# ELECTROMAGNETIC EFFECT OF HIGH VOLTAGE TRANSMISSION LINES ON HUMAN BEING

A Thesis Submitted in Partial Fulfilment

of the Requirements for the Award of the Degree of

**Dual Degree [B.Tech. & M. Tech.]**

in

**Electrical Engineering**

by


**SARBAJEET JENA**

**(Roll No.710EE2069)**


**May, 2015**


**Department of Electrical Engineering**

**National Institute of Technology**

**Rourkela-769008**

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Under the Guidance of

Prof. Subrata Karmakar

**Department of Electrical Engineering**
**National Institute of Technology**
**Rourkela-769008**
http://www.nitrkl.ac.in

**National Institute of Technology**

**Rourkela**

CERTIFICATE

This is to certify that the thesis entitled, "**ELECTROMAGNETIC EFFECT OF HIGH VOLTAGE TRANSMISSION LINES ON HUMAN BEING**" submitted by **SARBAJEET JENA** in partial fulfillment of the requirements for the award of Dual Degree B. Tech. and M. Tech. in Electrical Engineering with specialization in Power Control and Drives during 2014 - 2015 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date

Prof. S. Karmakar
Department of Electrical Engineering
National Institute of Technology
Rourkela-769008

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Sarbajeet Jena

Roll No.710EE2069

# Contents

# ABSTRACT

Once ignored electromagnetic field have become too hazardous in recent days due to the rampant rise of gadgets which are source of electromagnetic radiations such as mobile phones, power transmission lines and other such devices. This paper put forward a detailed model of electromagnetic field generating because of HV power lines with the use of technique of finite element method so that an idea on the physiological effects of electromagnetic field (EMF) generated by the HV power transmission lines are made available in the public domain. Because it is high time people should know safe limits for electromagnetic fields. The magnetic field and electric field around a HV 220 kV electrical overhead line is analyzed for various geographical region like agricultural land, coastal land and sandy soil. Two other models of 132 kV and 400 kV are also analyzed. All these analysis are done in presence of human being so as to include the proximity effect. And report so generated is compared with existing guidelines and some new safety measures are introduced too. All the above discussed analyses are done with ANSYS Maxwell 3D. This method is a useful tool for the evaluation of the biological effects and safety standards of high voltage transmission line.

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# List of Abbreviations

| Abbreviations | Expansion |
|---|---|
| AC | Alternating Current |
| ACSR | Aluminium Conductor Steel Reinforced |
| DC | Direct Current |
| DOF | Degree Of Freedom |
| EMF | Electro Magnetic Field |
| ELF | Extremely Low Frequency |
| FEM | Finite Element Method |
| HV | High Voltage |
| IEEE | Institute of Electrical & Electronics Engineers |
| IRPA | International Radiation Protection Association |
| LT | Low Tension |
| MRI | Magnetic Resonance Imaging |
| UK | United Kingdom |
| UNEP | United Nations Environment Programme |
| WHO | World Health Organization |

# List of Symbols

| Symbols | Expansion |
|---|---|
| A | Ampere |
| B | Magnetic Flux density |
| C | Coulomb |
| E | Electric Field |
| H | Magnetic Field |
| Hz | Hertz |
| kV | Kilovolt |
| V | Volt |
| m | Meter |
| mA | Miliampere |
| mT | Militesla |
| $\mu$ | Magnetic Permeability |
| $\omega$ | Angular Frequency |
| $\sigma$ | Conductivity |
| $\varepsilon$ | Relative permittivity |

# Chapter 1
## INTRODUCTION

- Introduction
- Motivation
- Objective and scope

# Chapter 1
Introduction

## 1.1 Introduction

Earlier human being experienced naturally generating electric and magnetic fields which are by and large harmless. But in the last 50 years due to technological advancement and population growth people’s demand have increased. Today we are generating more power, transmitting it more and distributing more which led to rise of artificial, extremely low frequency (ELF) electromagnetic fields at frequencies of 50 and 60 Hz mainly. Nowadays artificially generated electric field have more magnitude than natural fields at 50 and 60 Hz. Physiological functions such as neuromuscular action, glandular secretion, cell membrane building, and improvement, growth and repair of tissue are affected by internal electric field . As health of human being get affected from increase in electric fields and currents in the body as told by Grandolfo et al. 1985 [1], questions emerge concerning conceivable impacts of artificially created fields on biological system. To be able to sustainably live with advances in science and technology, time has come to fix a safe limit for exposure of ELF electromagnetic fields. So that future growth of technology is smoothly maintained.

With the inputs from Grandolfo and Vecchia, 1989, Regulatory and advisory committees have been set up in many countries to examine the possible harmful effects of ELF electromagnetic fields on human health [2].

## 1.2 Motivation

Today we have little learning about electromagnetic field's impact on individual due to absence of experimental research. People don't know necessary steps to be followed in case of exposure to magnetic field as they have been not informed about present day exposure limit to electromagnetic field by their competent authority. But everything is not so gloomy in some nations there is an on-going debate between promoter of prohibitive defensive measures and promoters of technological growth regarding increasing influence of electromagnetic fields.

## 1.3 Objective and scope

Till today experiments done on animals are extrapolated to human beings. This is not entirely correct data to limit the exposure of electromagnetic field to humans. There is need for study of electromagnetic field in presence of human. For this finite element analysis (FEM) is most appropriate. It can calculate electric field, electric potential, magnetic flux density and magnetic field strength more accurately then presently available simulation tools. We need to develop standard operating procedures for establishing safe limits for professionals and general public working or living near low frequency electromagnetic fields. We should also study the harmful health effect caused if any standard norms are violated.

Ahlbom et al. 1987, UNEP/WHO/IRPA 1984, UNEP/WHO/IRPA 1987 [3]- [6] and many other associate societies of IRPA, and various institutions and individual scientists have been told to put forward a detailed discussion of potential adverse effects and draft a temporary guidelines with their valuable comments. Many useful statements and criticisms were obtained, and are gratefully acknowledged.

The gravity of electromagnetic exposure is recognised by the committee and they said that there are many things to be found, when some exposure limits are established. The rationality of the observation made in the scientific reports must be questioned, as many of them have extrapolated the results on animals to the human being. Different countries may have different safety limits depending on their feasibility, economy, national public health priorities and social responsibility.

## 1.4 Organisation of thesis

Chapter 1 introduces the concept of exposure of electromagnetic field on human and its effect and motivates to develop a virtual environment for studying EMF around transmission line.

Chapter 2 reviews the literature published till now and gives an idea on end result of simulation.

Chapter 3 gives a detailed discussion on exposure of electromagnetic field to persons working near the transmission line and general public.

Chapter 4 gives minimum clearance to be maintained between transmission lines.

Chapter 5 shows equation used to model electromagnetic field of transmission line in presence of human.

Chapter 6 analyzed electromagnetic field of transmission line by using the method of finite element analysis with the software of ANSYS Maxwell 3D.

Chapter 7 simulation results are obtained and discussed in detail.

Chapter 8 summarizes the results obtained in various chapters and the scope for future work is provided.

