Magnetic Fields Around Gas-Insulated Transmission Lines Crossing

M. A. Abd-Allah
Electrical Technology Department
College of Technology, Jeddah
Kingdom of Saudi Arabia

Abstract: Gas-insulated transmission lines or cables (GITL), owing to their compact nature, offer an attractive alternative to overhead transmission lines where space is limited, such as in densely urban areas. Consequently, it is important to address the issue of power frequency magnetic fields emanating from GITL because of recent concerns that exposure to these fields might cause, or contribute to, adverse health.

This paper aims at evaluating the lateral distributions of magnetic fields near the crossing point of two GITLs. Also, the effects of the crossing angle, the vertical distance between the two lines, the phase arrangement and line loading on the magnetic fields are investigated. The implications of the lateral distributions of magnetic field components at different longitudinal distances from the crossing point of two GITLs are discussed. The effect of the direction of power flow in the crossing line on the magnetic fields is examined. Special attention is given to the case of parallel lines where, the effect of different factors on the magnetic fields for this arrangement is discussed.

Keywords: Gas insulated transmission line, crossing angle, magnetic field

I. INTRODUCTION

The electromagnetic environment associated with high voltage AC transmission systems continues to generate issues of some concern. During the last few years the effects of magnetic fields gained publicity as a result of several controversial epidemiological studies [1-5]. There is no doubt, however, that many people are concerned about the magnetic field effects of power frequency electric currents, associated with transmission and distribution systems, appliances, tools, etc. The use of gas insulated transmission lines or cables is increased in the last few years in densely populated areas and also in heavy industrialized areas[6-10]. While health studies are in progress, it has appeared desirable to conduct parallel technical studies related to the magnetic fields that can be found in occupational areas.

This paper discusses the magnetic fields emanating from two crossing gas insulated transmission lines. Also, the paper investigates the effects of crossing angle, i.e. the angle between the two lines, the vertical distance between the two lines, the phase arrangement of the crossing line and the loading of the crossing line on the magnetic field values. The effect of direction of power flow in the crossing line on the magnetic field values is also presented and discussed. This paper considers the three-conductor, 550 kV system, shown in Fig.1, where two crossing lines are studied as shown in Fig.2. This paper considers also two parallel lines as a special case of crossing lines. The effect of different factors, such as the horizontal distance between the two lines, the loading of the parallel line and the phase arrangement of the parallel line on the magnetic field values is discussed.

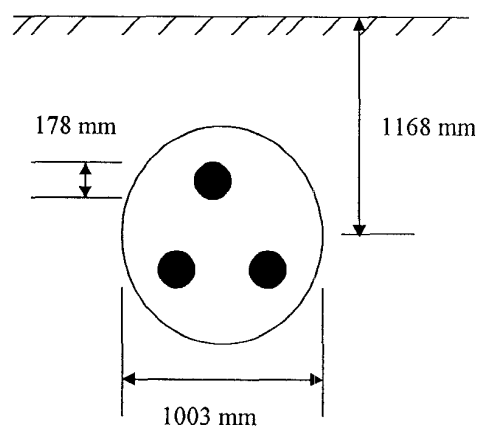

Fig.1 Three conductor, 500 kV GITL system

II. MAGNETIC FIELD CALCULATION

Magnetic field emanating from crossing gas insulated transmission lines can be calculated based on direct three dimensional modeling or based on the principle of superposition. In this paper the superposition technique is used to estimate the magnetic field components and the rms magnetic field above the crossing GITLs. Magnetic field components in Cartesian coordinates of the base line can be first calculated by opening the crossing line. The magnetic field components in Cartesian coordinates of the crossing line can then be calculated by opening the base line and rotating its axis by the crossing angle, α. Once the magnetic field components of crossing line are obtained in the rotated position they can be referred to the original axis position by rotating them back to the original one. Then the magnetic

field components of the base line and the crossing line are superimposed.

