5. One conductor and its image.

$$E_{xj} = \frac{Q_j}{2\pi\varepsilon_0}\left[\frac{x_i - x_j}{(y_i - y_j)^2 + (x_i - x_j)^2} - \frac{x_i - x_j}{(y_i + y_j)^2 + (x_i - x_j)^2}\right] \quad (13)$$

$$E_{yj} = \frac{Q_j}{2\pi\varepsilon_0}\left[\frac{y_i - y_j}{(y_i - y_j)^2 + (x_i - x_j)^2} - \frac{y_i + y_j}{(y_i + y_j)^2 + (x_i - x_j)^2}\right] \cdot \quad (14)$$

For a system of n conductors, superposition can be applied and the total components can be calculated from

$$E_{x\text{total}} = \sum_{j=1}^{n} E_{xj}, \qquad E_{y\text{total}} = \sum_{j=1}^{n} E_{yj} \quad .$$

As a check, the tangential component of the field $E_{x\text{total}}$ should be zero at the surface of the conductor and is obviously equal to zero at the surface of the ground. Deviations from zero will give the measure of accuracy of the calculations.

The computer programme will use the system configuration, voltage levels and phase differences between the two circuits of the power system used to calculate the x and y coordinates of the line charges and boundary points, and, consequently, the values of the line charges. The Gaussian elimination method is used to solve the matrix equation

$$[Q] = [P]^{-1}[V] \quad (15)$$

which consists of n equations in n unknowns. As a check, Eq. 12 is used to calculate the potential at the conductor surface and at the ground surface.

RESULTS AND DISCUSSION

The two methods were tested using three different case studies, each comprising a double-circuit, 3-phase line. The first example (Fig. 6a) is referred to as the EPRI/1 system; it operates at 362 kV. The second example (Fig. 6b) is the EPRI/2 system operating at 550 kV. For more detailed data about these two systems, EPRI (1982) should be consulted. The third example (Fig. 6c) is referred to as the Kuwaiti system which has a rated voltage of 132 kV. Comparison between the two methods described above gave identical results for all case studies presented in this paper. Moreover, for the cases comprising EPRI lines, these results were found to be in good agreement with the charts given in EPRI (1982). This represents another check for the validity of the two suggested techniques. Table 1 shows, for example, a sample output of the results obtained for the EPRI/2 system, where the transmission line has two circuits, each having two subconductors per phase. In this case the phase angle between the two circuits of the system is equal to zero.

These results show that: (1) The charges are in phase with the voltage at the corresponding conductors. Also, the voltage gradient (electric field strength) is in phase with the charge. (2) The field is always in a direction perpendicular to the surface of the wire, i.e. the tangential component is equal to zero.

The above remarks prove that the boundary conditions are satisfied at the surface of the conductor. However, for several case studies, a maximum deviation of 5% is found when the magnitude of maximum voltage gradient obtained from the computer programme is compared to values from EPRI (1982) (see Table 2).

Next, the programme was extended to calculate the electric field strength at ground level within the right-of-way of the transmission line. Since the electric field

