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Electromagnetic Fields Around a High Voltage 400 kv Electrical Overhead Lines.

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In the name of **God**, the Compassionate, the Merciful. All praise is for **Allah**, Lord of the Worlds, Master of the Day of Judgment whom we do worship, and whose pleasure and aid we seek. Blessings and peace of **Allah** be upon his last Prophet and Messenger **Mohammed** and upon his Family and Companions.

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I am forever profoundly indebted to my family, to whom this work is dedicated, for their unparalleled love, support and encouragement throughout my entire life.

DEDICATION

This Thesis is Gratefully Dedicated To My mother' s soul



ABSTRACT

In this thesis the magnetic field around a400kv.power line had been measured and simulated. The measurement results and simulated results had been compared, and then compared with the international standards.

Measurements of magnetic field intensity at the 1meter above the ground level carried out for an existing high voltage 400kv. overhead lines connected between Zawia and Tripoli-west substations, show that the emissions of magnetic fields around overhead line right of way(ROW) could be high, and a solution should be considered like increasing the right of way(ROW) distance, or lowering the current.

One of the main finding is that the transmission corridor(ROW) is not forced and people are living and still building houses right now under the transmission lines.

Highly concerned had been taken about the effects of magnetic fields on the health. Probable risk for leukemia, breast cancer neuropsychological disorders and reproductive outcomes had been reported due to this exposure. Especially when exposed for a long time.

ملخص البحث

في هذه الرسالة تم قياس وحساب المجال المغناطيسي حول خطوط نقل الطاقة جهد 400 ك ف.

تمت مقارنة النتائج العملية مع النتائج المحسوبة بالحاسوب ،ثم تمت مقارنتهما مع المعايير العالمية.

القياسات العملية للمجال المغناطيسي لخطوط نقل الطاقة جهد 400ك ف الرابطة بين محطة تحويل الزاوية ومحطة تحويل غرب طرابلس، أظهرت أن الجهد المنبثق عن هذه الخطوط عالي نسبياً في المنطقة حول مسار الخطوط . ونقترح كحل لهذه المشكلة زيادة المسافة الآمنة أو التقليل من تيار التحميل.

ولقد وجد أن مسار الخطوط غير مؤمن وأن الناس لازالوا يعيشون ويبنون منازل تحت خطوط نقل الطاقة إلي حد الآن .

تم التركيز بشكل كبير علي تأثير المجال المغناطيسي علي صحة الإنسان وعلي البيئة. حيث أنه من المحتمل أن التعرض للمجال المغناطيسي لفترات طويلة يسبب الإصابة ببعض الأمراض مثل سرطان الدم وغيره من أمراض أخري .

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List of symbols and abbreviation

symbol	meaning
HV	High Voltage
TL	Transmission Line
kv	Kilo volt
EMF	Electro Magnetic Fields
ELF	Extremely Low Frequency
ROW	Right Of Way
WHO	World Health Organization
E	Electric field intensity
D	Electric flux density
H	Magnetic field intensity
B	Magnetic flux density
J	Electric current density
M	Magnetic current density
Q_e	Electric charge density
Q_m	Magnetic charge density
emf	Electromagnetic force
Q_{te}	Total electric charge
Q_{tm}	Total magnetic charge
$\boldsymbol{\varepsilon_0}$	permittivity of free space
$\boldsymbol{\varepsilon_r}$	relative permittivity of the medium
μ_o	permeability of free space
μ_r	relative permeability of the medium
σ	conductivity of the medium
DC	Direct current
AC	Alternate current
ρ_e	Resistivity
t_0	Time instance
$\mathbf{T_0}$	Time period
$\boldsymbol{\omega_0}$	Angular frequency
$\boldsymbol{\phi_i}$	Current phase angle
$\boldsymbol{\phi_v}$	Voltage phase angle
GECOL	General Electrical Company Of Libya
µT	Micro Tesla
mG	Mille Gauss
MATLAB	Matrix Laboratory
ICNIRP	International Commission on Non-Ionizing Radiation Protection

Chapter one

Introduction

1.1 Background

Electromagnetic energy is generated through changes in the motion state of electrical charges. A change in state of motion will result in emission or absorption of energy. The wavelength of emitted or absorbed energy is inversely proportional to the magnitude of the energy change. An electromagnetic wave propagates in a direction which is oriented at right angle to the vibration directions of both the magnetic (B) and electric (E) oscillating field vectors, transporting energy from the radiation source to an undetermined final destination. The two oscillating energy fields are mutually perpendicular and vibrate in phase following the mathematical form of a sine wave. Not only are the magnetic and electrical field vectors perpendicular to each other, but also they are perpendicular to the direction of wave propagation.

High voltage overhead lines has an electric and magnetic fields around them. These fields increase with the increase in loading. In Libya the 400k.v overhead lines is the highest voltage in use. People who are living very close to the overhead lines could be harmed by the effect of its fields.

In this work we will try to measure and simulate the electromagnetic fields of high voltage overhead lines 400kv that extended from Zawia to Tripoli-West stations, and see if it is within the international standards and give recommendation based on the findings.

Many papers have been written about the distribution of electromagnetic fields under high voltage transmission lines. For example: Daniel Greenan from Ireland found that overhead lines have a negative visual impact and health implications.[4]

Dib Djalel and Mordjaoui Mourad from Algeria Confirmation of non-standards compliance to the limits of human exposure to ELF fields in the case of the town of Tebessa and approving the aggression on human health.[5]

Nmk Abdel-Gawad had discussed in his paper which had published in the open Environmental Engineering Journal.(2009) ,the Investigation into field Management under power Transmission Lines using Delta Configurations.[6]

Adel Z.Eldein had discussed his paper about the Mitigation of magnetic field under Egyptian 500kv Overhead Transmission line during the seventh International Multi-Conference on systems, signals and devices .(2010),[7]

These papers have explained only the lateral profile of the electromagnetic field distribution on the ground.

In this thesis the magnetic fields around high voltage overhead lines, one meter height above the ground will be measured with appropriate measurement device.

1.2 The Thesis Objective

The main objective of this Thesis is to give a detailed analysis and measurements of magnetic fields emitted by 400 kV power transmission lines in Libya. The Thesis starts by an overview on the latest developments in the power line designs, including recent configurations and the different ways of conductor placements that help in reducing the emitted magnetic fields and by a review of the basic magnetic field equations that will be used later in the comparison of theoretical and actual values. A research on major worldwide conducted studies that discuss the health impact of the high-voltage transmission lines as well as international guidelines and standards for minimum clearance is presented.

In the process of performing this study, field measurements are taken on each of the Zawia and Tripoli west power lines, which are 400 kV lines. This field work is followed by the development of an analytical model of the field estimation through the implementation of a software program that calculates the magnetic field of these power transmission lines. Moreover, a modeling is implemented using the Matlab software, which also estimates the magnetic field of the specific power lines. All the results obtained, either by measurement or using the software program are then compared and discussed.

To make the comparison clear the both results have been normalized to be in it's maximum value as **1**. This thesis is concluded by a set of guidelines related to power lines clearances taking into consideration the current level.

1.3 Organization of the Thesis

This thesis classified into six chapters in addition to an introductory chapter are follows:

- **Chapter2** "Theory of electromagnetic fields" This chapter is forwarded to a general review of Theory and Background of electromagnetic radiation emitted from high voltage power lines.
- **Chapter 3** " Effects of electromagnetic fields of high voltage over head lines " This chapter discuss more details about the effect of magnetic fields on human health and living organism.
- **Chapter 4** "Analysis of high voltage overhead lines", This chapter give the analysis of both electric and magnetic fields.
- **Chapter 5** "Measurements and Simulation of Magnetic Field" This chapter describes procedures to measure and simulate the magnetic fields.
- **Chapter Six**: "Conclusion and Recommendations" This chapter deals with conclusion and recommendations. Also the future work.

Chapter two

Theory of electromagnetic fields

2.1 Introduction

Electricity is such a basic element of modern life that makes everybody exposed to a certain degree of electromagnetic fields. The two fields associated with the use of electricity are electric fields which are produced by the voltage, and magnetic fields which are produced by the current. The two fields taken together are the electromagnetic fields (EMF).

In this thesis electromagnetic fields which are produced by power transmission lines will be measured. Several developments have taken place in the design of the power lines in order to reduce the electromagnetic field, such as increasing the distance between the lines and the residences, decreasing the current, shielding, changing the geometry of the conductors through the compaction method, the phase splitting method as well as the current-phase rearrangement method. It is important to implement these techniques because many researchers still suspect the existence of an association between the EMF induced from power lines and health damages.

At the beginning of the 21^{st} century, communities and individuals are still facing problems whenever a new overhead transmission power line has to be installed. The presumed effects of the electromagnetic fields on the individual health tend to scare people. Due to this fear protests usually tend to be issued in order to prevent the installation of these high voltage transmission lines.

High voltage (HV) transmission lines and electric equipment produce electric and magnetic field in their vicinity, which are likely to have harmful effects on plants, animals and human beings when their levels are beyond certain limits. Radiation from power transmission lines are inescapable. Magnetic field was measured under 400 kv lines. Data from these studies and biological effects of electric and magnetic fields are discussed.

In recent years the living or working condition near high voltage transmission lines are the subjects of many researches due to the harmful effects of electromagnetic field on human's health. This subject is very popular and it is now the research aim of national scientific organizations, so that the World Health Organization (WHO) has offered useful advises for the maximum time of being under electromagnetic field. That kind of organizations which are working in this subject believe that applying such as time limitations are not reliable enough and is just a discretionary act, but regarding to all this condition all of this organizations believe that living near electrical installations isn't safe. According to this and to better evaluate electromagnetic field around of the transmission lines, the simulation and also measurement of the magnetic field generated by **400kV** lines will be done.[14]

One of the main characteristics which defines an electromagnetic field (EMF) is its frequency or its corresponding wavelength. Fields of different frequencies interact with the body in different ways. One can imagine electromagnetic waves as series of very regular waves that travel at, the speed of light.

Another important characteristic of electromagnetic fields: Electromagnetic waves are carried by particles called quanta. Quanta of higher frequency (shorter wavelength) waves carry more energy than lower frequency (longer wavelength) fields. Some electromagnetic waves carry so much energy per quantum that they have the ability to break bonds between molecules. In the electromagnetic spectrum, gamma rays given off by radioactive materials, cosmic rays and X-rays carry this property and are called 'ionizing radiation'. Fields whose quanta are insufficient to break molecular bonds are called 'non-ionizing radiation. Man-made sources of electromagnetic fields that form a major part of industrialized life - electricity, microwaves and radiofrequency fields are found at the relatively long wavelength and low frequency end of the electromagnetic spectrum and their quanta are unable to break chemical bonds.[14]

2.2 Maxwell's Equations

Electric and magnetic fields are vectors quantities that have both magnitude and direction. The relations and variations of electric and magnetic fields, charges, and currents associated with electromagnetic waves are governed by physical laws, which are known as Maxwell's equations. These equations were arrived at mostly through various experiments carried out by different investigators, like Ampere, Gauss, and Faraday, but they were put in their final form by James Clerk Maxwell. These equations can be either in differential or in integral forms.[3]

2.2.1 Maxwell's Equations in Differential Form

The differential form of Maxwell's equations is the most widely used representation to solve boundary-value electromagnetic problems. It is used to describe and relate the field vectors, current densities, and charge densities at any point in space at any time. For these expressions to be valid, it is assumed that the field vectors are single-valued, bounded, continuous functions of position and time and exhibit continuous first derivatives. Field vectors associated with electromagnetic waves possess these characteristics except where there exist abrupt change in charge and current densities. Discontinuous distributions of charges and currents usually occur at interfaces between media where there are discrete changes in electrical parameters across the interface. The variations of the field vectors across such boundaries (interfaces) are related to discontinuous distributions of charges and currents by what are usually referred to as the boundary conditions. Thus a complete description of the field vectors at any point (including discontinuities) at any time requires not only Maxwell's equations in differential form but also the associated boundary conditions along with the electric and magnetic properties of the region.[3]

In differential form, Maxwell's equations can be written as:

$$\nabla \times \bar{E} = -\bar{M} - \frac{\partial \bar{B}}{\partial t} \qquad \textbf{(2-1)}$$

$$\nabla \mathrm{X}\, \bar{H} = \bar{J} + \frac{\partial \bar{D}}{\partial t} \qquad (2\text{-}2)$$

$$\nabla \bullet \bar{D} = Q_e \qquad (2\text{-}3)$$

$$\nabla \bullet \bar{B} = Q_m \qquad (2\text{-}4)$$

Where:

$\bar{E}$ is the electric field intensity (Volt/meter)

$\bar{H}$ is the magnetic field intensity (Amperes/meter)

$\bar{D}$ is the electric flux density (Coulombs/square meter)

$\bar{B}$ is the magnetic flux density (Webers/square meter)

$\bar{J}$ is the electric current density (Amperes/square meter)

$\bar{M}$ is the magnetic current density (assumed) (Volts/square meter)

Q_e is the electric charge density (Coulombs/cubic meter)

Q_m is the magnetic charge density (assumed) (Webers/cubic meter)

In addition to the four Maxwell's equations, there is another equation that relates the variations of the current density $\bar{J}$ and the charge density Q_e . Although not an independent relation, this equation is referred to as the *continuity equation* because it relates the net flow of current out of a small volume (in the limit, a point) to the rate of decrease of charge.[3]

It takes the form:

$$\nabla \bullet \bar{J} = - \frac{\partial Qe}{\partial t} \qquad (2\text{-}5)$$

2.2.2 Maxwell Equations in Integral Form

The integral form of Maxwell's equations describes the relations of the field vectors, charge densities, and current densities over an extended region of space. They have limited applications and are usually utilized only to solve electromagnetic boundary-value problems that possess complete symmetry (such as rectangular, cylindrical, spherical, etc., symmetries). However, the fields and their derivatives in question do not need to possess continuous distributions.