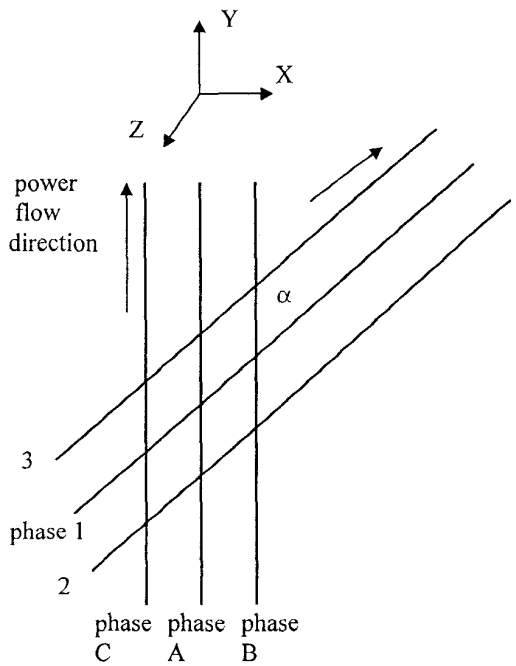

Fig.2 Gas-insulated transmission line crossing

For a single conductor located at (X_{cn}, Y_{cn}) and carrying a current I, the magnetic field components in X, Y and Z directions at an observation point located at (X_p, Y_p) can be expressed as [11].

$$B_{xn} = -2x10^{-7}\left[\frac{Y_{cn} - Y_p}{r_{cn}^2} - \frac{Y_p + Y_{cn} + \alpha}{r_{in}^2}\right] \quad (1)$$

$$B_{yn} = 2x10^{-7}\left[\frac{X_p - X_{cn}}{r_{cn}^2} - \frac{X_p - X_{cn}}{r_{in}^2}\right] \quad (2)$$

$$B_{zn}=0 \quad (3)$$

where, $r_{cn} = \sqrt{(X_p - X_{cn})^2 + (Y_{cn} - Y_p)^2}$

$$r_{in} = \sqrt{(X_p - X_{cn})^2 + (Y_{cn} + Y_p + \alpha)^2}$$

$$\alpha = 2\delta e^{-j\pi/4}$$

$$\delta = 503\sqrt{\frac{\rho_g}{f}}$$

where, δ is the skin depth of the earth, ρ_g is the ground resistivity in Ω-m and f is the frequency in Hz. The radial distance from the conductor to the observation point is much less in this case than the skin depth of the earth, so the formulas for B_x and B_y reduce to the magnetostatic formulas, i.e. neglecting the image terms.

For N conductors; $B_x = \sum_{n=1}^{N} B_{xn}$ & $B_y = \sum_{n=1}^{N} B_{yn}$

III. RESULTS AND DISCUSSIONS

Magnetic fields are calculated assuming that the line currents of the two GITLs are 1000.0 ampere, the conductors in each GITL are parallel lines, the relative permeability is unity everywhere for both air and ground and the earth is flat. The magnetic field values are computed at 1 m above ground level, i.e. at the standard reference height. The vertical distance between the crossing GITLs is measured between the two center lines.

Fig.3 shows the magnetic field components distribution at 1 m above ground level in lateral direction at the crossing point. The crossing angle, α, is taken as 30° and the vertical distance between the two lines is 1.5 m. The x-component is parallel to the ground plane and normal to the base line; the y-component is vertical and the z-component is parallel to the base line. It is seen that the x-component of the magnetic field is greater than that of the y-component immediately above the lines. Beyond this vicinity, the opposite is true. The z-component of magnetic field is relatively small and its value reduces as the observation point is moved farther from the lines.

The lateral distribution of the magnetic field from the crossing point for different crossing angles, α, is shown in Fig.4. The vertical distance between the two lines is taken as 1.5 m. It is shown that as the crossing angle increases, the magnetic field near GITLs decreases till about 4m away from the base line. Beyond that point the reverse is true. This is due to the fact that as the crossing angle increases the observation points far from the base line becomes nearer to the crossing line, thus magnetic field increased as the crossing angle increased for observation points far from the base line. As the crossing angle reaches 90°, the magnetic fields far from the base line becomes constant and the magnetic field is mainly due to the crossing line.