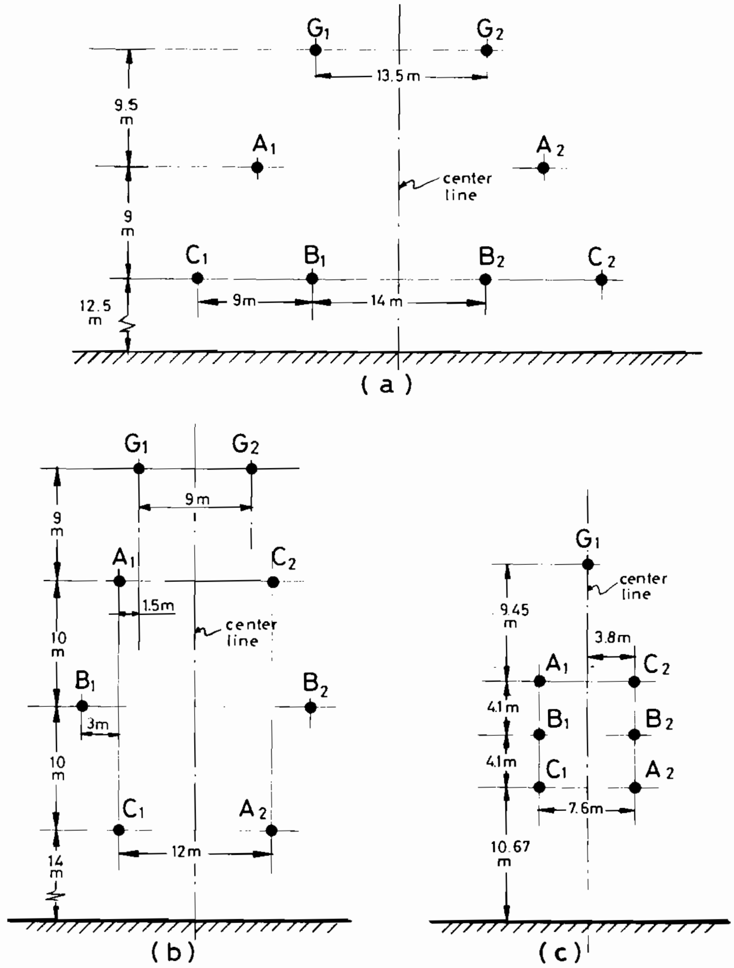


Fig. 6. Double circuit line configurations. (a) EPRI/1 system, 362 kV rms line to line. (b) EPRI/2 system, 550 kV rms to line. (c) Kuwaiti system, 132 kV rms line to line.

strength varies sinusoidally with time, as do the line charges creating the field, it is calculated at specific times. These were chosen as $\omega t = 0^\circ, 45^\circ, 90^\circ$ and 135° with respect to the voltage of phase A. Fig. 7 shows the ground level electric field strength profile as a function of lateral distance, where zero distance is the location of the projection of the extreme left conductor in the system on the ground. Comparing Figs 7a, b and c, it is noticed that the electric field strength magnitudes in the EPRI/2 and Kuwaiti systems are higher than that of the EPRI/1 system. This is because of the higher operating voltage level of the EPRI/2 system and because the conductors in the Kuwaiti system are closer to each other and to the ground as well. The distribution of the instantaneous values of the electric field strength is symmetrical around the centre line of the EPRI/1 and EPRI/2 systems. Moreover, Figs 7d, e and f show that the electric field increases with the number of subconductors n, but has the same profile for $n = 1, 2, 3$ and 4 conductors. It is noticed that the change in field is greater when n is changed from 1 to 2, while it is less when n is changed from 3 to 4.

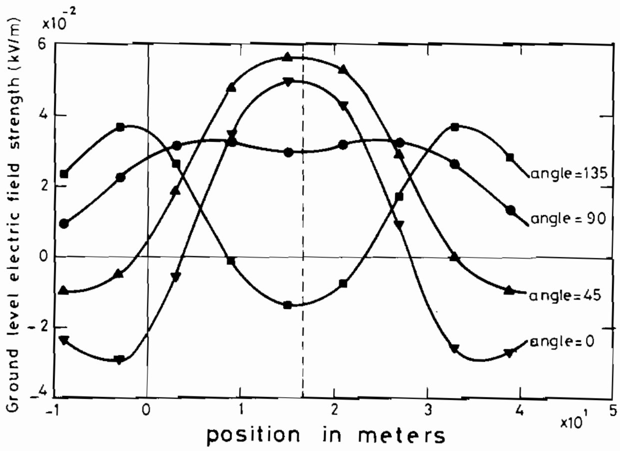


Fig. 7a. EPRI/1 system, one conductor per phase at specific instants (ωt = 0°, 45°, 90° & 135°).

