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SITE MEASUREMENTS AND CALCULATIONS OF ELECTROSTATIC AND ELECTROMAGNETIC FIELDS OF A 220-kV OVERHEAD TRANSMISSION LINE

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Abstract- Field measurements, whenever possible, still constitute the most direct method of obtaining quantitative as well as qualitative results concerning the values of both electrostatic and electromagnetic fields, provided adequate arrangements are used. It is also the usual practice to compare the results obtained by measurements with those obtained by calculations.

The paper presents the results of electrostatic and electromagnetic field measurements produced under a 220-kV overhead transmission line. Two different sites along the line are selected for field tests. Simplified measuring technique is used and the measurements are performed at different heights ranging from 1 m to 3 m above ground surface, with transverse distances up to 25 m around the centre of the transmission line.

Using image theory and the quasi-static approximation, corresponding results are calculated and compared with the test results. The comparison shows that the results obtained by field tests are in good agreement with those obtained by calculations. This concludes the adequacy of the simplified measuring technique used in this investigation.

1. INTRODUCTION

With the coming into reality of both EHV and UHV transmission systems, it becomes more important to accurately determine electrostatic and electromagnetic fields in the near vacinity of transmission lines and towers. In addition to the design considerations which must be given to the interaction of these fields with life forms in close proximity to the transmission line right-of-way, precise description of these fields is also necessary to intelligently estimate their interference with communication and radio networks.

Calculation methods of the electrostatic and electromagnetic fields emanating from transmission lines have been presented in many papers and texts[1-5]. Some of these papers[2,3,5] are only concerned with the calculation of electrostatic fields whereas some others[1,4] are interested only in determining the electromagnetic field. The methods of calculation presented in these papers differ in complexity. These range from approximate formulae[5] which will allow a transmission line designer to quickly establish, with a slide rule or small calculator, whether the field effects of a line exceeds tolerable levels, to a much more difficult process[4] requiring extensive computer aid. Little attention has however been given to field measurements of electric and magnetic fields of actual lines[3,6], probably because of the difficulty in obtaining results which include only very small error.

This paper presents the results obtained during an investigation into the magnitudes of electrostatic and electromagnetic fields produced under the 220-kV single circuit overhead transmission line which interconnects the substations at Talkha and Tanta, Egypt. The determination of these fields is carried out firstly by field measurements and secondly by calculation. In field measurements, simplified measuring technique is used[7]. This consists mainly of an oscilloscope connected to either a parallel-plate capacitor or to a search coil, depending on the particular field being measured. Calculated results for each corresponding observation point are obtained using image theory and the quasi-static approximations[4]. Comparison is made between measured and calculated results and it is found that the deviation does not exceed 10%. This would justify the adequacy of the simplified measuring technique adopted in this study.

2. FIELD MEASUREMENTS

Arrangement:

Simplified measuring arrangement is used to obtain the field results. When measuring the electrostatic field, the measuring system consists mainly of an oscilloscope (CRO) connected to a parallel-plate capacitor placed on a wooden cage. To avoid any interference, shielded cables are used for all connections. The electromagnetic field is measured by the same system but with the capacitor replaced by a search coil and the wooden cage by high-voltage sticks. The CRO is supplied from a portable 3-kVA, 220-V, 50 Hz generating unit placed at least 100 m away from the observation point. The capacitor is considered here as a gradient meter and consists of two similar aluminium plates, each is square in shape, 28 x 28 cm, by 1 mm in thickness and are 10 mm apart. The wooden cage is used to support the capacitor at different levels under the line to avoid the proximity effects of the researchers and any nearby objects. It is also adequately prepared to enable the capacitor to be placed either horizontally or vertically, depending on the component of field being measured. The search coil has 2500 turns and is 5 cm in length, with a square cross-sectional area of dimensions 1.8 x 1.8 cm. The high-voltage sticks are used to place the search coil in the appropriate position under the transmission line.