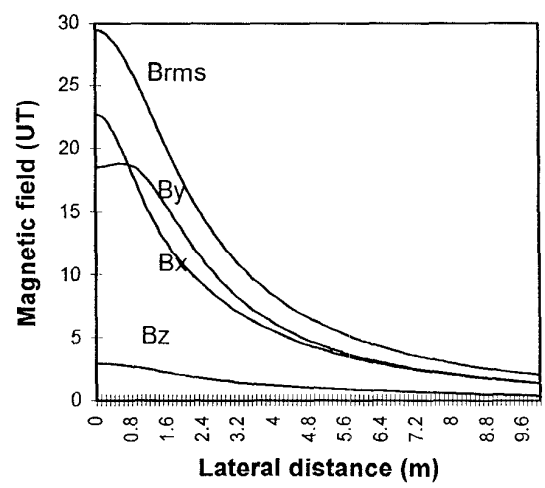

Fig.3 Magnetic fields distribution

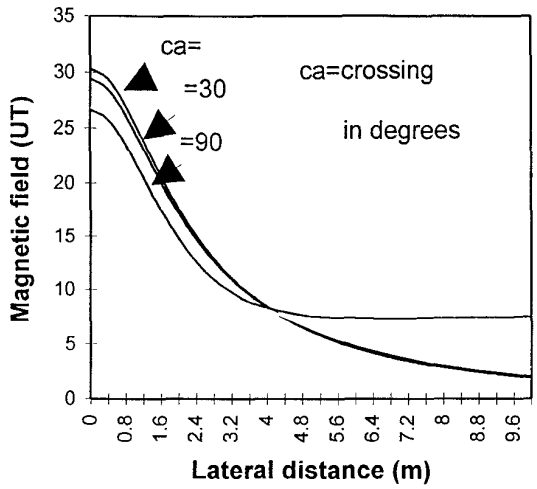

Fig 4 Effect of crossing angle

Fig.5 shows the lateral distribution of the magnetic field at one meter above ground level for different vertical distances between the two center lines of GITLs. The crossing angle, α, is kept constant at 30°. It is seen that the magnetic field values decreases as the depth of the crossing line increases. This is due to the fact that the magnetic fields emanating from the crossing line decreases as it becomes deeper causing over all decrease of fields. The magnetic field decreases by about 11% at the crossing point and by about 5% at 10 m away, as the vertical distance increases from 1.1 m to 2 m.

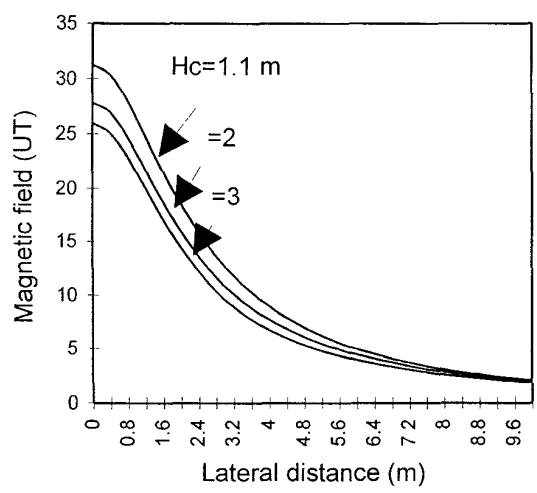

Fig.5 Effect of vertical distance between the two GITLs

The effect of the phase arrangement of the crossing line on the lateral distribution of magnetic fields is shown in Fig.6. The crossing angle, α, is taken as 30° and the vertical distance between the two lines is 1.5 m. The middle phase conductor takes the first letter, the right outermost conductor takes the second letter and the left outermost conductor takes the third one. It is seen that the phase arrangement CAB produces lowest magnetic field values, this is due to higher cancellation effects with this arrangement.