The integral form of Maxwell's equations can be derived from its differential form by utilize the Stokes' and divergence theorems. For any arbitrary $\bar{A}$ vector $\bar{A}$, Stokes' theorem states that the closed line integral of the vector $\bar{A}$ along a closed path C is equal to the integral of the dot product of the curl of the vector with the normal to the surface S that has the contour C as its boundary.[3]

In equation form, Stokes' theorem can be written as:

$$\oint \bar{A} \cdot d\bar{l} = \iint_s (\nabla \times \bar{A}) \cdot d\bar{s} \qquad (2\text{-}6)$$

The divergence theorem states that for any arbitrary vector $\bar{A}$ the closed surface integral of the normal component of vector $\bar{A}$ over the a surface S is equal to the volume integral of the divergence of $\bar{A}$ over the volume V enclosed by S . In mathematical form, the divergence theorem is stated as:

$$\oiint \bar{A} \cdot d\bar{s} = \iiint_v \nabla \cdot \bar{A}\, dv \qquad (2\text{-}7)$$

Taking the surface integral of both sides of (2.1), we can write:

$$\iint_s (\nabla \times \bar{E}) \cdot d\bar{s} = -\iint \bar{M} \cdot d\bar{s} - \frac{\partial}{\partial t} \iint \bar{B} \cdot d\bar{s} \qquad (2\text{-}8)$$

Applying Stokes' theorem, as given by (2-6), on the left side of (2-8) reduces it to:

$$\oint \bar{E} \bullet d\bar{l} = - \iint_s \bar{M} \bullet d\,\bar{s} - \frac{\partial}{\partial t} \iint \bar{B} \bullet d\,\bar{s} \qquad \textbf{(2-9)}$$

Which is referred to as Maxwell's equation in integral form as derived from Faraday's law. In the absence of an impressed magnetic current density, Faraday's law states that the electromotive force (emf) appearing at the open-circuited terminals of a loop is equal to the time rate of decrease of magnetic flux linking the loop.[3]

Using a similar procedure, we can show that the corresponding integral form of (2-2) can be written as:

$$\oint \bar{H}.\, d\bar{l} = \iint_s \bar{J} \bullet d\,\bar{s} + \frac{\partial}{\partial t} \iint_s \bar{D} \bullet d\,\bar{s} \qquad \textbf{(2-10)}$$

Which is usually referred to as Maxwell's equation in integral form as derived from Ampere's law. Ampere's law states that the line integral of the magnetic field over closed path is equal to the current enclosed.

The other two Maxwell's equations in integral form can be obtained from the corresponding differential forms, using the following procedure. First take the volume integral of both sides of (2-3); that is,

$$\iiint \nabla \bullet \bar{D}\, dv = \iiint Q_e\, dv = Q_{te} \qquad \textbf{(2-11)}$$

Where:

Q_{te} is the total electric charge. Applying the divergence theorem, as given by (2-7), on the left side of (2-11) reduces it to:

$$\oiint \bar{D} \bullet d\,\bar{s} = \iiint Q_e\, dv = Q_{te} \qquad \textbf{(2-12)}$$

Which is usually referred to as Maxwell's electric field equation in integral form as derived from Gauss's law. Gauss's law for the electric field states that the total electric flux through a closed surface is equal to the total charge enclosed. In a similar manner, the integral form of (2-4) is given in terms of the total magnetic charge Q_{tm} by:

$$\oiint \bar{B} \cdot d\bar{s} = Q_{tm} \qquad \textbf{(2-13)}$$

Which is usually referred to as Maxwell's magnetic field equation in integral form as derived from Gauss's law. Even though magnetic charge is nonphysical, it is used as an equivalent to represent physical problems. The corresponding integral form of the continuity equation, as given by (2-5) in differential form, can be written as:

$$\oiint \bar{J} \cdot d\bar{s} = \frac{-\partial}{\partial t} \iiint Q_e \, dv = \frac{-\partial Qte}{\partial t} \qquad \textbf{(2-14)}$$

The constitutive relations of the electromagnetic field vectors are as follows:

$$\bar{D} = \varepsilon_0 \varepsilon_r \bar{E} \qquad \textbf{(2-15)}$$
$$\bar{B} = \mu_0 \mu_r \bar{H} \qquad \textbf{(2-16)}$$
$$\bar{J} = \sigma \bar{E} \qquad \textbf{(2-17)}$$

Where,

ε_0 is the permittivity of free space, 8.654×10^{-12} (Farads/meter).

ε_r is the relative permittivity of the medium, equals 1 for air.

μ_o is the permeability of free space, $4\pi \times 10^{-7}$ (Henries/meter).

μ_r is the relative permeability of the medium, equals 1 for air.

σ is the conductivity of the medium (Siemens/meter). [1],[3]

2.3 Boundary Conditions

The differential form of Maxwell's equations are used to solve for the field vectors provided the field quantities are single valued, bounded, and possess (along with their derivatives) continuous distributions. Along boundaries where the media involved exhibit discontinuities in electrical properties (or there exist sources along these boundaries), the

field vectors are also discontinuous and their behavior across the boundaries is governed by the boundary conditions.

Maxwell's equations in differential form represent derivatives, with respect to the space coordinates, of the field vectors. At points of discontinuity in the field vectors, the derivatives of the field vectors have no meaning and cannot be properly used to define the behavior of the field vectors across these boundaries. Instead the behavior of the field vectors across the discontinuous boundaries must be handled by examining the field vectors themselves and not their derivatives. Integral form of Maxwell's equations provide the most convenient formulation for derivation of the boundary conditions, and will be presented only for completeness.[3]

For tangential electric field intensity:

$$-\ \bar{n} \times (\bar{E}_2\ -\ \bar{E}_1\ ) = \bar{M}_{ms}$$

For tangential magnetic field intensity:

$$\bar{n} \times (\bar{H}_2\ -\ \bar{H}_1\ ) = \overline{J_{es}}$$

For the normal electric flux density:

$$\bar{n} \bullet (\bar{D}_2\ -\ \bar{D}_1\ ) = Q_{es}$$

For the normal magnetic flux density:

$$\bar{n} \bullet (\bar{B}_2\ -\ \bar{B}_1\ ) = Q_{em}$$

Where:

$\bar{n}$ is the normal unit vector to the boundary interface directed from region 1 to region 2(region 1 is the region from which the wave start).

$\bar{M}_{ms}$ is the magnetic linear (per meter) current density (assumed).

$\bar{J}_{es}$ is the electric linear (per meter) current density.

Q_{es} is the electric surface (per square meter) charge density.

Q_{ms} is the magnetic surface (per square meter) charge density (assumed).[3]

2.4 ELF Approximations of Maxwell's Equations

For high voltage (HV), 50Hz power transmission lines, due to the large wavelength , 6000km, the field problem can be considered as a quasi-static, and the electric and magnetic field components can be analyzed separately using a static technique. The coupling between the electric and magnetic field quantities, generally provided under time-varying conditions by the terms:

$\frac{\partial \bar{B}}{\partial t}$ and $\frac{\partial \bar{D}}{\partial t}$ appearing in equations (2-1) and (2-2) can be approximated to zero and the solution can be determined by static techniques.

Thus Maxwell's equations for time-static fields can be deduced from the time varying modal system by the approximation :

$\left(\frac{\partial \bar{B}}{\partial t} \text{ and } \frac{\partial \bar{D}}{\partial t}\right) = 0$, as follows:

$$\nabla \times \bar{E} = 0 \qquad (2\text{-}18)$$

$$\nabla \times \bar{H} = \bar{J} \qquad (2\text{-}19)$$

$$\nabla \bullet \bar{D} = Q_e \qquad (2\text{-}20)$$

$$\nabla \bullet \bar{B} = 0 \qquad (2\text{-}21)$$

$$\nabla \bullet J = 0 \qquad (2\text{-}22)$$

$$\oint_C \bar{E} \cdot d\bar{l} = 0 \qquad (2\text{-}23)$$

$$\oint_C \bar{H} \cdot d\bar{l} = \iint_S \bar{J} \cdot d\bar{s} \qquad (2\text{-}24)$$

$$\oiint_S \bar{D} \cdot d\bar{s} = Q_{te} \qquad (2\text{-}25)$$

$$\oiint_S \bar{B} \cdot d\bar{s} = 0 \qquad (2\text{-}26)$$

$$\oiint_S \bar{J} \cdot d\bar{s} = 0 \qquad (2\text{-}27)$$

Where in this case the source of electrostatic and magneto static fields are the static charge density and the static currents (DC) as assumed to be quasi-static respectively.[3]

Table(2.1) : Maxwell's equations and the continuity equation in differential and integral forms for time invariant fields.

Differential form	Integral form
$\nabla \times \overline{E} = 0$	$\oint_C \overline{E} \cdot d\overline{l} = 0$
$\nabla \times \overline{H} = \overline{J}$	$\oint_C \overline{H} \cdot d\overline{l} = \iint_S \overline{J} \cdot d\overline{s}$
$\nabla \cdot \overline{D} = Q_e$	$\oiint_S \overline{D} \cdot d\overline{s} = Q_{te}$
$\nabla \cdot \overline{B} = 0$	$\oiint_S \overline{B} \cdot d\overline{s} = 0$
$\nabla \cdot \overline{J} = 0$	$\oiint_S \overline{J} \cdot d\overline{s} = 0$

2.4.1 Gauss's Law

Equation (2-25) is very well known as Gauss's law for electric field, mathematically, the equation states that the total electric flux through any closed surface is equal to the total electric charge enclosed by the surface. Thus, equation (2-25) can be rewritten in terms of the electric field as follows:

$$\oiint \varepsilon_0 \, \overline{E} \cdot d\,\overline{s} = Q \qquad \textbf{(2-28)}$$

For a problem with particular spatial symmetry, Gauss's law may be employed to find the solutions for the electric field vector whenever the charge distribution is known. For the case of a line charge, as we will see in chapter 3, this law will be used to solve for the electric field by assuming a symmetrical imaginary right cylindrical surfaces.[3]

2.4.2 Biot-Savart's Law

For a current **I** flowing in a differential vector length $d\,\overline{L}$ of filamentary

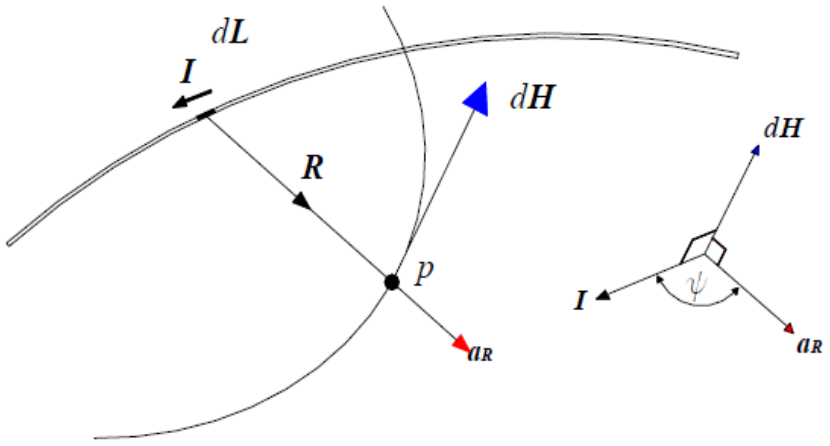
conductor, as shown in figure(2.1). The mathematical form of the Biot-Savart law is :

$$d\bar{H} = \frac{I\,\bar{dL} \times \bar{a_R}}{4\pi R^2} \qquad \textbf{(2-29)}$$

or

$$d\bar{B} = \mu_0 \frac{I\,\bar{dL} \times \bar{a_R}}{4\pi R^2} \qquad \textbf{(2-30)}$$

Which states that at any point **P** , from figure(2.1) the magnitude of the magnetic field intensity produced by the differential element is proportional to the product of the current, the magnitude of the differential length, and the sine of the angle lying between the filament and the line connecting the filament to the point **P** where the field is desired.



Figure(2.1)Differential field intensity $d\bar{H}$ produced by a differential current element I $d\bar{L}$.

The magnitude of the magnetic field intensity is inversely proportional to the square of the distance from the differential element to the point **P** . The direction of the magnetic field intensity is normal to the plane containing the differential filament and the line drawn from the filament to the point **P** . The normal direction is always taken to match

the right-hand rule. The law of Biot-Savart can be obtained from Maxwell's Equations (2-19) and (2-21), by introducing the concept of the magnetic potential vector and solving the resulted vector form Poisson equation .[3]

2.5 The Libyan Electricity network

GECOL is a state-owned vertically structured power utility responsible for generation, transmission and distribution of electric power throughout Libya.