# Chapter 2

## LITERATURE REVIEW

- Introduction
- Experimental study
- Summary

# Chapter 2

Literature review

## 2.1 Introduction

To safeguard the human being's health from the seemingly harmful effects of exposure to magnetic fields and electric fields at frequencies of 50/60 Hz many research work have been conducted. Most of the studies were animal based and extrapolated to human being. Few were done on humans. Recent dosimetric studies have provided the link for extrapolating the studies on animals to human being. Comparisons of exposure can be made by comparing development of internal current densities and field around body surfaces.

## 2.2 Experimental study

As per an experiment conducted by Kaune et al. in 1985, electric field of 25 kV/m faced by pigs are equivalent to the 9.3 kV/m of peak electric field experienced at surface of the human body and 13 kV/m normal electric field strength experienced at the surface of human body [7].

Comparison of exposure of rats, swine and human being were put forwarded by Kaune and Forsythe (1988) which roughly estimated the limits of exposure. Electric fields at 60 Hz bring about current densities 7.3 times more in people than in pigs, and 12.5 times more in people than in rodents at the same undisturbed field strength. Human facing an exposure at 8 kV/m is equivalent to 100 kV/m electric field experienced by rats and 13.7 kV/m faced by pigs. Hence it can be concluded that there is no noticeable harmful effects in human to the electric field ranging between 8 to 15 kV/m [8].

For 50/60 Hz frequency some individuals face sensations from their head hair or itching within bodies and garment at electric field of 20 kV/m; but Cabanes and Gary 1981, IEEE 1978 had shown that under lab conditions a small percentage of individuals can confront field strength of 2 or 3 kV/m [9].

At the point when a few volunteers were tested in controlled environment with electric field strength of up to 20 kV/m demonstrated no noteworthy impacts, it was presented by Hauf and Wiesinger 1973, Hauf 1974, Rupilius 1976, Sander et al. 1982. But this cannot prove that long-term exposure (months or years) don't have any health effect [10]- [13].

Relationship between childhood cancer and exposure of mild magnetic field was proposed by Wertheimer N. Leeper 1979 which can be confirmed by studies conducted by Savitz 1988. [14], [15]. These reports can't be summed up as both studies were done in the same land region and on a similar populace. But according to some scientific panel (Ahlbom et al. 1987) still there is no confirmation regarding link between cancer and 60Hz electromagnetic field exposure and according to them it is a hypothesis. The U.K. Stakeholder Advisory Group on Extremely Low Frequency EMFs (2007) have provided links between EMFs and childhood and adult leukemia, adult brain cancer, Alzheimer’s disease, Lou Gehrig’s disease, breast cancer, depression, electrical sensitivity symptoms childhood cancers, depression, electrical sensitivity symptoms, certain types of heart disease, miscarriage and suicide. At the same time, deficient information on electromagnetic field impact on cancer is a matter of debate.

Making contact with a charged object also brought about numerous unsafe influences to human body yet its seriousness relies on various variables including nature of grounding, the size of current in contact, the term of current flow, and mass of body. Individual may not have the capacity to discharge a charged object because of automatic muscle compressions (IEEE 1978, IEEE 1984) caused by the currents above 10 mA level as this is the current which over reaches the let go threshold, [10], [16]. Small children roughly have let go threshold value one and half times more than the adult man, so extra precaution should be taken for small children. On the off chance if the current is raised over the let-go level, there is a risk that ventricular fibrillation can happen. According to Guy, 1985 short circuit current emanating from contacting charged objects can be related to unruffled field strengths [17].

There is very little understanding about the effect of magnetic flux densities in humans. Indeed, even studies on human volunteers exposed to magnetic flux densities of up to 5 mT for four to six hours every day for a few days that to in a controlled set up along with electric fields of up to 20 kV/m did not show any huge impacts. Above generalization was done by UNEP/WHO/IRPA 1987 and Sander et al. 1982. Henceforth, it’s by and large presumed that short term professional exposure ought not to surpass 5 mT and 25 mT for very extreme conditions and induced current densities also should not rise above $10 mA/m^2$ [5], [6].

**Summary**

From investigations on lab animals it is evident that cellular, physiological and behavioural changes in human being are caused by powerful ELF electric fields. Although not all the results can be scaled to human beings but these studies gives us a warning that we should try to avoid unnecessary interactions with strong electric fields as much as possible. Even though a full proof evidence is not there for adverse effect of electromagnetic fields but in around electric fields of 3 kV/m some people feel spark which is considered as threshold for many human. Some cases of cancer among children and adult have been linked to increased exposure to fields at 50/60 Hz. But some more detailed study will be required before forming a risk assessment based on these data. Electric field varying between 1 to 10 kV/m is may be termed as the safe regions even one is associated with it for very long time. In case of general public it is very hard to link any diseases with exposure to ELF electromagnetic fields as they seldom confronts such fields in their daily life.

Current induced by magnetic flux density more or less decides its effect on human being Induced current density between 1 and 10 mA/m$^2$ induced by magnetic flux densities above 0.5 and up to 5 mT at 50 or 60 Hz leads to minor health complications. Current densities between 10 and 100 mA/m$^2$ due to magnetic flux density of 5 mT and up to 50 mT at 50 or 60 Hz causes some serious effects, which include visual system and nervous system; but current densities between 100 and 1000 mA/m$^2$ having magnetic flux density above 50 mT and up to 500 mT at the frequency of 50 or 60 Hz causes secretion of excitable tissue that leads to possible health hazards. Most dangerous and life threatening is the current densities above 1000 mA/m$^2$ with magnetic flux density more than 500 mT at 50 or 60 Hz which causes extra systoles and ventricular fibrillation.

# Chapter 3

## EXPOSURE LIMIT OF ELECTROMAGNETIC FIELD FOR HUMAN BEING

- Introduction
- Electric field
- Magnetic field
- Professionals working near transmission line
    - Electric field limit
    - Magnetic field limit
- General public
    - Electric field limit
    - Magnetic field limit
- Summary

# Chapter 3

## Exposure limit for electromagnetic field for human being

### 3.1 Introduction

The initial phase in building up exposure limits is to characterize the population to be secured. Exposure limits may be related to common public or to a specific member within it. A division is made between as far as possible for laborers and the general public for safe limits of facing electromagnetic fields. People who are more exposed to electromagnetic fields in workplace are professionals who are trained and aware of the potential risk associated with the work. They are bound to follow certain precautionary measures. A professional may work in the hazardous conditions for whole life with a daily shift of some hours so any exposure limit calculated should be based on his working duration. The general public involves people of all ages and diverse status group. In numerous occurrences individuals from the general public are not aware that magnetic field exposures happen. Exposure limit for general public should be calculated for 24*7 and for whole lifetime. For general public it is very rare to face hazardous conditions of exposure so a lower exposure limit is adopted for them.