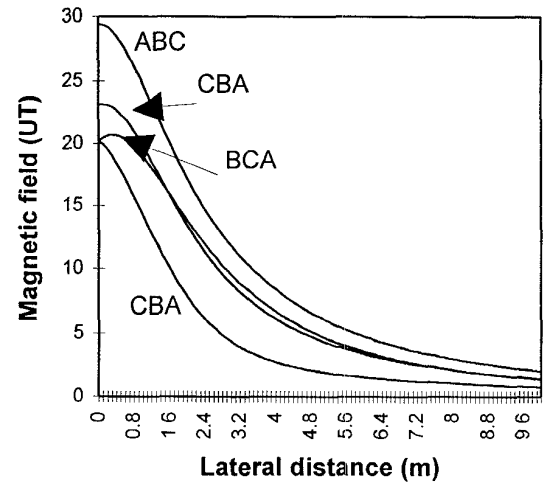

Fig.6 Effect of phase arrangement of the crossing line

Fig.7 shows the lateral distribution of the magnetic field at one meter above ground level for different loading of the crossing line. The line current of the base line is kept constant at 1000 A. The crossing angle, α, is taken as 30° and the vertical distance between the two lines is 1.5 m. It is seen that the magnetic field values decreased with decreasing the line currents of the crossing line.

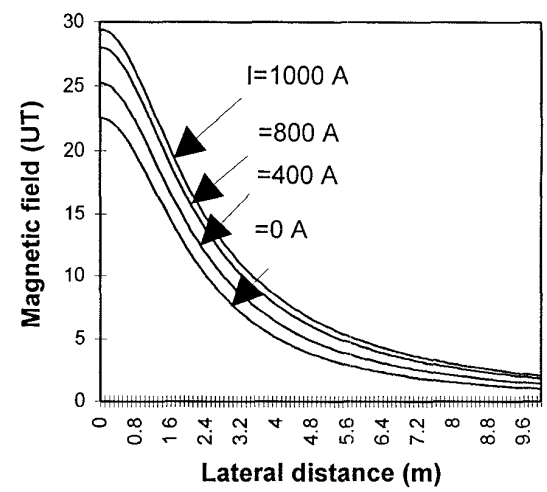

Fig.7 Effect of crossing line loading

The lateral distribution of the magnetic field at one meter above ground level at different longitudinal distances is shown in Fig.8. The crossing angle, α, is taken as 30° and the vertical distance between the two lines is 1.5 m. It is noticed that the magnetic field decreases at the center line of the base GITL with increasing the longitudinal distance. It is clear that the magnetic field decreased with increasing the lateral distance and then it increased when the observation point becomes nearer to the crossing line.

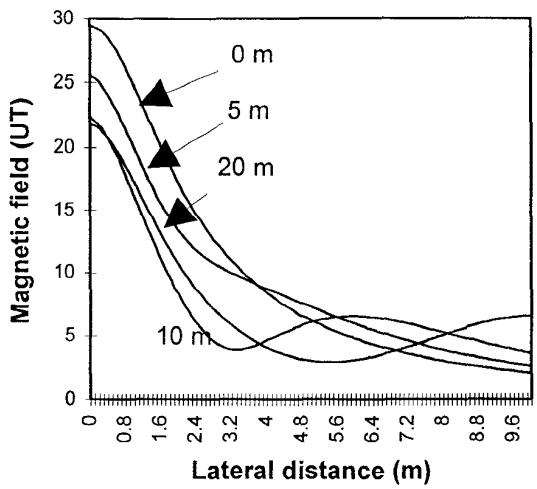

Fig.8 Lateral distribution of magnetic field at different longitudinal distances.

Fig.9 shows the lateral distribution of the magnetic field at one meter above ground level for the two cases: when the direction of power flow in the crossing line is the same as that of the base line and when it is the opposite direction. The line currents of the two GITLs are assumed to be 1000.0 ampere, the crossing angle, α, is taken as 30^0 and the vertical distance between the two lines is 1.5 m. It is seen that the magnetic field values sharply decrease when the power flow in the crossing line is opposite to that in the base line, due to higher cancellation effect.