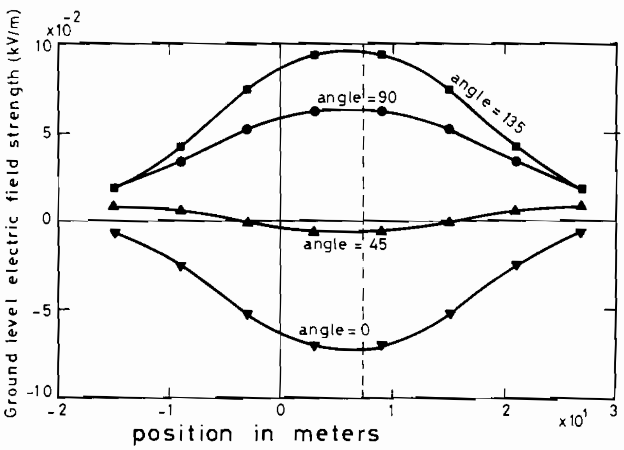


Fig. 7b. EPRI/2 system, one conductor phase at specific instants (ωt = 0°, 45°, 90° & 135°).

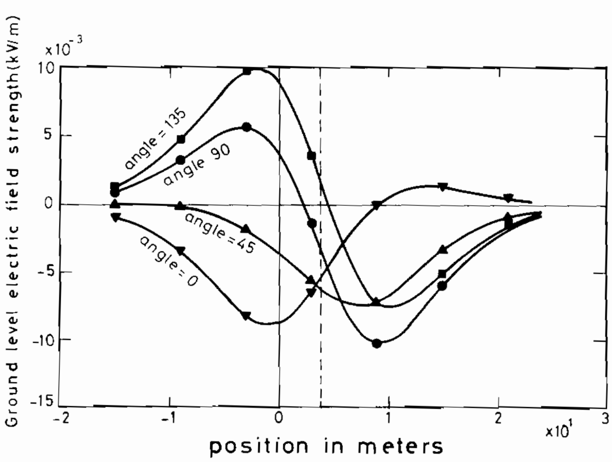


Fig. 7c. Kuwaiti system, one conductor per phase at specific instants (ωt = 0°, 45°, 90° & 135°).

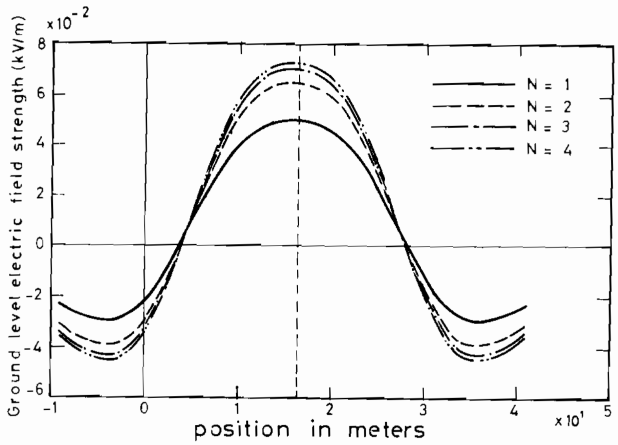


Fig. 7d. EPRI/1 system, $n = 1, 2, 3$ & 4 semiconductors at $\omega t = 0°$.

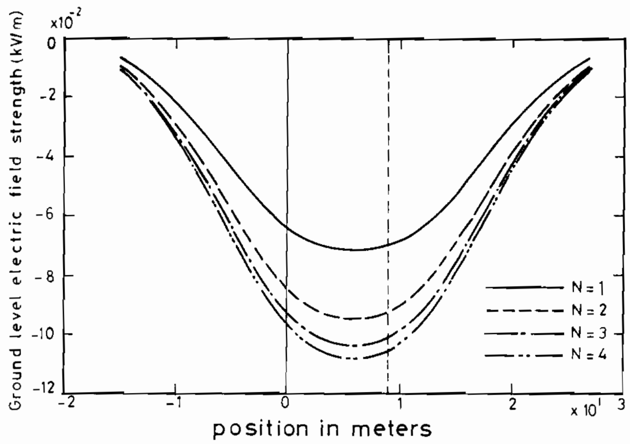


Fig. 7e. EPRI/2 system, $n = 1, 2, 3$ & 4 subconductors at $\omega t = 0°$.