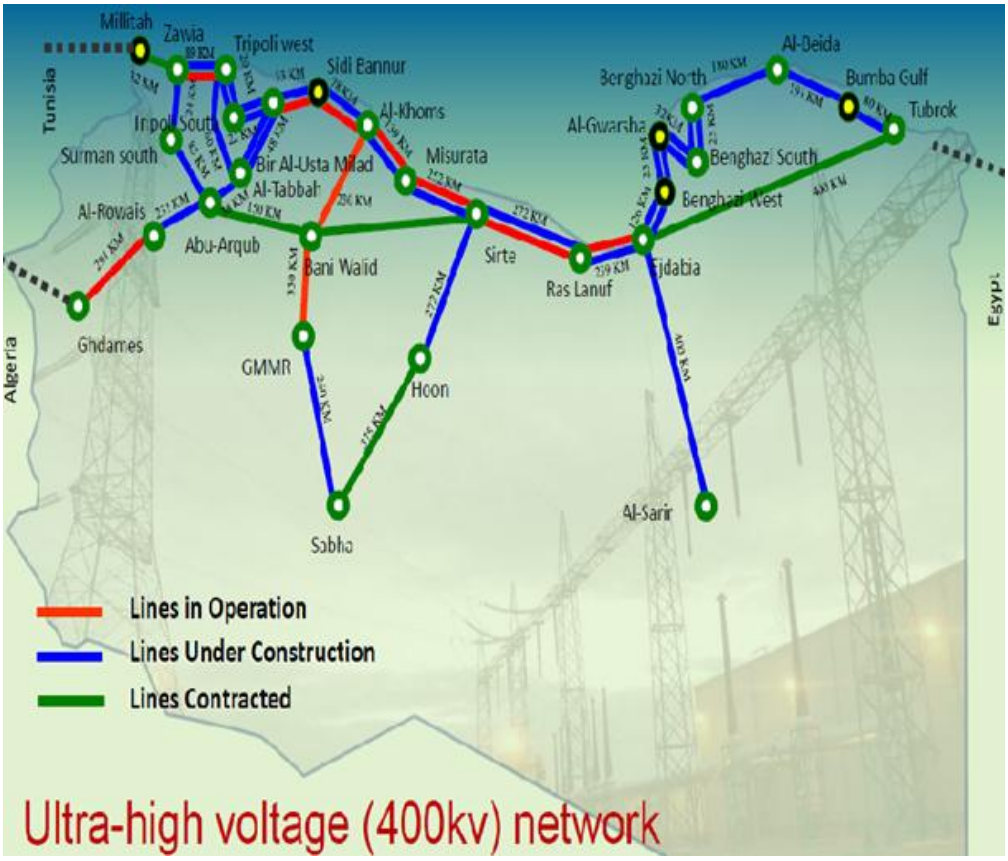
The following data has been taken from GECOL Site.

Peak Load	5,759 MW
Installed Generation Capacity	8,907 MW
Generated Energy	32.6 TW
400 kV Transmission system	2,823 km
220 kV Transmission system	13,782 km
30, 66 kV Sub transmission	23,132 km

11 kV distribution	52,260 km
Customers	1,224,193
Per-Capita Consumption	4,351 kWh
Urban & Rural Electrification Rate	≈ 99%

There are different types of design for every overhead line. The 400kv overhead line which is the topic of this thesis. The dimensions of one of the 400kv tower are: The total height of the tower is 66.8 meter, the height of phases from the ground are (24, 37 and 50) meter, respectively and the wings width are (11.5 ,10 and 9) meter respectively.

The 400kv power lines, network extended through Libyan land for more than 2,823km .The next map shows the 400kv lines which are in operation(red color) and which under Construction(blue color).



Figure(2.2) Libyan high voltage coverage.

2.5.1 Single Circuit 3-Phase Transmission Lines

In single circuit transmission line system, electrical power is transmitted over a group of conductors constituting the 3-phase sequence of the total or part of the power generated. Each group of conductors may be made up of a single conductor or more bundled conductors arranged in a technical way. Two, three, and four Bundled conductor per phase are widely used in one way or another as shown in Figure(2-3). In the case of single circuit transmission line systems, the phases are usually configured horizontally or in a triangular configuration. The supporting tower is usually designed with a configuration convenient to support the conductors. More flexibility and space are available on the tower in the case of single circuit to construct the best configuration.

Another wire, sometimes two, is used for earthing with the single circuit transmission system. A single circuit transmission line system is usually used in case of extra high voltages where large insulation spacing between phases is required as well as between conductors and the support structures.

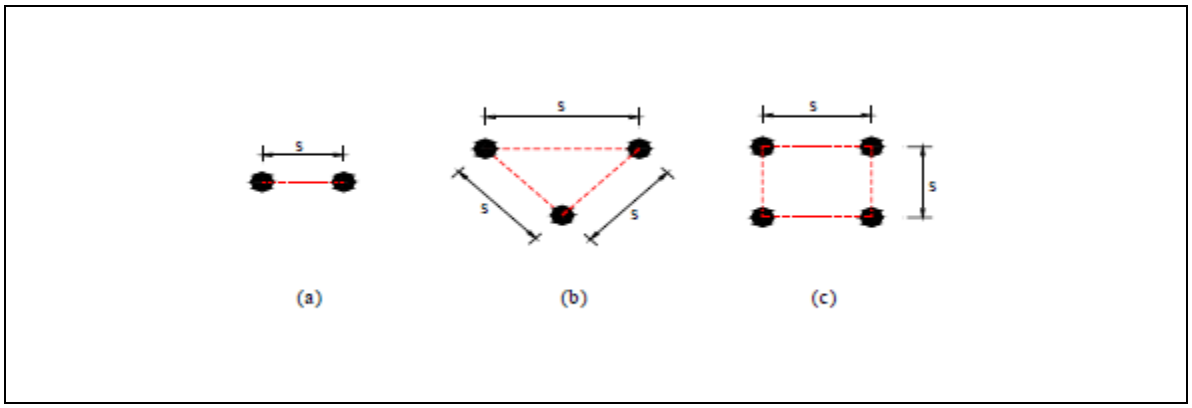
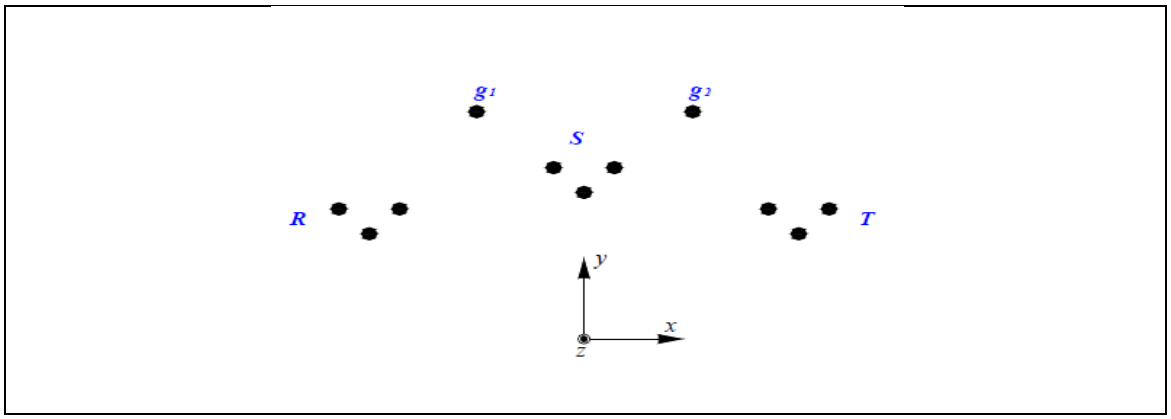


Figure 2-3: *Bundled conductors, (a) two bundled conductors, (b) three bundled conductors, (c) Four bundled conductors.[3]*

A 400kV single circuit 3-phase typical line configuration constructed in Libya is shown in Figure(2-4a), with the phasing arrangement confirmed from the substation side.[3]

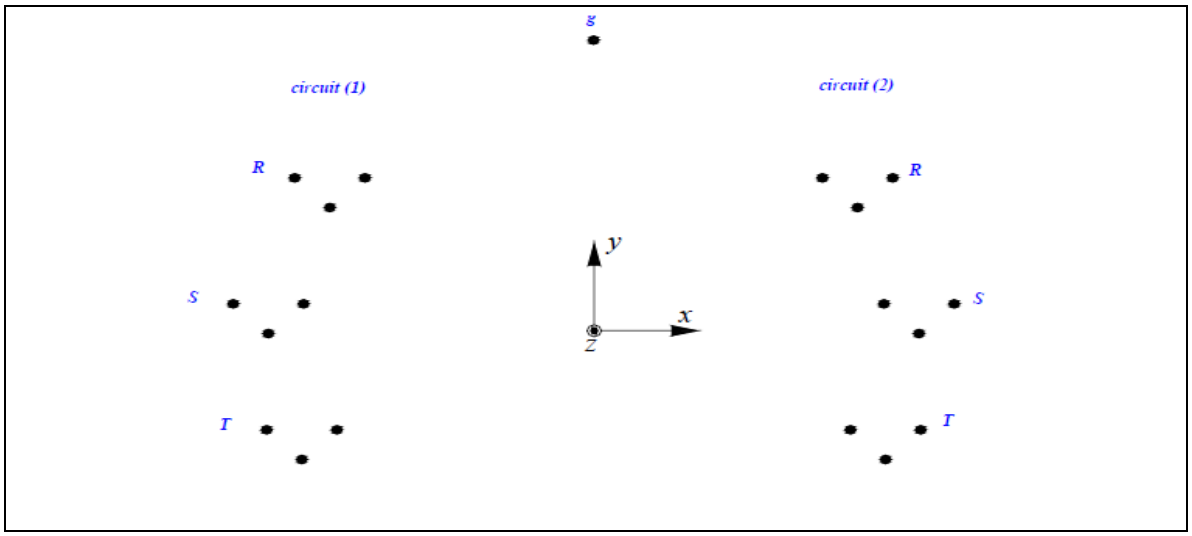


Figure(2-4a) : Typical 400kv single circuit line configuration using bundled conductors and two earth wires (cross-sectional view).[3]

2.5.2 Double Circuit 3-Phase Transmission Lines

For larger amounts of power or in case of a part load centers, double circuits can be used to transmit power instead of single circuit system. Two single circuits on each side of a transmission tower can be supported with enough spacing between them. A common earthing wire can be used for protection. The two single circuits supported by the single tower are called double circuits. The two circuits may supply the same load center or at some point they may separated to supply different load centers. The line configuration of the two circuits is usually vertical on either tower sides.

A 400kV typical line configuration for double circuit system is shown in Fig (2.3b). [3]



Figure(2-4b): Typical 400kv double circuit line configuration using triangular bundled conductors and single earth wire (cross-sectional view).[3]

The magnetic field analysis will be discussed later for the single and double circuits described above.

2.5.3 Multi-Circuits, 3-Phase Transmission Lines

In multi-circuit systems, the span is constituted from more than two circuits that may be charged with the same voltage or may have different voltages. The line configuration of these circuits and the spacing between them is a design issue that has to take into consideration the line voltages and the maximum load for each circuit. No such system exists in Libya.[3]

Chapter Three

Effects of High Voltage Overhead Lines

3.1 Introduction

Electromagnetic fields (EMFs) of various frequencies are existing in our environment. Power transmission lines and high voltage cables carrying electrical currents with very low frequency produce electromagnetic fields. Scientists have wondered for a long time about the health hazards resulting from these fields on peoples and the living organisms. So, a lot of researches have been conducted on this topic. However, the results of researches, did not give any definitive conclusions for the development of clear rules and unambiguous of this issue.

This chapter will cover the effects of electromagnetic fields of a high voltage overhead lines on the human health and our environment. Also the world standard which had been put by the world health organization.

3.2 High voltage fields effect

Based on the researches and studies , the World Health Organization(WHO) classified electromagnetic fields as the fields which may cause some disease. With the increasing awareness of people about the negative health effects caused by electromagnetic fields emitted from high power transmission lines, investigations on this issue had been raised day by day. Several research articles presented survey results showing that the exposure to magnetic fields increases the cancer occurrence. Studies linked the childhood leukemia to transmission line generated magnetic field exposure. This triggered research in both biological and electrical engineering fields. The biological research studied the magnetic field effect on cells and performed statistical studies in order to determine the correlation between field exposure and cancer occurrence.

Nowadays, a multi-line power system is present in our neighborhood to satisfy increasing need for electric power**.** To distribute power from the power plant to the load center is required a network starting from the transmission line until the consumer, so that in the vicinity of the transmission line and distribution network it will be a strong electromagnetic field caused by currents that are drawn by their Conductors. Electromagnetic field (EMF) is a form of energy emitted by charged particles. In classical physics, EMF is considered to be produced when charged particles are accelerated by forces acting on them. Electrons are responsible for emission of most EMF because they have low mass, and therefore they are easily accelerated by a variety of mechanisms.[14]

Exposure to electromagnetic fields is not a new phenomenon. However, during the 20^{th} century, environmental exposure to man-made electromagnetic fields has been steadily increasing as growing electricity demand, ever-advancing technologies and changes in social behavior have created more and more artificial sources. Everyone is exposed to a complex mix of weak electric and magnetic fields, both at home and at work, from the generation and transmission of electricity, domestic appliances and industrial equipment, to telecommunications and broadcasting. Tiny electrical currents exist in the human body due to the chemical reactions that occur as part of the normal bodily functions, even in the absence of external electric fields. For example, nerves relay signals by transmitting electric impulses. Most biochemical reactions from digestion to brain activities go along with the rearrangement of charged particles. Even the heart is electrically active. Low-frequency electric fields influence the human body just as they influence any other material made up of charged particles. When electric fields act on conductive materials, they influence the distribution of electric charges at their surface. They cause current to flow through the body. Low-frequency magnetic fields induce circulating currents within the human body. [14]

The strength of these currents depends on the intensity of the outside magnetic field. If sufficiently large, these currents could cause stimulation of nerves and muscles or affect other biological processes. Figure(3-1) indicates the low frequency electric and magnetic fields induce weak currents in human body. The body has sophisticated mechanisms to adjust to the many and varied influences we encounter in our environment. Ongoing change forms a normal part of our lives. But, of course, the body does not possess adequate compensation mechanisms for all biological effects. Changes that are irreversible and stress the system for long periods of time may constitute a health hazard. An adverse health effect causes detectable impairment of the health of the exposed individual or of his or her off spring, a biological effect, on the other hand, may or may not result in an adverse health effect."[14]