### 3.2 Electric field

The electric fields are made in the region of charged particles and are represented by a vector denoted by the electric field strength, E. This vector is the force applied by an electric field on a unit charge and is measured in volts per meter (V/m). For single phase source electric field vector move along a fixed axis and for three phase source it depicts an ellipse. For measurement purpose we take into account the undisturbed electric field because electric fields are easily influenced by the objects present in proximity. And proximity effect makes calculation of electric field somewhat difficult. The magnetic field is a vector quantity. Like in electric field, magnetic fields also show same behavior with single phase source and three phase source. Electric field is represented in complex form as

$$\mathbf{E} = E\, e^{j\omega t,}$$

## 3.3 Magnetic field

Curl of the magnetic field strength, H, resembles the current density vector, and displacement current, H is denoted in amperes per meter (A/m). Biological organisms are seen to make interaction with the magnetic flux density, B, which is also known as B-field. It is the B field that causes harmful effects to human body. Force applied on a charge moving in the magnetic field is known as magnetic flux density. Tesla (T) is the unit of magnetic flux density. One tesla is equivalent to 1 V×s/$m^2$ or 1 weber per meter square (Wb/$m^2$). If a medium has total polarization of magnetic dipoles then there is possibility of finding vital differences between B- and H-fields. B and H are proportional in the free space due to practical purposes. The proportion B/H is known as the magnetic permeability of the free space, $\mu_0 = 4\pi10\text{-}7$ H/m, and it is written in henry per meter (1 H/m = 1 Wb/A-m). The time-changing sinusoidal component along three orthogonal axes is denoted by the E-, B- and H-fields. To get the total field strength in free space E-, B- and H-fields should be square rooted and added upon. Magnetic field in complex form is given as

$$\mathbf{H} = He^{j\omega t}$$

Till now electromagnetic fields are considered in an environment where there is no obstruction to them. But, it is a very unfair circumstance, as a correction to it electromagnetic field should be calculated in the presence of human being. Hence it will be obvious that undisturbed electric fields or magnetic fields may be different as compare to with the presence of objects or human. Biological impacts ought to be identified with the field on the body surface, and also to the electric fields, currents and current densities induced inside the body. An electric charge of 1 coulomb moving past a given point every second (C/s) is known as electric current and is expressed in ampere (A). Current density is equivalent to the charge that passes a unit surface region normal to the flow of charge every unit of time. Amperes per square meter (A/$m^2$) is the unit of current density. Keeping in mind the end goal to infer a significant measurements idea, the reliance of natural impacts caused due to the duration of exposure and the spread of the measurement rate in time and space, must be investigated and considered. Current density generated inside the body affects the volatile layer of nerve and muscle cell. But currents induced in the body cannot be measure accurately because of proximity effect. In such case undisturbed H- field and magnetic flux density should be calculated and values for disturbed electromagnetic field should be estimated from these values.

## 3.4 Professionals working near transmission line

### 3.4.1 Electric field limit

Constant exposure of unperturbed electric field strength shouldn't increase more than 10 kV/m for daily workers in switch yards or near power lines. They are allowed to an exposure of electric field strength somewhere around 10 and 30 kV/m in a short term basis if and only if electric field multiplied by duration of exposure doesn't exceed 80 for entire day of working.

### 3.4.2 Magnetic field limit

Magnetic flux densities should not be more than 0.5 mT for a professionals working whole day near power lines. But for a short duration i.e. two hours per workday they can be allowed to an exposure of magnetic flux density not more than 5 mT. Magnetic flux density of 25 mT is an allowable limit for limbs.

## 3.5 General public

### 3.5.1 Electric field limit

For normal people following their routine life electric field should not be more than 5 kV/m. These limitations applies to recreational zones, meeting grounds and so forth where a normal individual is expected to spent maximum portion of his outdoor life. A person can face a electric field of around 5 and 10 kV/m for couple of hours every day. Also one can be exposed to fields in overabundance of 10 kV/m for couple of minutes every day, if the induced current density doesn't surpass 2 mA/$m^2$ and precautionary measures is need to be taken to avert risky indirect coupling impacts. It ought to be noticed that structures in a 5 kV/m outer field have field strength of very low value inside the building.

### 3.5.2 Magnetic field limit

A continuous magnetic flux density of 0.1 mT is harmful for general populace. This restriction is applied to more common areas where general public are found to spend quality amount of time every day. A person can be allowed to magnetic flux density somewhere around 0.1 and 1.0 mT for couple hours a day. Magnetic flux densities in abundance of 1 mT are also considered safe if a person is exposed to it for couple of minutes every day.

## 3.6 Summary

Useful information required for professional and general population regarding exposures to 50Hz or 60 Hz electromagnetic field is given in Table 3.1.

**Table 3.1** Exposure limits for 50 or 60 Hz electromagnetic field for human being

| Exposure characteristic | Electric field strength (kV/m) | Magnetic flux density (mT) |
|---|---|---|
| **Occupational** | | |
| 24 hour job | 10 | 0.5 |
| Short term job | 30 | 5 |
| For limbs | - | 25 |
| **General Public** | | |
| For 24 hrs/day | 5 | 0.1 |
| Few hrs/day | 10 | 1 |

Despite the fact that electrical hardware, equipment, and electrical transmission line produce both electric and magnetic fields, latest examination has concentrated on potential health hazards of magnetic field exposure. This is on account of some epidemiological studies which have reported an increased cancer risk connected with exposure of magnetic field to human being. No comparative studies have been accounted for electric fields; a considerable lot of the studies analyzing organic impacts of electric fields were basically negative.

# Chapter 4

## MINIMUM PERMISSIBLE CLEARANCE FOR TRANSMISSION LINES

- Ground clearance for most minimal conductor of transmission line
- Power line intersection
- Vertical clearance between ground wire and top conductor

# Chapter 4

## Minimum permissible clearance for transmission lines

### 4.1 Introduction

Indian Electricity Rules, or Standards set by government of India for protection reasons, has stated that transmission line conductors should follow a system of minimum clearance from the ground in open spaces, national expressways, streams, railroads tracks, telecom lines, other electrical cables, and so forth.

### 4.2 Ground clearance for most minimal conductor of a transmission line

As per the principle 77(4) of the Indian Electricity Rules, 1956, it is necessary to have a clearances over the ground for the lowest point of conductor in transmission line: For ultra-high voltage transmission lines, the clearance over the ground should not be under 5.182 meters in addition to that for every 33 kV there onwards, 0.305 meters should be added. Appropriately, the qualities for the different voltages, 66kV to 400 kV, are:

66 kV - 5.48m

132 kV - 6.11m

220 kV - 7.0m

400 kV - 8.85m

### 4.3 Power line intersections

In intersections over streams, telecom lines, railroad tracks, and so on.., the accompanying clearances are kept up:

1. crossing over the streams

a. Over streams which are not meant for navigation. 3.05 m over maximum surge level is the minimum clearance of conductor.

b. Over traversable waterways: In consultation with concerned naval authorities clearance is fixed for highest point of ship passing through the river.

2. Interaction with telecom lines. The lowest clearances between the conductors of an electrical transmission line and telecom wires are

66 kV → 2,430mm

132 kV → 2,750mm

220 kV → 3,060mm

400 kV → 4,860mm

3. Running over rail line tracks: for lowest part of conductor having maximum sag in the transmission line minimum height over the railway line should be maintained as per the regulations for Electrical Crossings of Railway Tracks, 1963, which is given in Table 2 & 3.