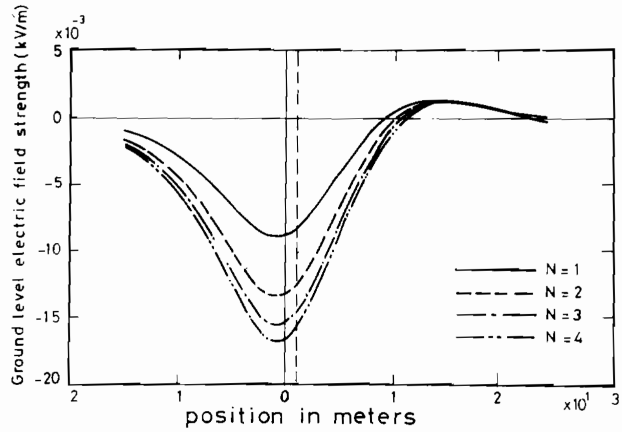
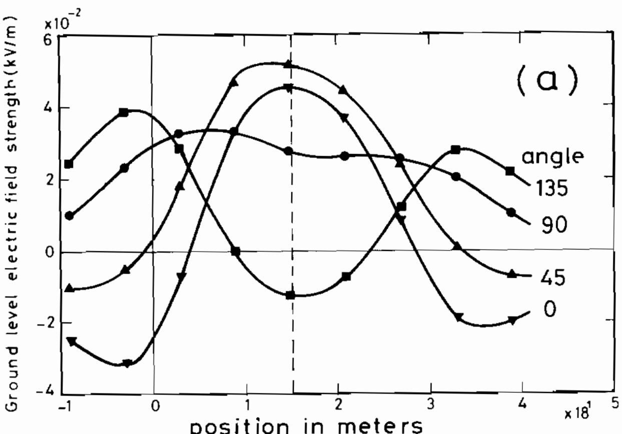


Fig. 7f. Kuwaiti system, $n = 1, 2, 3$ & 4 subconductors at $\omega t = 0°$.

Table 1. Computer results for EPRI/2 system

Cond. No.		Field magn. (kV/cm)	Field angle (degrees)	Charge magn. (kCoulomb/cm)	Charge angle (degrees)	Potential (Volt) Real	Potential (Volt) Imaginary
A1	1	14·4355	1·9647	·1992 E−10	1·8040	·3175 E+6	·3671 E−2
	2	14·3215	2·9833	·1976 E−10	2·8269	·3175 E+6	·2725 E−2
B1	3	14·1697	240·0924	·1959 E−10	−120·2011	−·1588 E+6	−·2750 E+6
	4	14·0751	240·0438	·1946 E−10	−120·2468	−·1588 E+6	−·2750 E+6
C1	5	14·4660	118·4506	·2004 E−10	118·2984	−·1588 E+6	·2750 E+6
	6	14·3718	117·4907	·1992 E−10	117·3308	−·1588 E+6	·2750 E+6
A2	7	14·3219	117·0176	·1976 E−10	117·1741	−·1588 E+6	·2750 E+6
	8	14·4359	118·0362	·1992 E−10	118·1970	−·1588 E+6	·2750 E+6
B2	9	14·0751	239·9556	·1946 E−10	−119·7539	−·1588 E+6	−·2750 E+6
	10	14·1697	239·9070	·1959 E−10	−119·7995	−·1588 E+6	−·2750 E+6
C2	11	14·3718	2·5095	·1992 E−10	2·6693	·3175 E+6	·3321 E−2
	12	14·4659	1·5495	·2004 E−10	1·7017	·3175 E+6	·1800 E−2
G1	13	5·6448	183·2206	·2392 E−11	−165·7140	−·8205 E−2	·1229 E−2
G2	14	5·6902	296·8459	·2394 E−11	−74·2266	−·3675 E−2	−·2418 E−3