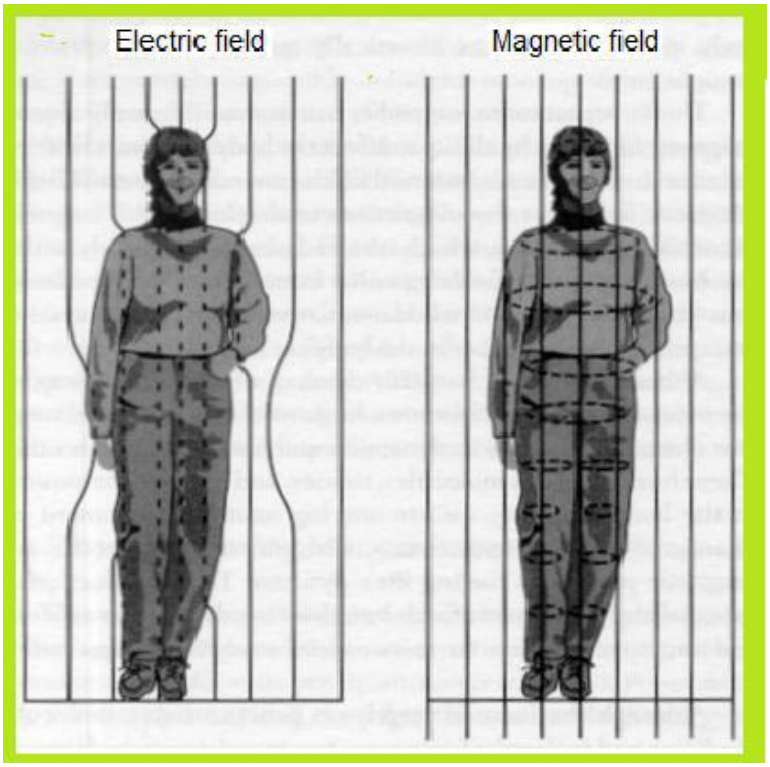


Figure (3-1): Low frequency electric and magnetic fields induce weak electric currents in humans body.[12]

It is not disputed that electromagnetic fields above certain levels can trigger biological effects. Experiments with healthy volunteers indicate that short-term exposure at the levels present in the environment or in the home do not cause any apparent detrimental effects. Exposures to higher levels that might be harmful are restricted by national and international guidelines. In response to growing public health concerns over possible health effects from exposure to an ever increasing number and diversity of electromagnetic field sources, in 1996 the World Health Organization (WHO) launched a large, multidisciplinary research effort. The International EMF Project brings together current knowledge and available resources of key international and national agencies and scientific institutions. In the area of biological effects and medical applications of non-ionizing radiation approximately 25,000 articles have been published over the past 30 years.[14]

Despite the feeling of some people that more research needs to be done, scientific knowledge in this area is now more extensive than for most chemicals. Based on a recent in-depth review of the scientific literature, the WHO concluded that current evidence does not confirm the existence of any health consequences from exposure to low level electromagnetic fields. However, some gaps in knowledge about biological effects exist and need further research. Some members of the public have attributed a diffuse collection of symptoms to low levels of exposure to electromagnetic fields at home. Reported symptoms include headaches, anxiety, suicide and depression, nausea, fatigue and loss of libido. To date, scientific evidence does not support a link between these symptoms and exposure to electromagnetic fields. At least some of these health problems may be caused by noise or other factors in the environment, or by anxiety related to the presence of new technologies. The overall weight of evidence shows that exposure to fields at typical environmental levels does not increase the risk of any adverse outcome such as spontaneous abortions, malformations, low birth weight, and congenital diseases.[14]

There have been occasional reports of associations between health problems and presumed exposure to electromagnetic fields, such as reports of prematurity and low birth weight in children of workers in the electronics industry.[14]

A number of epidemiological studies suggest small increases in risk of childhood leukemia with exposure to low frequency magnetic fields in the home. However, scientists have not generally concluded that these results indicate a cause-effect relation between exposure to the fields and disease (as opposed to artifacts in the study or effects unrelated to field exposure). In part, this conclusion has been reached because animal and laboratory studies fail to demonstrate any reproducible effects that are consistent with the hypothesis that fields cause or promote cancer. Large-scale studies are currently underway in several countries and may help resolve these issues. Some individuals report "hypersensitivity" to electric or magnetic fields. They ask whether aches and pains, headaches, depression, lethargy, sleeping disorders, and even convulsions and epileptic seizures could be associated with electromagnetic field exposure. Recent Scandinavian studies found that individuals do not show consistent reactions under properly controlled conditions of electromagnetic field exposure. Nor is there any accepted biological mechanism to explain hypersensitivity. Research on this subject is difficult because many other subjective responses may be involved, apart from direct effects of fields themselves. More studies are continuing on the subject. [14].

In Libya some people are living and still building houses right now under the power lines, figure (3.2) shows that. The right of way (ROW) is not forced.



Figure(3.2) Building under overhead lines.

During measurements under and vicinity of overhead transmission lines it's found there are some Olive trees are drying, and those are not dry have their leaves nearly to being dry. It could be from H.V field effect, because the tree far from the lines are normal, as figure (3.3) indicates.



Figure(3.3) Olive trees under overhead lines.

3.3 Standard Guidelines Limits

There are European Union and International Commission on Non-Ionizing Radiation Protection (ICNIRP), standards. In these criteria, the frequencies of different Electromagnetic fields have a “reference value”. In 1999, the World Health Organization (WHO) set the limit values of electric and magnetic fields for public and occupation area as shown in Table (3-1).

Table (3-1): Recommendation limits the strength of electric and magnetic fields .

Organization	Public Area		Occupational Area	
	E(kv /m)	B(μT)	E(kv/m)	B(μT)
ICNIRP	5	100	10	500
European Union	5	100	10	500

[Note: All values are rms values **]**

Occupational_limits of exposure apply to employees and contractors of the business who, by their training or experience, would be aware of possible risks associated with EMF from various sources.

General_public_limits of exposure apply to all others, such as employees of the business, visitors, etc., who from their backgrounds would be unaware of possible risks associated with EMF from various sources.

Chapter Four

Analysis of H.V Overhead lines

4.1 Introduction

A current carrying conductor produces a static magnetic field around it if its current is DC, but the field will be electromagnetic if the current is AC. The magnitude of the field and the distance over which it extends depends on the magnitude of the current, and its frequency. It is the aim of this chapter to find the fields near high voltage lines.

4.2 Single-Line Circuit

As a simple example to start the analysis of multi-line multi-phase over head power transmission lines for the electric and magnetic fields, a single-line can be modeled to simplify the problem. The geometry of the line source is that of Figure(4-1a) where it is assumed that the line extends to infinity over a flat earth infinite in extent with some resistivity $\boldsymbol{\rho_e}$ **(Ω / m)** . The line instance current and voltage can be represented by:

$$\mathbf{i(t_o) = I_0 \cos(\omega_0 t_0 + \phi_i)} \qquad \mathbf{(4\text{-}1)}$$

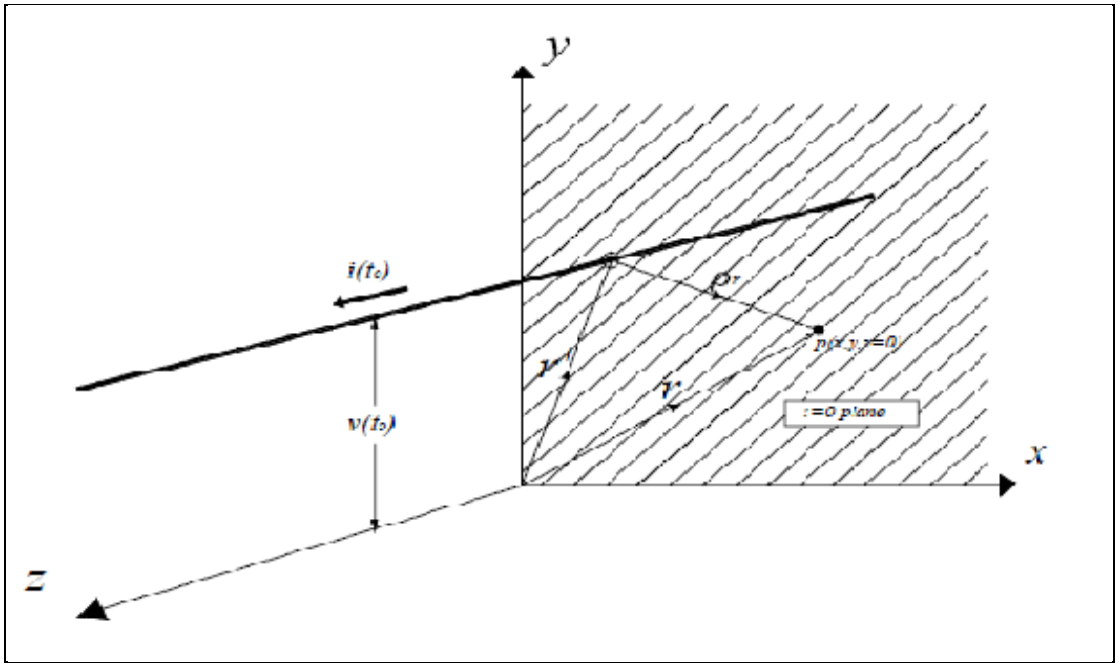
$$\mathbf{v(t_o) = V_0 \cos(\omega_o t_o + \phi_v)} \qquad \mathbf{(4\text{-}2)}$$

Where:

$\boldsymbol{t_0}$ is a time instance within the time period (interval) T_o. $(0 < to < T_0)$,

$\boldsymbol{\omega_0}$ is the angular frequency, and ϕ_i and ϕ_v are the current and voltage phase angles.

The current is considered directed along the positive **z** direction as shown in Figure(4.1a).



Figure(4-1a) : The geometry and the coordinate system for an infinite electric line source and an observational point p(x , y) in the z=0 plane.

The electric field strength about the line caused by the high-voltage is radial and in the cylindrical coordinates according to the geometry of Figure(4-1b) in the z=0 plane is given by:

$$\bar{E}(\rho_r,\varphi_r,z=0,t_0) = \frac{Q(t_0)}{2\pi\varepsilon\rho}\,\overline{a\rho_r} = E_{\rho_r}\,\overline{a\rho_r} \qquad (4\text{-}3)$$

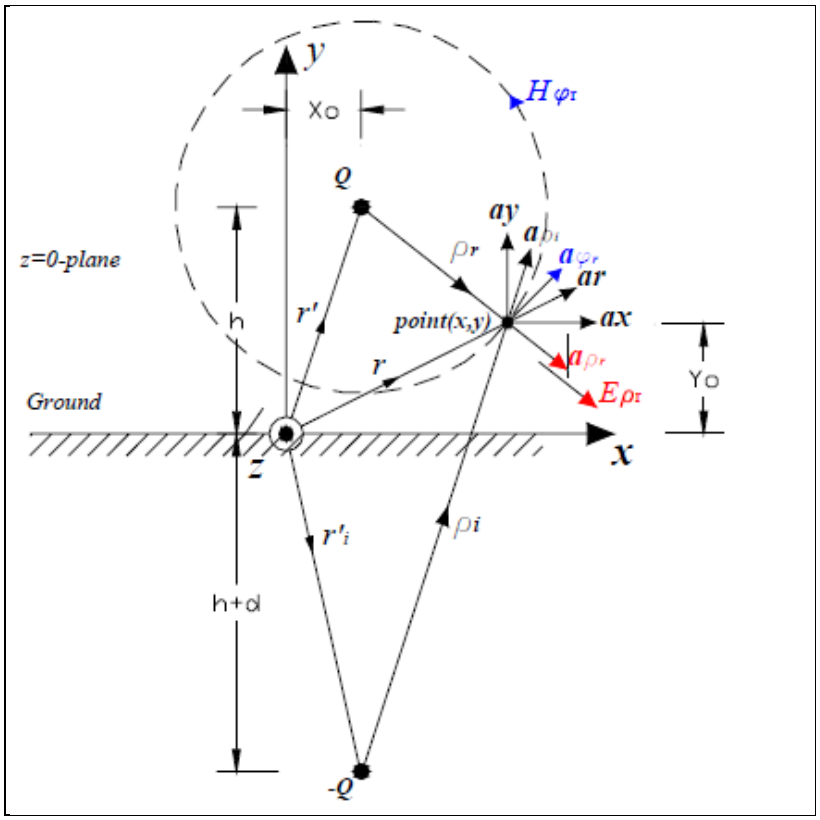


Figure (4-1b): Cross-sectional view shows geometry and coordinate system for an infinite electric line source and its image.

Where:

(ρ_r ,ϕ_r ,z) are the cylindrical coordinates local to the line charge.

($E_{\rho r}$) is the local radial component of the electric field intensity in *Volts/meter*.

Q (t_0) is the quasi-static line charge per unit length at the instance t_0 within *the time interval* T_0.

(ρ_r) is the local radial distance from the line charge to the observational point and perpendicular to the line charge in the z = 0 plan. i.e. the normal distance between the line and the field point.

($\varepsilon = \varepsilon_r \varepsilon_o$) is the permittivity (for air, ε_r =1).

(a_{ρ_r}) is the unit vector in the local radial direction .

From Biot-Savart law and by the aid of figure (4-1a) and figure(4-1b) the local ϕ -component of the magnetic field intensity caused by the current passing through the line in the z=0 plane is given by:

$$\bar{H}(\rho_r,\varphi_r,z = 0,t_0) = \frac{i(t0)}{2\pi\rho}\ \bar{a}\varphi_r = H\varphi_r\ \overline{a\ \varphi_r} \qquad (4\text{-}4)$$

or

$$\bar{B}(\rho_r,\varphi_r,z = 0,t_0) = \mu_0\bar{H}(\rho_r,\varphi_r, z = 0,t_0) = \mu_0 \frac{i(t0)}{2\pi\rho}\ \bar{a}_{\phi r} = B_{\phi r}\ \bar{a} \qquad (4\text{-}5)$$

Where:

$H\phi_r$: is the local ϕ -component of the magnetic field intensity in Amperes/meter.