**Table 4.1**: Minimum clearance for un-electrified tracks or 1.5 kV DC system tracks

| System voltage | Broad gauge | | Metre and narrow gauge | |
|---|---|---|---|---|
| | **Inside station limits (m)** | **Outside station limits (m)** | **Inside station limits (m)** | **Outside station limits (m)** |
| **66 kV** | 10.2 | 7.8 | 9.2 | 6.6 |
| **132 kV** | 10.8 | 8.4 | 9.9 | 7.2 |
| **220 kV** | 11.0 | 8.9 | 10.2 | 7.5 |
| **400 kV** | 13.5 | 11.0 | 12.5 | 10.2 |

**Table 4.2**: Minimum clearance for 25 kV AC system tracks

| System voltage | Broad gauge, metre gauge and narrow gauge | |
|---|---|---|
| | **Inside station limit (m)** | **Outside station limit (m)** |
| **66 kV** | 13.2 | 11.2 |
| **132 kV** | 14.2 | 12.2 |
| **200 kV** | 15.2 | 13.2 |
| **400 kV** | 16.2 | 14.2 |

**Table 4.3**: Minimum clearance between lines crossing each other (IE-1957)

| **System Voltage** | **132 kV** | **220 kV** | **400 kV** | **800 kV** |
|---|---|---|---|---|
| **Low & Medium** | 3.05m | 4.58m | 5.49m | 7.94m |
| 11-66 kV | 3.05m | 4.58m | 5.49m | 7.94m |
| 132 kV | 3.05m | 4.58m | 5.49m | 7.94m |
| 220 kV | 4.58m | 4.58m | 5.49m | 7.94m |
| 400 kV | 5.49m | 5.49m | 5.49m | 7.94m |
| 800 kV | 7.94m | 7.94m | 7.94m | 7.94m |

### 5.4 Vertical clearance between ground wire and top conductor

To maintain a clearance between ground and top conductor angle of shielding should be taken into consideration i.e. the angle made by ground wire and outermost conductor. Angle of shielding is require to restrict direct interference of lightning stokes on the tower. Depending upon the number of ground wires and configuration of conductor the shield angle varies from about 25° to 30°.

# Chapter 5

## MODELING OF ELECTROMAGNETIC FIELD OF TRANSMISSION LINE

- Designing of electric field around electric power transmission lines
- Magnetic field designing for power transmission line
- Finite element formulation

# Chapter 5

## Modeling of electromagnetic field of transmission line

### 5.1 Designing of electric fields around electric power transmission lines

Wave equation or Helmholtz's equation is used to show electric fields (**E**) radiating from a transmission line as in Eq. (1) [18], [20] as per Faraday's law.

$$\nabla^2 E - \sigma\mu\frac{\partial E}{\partial t} - \varepsilon\mu\frac{\partial^2 E}{\partial t^2} = 0 \tag{1}$$

Here ε is equal to the dielectric permittivity of medium, μ and σ are equal to the magnetic permeability and the conductivity of conductors, respectively.

The time harmonic mode has been considered in this paper as system governor and electric field is represented in complex form,

$$\mathbf{E} = E\,e^{j\omega t},$$

Therefore,

$$\frac{\partial E}{\partial t} = j\omega E \;\; and \;\; \frac{\partial^2 E}{\partial t^2} = -\omega^2 E \tag{2}$$

Here ω is known as angular frequency. From Eq. (1), is substituted by the complex electric field, Eq. (1) can be written as follows.

$$\nabla^2 E - j\omega\sigma\mu E + \omega^2\varepsilon E = 0 \tag{3}$$

When considering the problem of two dimensions in Cartesian coordinate *(x, y)*, hence

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial E}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial E}{\partial y}\right) - (j\omega\sigma - \omega^2\varepsilon)E = 0 \tag{4}$$

Analytically, no simple solution exists for the above equation. Consequently, in this paper the FEM is decided to be a potential apparatus for discovering estimated electric field solution for the equations described in Eq.(4) [21].

## 5.2 Magnetic field designing for a power transmission line

Magnetic field intensity H when multiplied with magnetic permeability $\mu$ , it results in magnetic fields (**B**) caused by a power transmission line carrying high current.

$$\mathbf{B} = \mu \mathbf{H}.$$

Utilizing the wave equation (Helmholtz's equation) as in (1) [20], [21], magnetic field modeling that follows the Ampere's circuital law is defined.

$$\nabla^2 H - \sigma\mu \frac{\partial H}{\partial t} - \varepsilon\mu \frac{\partial^2 H}{\partial t^2} = 0 \tag{5}$$

Here $\varepsilon$ is equal to the constant dielectric permittivity, $\mu$ is equal to the magnetic permeability, and $\sigma$ is equal to the conductivity.

The time harmonic mode has been considered in this paper as system governor and magnetic field is represented in complex form as

$$\mathbf{H} = He^{j\omega t} \text{ [8]},$$

Therefore

$$\frac{\partial H}{\partial t} = j\omega H \ \ and \ \ \frac{\partial^2 H}{\partial t^2} = -\omega^2 H \tag{6}$$

Here $\omega$ is the angular frequency Therefore, refer to (1) can be written as

$$\nabla^2 H - j\omega\sigma\mu H + \omega^2 \varepsilon H = 0 \tag{7}$$

Considering the problem in two dimension (x, y) plane, then

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial H}{\partial y}\right) - (j\omega\sigma - \omega^2\varepsilon)H = 0 \tag{8}$$

Analytically, no simple solution exists for the above equation. Consequently, in this paper the FEM is decided to be a potential apparatus for discovering estimated electric field solution for the equations described in.

## 5.3 Finite element formulation

Galerkin approach has been adopted to govern equations of Maxwell's equations, which is the particular weighted residual method for which the weighting functions are the same as the shape functions [19]. According to the method, the electric field is expressed as follows.

$$E(x, y) = E_i N_i + E_j N_j + E_k N_k \tag{9}$$

Here $N_n$, $n = i, j, k$ is the element shape function and the $E_n$, $n = i, j, k$ is the approximation of the electric field at each node ($i, j, k$) of the elements, which is

$$N_n = \frac{a_n + b_n x + c_n y}{2\Delta_e}$$

Here $\Delta_e$ is the area of the triangular element and,

$$a_i = x_j y_k - x_k y_j\,, \quad b_i = y_j - y_k, \quad c_i = x_k - x_j$$
$$a_j = x_k y_i - x_i y_k\,, \quad b_j = y_k - y_i, \quad c_k = x_i - x_k$$
$$a_k = x_i y_j - x_j y_i\,, \quad b_k = y_i - y_j, \quad c_k = x_j - x_i$$

The method of the weighted residue with Galerkin approach is then applied to the differential equation, Eq. (4) & (8), where the integrations are performed over the element domain $\boldsymbol{\Omega}$.

$$\int N_n \left(\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial E}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial E}{\partial y}\right)\right) d\Omega - \int N_n \left(j\omega\sigma - \omega^2\varepsilon\right) E d\Omega = 0 \tag{10}$$

$$\int N_n \left(\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(\frac{1}{\mu}\frac{\partial H}{\partial y}\right)\right) d\Omega - \int N_n \left(j\omega\sigma - \omega^2\varepsilon\right) H d\Omega = 0 \tag{11}$$