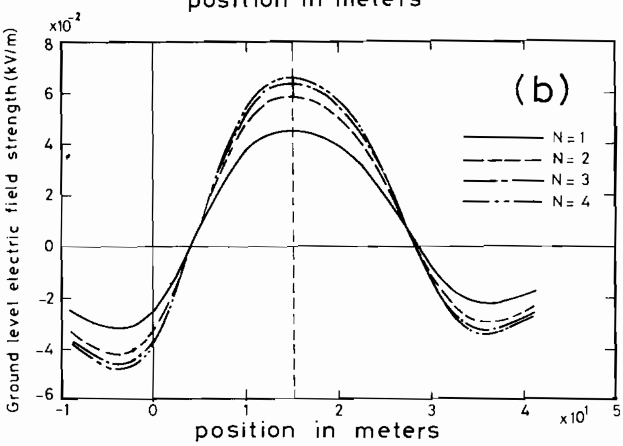


Fig. 8. Ground level electric field for two different voltage levels (380 kV & 275 kV) with phase shift equal to zero. (a) Case of one conductor per phase at $\omega t = 0°$, 45°, 90° & 135°. (b) Case of $n = 1, 2, 3$ & 4 subconductors per phase at $\omega t = 0°$.

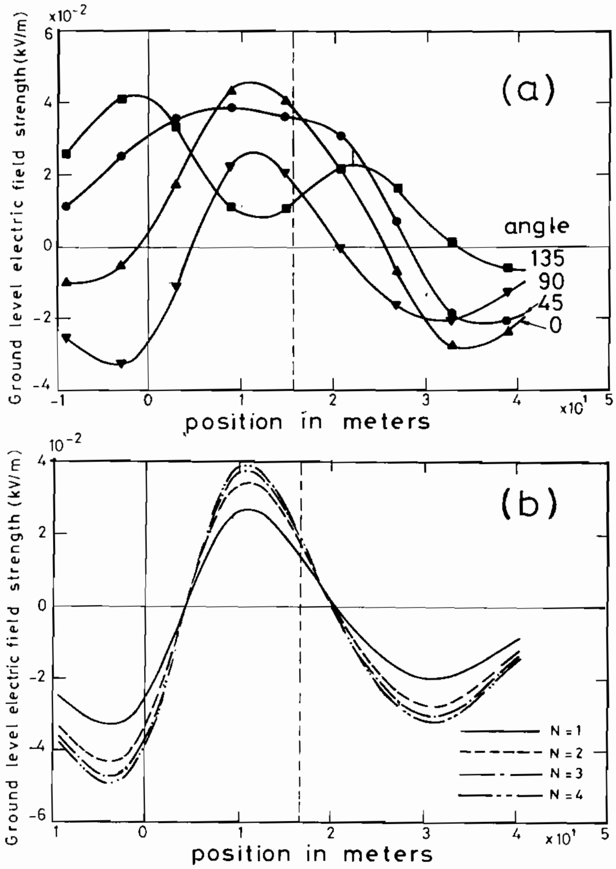


Fig. 9. Ground level electric field strength for two different voltage levels (380 kV & 275 kV) with phase shift 30°. (a) Case of one conductor per phase at $\omega t = 0°$, 45°, 90° & 135°. (b) Case of $n = 1$, 2, 3 & 4 subconductors per phase at $\omega t = 0°$.