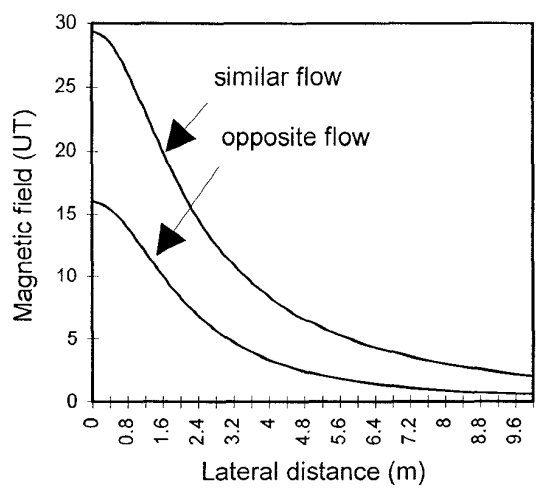

Fig.9 Effect of power flow direction

IV. PARALLEL LINES

Parallel lines is a special case of crossing lines, where the crossing angle equal zero, the vertical distance between the two lines is zero. The line currents are assumed to be 1000.0 ampere. The magnetic field values are computed at 1m above ground level. The left hand side line is assumed to be the base line and the right hand side line is the parallel line. The lateral distance is measured from the center line of the base line.

Fig.10 shows the lateral distribution of the magnetic field components. The horizontal distance between the center lines of two lines, xc, is assumed to be 5m. The peak values of the magnetic field occur at the center line of the two lines. The magnetic field values decreases rapidly to lower values at the center line between the two GITLs, due to higher cancellation effect. The peak value at the parallel line is slightly larger than that at the base line.

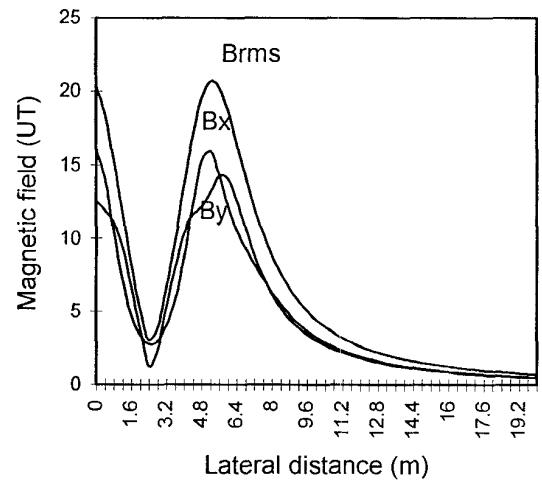

Fig.10 Lateral distribution of magnetic field.

The effect of the horizontal distance between the two lines, xc, on the lateral distribution of the magnetic field values is shown in Fig.11. The magnetic field distribution has two peaks occurring at the central line of each GITL. As the parallel line gets closer to the base line, i.e. xc≤2 m, the magnetic field values in the area above the two lines increased. When the horizontal distance, xc, is greater than 2 m, the cancellation effect between the two lines becomes higher and the magnetic field values in this area are decreased.

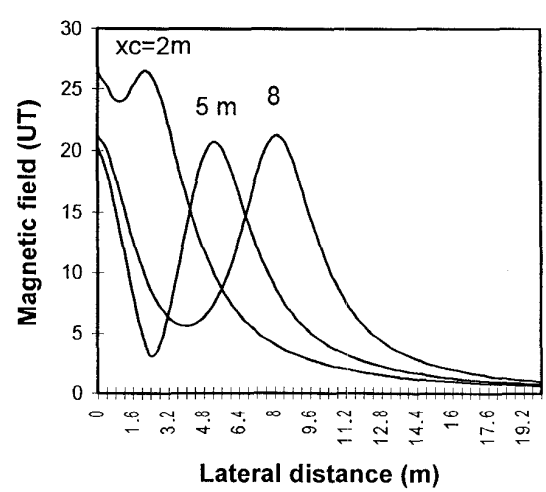

Fig.11 Effect of horizontal distance between lines.