$B\phi_r$: is the local ϕ -component of the magnetic flux density in Tesla or Weber/square meter.

$i(t_0)$: is the quasi-static line current at the instance t_0 within the time interval T_o in the positive z-direction.

ρ_r: is the radial distance from the line charge to the observational point and perpendicular to the line charge in the z = 0 plane.

μ_0 : is the free space permittivity (μ_r =1).

$a_{\phi r}$: is the unit vector in the local ϕ –direction.[3]

Figure(4-2) shows a photo of the real single circuit under which the magnetic field intensity is measured .



Figure(4.2)Single circuit overhead line.

4.2.1 Electric Field Analysis

From Gauss's law,

$$\int\int_s \bar{D}.\overline{ds} = \dot{Q} \qquad \textbf{(4-6)}$$

the total electric flux through a closed surface is equal to the net electric charge enclosed. Considering an imaginary cylindrical surface of length *l* around a thin charged wire along the *z*-axis and integrating over its boundaries according to equation (4-6) yields the radial electric field of equation (4-3) as follows:[3]

$$\int\int_s \bar{D}.\overline{ds} = \int_0^{2\pi}\int_{-0.5}^{0.5} \varepsilon_0 \; E_\rho \, \bar{a}\rho.\rho d\varphi dz \; \bar{a}\rho = 2\pi\varepsilon_0\rho l E_\rho \qquad \textbf{(4-7)}$$

Thus:

$$\mathbf{2\pi\varepsilon_0\rho l E_\rho = Q}$$

Or

$$\bar{\mathbf{E}} = \frac{\mathbf{Q}}{\mathbf{2\pi\varepsilon_0\rho}}\,\bar{\mathbf{a}}\boldsymbol{\rho} \qquad \textbf{(4-8)}$$

Where:

Q, is the linear charge density. The electric field vector of equation (4-8) can be represented in the Cartesian coordinates by the x- and y-components as follows,

$$\bar{E}=\frac{Q}{2\pi\varepsilon\rho}\bar{a}\rho = E_\rho\,\bar{a}\rho = E_x a_x + E_y a_y \qquad \textbf{(4-9)}$$

The magnitude of the electric field vector is,

$$|E| = [E_x^2+E_y^2]^{\frac{1}{2}} \qquad \textbf{(4-10)}$$

4.2.2 Magnetic Field Analysis for Single and Double Circuit

The integral equation for Biot-Savart law, expressed directly of the quasi-static line current of a thin wire in free space is:[2]

$$\bar{B} = \frac{\mu_0}{4\pi}\int_{-\infty}^{\infty}\frac{\bar{I}\times\bar{a}R}{R^2}\bar{dl} \qquad \textbf{(4-11)}$$

which states that the magnetic flux density, in Tesla, at point $p(x, y, z = 0)$ in free space is the integration of the differential contributions, *dB's* , which are proportional to the cross product of the current and the unit vector normal to the differential element, and are inversely proportional to the square of the distance from the differential element to the point $p(x, y, z = 0)$.

when ,

$\bar{I}=i(t_0)\,\bar{a}z$, and $\bar{dl}=dż$, then equation (4-11) becomes:

$$\bar{B} = \frac{\mu_0}{4\pi}\int_{-\infty}^{\infty}\frac{i(t_0)\,\bar{a}z\times\bar{a}R}{R^2}dż$$

The following equations are used to calculate the magnetic field. The results of Equations (4-12) and (4-13) depends on the number of conductors on the line and the distance of all the conductors from a given point along the one meter height.

$$B_x=\sum_{j=1}^{n} \frac{\mu_0 * I_j * y_j}{2\pi(x_j^2+y_j^2)} \qquad \textbf{(4-12)}$$

$$B_y=\sum_{j=1}^{n} \frac{\mu_0 * I_j * x_j}{2\pi(x_j^2+y_j^2)} \qquad \textbf{(4-13)}$$

The magnitude of magnetic field :

$$|B| = [B^2{}_x + B^2{}_y]^{\frac{1}{2}} \qquad \textbf{(4-14)}$$

$[B = \mu_0 . H]$,

where:

$(\mu_0 = 4\pi.10^{-7})$

Considering the system as a balanced one the line currents are equal in magnitude and 120° a part so,

$$I_1 = I\ e^{-j0} \ , \ I_2 = I \cdot e^{-j120} \text{ and } I_3 = I \cdot e^{-j240} \qquad \textbf{(4-15)}$$

These are the equations that will be used to compute the magnetic flux density.

Chapter Five

Measurement and Simulation of Magnetic field

5.1 Introduction

Low frequency magnetic fields induce circulating eddy currents with their intensity depends on the field level which depends on voltage, current and distance from the line.

This chapter will be devoted to the main part of this thesis that is to measure the magnetic field intensity around the line and also use the equations to find the theoretical magnetic field intensity. The line used starts with double circuits on the same tower then for unknown reason the two circuits are split into two parallel paths each tower group carries one circuit and the two lines are closed to each other.

The first step was to take measurements of magnetic field near the high voltage power line and on several points at different distances. The measuring instrument used is the model: Electromagnetic radiation detector(DT-1130), 50-2000MHz.which is highly sensitive and measures the magnetic fields. The technical specifications of the measuring instrument are given in Appendix-1

Figures,(5-1a) and (5-1b) show the measurement area.



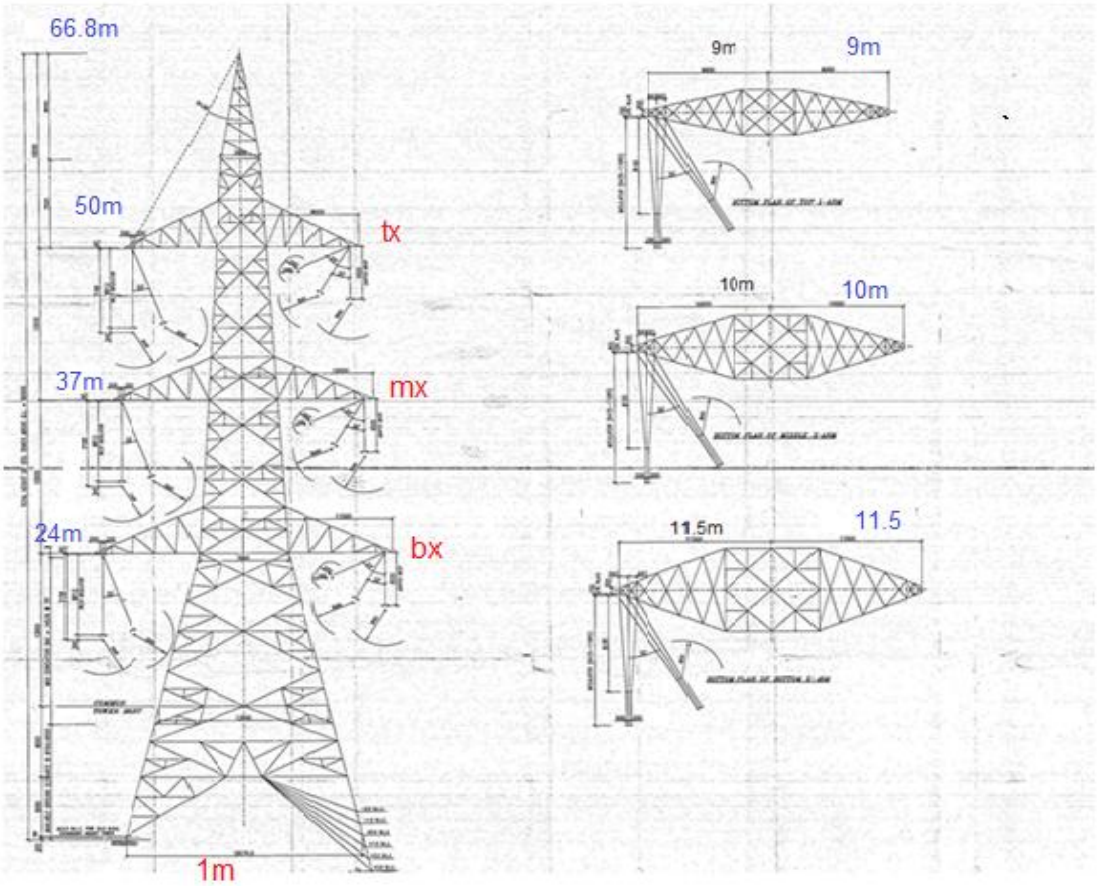
Figure(5-1a). Measurement area



figure(5-1b).Houses under H.V

.

The towers in that area are of the type shown in figure(5-2).These dimensions have given by **GECOL.**



Fig(5-2) Dimensions of the 400kv tower.

The dimentions of the 400kv tower are:

1-The height of the first phase from the ground is 24 meter.

2-The height of the second phase from the ground is 37 meter.

3- The height of the third phase from the ground is 50 meter.

4- The width of wings from the tower center are 11.5, 10,and 9 meter respectively.

Note:(mx),(bx) and (tx) are the labels assigned to the conductors in MatLab program.

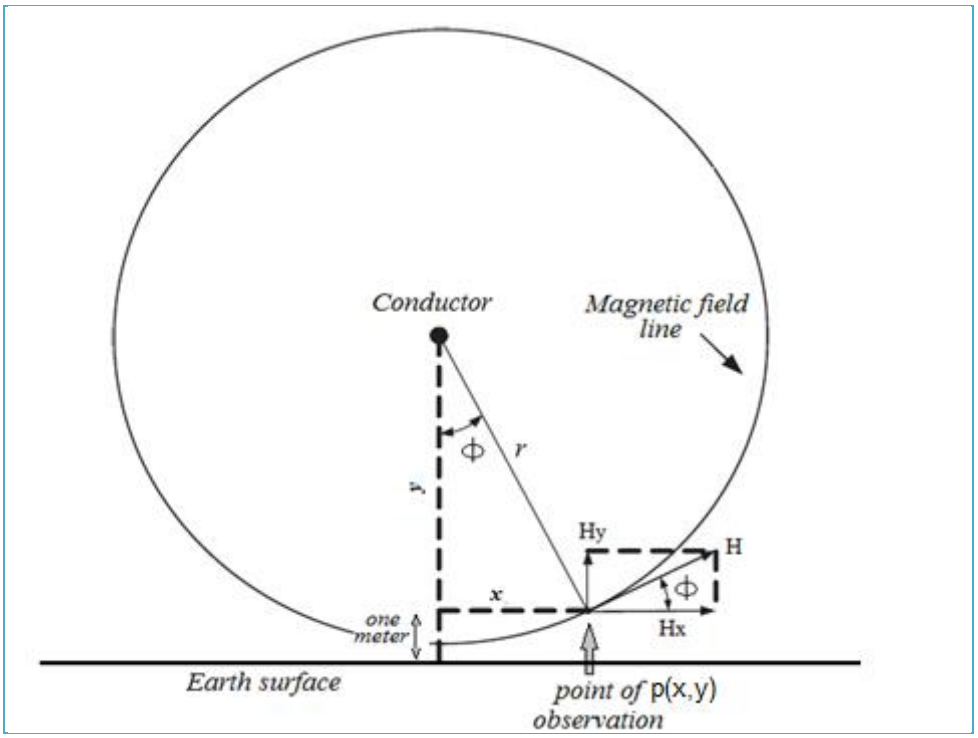


Figure (5-3): Geometry to find the magnetic field at the point p (x , y) due to the phase conductor.

5.2 Measurement Results

The measurements were taken ± 50 meters on each side of the line with the meter's reading and computer program for plotting are given in Appendix-2.

These measurements were taken at points half way between the towers where the lines are at the closest distance to the ground.

Practical measurements are conducted in both sides of the transmission line in a step of 5 m from the center line.

5.2.1 Measurement of Magnetic Field for Single Line Circuit

When the magnetic field under the single circuits overhead line was measuring, the two lines found very near to each other, so there is a big interference between fields.(i.e. the field produced by circuit-1 reach the area of field produced by circuit-2), Figure(5-4) shows that.

The results are shown in the figures (5-5), (5-6) and Table -1 in Appendix 2.

The measurements are made between the towers and on both sides of them, this makes the magnetic field in the region between the circuits almost constant and decay outside them, a phenomena do not exist for double circuit case.

To make the comparison with the calculation have judging value the maximum value for both will be normalized to 1.



Figure(5-4)Two close by single circuits.

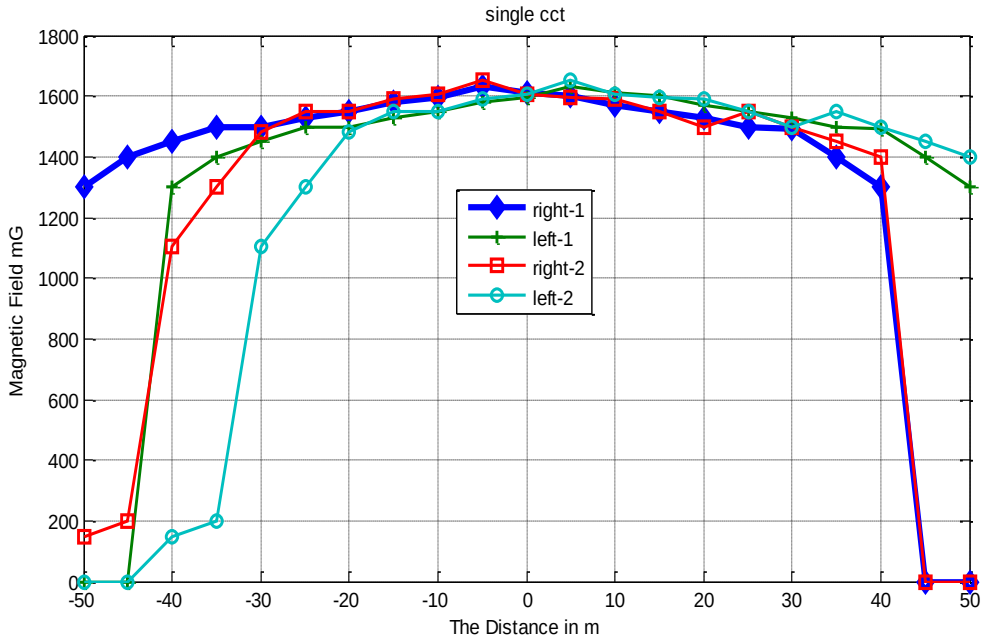


Figure (5-5): Measured magnetic flux density of 400kv single circuit.