To study the effects of different voltage levels of two 3-phase circuits on the same tower, on the ground level electric field strength, the EPRI/1 system with operating voltages of 380 kV and 275 kV for the left and right circuits, respectively, was chosen as an example. The phase difference between the two lines was first assumed to be zero. The computer results are presented in Fig. 8. Comparing this to Figs 7a and d, it is noticed that the significant difference is the lack of symmetry in the case of different voltage levels, while the ground level electric field strength profiles are of the same order of magnitude. Figs 9 and 10 present the same case as Fig. 8 except that

Table 2. Maximum surface voltage gradients of the EPRI/2 system

Phase	$\|E\|$ (kV/cm) from Table 1	$\|E\|_{max}$ (kV/cm) from programme	$\|E\|_{max}$ (kV/cm) from EPRI report [1]	% Error
A	14·43	15·1	15·8	−4·4
B	14·17	14·85	15·5	−4·1
C	14·47	15·2	16·0	−5·0

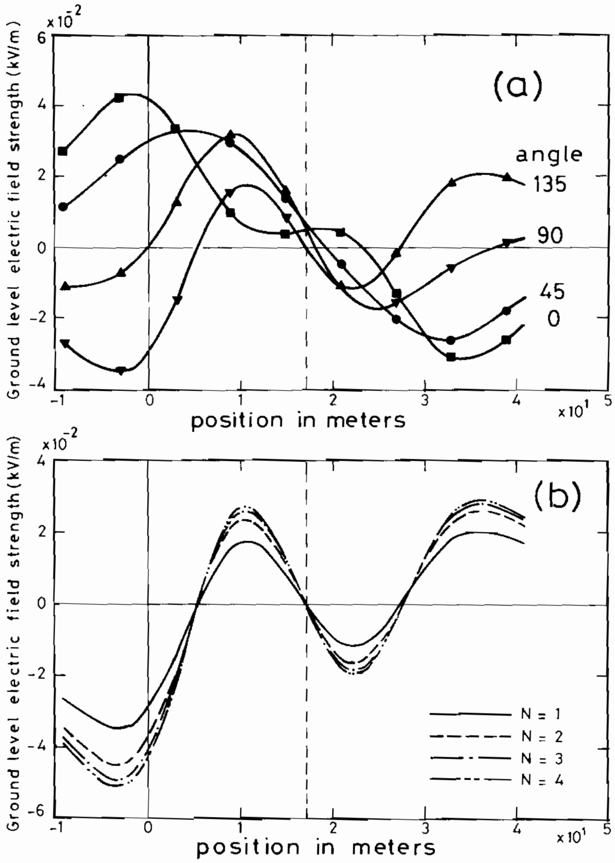


Fig. 10. Ground level electric field strength for two different voltage levels (380 kV & 275 kV) with phase shift 60°. (a) Case of one conductor per phase at ωt = 0°, 45°, 90° & 135°. (b) Case of n = 1, 2, 3 & 4 subconductors per phase at ωt = 0°.

the phase angle between the two circuits is changed from zero to 30° and 60°, respectively. The results obtained indicate that the phase difference between the circuits will cause a change in the profile of the ground level electric field strength.

In addition, the computer programme can be used to calculate the induced potential at any point in the vicinity around the transmission line conductors. A typical application is to calculate the induced potential of the ground wires if these were insulated from the tower. This is of great importance if these conductors are to be used for the capacitive tapping-off of power from HVAC lines (Maruvada & Harbec 1978; Saied 1982). In normal operating conditions, these wires are connected to the ground, and therefore, have zero potential. However, if these wires are isolated from the ground, the capacitive coupling with the phase conductors can result in raising their potential up to several kilovolts. Using a double-circuit, single ground wire system presented by Maruvada & Harbec (1978), the capacitively induced potential of the insulated ground wire is calculated at different phase angles, δ, between the two circuits of the system. The results are presented in Fig. 11 and found to be identical to those shown in Maruvada & Harbec (1978). They show that the potential levels of the ground wires can be effectively controlled by the angle δ. Results