Fig.12 shows the lateral distribution of the magnetic field values at different loading of the parallel line. The horizontal distance between the two lines is assumed to be 5m and the line current of the base line is 1000 ampere. It is seen that the magnetic field peak value above the base line is decreased by about 10% when the line currents of the parallel line increased from 0 to 1000 ampere. The rate of decrease of magnetic field between the two lines increased as the loading is increased. The peak value of the magnetic field above the parallel line increased with increasing the loading of the parallel line.

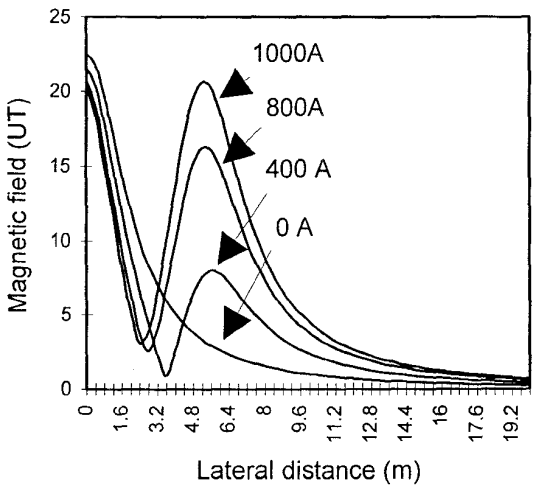

Fig.12 Effect of right line loading

The effect of the direction of power flow in the parallel line w.r.t. the power flow in the base line on the magnetic field values is shown in Fig.13. The horizontal distance between the two lines is assumed to be 5m and the line currents of the two lines are 1000 ampere. It is seen that the opposite flowing of the power in the two lines will result in increasing in the peak magnetic field values by about 30% and 25% w.r.t. the same flowing in areas above original line and the parallel line, respectively. The cancellation effect in the area between the two line is

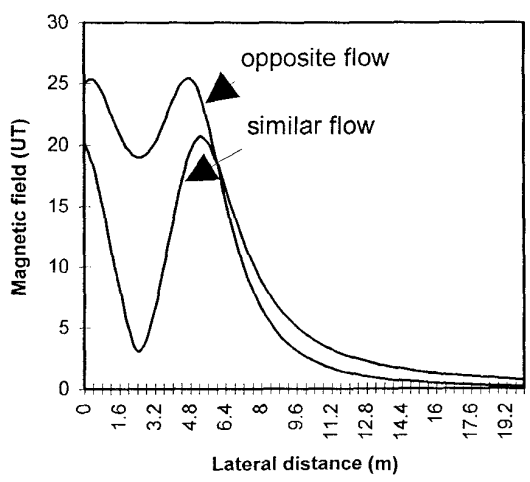

Fig.13 Effect of power flow

higher when the power flow at the same direction. The rate of decay of the magnetic field beyond the parallel line is higher in case of opposite power flow, resulted in lower magnetic field values at this area.

Fig.14 shows the lateral distribution of magnetic field for different phase arrangement of parallel line. The horizontal distance between the two lines is assumed to be 5m. It is seen that the phase sequence ABC of the parallel line resulted in lowest magnetic field values.