Technique:

The technique of electrostatic field measurements is as follows. When the capacitor is placed in electric field, the plates will intercept the electric flux and a displacement current will cause a conduction current to flow through the RC shunt of the dielectric (air). This current generates a voltage which is proportional to the component of electric field normal to the plate surfaces and, appearing on the CRO screen, it can be measured and converted to electrostatic field dimensions by calibration. The calibration procedure is carried out in the laboratory by using same capacitor to measure a predetermined electric field provided by two parallel plates, each measures 60 x 100 cm and spaced 50 cm apart, which are energised to a known voltage (r.m.s. value of up to 80 kV). The dimensions of the plates are large enough compared to the capacitor, to minimize any end effect.

The technique for measuring the electromagnetic field is quite similar. The voltage induced in the search coil is proportional to the component of the field being measured. Appearing on the CRO screen, this voltage can be measured and converted to the dimensions of magnetic flux, as already calibrated. In this case, the calibration is carried out, also in the laboratory, using a standard solenoid of 450 turns, 1 m long and a mean diameter of 10 cm. The magnetic field produced inside this solenoid may be considered to be uniformly distributed and can easily be calculated and its value, also measured by the search coil, is used for calibration.

3. METHOD OF FIELD CALCULATIONS

The method of image theory and quasi-static approximations[4] is well suited for this purpose. Using this method, it can be shown that the electric and magnetic fields in the air are given by[4]

$$\mathbf{E} = \frac{1}{2\pi\epsilon_o} \sum_{n=1}^{N} \left\{ Q_n \left[\frac{(x-x_n)\bar{x} + (y-y_n)\bar{y}}{(x-x_n)^2 + (y-y_n)^2} \right] - Q_n' \left[\frac{(x-x_n)\bar{x} + (y+y_n)\bar{y}}{(x-x_n)^2 + (y+y_n)^2} \right] \right\} \quad \ldots\ldots(1)$$

for the electric field intensity, and

$$B = \frac{\mu_o}{2\pi} \sum_{n=1}^{N} \left\{ I_n \left[\frac{-(y-y_n)\bar{x} + (x-x_n)\bar{y}}{(x-x_n)^2 + (y-y_n)^2} \right] - I'_n \left[\frac{-(y+y_n)\bar{x} + (x-x_n)\bar{y}}{(x-x_n)^2 + (y+y_n)^2} \right] \right\} \quad \ldots\ldots(2)$$

for the magnetic flux density, where

$Q'_n = (\frac{\epsilon - 1}{\epsilon + 1})\, Q_n \approx Q_n$ for high earth resistivity

Q_n = charge on nth conductor

ϵ = relative permittivity of earth $= \epsilon' - \frac{j}{\rho\omega}$

ϵ' = relative earth dielectric constant

ρ = earth resistivity

I_n = current of nth conductor

$I'_n = (\frac{1 - \mu}{1 + \mu})\, I_n \approx 0$ for overhead transmission lines

μ = relative earth permeability

(x_n, y_n) = location of nth conductor, see Fig. 1

(x, y) = location of observation point

$(\bar{x}, \bar{y})$ = unit vectors.