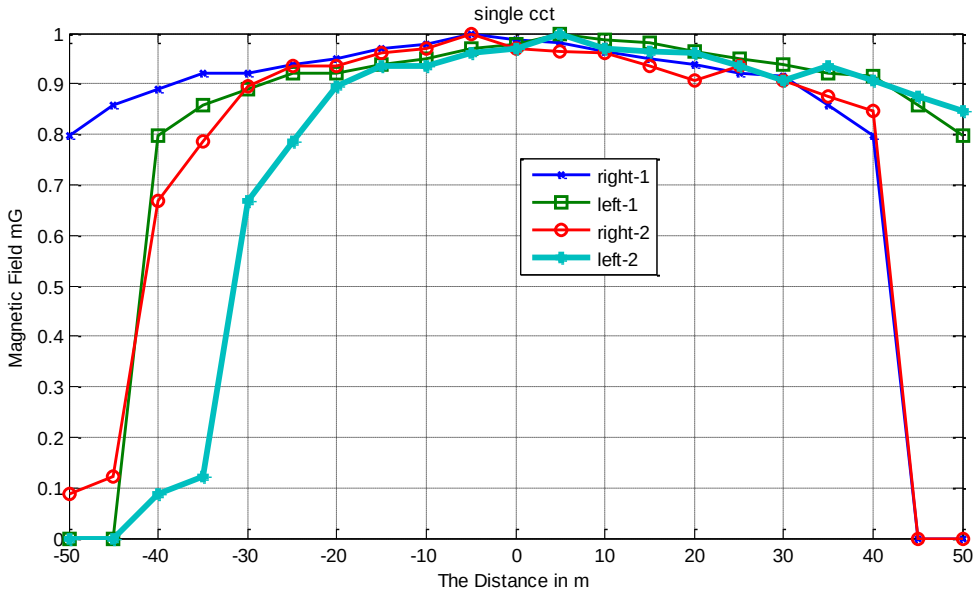


Figure (5-6):Normalized Magnetic flux density of 400kv single circuit.

Where:

Right-1 means the measurement reading taken of circuit-1which is on the right side.

Left-1 means the measurement reading taken of circuit-2 which is on the left side.

Right-2 means the measurement reading taken of circuit-1 at different place and time.

Left-2 means the measurement reading taken of circuit-2 at different place and time.

5.2.2 Measurement of Magnetic Field for Double Circuit Line

The results of measured magnetic field of double circuit 400kv overhead lines are listed in Table-2 in Appendix 2, with the plotting given in figures(5-8)and(5-9).



Figure (5-7)Double circuit lines which it´s magnetic field has measured.

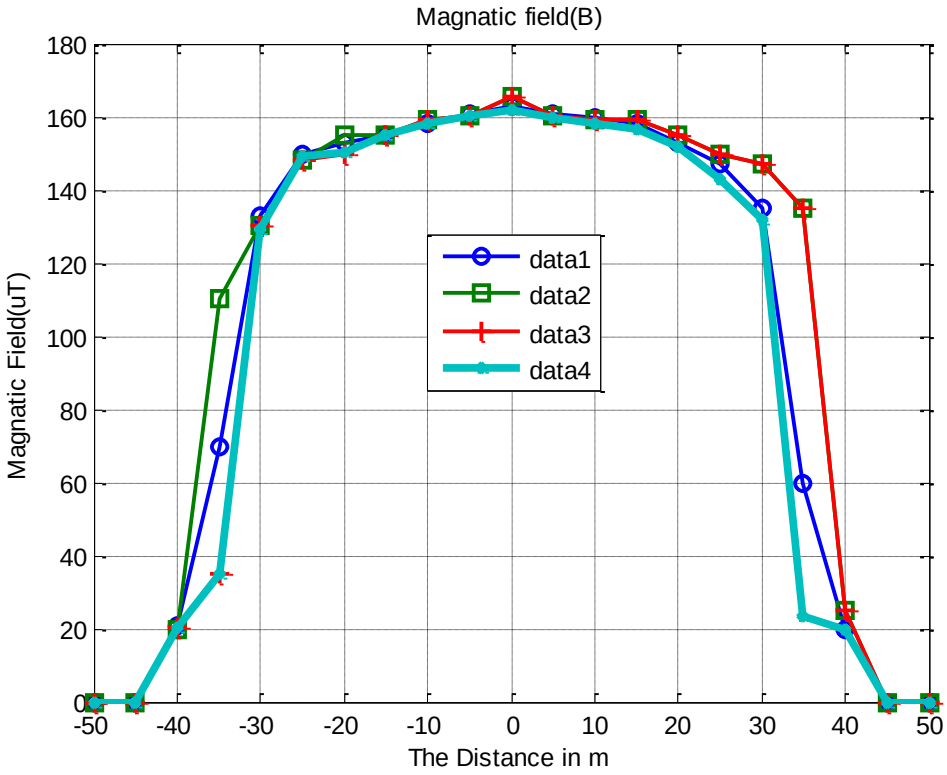


Figure (5-8): Measurements of flux density of 400kv double circuit.

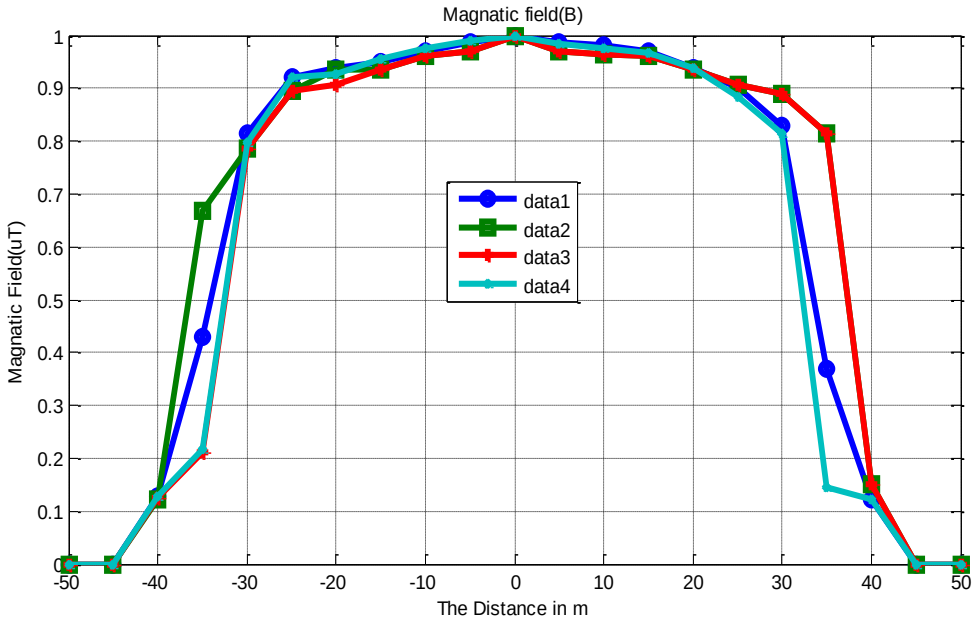


Figure (5-9):Normalized measurement of flux density of 400kv double circuit

Where:

Data-1, means the measurement reading taken for each sides of the power line.

The date of:

Data-1 reading was on Wednesday, 15/5/2015,at 11:30am.

Data-2 reading was on Friday , 29/5/2015,at 19:00pm.

Data-3 reading was on Saturday, 30/5/2015, at 10:30am.

Data-4 reading was on Monday , 1/6/2015, at 11:30am.

5.3 Simulation Result

The MATLAB computer programs (M-files) used to simulate the magnetic field at different distances. The results obtained have been compared to those already measured on site.

The equations (4-12), (4-13), (4-14), and (4-15) are used for field simulation, with the current having a magnitudes of 204Ampers,(which is a maximum current as given by GECOL).

The physical and geometrical data needed for the computations were taken from GECOL.

Simulation result is showing in the figures (5-10) and (5-11):

For sure there is a little different between site measurement and the simulation results, because simulation results is ideal and very difficult to get the same results in reality.

The maximum magnetic field had found under the line and it is decreased as we step away from the line.

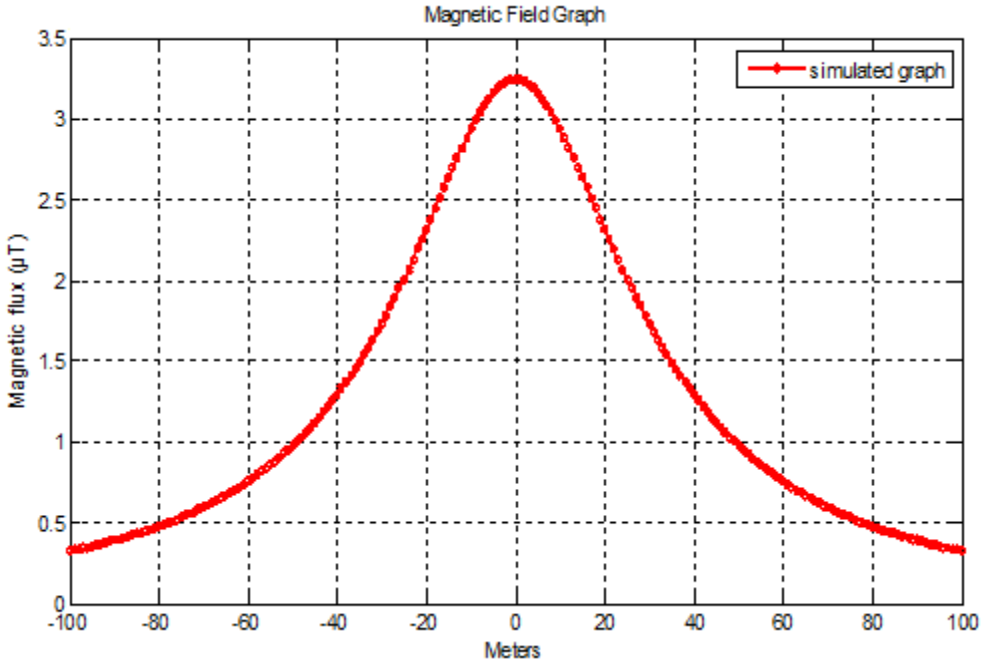


Figure (5-10): magnetic flux density around 400kV double-circuit transmission line system at 1m above ground level.

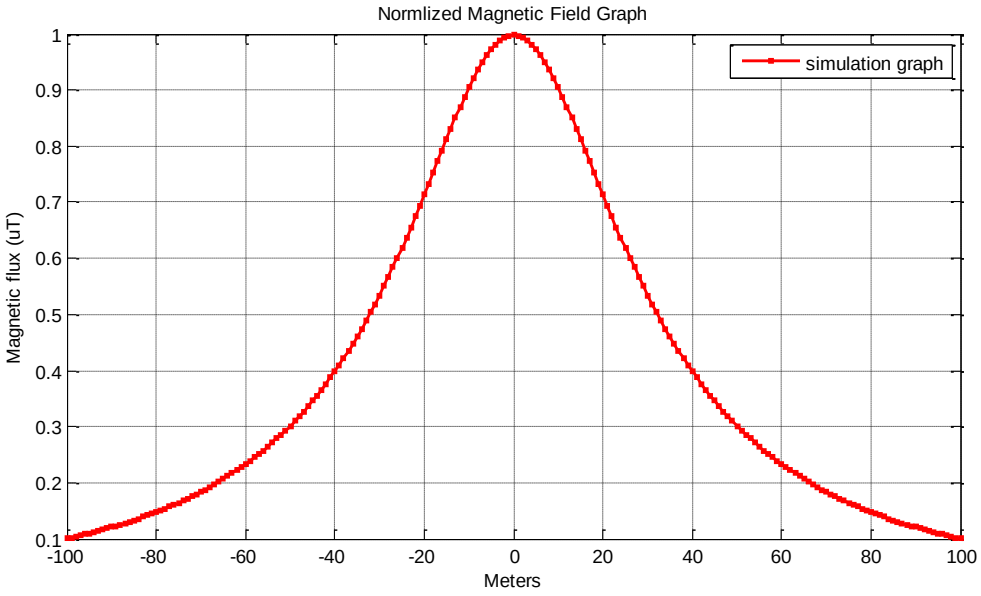


Figure (5-11): Normalized magnetic flux density around 400kV double-circuit transmission line system at 1m above ground level.

5.4 Comparison Between Measured and Simulation Results

Figure (5-12) shows the comparison between the real measurements and simulated results. It could be seen very obviously that the practical measurements are higher than the simulation results.