[M+K]{E} = 0

$$M = (j\omega\sigma - \omega^2 E)\int N_n N_m \, d\Omega \tag{12}$$

$$= \frac{(j\omega\sigma - \omega^2 E)\Delta_e}{12}\begin{bmatrix} 2 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 2 \end{bmatrix}$$

$$K = v\int \left(\frac{\partial N_n}{\partial x}\frac{\partial N_m}{\partial x} + \frac{\partial N_n}{\partial y}\frac{\partial N_m}{\partial y}\right) \, d\Omega$$

$$= \frac{v}{4\Delta_e}\begin{bmatrix} b_i b_i + c_i c_i & b_i b_j + c_i c_j & b_i b_k + c_i c_k \\ b_j b_i + c_j c_i & b_j b_j + c_j c_j & b_j b_k + c_j c_k \\ b_k b_i + c_k c_i & b_k b_j + c_k c_j & b_k b_k + c_k c_k \end{bmatrix}$$

Where v is the material reluctivity ($\upsilon = 1/\mu$) FEM approximation of a 3×3 matrix is written for one element containing 3 nodes. When each and every element of a system of n nodes are present then the system equation is represented as n×n matrix.

# Chapter 6

## FINITE ELEMENT ANALYSIS OF ELECTROMAGNETIC FIELD OF TRANSMISSION LINE USING ANSYS

- Introduction
- Why FEA is needed?
- Electrostatic solver
    - Steps for solving electrostatic problem
- Magneto static solver
    - Steps for solving magneto static problem
- Designing transmission line along with human being

# Chapter 6

## Finite element analysis of electromagnetic field of transmission line using ANSYS

### 6.1 Introduction

Finite element analysis is an approach to replicate loading conditions on a model and generates the model's reaction to those conditions. FEA is taking into account the thought of building a complicated material with straightforward technique of blocks. Utilization of this basic thought can be discovered all over the place in regular life and also in engineering. In FEM a complicated space is partitioned into simple geometric shapes called elements. Within elements specific nodes are chosen where mathematical analysis are conducted.

Individual elements are linked to given system through an assembly procedure. A group of linear or nonlinear algebraic equation is usually obtained when boundary and load conditions are taken into account.

Arrangement of this sort of comparison gives the approximate conduct of continuum or framework. The continuum (any framework which is considered for examination) has an interminable number of degrees of freedom (DOF), while the discreet model has a limitless number of DOF. This is what gives name to finite element method. Very high speed computers are often require to calculate large numbers of equation associated with FEM.

Two highlights of the Finite Element method are significant.

1. The piece wise estimate of the physical field on finite elements which give great accuracy even with normal approximating capacities.
2. More precision could be achieved by simply expanding the number of elements. One technique to take care of a wide number of problems, including issues in solid mechanics, fluid mechanics, chemical reaction, electromagnetism, heat transfer, biomechanics and acoustic, to give some examples.

**7.2 Why FEA is needed**?

FEA is required for following reason,

1. To decrease the amount of model testing. As it is a computer based simulation one can ask questions at every stage of simulation process.

2. There are many things like artificial knee which are very expensive even for making a prototype. In such case FEM can be used to solve the problem.
3. But most important thing is it saves money, time and more reliable in making a better quality model.

## 6.3 Electrostatic solver

Static electric fields generating from stationary charge distribution or voltage given is solved by using electrostatic solver. Scalar potential automatically calculate Electric Field (E) and Electric Flux Density (D). When no current flow that means when electrostatic equilibrium is established then fields inside a conductor is equipotential, thus joule losses are said to be zero. To achieve the perfect accuracy point, the electrostatic solver uses an automatic adaptive mesh refinement technique which is an added advantage.

### 6.3.1 Steps for solving electrostatic problem

**1. Selecting the electrostatic solver**

When ANSYS is opened automatically magnetostatic problem get selected. To select electrostatic solver give command ***Maxwell 3D*** in the menu and choose ***Solution Type.*** In the solution window that next appear select **Electric** and then **Electrostatic** and then press **OK**

**2. Defining material properties**

Many parameters need to be assigned to define electrostatic material properties some of those are

**Relative permittivity:**

Permittivity (ε) is the ability of a substance to store charge from applied electromagnetic field and transmitting that energy. Electric field solution in the insulators is determined by relative permittivity. In ANSYS there are two modes for relative permittivity; it can be either simple or anisotropic

**Bulk conductivity:**

Conducting and insulating properties of an object define its conductivity. In electrostatic solver perfect conductors are only considered. In ANSYS there are two modes for bulk conductivity; it can be either simple or anisotropic. Questions arising out of insulator or conductor can be solved by choosing **Material threshold** in **Design settings** of **Maxwell 3D.**

**3. Defining condition of boundary in 3D**

Nature of the electric field at the crossings or the edges of the problem area is defined by boundary conditions. To select boundary in **Maxwell 3D** one need to choose **boundaries** and from there choosing requisite boundary type.

**Boundary types for Maxwell 3D**

**De fault (No Boundary Assigned):** In case of condition when no boundary is selected for an area there are two possible choices to be followed and these are

- **Natural**: If it is an interface between the objects then natural is chosen. Values of surface charge density near the boundary change the value of normal component of the filed D.
- **Neumann:** If boundaries are at the outside of solution domain we choose Neumann where E Field is tangential to the boundary and flux cannot pass it.

**Insulating:**

In the insulating type of boundary electric field can have discrete type of conditions. Insulating boundaries are generally used to model thin layers where permittivity of each layer can be specified.

**Master/ Slave:**

It is used to decrease the length of design by enabling users the freedom to generate one period of a periodic structure. By seeing E and V vectors it compares the electric field of the slave boundary to that of the master boundary.

**Symmetry boundary:** This is good for reducing the size and complexity of the design or making short the solution duration by helping user to model a small portion of structure. It is commonly used for outside boundaries.

**4. Selecting excitation**

Providing excitation is nothing but electrically loading the model. It is given by choosing **Assign Excitation** from **Excitation** window of **Maxwell 3D**.

**Excitations are of following types**

**Voltage:** DC voltage is provided to the selected portion. It is a point to remember that only objects or their faces can be assigned voltages in 3D model.

**Charge:** giving charge to the selected object or face of a 3D object

**Floating:** when potential is not known inside a conductor then floating is used across object or face of the 3D object

**Charge density:**

In case of 3D object volume charge density is provided.

**5. Analysis setup**

In analysis setup it is require mentioning how many iterative step is needed so as to quicken the solution process when it is simulated. To add solution set up we select **analysis setup** in **Maxwell 3D**.

**6. Electrostatic solution process**

It is the final step to start simulation of the model, to do this we click **analyze all** in **solution process** window of **Maxwell 3D**.