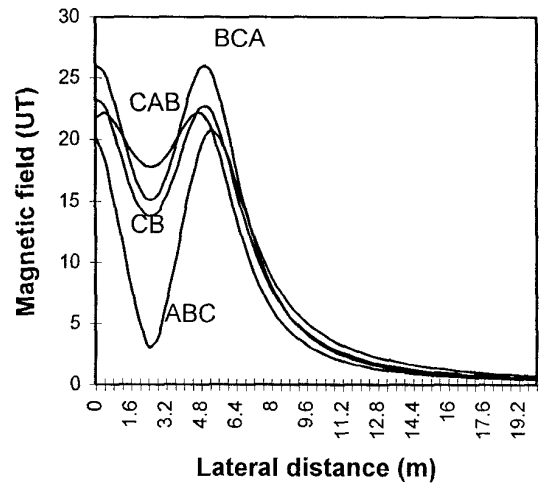

Fig.14 Effect of phase sequence of right line

V. CONCLUSIONS

1. The magnetic field at the crossing area decreased with increasing the crossing angle and the depth of the crossing line.
2. The magnetic field at the crossing area varies markedly with changing the phase arrangement of the crossing line and the best arrangement gives the lowest magnetic field values is CAB.
3. The magnetic field at the crossing area decreased as the loading of the crossing line decreased.
4. The magnetic field at the crossing area decreased sharply when the power flow in the crossing line is in opposite direction with that in the original line.
5. For parallel lines the opposite flowing of power in the parallel line resulted in increasing the magnetic field values above the lines, while they decreasing beyond the parallel line.
6. The best phase arrangement of the parallel line gives the lowest magnetic field values is ABC.

VI. REFERENCES

[1]. P. H. Pretorius, "An attempt to Quantify The Suggested Risk Associated With Power Frequency Magnetic Field Exposure", CIGRE, Paris, Paper 36-101, 1996.

[2]. R. Conti, L. D'Ajello and P. Nicolini, "ENEL's Experience in Assessing Occupational and Residential Exposure to Power Frequency Electric and magnetic Fields", CIGRE, Paris, Paper 36-104, 1996.

[3]. O. Bottauscio and R. Conti, "Magnetically and Electrically Induced Currents in Human Body Models by ELF Electromagnetic Fields",

10th International Symposium on High Voltage Engineering (ISH), Canada, Session TS1, 1997.

[4]. A. Ahllbom, "Cancer and Residential Exposure To Weak Extremely Low Frequency Magnetic Fields", CIGRE, Paris, Panel 1-01, 1994.

[5]. W. Dab, J. Lambrozo and M. Souques, "Magnetic Field and Cancer: Recent Studies in Adults", CIGRE, Paris, Panel 1-03, 1994.

[6]. P. S. Wong, T. M. Rind, S. M. Harvey and R. R. Scheer, "Power Frequency Electric and Magnetic Fields From a 230 kV Gas-Insulated Substation", IEEE Trans. on Power Delivery, Vol. 9, No.3, July 1994.

[7]. Alan H. Cookson, "Gas-Insulated Cables", IEEE Trans. on Electrical Insulation, EI-20, No.5, Oct. 1985.

[8]. A. Eriksson, K. G. Pettersson, A. Krenicky, R. Baker, J. R. Ochoa and A. Leibold, "Experience With Gas Insulated Substations in The USA", IEEE Trans. on Power Delivery, Vol. 10, No. 1, pp. 210-218, 1995.

[9]. T. Nojima, et. al., "Installation of 275 kV-3.3 km Gas-Insulated Transmission Line For Underground Large Capacity Transmission in Japan", CIGRE, Paris, Paper 21/23/33-01, 1998.

[10]. Y. Kuroyanagi, et. al., "Construction of 8000 A Class 275 kV Gas Insulated Transmission Line", IEEE PES 89 SM 637-0 PWRD.

[11]. M. A. Abd-Allah, H. I. Anis and Shaher A. Mahmoud, "Measurements of Magnetic Fields in Places of Work and Residence- An Egyptian Case Study", 28th North American Power Symposium (NAPS), MIT, Cambridge, USA, pp. 223-229, 10-12 Nov. 1996.

[12]. M. A. Abd-Allah, H. Anis and Shaher A. Mahmoud, "Comparative Study of Magnetic Fields Near EHV and Distribution Power Lines", North American Power Symposium, Howard University, Washington, USA, pp. 427-435, Oct. 1993.

VII. BIOGRAPHIES

Mousa A. Abd-Allah was born in Cairo, Egypt, on August 16, 1961. He received his B.Sc. with honor degree and M.Sc. degree from Zagazig University in 1984 and 1988, respectively. He received his Ph.D. degree from Cairo University, Egypt in 1991. Since 1997, he is an associate professor in Zagazig University. His main research interests include electromagnetic fields assessment, management and environmental impacts. His current interests cover the investigation of aging and breakdown phenomena in gases and liquids dielectrics.