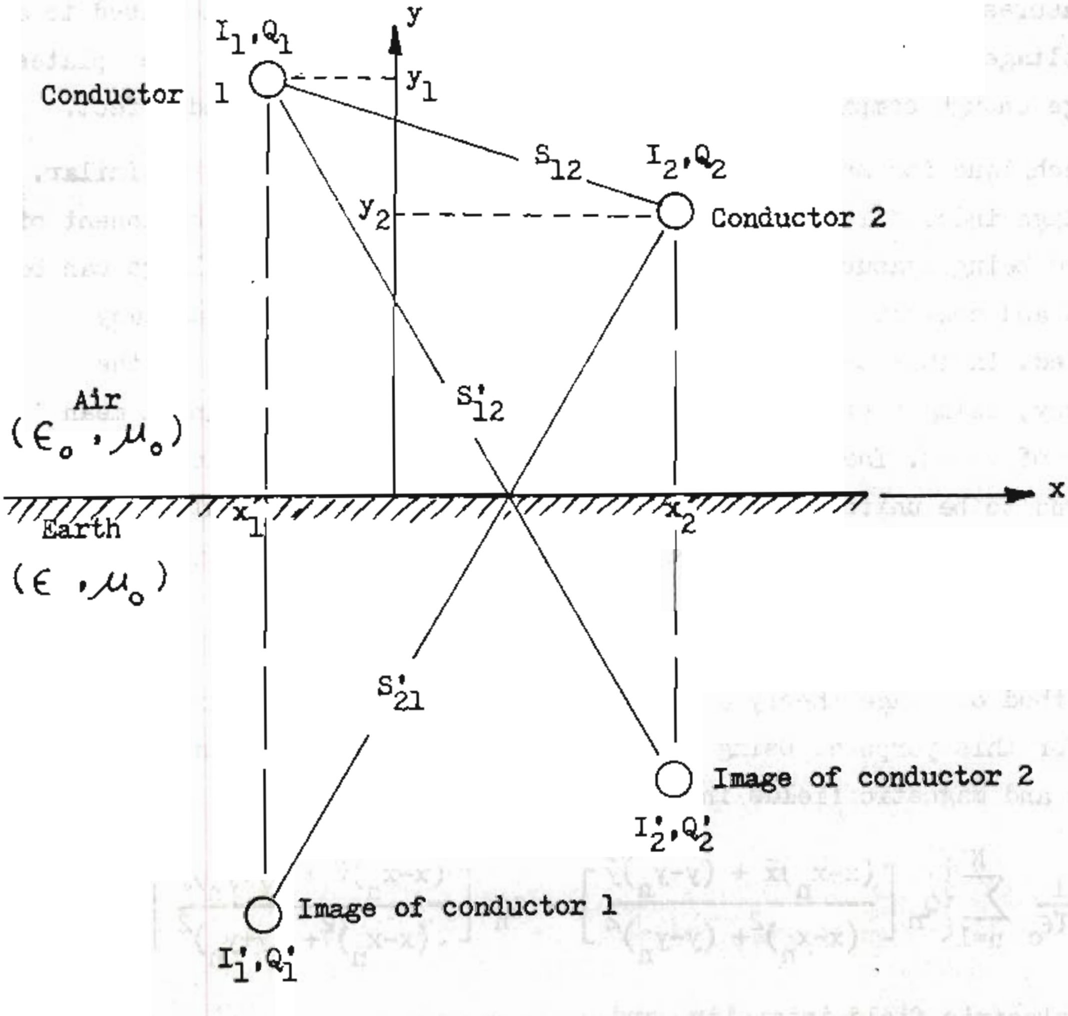

Fig. 1. Conductors of a two-wire system.

The conductor charge, Q_n, in equation (1) is related to the nth conductor line-to-ground voltage, V_n, by the matrix equation

$$[V] = [P][Q] \qquad \qquad \ldots\ldots\ldots(3)$$

where $[P]$ is known as the Maxwell coefficient matrix of the line and whose elements are given by

$$P_{ii} = \frac{1}{2\pi\epsilon_0} \ln\left(\frac{2y_i}{r_i}\right) \qquad \text{and} \qquad P_{ij} = \frac{1}{2\pi\epsilon_0} \ln\left(\frac{S'_{ij}}{S_{ij}}\right)$$

where r_i is the radius of the ith conductor, S_{ij} and S'_{ij} are as shown in Fig.1. The line construction and its parameters, as well as the complete matrix $[P]$, are given in the Appendix.

4. TEST SITES

Two sites under the 220-kV single-circuit line considered are selected for performing the measurements. The first site lies very close to the Talkha end of the line. The second site, 55 km away from the first site, lies at Toukh-Mazied; a village near Tanta. Both aites are chosen to be far enough from any nearby object to avoid any disturbing effect which these object, if close, may impose on the measured field values.

Although there are many transmission lines, operating at different different voltage levels, terminate at each substation, care is taken to ensure that only the fields of the line in question are effective to the measuring equipment. The measurements are performed under and adjacent to the line; maximum transverse distance (that of direction perpendicular to the transmission line) is limited to 25 m on either side of the line centre.