## 6.4 Magnetostatic solver

DC current flowing through a coil or a permanent magnet produces static magnetic field and this static magnetic field is solved by the magnetostatic solver of ANSYS Maxwell. Magnetic field is decoupled with the electric field inside the current carrying coil. Losses in a current carrying conductor are mainly due to Ohmic losses. To achieve the perfect accuracy point, the magnetostatic solver uses an automatic adaptive mesh refinement technique which is an added advantage.

### 6.4.1 Steps for solving magnetostatic problem

**1. Selecting the magnetostatic solver**

When ANSYS is opened automatically magnetostatic problem get selected. **Magnetostatic** from **magnetic** is selected from **solution type** window provided in the **Maxwell 3D**

**1. Defining material properties**

Many parameters need to be assigned to define magnetostatic material properties some of those are

**Relative permeability:** A magnetic property of a material is defined by magnetic permeability along with magnetic coercivity. In ANSYS there are two mode for relative permeability, it can be either simple (linear $\mu_r$) or Nonlinear (BH Curve) or/and anisotropic.

**Bulk conductivity:** It does not alter the magnetic portion of analysis and commonly used to find the current distribution in current carrying conductors. There are two ways to represent them like it could be simple or anisotropic.

**Magnetic coercivity:** Permanent magnetization of the magnetic object is confirmed by it. It is always required to specify magnitude and direction of magnetic coercivity.

**Boundary types for Maxwell 3D**

**De fault (No Boundary Assigned):** In case of condition when no boundary is selected for an area there are two possible choices to be followed and these are

- **Natural**: If it is an interface between the objects then natural is chosen. Values of surface charge density near the boundary change the value of normal component of the filed D.
- **Neumann:** If boundaries are at the outside of solution domain we choose Neumann where E Field is tangential to the boundary and flux cannot pass it.

**Insulating:**

In the insulating type of boundary electric field can have discrete type of conditions. Insulating boundaries are generally used to model thin layers where permittivity of each layer can be specified.

**4. Assigning excitations**

Providing excitation is nothing but electrically loading the model. It is given by choosing **Assign Excitation** from **Excitation** window of **Maxwell 3D**.

**Excitations are of following types**

**Voltage:** DC voltage is provided to the selected portion. It is a point to remember that only objects or their faces can be assigned voltages in 3D model.

**Charge:** giving charge to the selected object or face of a 3D object

**Floating:** when potential is not known inside a conductor then floating is used across object or face of the 3D object

**Charge density:**

In case of 3D object volume charge density is provided.

**Voltage drop:** It is equal to voltage but can only be given to planes lying inside the conduction path.

**5. Analysis setup**

In analysis setup it is require mentioning how many iterative steps is needed so as to quicken the solution process when it is simulated. To add solution set up we select **analysis setup** in **Maxwell 3D**.

### 1. Electrostatic solution process

It is the final step to start simulation of the model, to do this we click **analyze all** in **solution process** window of **Maxwell 3D**.

## 6.5 Designing of transmission line along with human being

### 6.5.1 Creating a transmission line segment

Consider a 132 kV or 220 kV or 400 kV transmission line consisting of 6 conductors (double circuit) with 3 conductors on each circuit as shown in Fig 1.

The power lines are bare conductor of ACSR (Aluminium Conductor Steel Reinforced) having

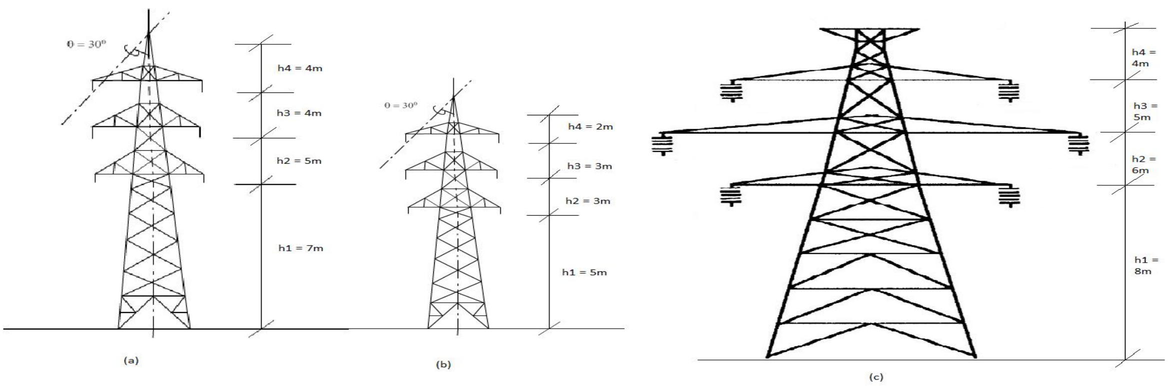


**Figure 1** (a) 220kV, (b) 132kV, (c) 400 kV transmission line tower

radius of 30mm. The system frequency is 50 Hz and air is considered as surrounding medium. The ground may be agricultural land, coastal land or sandy soil depending upon different locations in India.

**Table 6.1**: Electromagnetic properties of material used in ANSYS [22]

| Material | Relative permittivity(ε) | Conductivity(σ) (S/m) | Relative permeability(μ) |
|---|---|---|---|
| **ACSR** | 3.5 | $0.8\times10^{8}$ | 300 |
| **Air** | | | |
| **Agricultural land** | 15 | 10 | 1 |
| **Coastal land** | 10 | 1 | 1 |
| **Sandy soil** | 4 | 0.001 | 1 |

### 6.5.2 Setting the boundary conditions

The boundary conditions are implemented as a simple bounding region of open air. The default setting for a new bounding region is the smallest box that encloses all of the objects in the model. Since the fields will only be solved inside the bounding region, we must pad the default region to create a meaningful view of the fields around the transmission line.

### 6.5.3 Setting the excitations

Now we will apply a voltage to each end of the transmission line. With the end highlighted, right-click on that end and select Assign Excitation->Voltage. Apply 220 kV for 220 kV transmission line at Y = 20m. As we are observing the transmission line for a span of 20m. Then select other end of the transmission. Subtract 100 V from the transmission line voltage and apply 219.9 kV to the transmission line end at Y = 0.

Ground is given 0V excitation.

### 6.5.4 Analysis

In the **Project Manager** window, right click on **Analysis** and choose “Add Solution Setup.” In the **Solution Setup** pop-up window, under the **General** tab, in the “Adaptive Setup” section, change the “Maximum Number of Passes” to 7 and the “Per cent Error” to 1, to get the simulations, and then select OK. Then select **Maxwell 3D->Analyse All** to run the simulation, which may take a few minutes.

## 6.6 Human body model

A human body contains many types of tissues, cells, organs and many more things which should be replicated in an artificial human body model to a large extent. So experiments with these human bodies are realistic to certain extent.