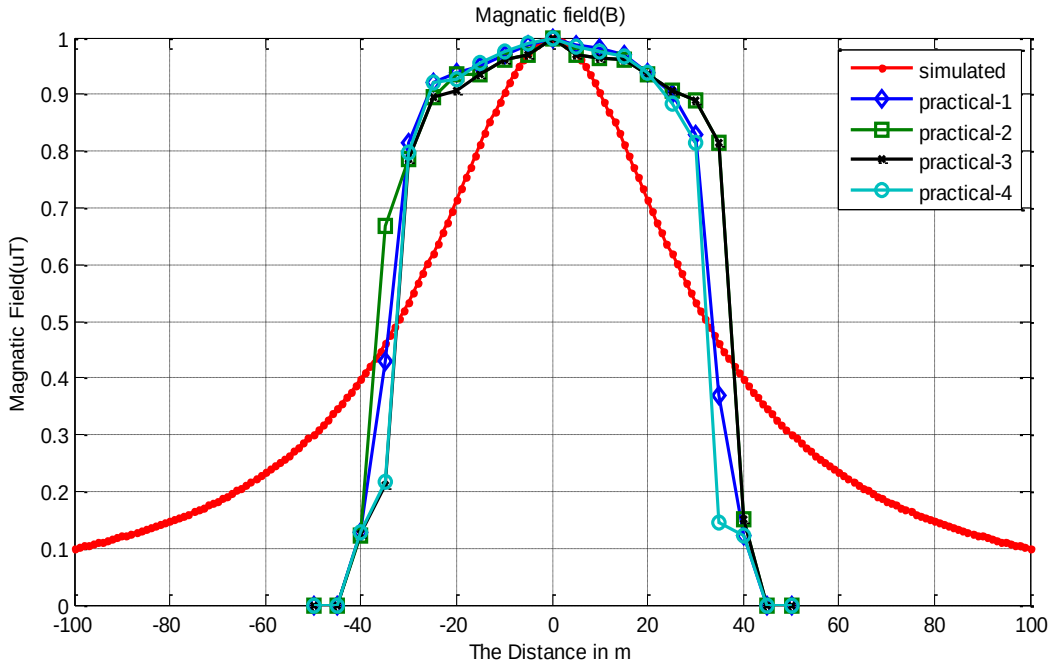


Figure (5-12): Measurement and simulation magnetic field.

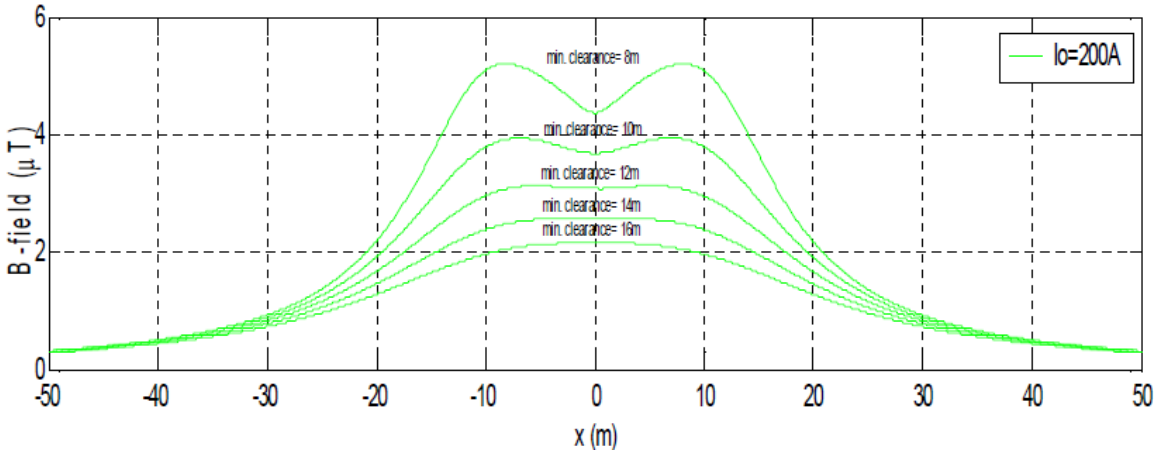
When the comparison between this work measurement results and previous work results,[3] which are shown in Figures(5-13) and (5-14).

It's found that the comparison was very difficult because of many reasons:

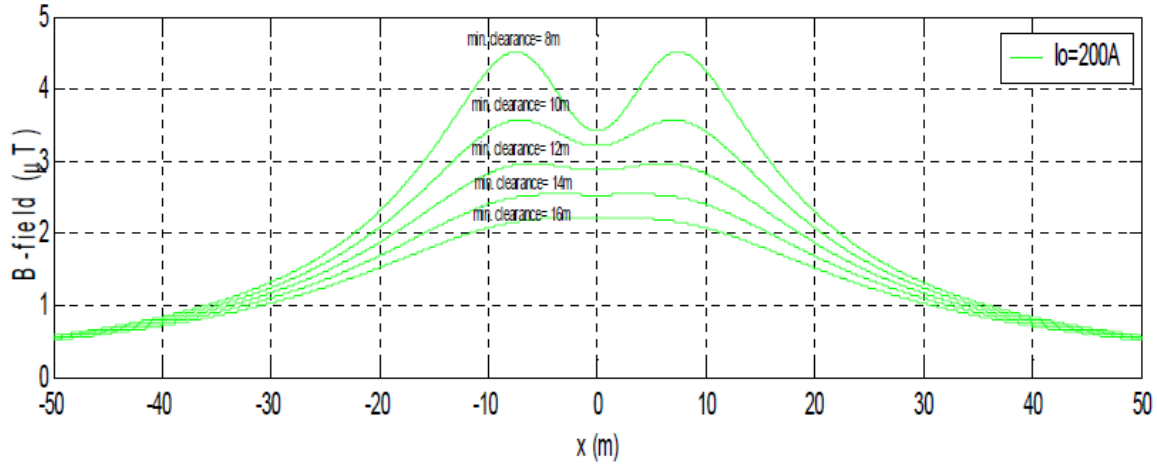
1-The measurement areas are different.

2-The towers dimensions are not the same.

3- Different current level.



Fig(5-13) Magnetic flux density around 400kV single-circuit transmission line system at 1m above ground level.[3]



Fig(5-14):Magnetic flux density around 400kV double-circuit transmission line system at 1m above ground level.[3]

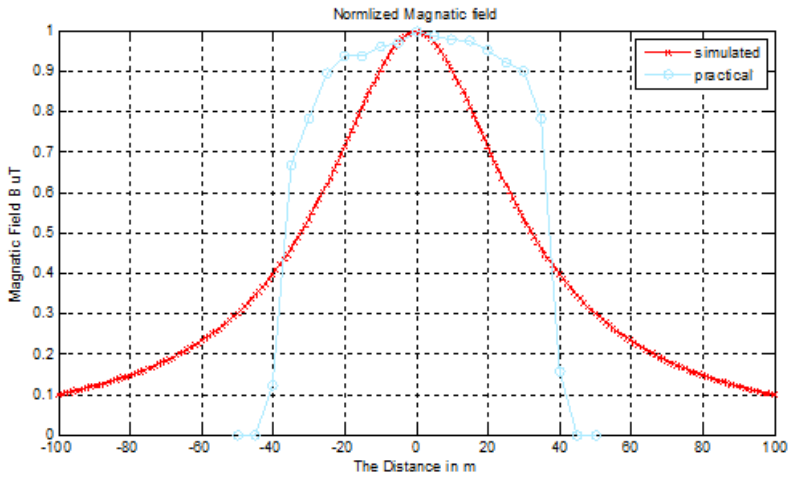
5.5 Result discussion

When the measurements results of magnetic field have been compared with a simulation results, it found that the measurements are higher than simulation results, and they are nearly at the maximum level of international standards. comparison between measured results and simulated result could be seen clearly in figure (5-15) .

The variations of the magnetic flux density with the lateral distance is shown in Figure(5-6)and figure(5-9). At 1m above ground level, it can very clearly be seen that for lateral distances near ±30m and away from the center line, the magnetic flux density is smaller than the reference magnetic flux density set by the ICNIRP (100μT) and (500μT)for all the assumed line current. For the line current, 204A, and 20m as a minimum clearance, the maximum magnetic flux densities associated with current at the right of way(ROW) edge (±30m) is 165 μT. In the area bounded by the ROW edges which is assumed to be the occupational area (transmission corridor area between ±30m), the maximum magnetic flux density ranges between 120 μT and 165 μT.

Although, these maximum field values occurs just under the high voltage transmission Lines, they are high compared to the reference field level (100μT).

Metallic building(object) under the transmission line should be avoided to reduce the eddy current generated with the “minimum clearance of 20meter for 400kv lines.



Figure(5-15) Measurement results and Simulated results

Chapter Six

Conclusion and Future work

6.1 Conclusion

The measurement of magnetic fields and implementation of new techniques of power lines design that enhance the reduction of the exposure to this field which induced by the power lines have been the concern of many researchers for the past years, this lead to the publication of many studies and development research in this subject .

In this work a simulation model for calculations of magnetic field density (B) in a high voltage power transmission line 400 KV has been conducted.

Regarding the possible health effects that electromagnetic fields around high voltage power transmission lines may cause, there have to be two important points that should be considered and taken seriously. The first is not to expect the general public have to prove that electromagnetic fields from power lines constitute a health risk; but it's the GECOL and the environment protection authorities to make the required legislations and foreword steps to provide safety to the public. The second point, the GECOL and the environment protection authorities should follow a scientific policy and support the research way to investigate and find out how to limit the electromagnetic fields around the high-voltage power transmission lines, and consequently limit public exposure to EMFs.

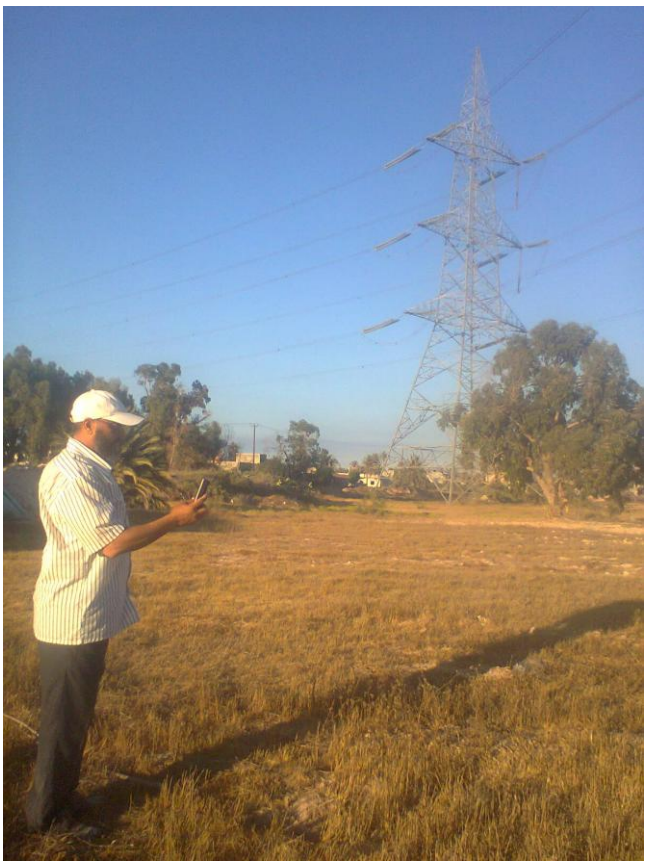
- The comparison of measurements with the international standard reference values of electromagnetic fields arising from the extension of high-tension transmission lines 400 KV in Zawia and Tripoli-West didn't exceed the international standard exposure limits(within the acceptable exposure limits). So we can conclude that there is no risk due to exposure to electromagnetic fields if the exposure is for a short time and for discontinues periods .

6.2 Future work

All the measurements have been taken during Summer Season where the humidity was very low, it is expected that the higher the humidity the higher the electromagnetic field. To study the EM field at all frequencies around the H V line (due to discharging) spectrum analyzer system has to be used .

6.3 Recommendation

- It is necessary to force the ROW distance not to allow people to build in.
- Medical follow up over long period to those who are living close to the ROW.
- Effect on farming the ROW distance should be studied.



References

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(www.who.int/peh-**emf**/about/Whatis**EMF**/en/index1.html)

[15] Girish Kulkami,w.z Gandhar, "Proximity effect of high voltage Transmission Lines on humans",ACEEE Int.J.on electrical power Eng.vol.03 No.01 (Feb.2012).

Appendix-1

Measurement Device Description:



Features

- Model: DT-1130.
- Color: black.
- Shell material: durable ABS plastic.
- 100% brand new and high quality electromagnetic radiation detector.
- Designed to meet CE industrial standard.
- Great for the environmental electromagnetic radiation testing:
bedroom, office, computer room, control room, cable, power lines, monitors, transmitters and other sources of measurement.
- Can be used in home electrical equipment, measurement of electromagnetic radiation: mobile phone, computers, televisions, copiers, fax machines, air conditioners and other power sources of test analysis.
- Wide range of detectable frequency.
- Come with a built-in stand for convenient to put in on the table or other
smooth surfaces.
- Portable design, light weight, easy to use and convenient to carry.

Specifications

- Frequency range: 50Hz~2000MHz.
- Reacting time: 0.4 seconds
- Operating voltage: 9V.
- Battery model: 6F22 9V (included).
-The device measures electromagnetic fields in Mille Gauss (mG).

Appendix-2

This Matlab function is to compute the magnetic flux density around a single-circuit 400kV overhead transmission lines,3- phase.