The line operating voltages and currents are recorded at the substations during the course of the tests. The line current is found to be around 300A wheras the line voltages vary by less than 1 percent around the value of 210 kV.

5. RESULTS

All results are recorded in places which are at least 50 m away from the nearest tower in order to avoid any interference on the field readings. The results are obtained under steady-state loading conditions of about 210 kV for the line voltage and about 300 A for the line current. The weather during the tests was fair and an atmospheric temperature of about 25 ^{o}C has prevailed throughout the investigation.

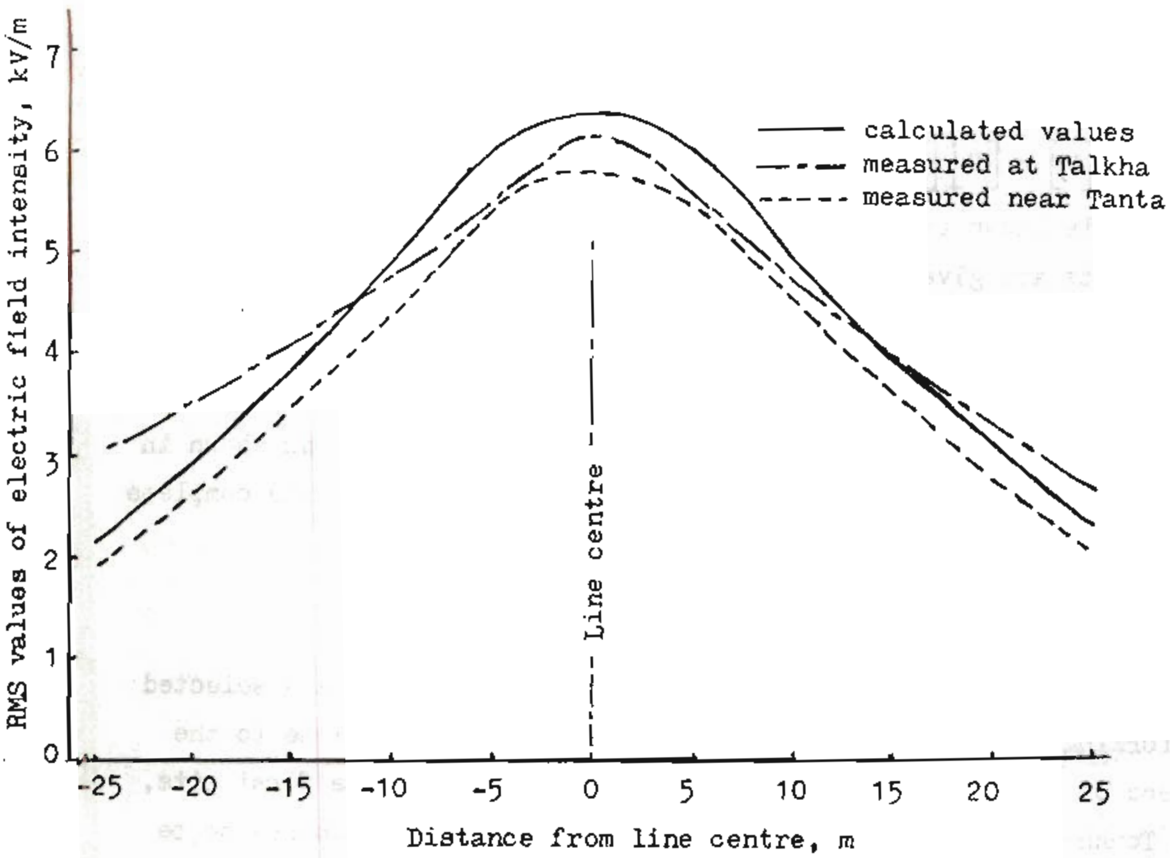

Fig. 2. Variation of electric field intensity with transverse distance at 1 m above ground surface.