**Table 6.2**: Tissue properties and thickness of 3-layer human head model [23]

| Tissue | Relative permittivity(ε) | Conductivity(σ) in S/m | Relative permeability(μ) | Thickness in mm |
|---|---|---|---|---|
| **Skin** | 40.7 | 0.65 | 1 | 1 |
| **Bone** | 20.9 | 0.33 | 1 | 1.25 |
| **Brain** | 41.1 | 0.86 | 1 | 77.75 |

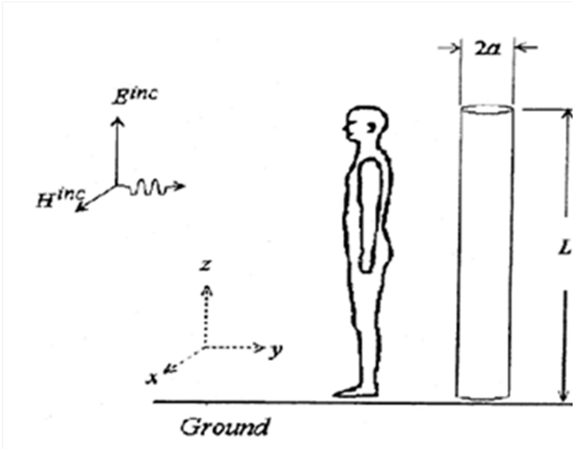


**Figure 1.2:** Human body model used for simulation in ANSYS

Most of these models have been developed by computer segmentation of data from magnetic resonance imaging (MRI) and allocation of proper tissue type. Some of scientist who have developed artificial human body model are Dawson in 1997; Dawson, Moerloose & Stuchly in 1996; Dimbylow in 1997; Dimbylow in 2005; Gandhi in 1995; Gandhi & Chen in 1992; Zubal in 1994.

Here a 3 layered head (skin, bone, brain) and 1 layered body (skin) is used.

# Chapter 7

## Results and discussion

In Fig.2 a transmission model of 220 kV is considered which is situated near coastal region. A surrounding of x = 30m, y = 20m and z = 21m is considered.

In Fig 4.1 the electrical field is more pronounced in lower conductors than in upper conductors because of its proximity to human being.