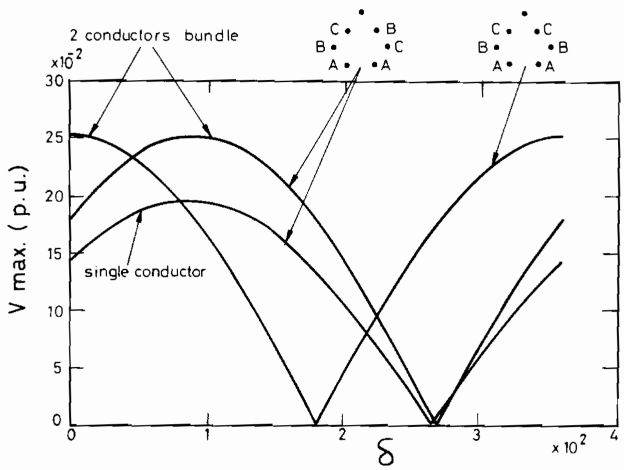


Fig. 11. The maximum induced voltage on the ground conductor for different phase shifts δ between two circuits.

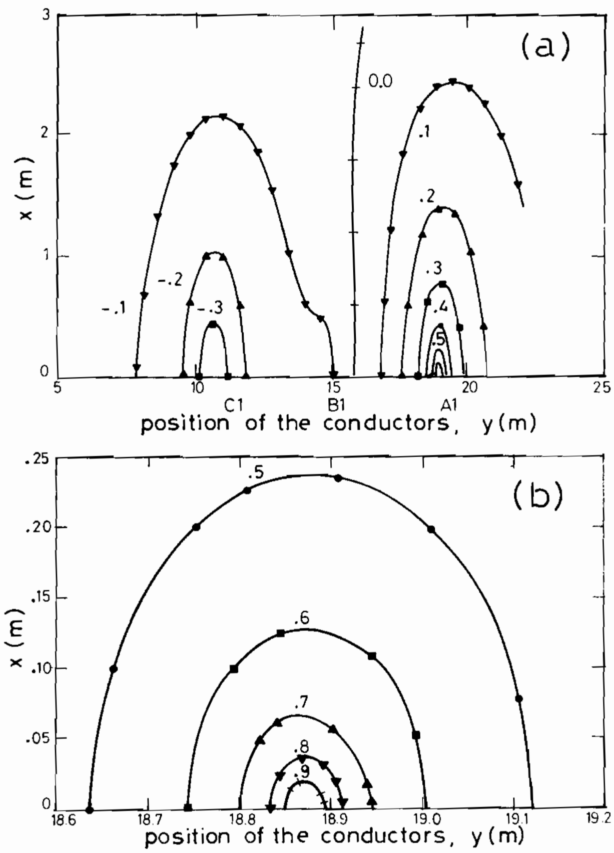


Fig. 12. Computed equipotential lines at $\omega t = 105°$ in the region to the left of the first circuit. (a) Case of Kuwaiti system, one conductor per phase. (b) Case of detailed lines for the conditions around conductor A1.

also show that the phase sequence affects the induced potential of the ground wire in a double-circuit system, e.g. for positive–positive sequence if $\delta = 90^\circ$, then $V_{max} = 0{\cdot}18$ p.u. (from Fig. 11) while for the same angle, for positive–negative sequence, $V_{max} = 0{\cdot}253$ p.u.

The computer programme can also be used to find and plot the equipotential lines around the conductor of any double-circuit system. Fig. 12 shows the equipotential lines for the Kuwaiti system for the case of one conductor per phase, and at a time angle $\omega t = 105^\circ$ measured with respect to phase A.

CONCLUSIONS

1. The significance of the exact evaluation of the electric field effects in the vicinity of HVAC power lines has been discussed.
2. Two methods have been presented to estimate the electric field strength and potential distribution considering the effect of ground, ground wires and conductor bundling.
3. Two methods have been utilized for the analysis of three different case studies. Results have been compared to numerical results published elsewhere and a reasonably good agreement has been found.
4. The two techniques presented here can be of great help to transmission line engineers during the planning, design and operation of HVAC lines. Also, the paper gives information required to evaluate many related effects such as possible corona discharges, corona losses, radio and T.V. interference phenomena, and audible noise performance.

ACKNOWLEDGEMENT

This work was supported by Research Grant No. EE 011, Kuwait University.