The program's results are in the form of graphs of the magnetic flux density against lateral distance that is perpendicular to the line conductors. the computations are for the maximum magnetic flux density measured for a complete time period corresponding to 50Hz power frequency.

```
figure(1);
d=(-50:5:50);
a=[1300,1400,1450,1500,1500,1530,1550,1580,1594,1630,1610,1600,1570,155
0,1530,1500,1490,1400,1300,0,0]/1630;
figure(1);
d1=(-50:5:50);
a1=[0,0,1300,1400,1450,1500,1500,1530,1550,1580,1594,1630,1610,1600,157
0,1550,1530,1500,1490,1400,1300]/1630;
figure(1);
d2=(-50:5:50);
a2=[145,200,1105,1300,1480,1550,1550,1590,1605,1655,1605,1594,1590,1550
,1500,1550,1500,1450,1400,0,0]/1655;
figure(1);
d3=(-50:5:50);
a3=[0,0,145,200,1105,1300,1480,1550,1550,1590,1605,1655,1605,1594,1590,
1550,1500,1550,1500,1450,1400]/1655;
plot(d,a,d1,a1,d2,a2,d3,a3);
grid;
xlabel('The Distance in m');
ylabel('Magnetic Field mG');
title('single cct')
```

Table-1:The measured magnetic flux density (B) in micro Tesla at (1 m) under 400 kv single circuit.

Distance from the line center(m)	Measured values of B (μT)	Distance from the line center(m)	Measured values of B (μT)
-50	0	50	0
-45	14.5	45	140
-40	20	40	145
-35	110	35	150
-30	130	30	150
-25	148	25	155
-20	155	20	159
-15	155	15	159.4
-10	159	10	160
-5	160	5	160.5
0	165.5	0	165.5

Note:(-) minus sign means measurements of the opposite side of power line.

……

```
figure(1);
d=(-50:5:50);
a=[1300,1400,1450,1500,1500,1530,1550,1580,1594,1630,1610,1600,1570,1550,1530,1
500,1490,1400,1300,0,0];
figure(1);
d1=(-50:5:50);
a1=[0,0,1300,1400,1450,1500,1500,1530,1550,1580,1594,1630,1610,1600,1570,1550,15
30,1500,1490,1400,1300];
plot(d,a,d1,a1);
grid;
xlabel('The Distance in m');
ylabel('Magnetic Field mG');
title('single cct')
```

…….



```
 figure(1),
d=(-50:5:50);
a=[0.7975,0.8589,0.8896,0.9202,0.9202,0.9387,0.9509,0.9693,0.9779,1.0000,0.9877,0.9
816,0.9632,0.9509,0.9387,0.9202,0.9141,0.8589,0.7975,0,0];
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field mG');
title('Magnatic field(B)')
figure(1);
d1=(-50:5:50);
a1=[0,0,0.7975,0.8589,0.8896,0.9202,0.9202,0.9387,0.9509,0.9693,0.9779,1.0000,0.987
7,0.9816,0.9632,0.9509,0.9387,0.9202,0.9141,0.8589,0.7975];
plot(d,a,d1,a1)
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field mG');
title('Normlized Magnatic field for single circuit')
```

This Matlab function is to compute the magnetic flux density around a double-circuit 400kV overhead transmission lines,3- phase.

The program's results are in the form of graphs of the magnetic flux density against lateral distance that is perpendicular to the line conductors. the computations are for the maximum magnetic flux density measured for a complete time period corresponding to 50Hz power frequency.

```
figure(1);
d=(-50:5:50);
a=[0,0,20.8000,70.0000,133.0000,150.0000,153.0000,155.0000,158.0000,161.0000,163.0000,161.0000,16
0.0000,158.0000,153.0000,147.0000,135.0000,60.0000,20.0000,0,0,];
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d1=(-50:5:50);
a1=[0,0,20.0000,110.5000,130.0000,148.0000,155.0000,155.0000,159.0000,160.5000,165.5000,160.5000,
159.4000,159.0000,155.0000,150.0000,147.0000,135.0000,25.0000,0,0];
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d2=(-50:5:50);
a2=[0,0,20.5000,35.0000,130.0000,148.0000,150.0000,155.0000,159.0000,160.5000,165.5000,160.5000,1
59.4000,159.0000,155.0000,150.0000,147.0000,135.0000,25.0000,0,0];
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
figure(1);
d3=(-50:5:50);
a3=[0,0,20.5000,35.0000,129.0000,149.0000,150.3000,155.0000,158.0000,160.2000,162.0000,159.6000,1
58.0000,156.5000,152.0000,143.0000,132.0000,23.5000,20.0000,0,0];
plot(d,a,d1,a1,d2,a2,d3,a3);
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
```

……

```
figure(1);
d=(-50:5:50);
a=[0,0,20.8000,70.0000,133.0000,150.0000,153.0000,155.0000,158.0000,161.0000,163.0000,16
1.0000,160.0000,158.0000,153.0000,147.0000,135.0000,60.0000,20.0000,0,0,]/163.00;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d1=(-50:5:50);
a1=[0,0,20.0000,110.5000,130.0000,148.0000,155.0000,155.0000,159.0000,160.5000,165.5000,
160.5000,159.4000,159.0000,155.0000,150.0000,147.0000,135.0000,25.0000,0,0]/165.50;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d2=(-50:5:50);
a2=[0,0,20.5000,35.0000,130.0000,148.0000,150.0000,155.0000,159.0000,160.5000,165.5000,1
60.5000,159.4000,159.0000,155.0000,150.0000,147.0000,135.0000,25.0000,0,0]/165.50;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
figure(1);
d3=(-50:5:50);
a3=[0,0,20.5000,35.0000,129.0000,149.0000,150.3000,155.0000,158.0000,160.2000,162.0000,1
59.6000,158.0000,156.5000,152.0000,143.0000,132.0000,23.5000,20.0000,0,0]/162.00;
plot(d,a,d1,a1,d2,a2,d3,a3);
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
```


Appendix-2

Table.2: The measured magnetic flux density (B) in micro Tesla and at (1 m) under 400 kv Double Circuit.

Distance from the line center(m)	Measured values of B (μT)	Distance from the line center(m)	Measured values of B (μT)
-50	0	50	0
-45	0	45	0
-40	20.8	40	20
-35	70.0	35	60
-30	133	30	135
-25	150	25	147
-20	153	20	153
-15	155	15	158
-10	158	10	160
-5	161	5	161
0	165	0	165

The MATLAB computer programs (M-files) used to simulate the magnetic field at different distances for Double circuit.

```
%% Code for Magnetic Plots
%% Fixed
u = 4*pi*10^(-7);
u1 = u/(2*pi);
y1 = 24;
y2 = 37;
y3 = 50;
%% Defining each conductor from point (0,1)
bx11 = -1.75 +100;
bx12 = -1.25 +100;
bx21 = 1.25 +100;
bx22 = 1.75 +100;
mx11 = -10.25 +100;
mx12 = -9.75 +100;
mx21 = 10.25 +100;
mx22 = 9.75 +100;
tx11 = -9.25 +100;
tx12 = -8.75 +100;
tx21 = 9.25 +100;
tx22 = 8.75 +100;
%%%Phase Currents
```

```
I1 = complex(204,0); %(Convert from Polar to Rectangular)
I2 = complex(-102,176.7); %(204,<-120);
I3 = complex(-102,-176.7); %(204,<-240);
B =[]; %%%%Working out magnetic field starting at 50m to the left
for i =0:200
Bx = (-u1*I1*y1)/(bx11^2+y1^2) + (-u1*I1*y1)/(bx12^2+y1^2) + (-
u1*I1*y1)/(bx21^2+y1^2)+ (-u1*I1*y1)/(bx22^2+y1^2) + (-u1*I2*y2)/(mx11^2+y2^2)
+ (-u1*I2*y2)/(mx12^2+y2^2) + (-u1*I2*y2)/(mx21^2+y2^2)+ (-
u1*I2*y2)/(mx22^2+y2^2) + (-u1*I3*y3)/(tx11^2+y3^2) + (-u1*I3*y3)/(tx12^2+y3^2) +
(-u1*I3*y3)/(tx21^2+y3^2)+ (-u1*I3*y3)/(tx22^2+y3^2);
By = (u1*I1*bx11)/(bx11^2+y1^2) + (u1*I1*bx12)/(bx12^2+y1^2) +
(u1*I1*bx21)/(bx21^2+y1^2)+ (u1*I1*bx22)/(bx22^2+y1^2) +
(u1*I2*mx11)/(mx11^2+y2^2) + (u1*I2*mx12)/(mx12^2+y2^2) +
(u1*I2*mx21)/(mx21^2+y2^2)+ (u1*I2*mx22)/(mx22^2+y2^2) +
(u1*I3*tx11)/(tx11^2+y3^2) + (u1*I3*tx12)/(tx12^2+y3^2) +
(u1*I3*tx21)/(tx21^2+y3^2)+ (u1*I3*tx22)/(tx22^2+y3^2);
B = [B abs(sqrt((abs(Bx)^2)+(abs(By)^2)))];
%% Defining X values along the 1 meter line
bx11 = bx11-1;
bx12 = bx12-1;
bx21 = bx21-1;
bx22 = bx22-1;
mx11 = mx11-1;
mx12 = mx12-1;
mx21 = mx21-1;
mx22 = mx22-1;
tx11 = tx11-1;
tx12 = tx12-1;
tx21 = tx21-1;
tx22 = tx22-1;
end
figure
X = [-100:1:100];
plot(X,B)
ylabel 'Magnetic flux (uT)'
xlabel 'Meters'
title 'Magnetic Field Graph' %%%Only used for plotting multiple scenarios
hold on;
```

……

Comparative program:

```
%% Code for Magnetic Plots
%% Fixed
u = 4*pi*10^(-7);
u1 = u/(2*pi);
y1 = 24;
y2 = 37;
y3 = 50;
%% Defining each conductor from point (0,1)
bx11 = -1.75 +100;
bx12 = -1.25 +100;
bx21 = 1.25 +100;
bx22 = 1.75 +100;
mx11 = -10.25 +100;
mx12 = -9.75 +100;
mx21 = 10.25 +100;
mx22 = 9.75 +100;
tx11 = -9.25 +100;
tx12 = -8.75 +100;
tx21 = 9.25 +100;
tx22 = 8.75 +100;
%%%Phase Currents
I1 = complex(204,0); %(Convert from Polar to Rectangular)
I2 = complex(-102,176.7); %(204,<-120);
I3 = complex(-102,-176.7); %(204,<-240);
B =[]; %%%%Working out magnetic field starting at 50m to the left
for i =0:200
Bx = (-u1*I1*y1)/(bx11^2+y1^2) + (-u1*I1*y1)/(bx12^2+y1^2) + (-
u1*I1*y1)/(bx21^2+y1^2)+ (-u1*I1*y1)/(bx22^2+y1^2) + (-
u1*I2*y2)/(mx11^2+y2^2) + (-u1*I2*y2)/(mx12^2+y2^2) + (-
u1*I2*y2)/(mx21^2+y2^2)+ (-u1*I2*y2)/(mx22^2+y2^2) + (-
u1*I3*y3)/(tx11^2+y3^2) + (-u1*I3*y3)/(tx12^2+y3^2) + (-
u1*I3*y3)/(tx21^2+y3^2)+ (-u1*I3*y3)/(tx22^2+y3^2);
By = (u1*I1*bx11)/(bx11^2+y1^2) + (u1*I1*bx12)/(bx12^2+y1^2) +
(u1*I1*bx21)/(bx21^2+y1^2)+ (u1*I1*bx22)/(bx22^2+y1^2) +
(u1*I2*mx11)/(mx11^2+y2^2) + (u1*I2*mx12)/(mx12^2+y2^2) +
(u1*I2*mx21)/(mx21^2+y2^2)+ (u1*I2*mx22)/(mx22^2+y2^2) +
(u1*I3*tx11)/(tx11^2+y3^2) + (u1*I3*tx12)/(tx12^2+y3^2) +
(u1*I3*tx21)/(tx21^2+y3^2)+ (u1*I3*tx22)/(tx22^2+y3^2);
B = [B abs(sqrt((abs(Bx)^2)+(abs(By)^2)))];
B1=B/3.25*10^(6)
%% Defining X values along the 1 meter line
bx11 = bx11-1;
bx12 = bx12-1
bx21 = bx21-1;
bx22 = bx22-1;
mx11 = mx11-1;
mx12 = mx12-1;
mx21 = mx21-1;
mx22 = mx22-1;
tx11 = tx11-1;
```

```
tx12 = tx12-1;
tx21 = tx21-1;
tx22 = tx22-1;
end
figure(1);
X = [-100:1:100];
plot(X,B1)
grid;
ylabel 'Magnetic flux (uT)'
xlabel 'Meters'
title 'Magnetic Field Graph' %%%Only used for plotting multiple
scenarios
hold on;
figure(1);
d=(-50:5:50);
a=[0,0,20.8000,70.0000,133.0000,150.0000,153.0000,155.0000,158.0000,161
.0000,163.0000,161.0000,160.0000,158.0000,153.0000,147.0000,135.0000,60
.0000,20.0000,0,0,]/163.00;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d1=(-50:5:50);
a1=[0,0,20.0000,110.5000,130.0000,148.0000,155.0000,155.0000,159.0000,1
60.5000,165.5000,160.5000,159.4000,159.0000,155.0000,150.0000,147.0000,
135.0000,25.0000,0,0]/165.50;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field uT');
title('double cct')
figure(1);
d2=(-50:5:50);
a2=[0,0,20.5000,35.0000,130.0000,148.0000,150.0000,155.0000,159.0000,16
0.5000,165.5000,160.5000,159.4000,159.0000,155.0000,150.0000,147.0000,1
35.0000,25.0000,0,0]/165.50;
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
figure(1);
d3=(-50:5:50);
a3=[0,0,20.5000,35.0000,129.0000,149.0000,150.3000,155.0000,158.0000,16
0.2000,162.0000,159.6000,158.0000,156.5000,152.0000,143.0000,132.0000,2
3.5000,20.0000,0,0]/162.00;
plot(d,a,d1,a1,d2,a2,d3,a3);
grid;
xlabel('The Distance in m');
ylabel('Magnatic Field(uT)');
title('Magnatic field(B)')
title('Normlized Magnatic field');
```


Appendix-2