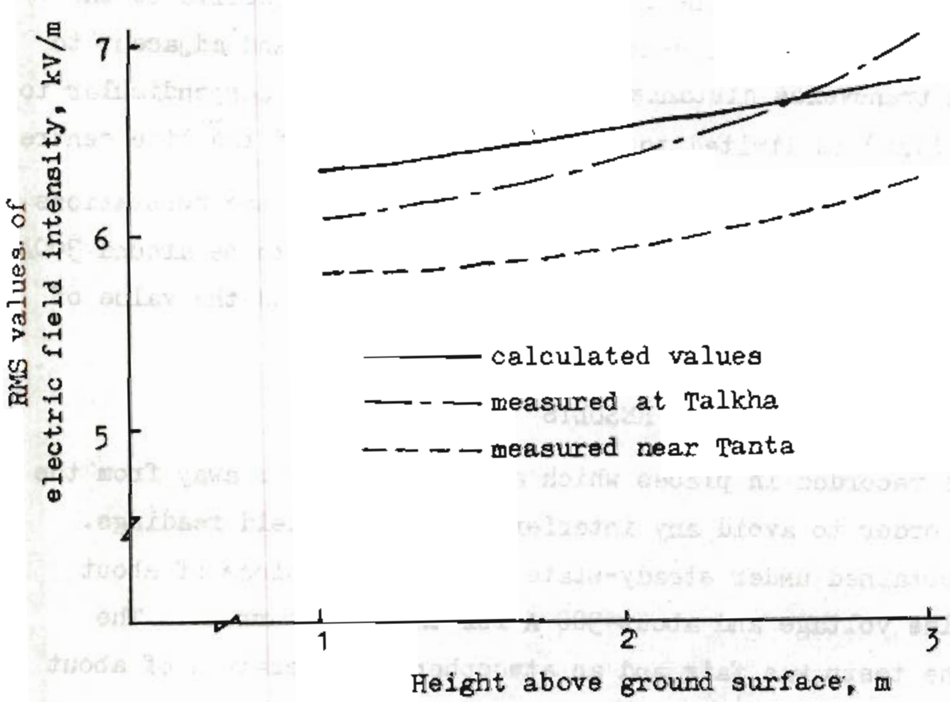

Fig. 3. Variation of electric field intensity with the height above ground surface directly under the transmission line.

It should be noted that each result obtained during the tests is estimated by the mean of not less than ten successive measurements. Also, each kind of field is measured separately with its horizontal component usually comes first.

Electrostatic Field:

Fig. 2 gives the results of the electric field distribution obtained at 1 m height above ground level. As expected, the maximum value of electric field intensity occurs directly under the line centre. It then decreases as we distant away from the line centre in either traverse direction. The curves also show that, the electric field at Talkha is slightly higher than that recorded near Tanta. This is due to the fact that the voltage at Talkha is slightly higher than that near Tanta; Talkha being the source end of the line. Although the calculated values (continuous line in Fig. 2) appear to be always on the higher side compared with the results obtained near Tanta, this is not always the case with regard to the results obtained at Talkha. For transverse distances of more than about 13 m from centre, the field results obtained at Talkha are higher than the calculated results. Of the two results, the former are more accurate because of some approximation in the calculated results. However, it is seen that the deviation between measured and calculated results does not exceed 10%, with the calculated results generally higher.

As the height above ground surface is increased, one expects higher values of electric field intensity. This effect has been examined for most of the corresponding observation points considered in Fig. 2. However, only the results obtained directly under the line centre are given in Fig. 3 for comparison puposes. It is seen that, the increase in the electric field intensity is nearly linear with the height above ground surface. Also, for the same reason mentioned above, the field values recorded at Talkha are always higher than those measured near Tanta.

Electromagnetic Field:

The results for the measured and calculated electromagnetic flux density are shown by the curves of Fig. 4 which gives the values of magnetic flux density at a height above ground surface of 1 m as we move up to 25 m in either transverse direction. Again, the maximum values are seen to occur under the line centre and then decreases as the transverse distance is increased in either direction.