REFERENCES

Chang, W.S. & Zinn, C.D. 1976. Minimization of the cost of an electrical transmission line system. Institute of Electrical and Electronic Engineering Transactions on Power Apparatus and Systems **95**: 1091–97.

Denzel, P. 1966. Grundlagen der Übertragung elektrischer Energie. Springer-Verlag, Berlin, 206 pp.

EPRI (Electric Power Research Institute) 1982. Transmission line reference book 345 kV and above. EPRI, Palo-Alto, California, USA.

Grant, I. S. & Stewart, J.R. 1984. Mechanical and electrical characteristics of ehv high phase order overhead transmission. Institute of Electrical and Electronic Transactions on Power Apparatus and Systems **103**: 3380–86.

Maruvada, P.S. & Harbec, G. 1978. Capacitive tap-off from transmission lines using ground wires: calculation of equivalent circuit parameters. Institute of Electrical and Electronic Engineering Transactions on Power Apparatus and Systems **97**: 1194–1200.

Saied, M.M. 1982. An almost symmetrical three-phase supply, capacitively tapped-off from transmission lines using two earth wires. Jahresbericht der Forschungsgesellschaft Energie (FGE), TH Aachen, Aachen, West Germany.

Singer, H., Steinbil, H. & Weiss, P. 1974. A charge simulation method for the calculation of high voltage fields. Institute of Electrical and Electronic Engineering Transactions on Power Apparatus and Systems **93**: 1660–68.

(*Received 29 June 1985, revised 15 December 1985*)

أساليب حسابية لتقدير قيمة
تأثير المجال الكهربائي للخطوط الهوائية ذات الجهد الفائق

محمد حسن سلامه و يوسف عبد النبي صفر و محمد مصطفى سعيد
قسم الهندسة الكهربائية وهندسة الكمبيوتر بجامعة الكويت

خلاصة

يقدم البحث شرحا علميا لاسلوبين حسابيين لدراسة تأثيرات الظروف البيئية على المجال الكهربائي لخطوط القوى الكهربائية ذات الجهد الفائق ، وذلك باستخدام الحاسب الآلي ، بحيث يشتمل البرنامج الحسابي على أبراج كهربائية مختلفة الابعاد وتحمل نظم قوى ثلاثية الاوجه ، قد تختلف فيما بينها في الجهد ، والزوايا ، وأنصاف أقطار الموصلات ، وعدد شعيرات هذه الموصلات . وتتمثل نتائج هذا البرنامج فى حساب تدرج الجهد على سطح موصلات الخط الكهربي (بما فيها الموصلات الارضية) ، وعلى سطح الارض ، بالاضافة إلى توزيع فرق الجهد كدالة من الزمن والموقع .

ويعتمد الاسلوب الاول على احلال شحنة مكافئة محل كل شعيرة ذات طاقة . وباستخدام البيانات الوصفية والقوانين الكهروستاتيكية والطرق الرياضية يمكن حساب تدرج الجهد وتوزيع فرق الجهد . أما الاسلوب الثاني فيستغل طريقة المحاكاة ، ويعتمد على فرض وجود مجموعة من الشحنات على كل شعيرة ذات طاقة بحيث تحقق شروطا مختلفة محيطة بهذه الشعيرة ، كأن يكون المجال المماس عند سطح الموصل مساويا الصفر . وعند تطبيق هذا الاسلوب على خطوط القوى الكهربائية لمنظومة ما ، نحصل على مجموعة من المعادلات الخطية . وباستخدام الحاسب الآلي يمكن حساب الخواص المكافئة لجميع الموصلات في منظومة القوى المقترحة .

ويتميز هذان البرنامجان بعدة خواص مرنة منها أنهما يشتملان على عدد من الدوائر ومستويات الجهد المختلفة . ولقد تم اختبارهما لحالات معروفة ومنشورة في تقارير علمية ، وكانت النتائج متوافقة بشكل جيد مع خرائط بيانية قياسية لهذه الحالات .