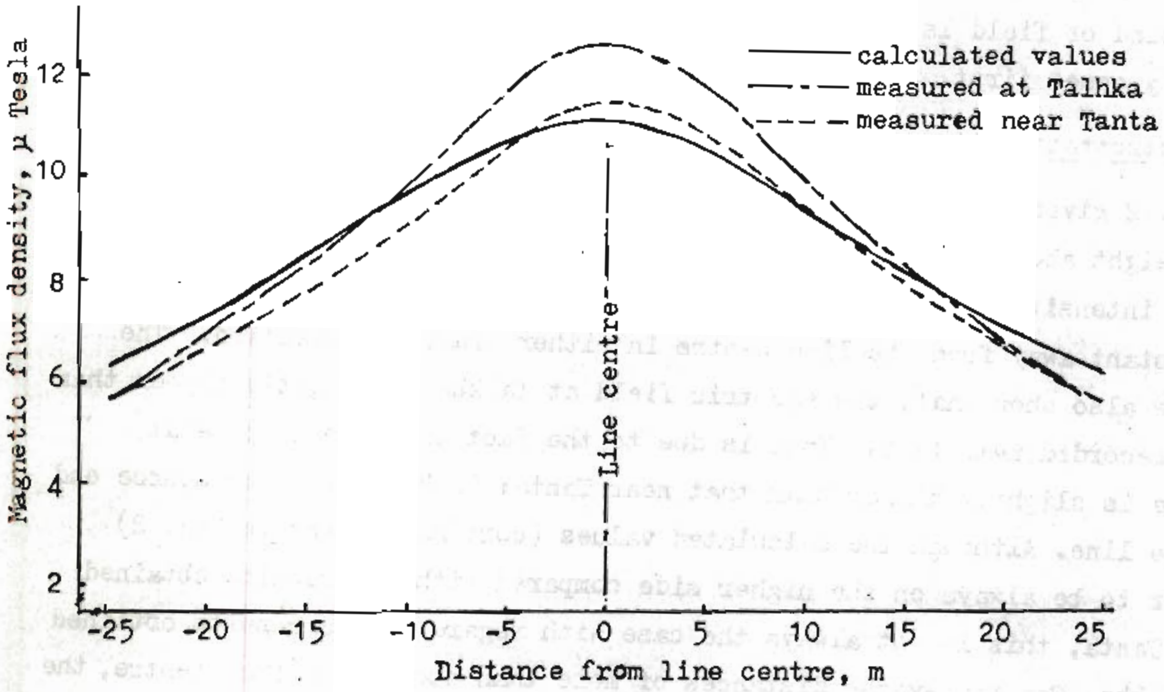

Fig. 4 Variation of magnetic flux density with transverse distance at 1 m above ground surface.

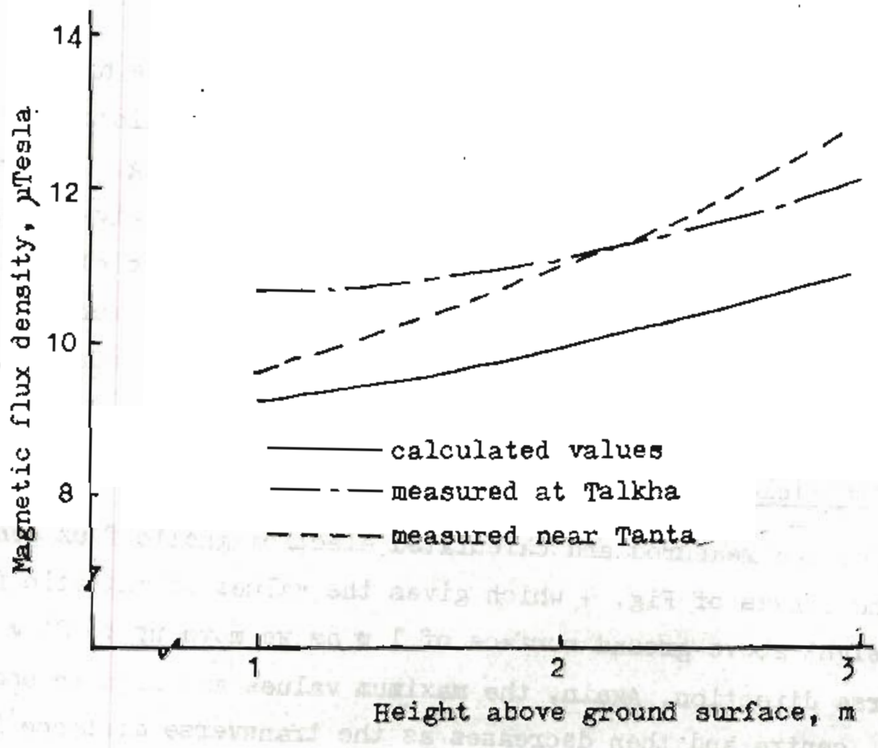

Fig. 5. Variation of magnetic flux density with the height above ground surface directly under the transmission line.

As with the electrostatic field, the results of the magnetic flux density obtained at Talkha are somewhat higher than those obtained near Tanta. This is again attributed to the fact that the Talkha end of the line constitutes the sending end, at which slightly higher current is flowing in the line. The curves show also that there is a good agreement between field and calculated results and that the deviation in the results does not exceed a value of about 10%.

The effect of increasing the height above ground surface from 1 m to 3 m, is given by the curves of Fig. 5. These give the variation in the values of magnetic flux density with the height above ground surface, when the tests are performed directly under the transmission line. The corresponding calculated results are also included for comparison. Although the rate of change in the flux density values is not the same for every curve, nevertheless the overall effect is an increase in the field values as the height above ground surface in increased.

It was also found that, for both electrostatic and electromagnetic fields the frequency of either component of each field decreases as the height above ground surface is increased. At the same height, however, the frequency of either horizontal or vertical component of one field is the same.

6. CONCLUSIONS

The results of electrostatic and electromagnetic fields produced under the 220-kV transmission line interconnecting the substations at Talkha and Tanta are presented. The results are obtained by both site tests and calculations. For the site tests, simplified measuring techniques are used. For the computed results, the theory of image and the quasi-static apprxi-mation method is employed.

As expected, highest values for both electric and magnetic fields are obtained directly under the transmission line and decreases, for the same height above ground surface, as the tranverse distance is increased. The values obtained at Talkha are found to be slightly higher than those recorded near Tanta. This may be explained by the fact that slightly higher values of voltage and current existed at Talkha at the time of tests.

With the height above ground surface is increased, higher values of fields are obtained for the same transverse distance. Though the frequency of either field components are found to decrease with increasing values of height above ground surface.

In all cases, it is found that, field results are in good agreement with those obtained by calculations. The deviation does not exceed a value of about 10%. This would justify the adequacy of the simplified measuring technique used in this investigation.

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8. APPENDIX

The transmission line considered here is located above a flat homogeneous ground surface. The line consists of three SCA - standard conductors each of a cross-sectional area of 400 square mm, corresponding to a radius of 1.1284 cm. The conductors are supported by steel towers each of about 36 m in height and each has three cross-arms, two on one side and one on the other.

Considering the y - x plane, with the y-axis coinciding with the tower centre line and the x-axis lies directly on the ground surface, the geometry of the conductors , expressed in metres, are :

(29.96 , 5.04) for the highest power conductor;
(23.28 ,-6.23) for the middle conductor; and
(19.87 , 5.34) for the lowest conductor.

Thus, applying the above mentioned dimensions to calculate the elements of the Maxwell coefficient matrix defined in Sec. 3, we have

$$[P] = 10^9 \begin{bmatrix} 143.33 & 37.02 & 24.73 \\ 37.02 & 145.12 & 35.86 \\ 24.73 & 35.82 & 142.18 \end{bmatrix} \quad V/C$$

Considering a balanced line voltage of 210 kV and applying equation (3), Sec. 3, the elements of the $[Q]$ matrix are evaluated and substituted for in equation (1) to obtain the computed values of the electrostatic field at different observation points.