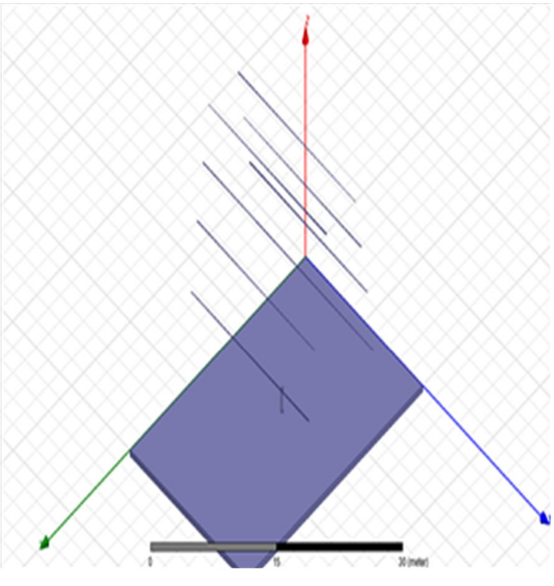

**Figure 2**: 220 kV transmission line model in ANSYS

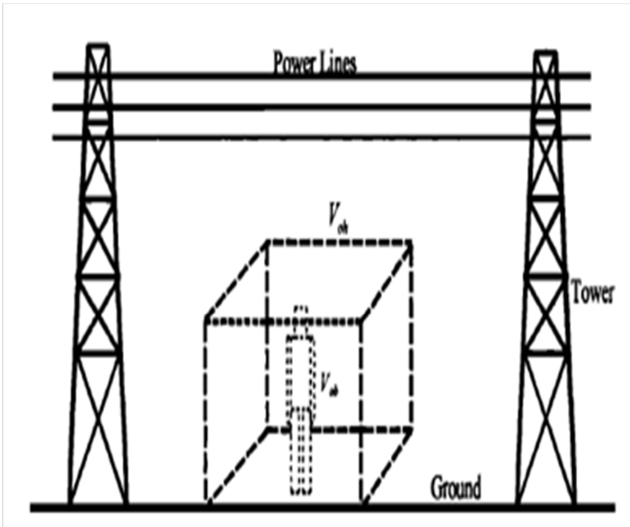


**Figure 3**: Schematic diagram of human being under a transmission line

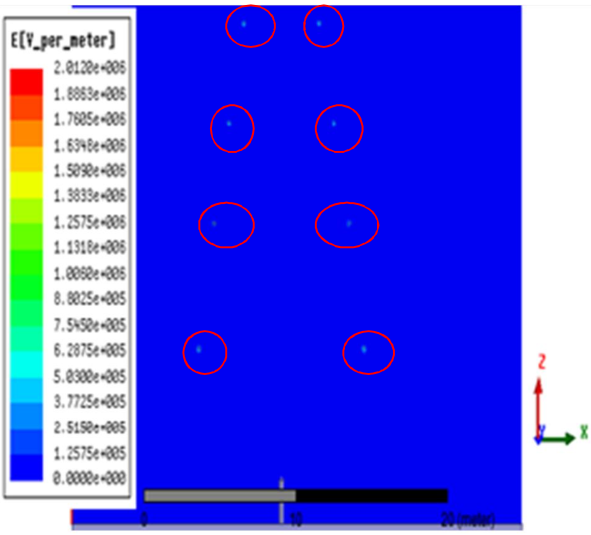


**Figure 4:** Contour plot of electric field in ANSYS

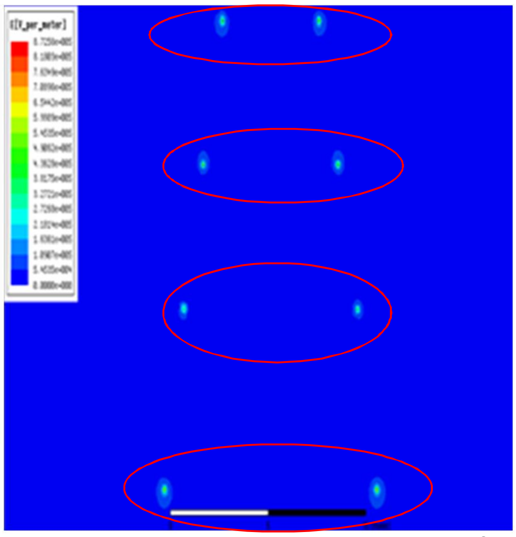

**Figure 4.1:** Detailed contour plot of electric field around conductor

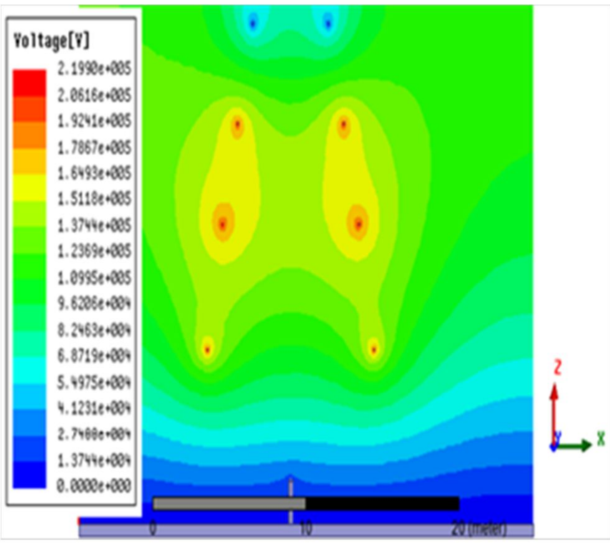


**Figure 5:** Contour plot of electric potential in ANSYS

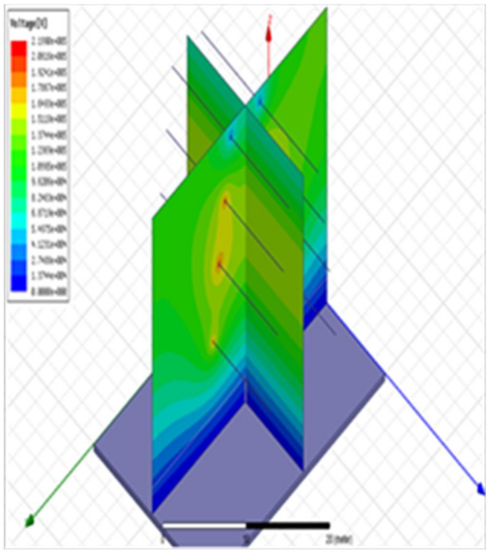

**Figure 5.1:** Contour plot of electric potential in both x and y direction

In Fig 5 and Fig 5.1 earth conductor at top is seen to be having 0 potential, electric potential of middle phase conductor is more compared to other two phases of conductors

In Fig 6.1 the magnetic field strength around ground line is 0. Like electric field, magnetic field is more pronounced in lower conductor due to proximity effect.

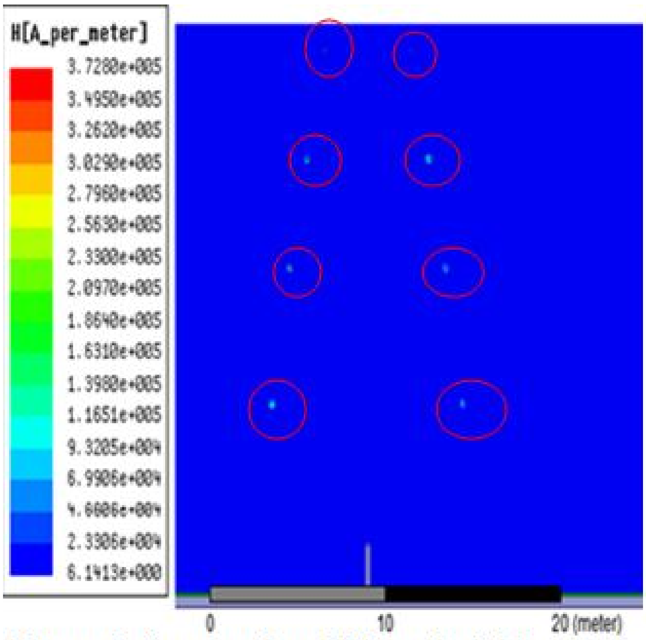


**Figure 6:** Contour plot of Magnetic field strength at 220 kV line near coastal area

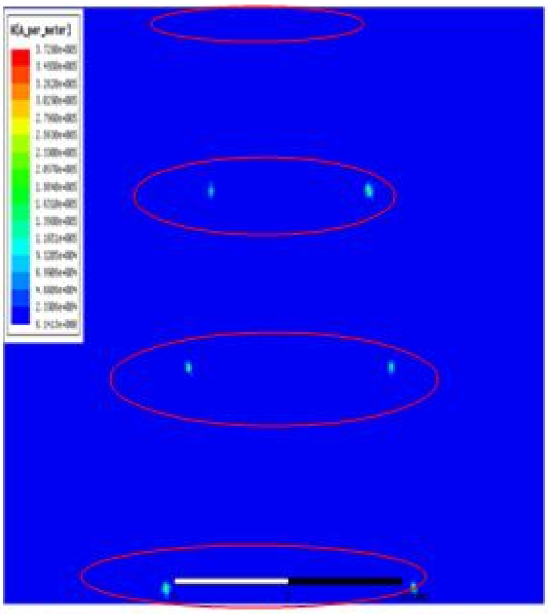

**Figure 6.1:** Detailed contour plot of Magnetic field around conductor of 220 kV line

With the help of ANSYS Maxwell, many configuration of transmission line like 132 kV, 220 kV and 400 kV is modeled and studied. Different geographies like agricultural land, coastal land and sandy region is also taken into account. Data collected from these large varieties of simulations are plotted using MATLAB.

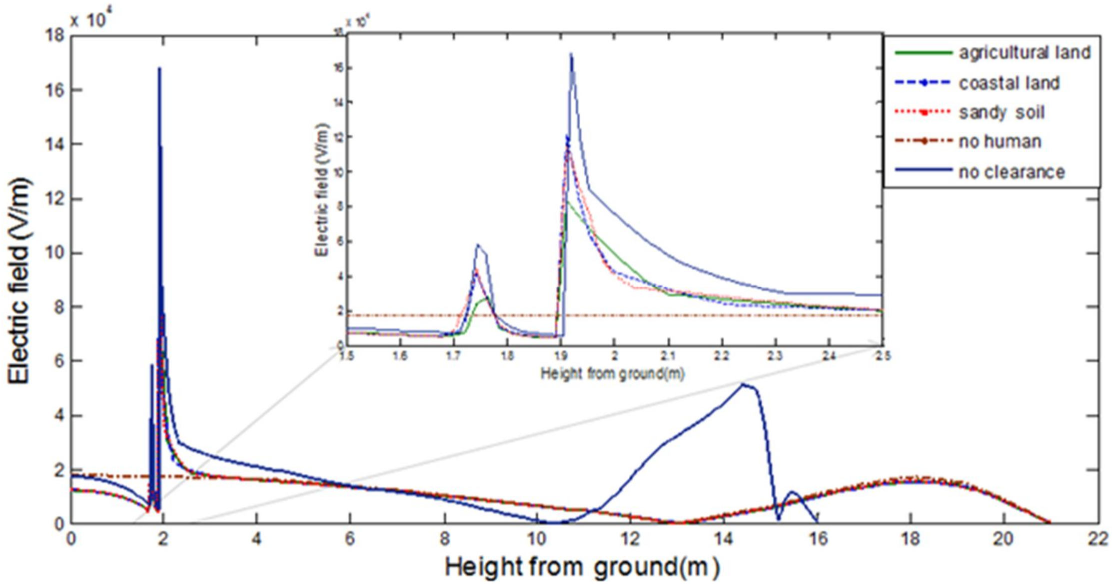


**Figure 7**: Variation of electric field on different geographical areas for a 220 kV line

Fig. 7 shown above represents plot between electric field (E) and height from ground for a 220 kV transmission line. In Fig.7 E is almost similar for agricultural land, coastal land and sandy soil but when requisite clearance is not provided then values of E is very high as compared to safe limits given in table. In the zoomed out E is very high when no human are present in the vicinity of power line. But when a person of height 1.83 m is standing below the power line, the value of E decreases this due to the proximity effect. Presence of moisture also play a great role in determining the value of E that’s why for coastal land E is high but for sandy soil it is low. [24]

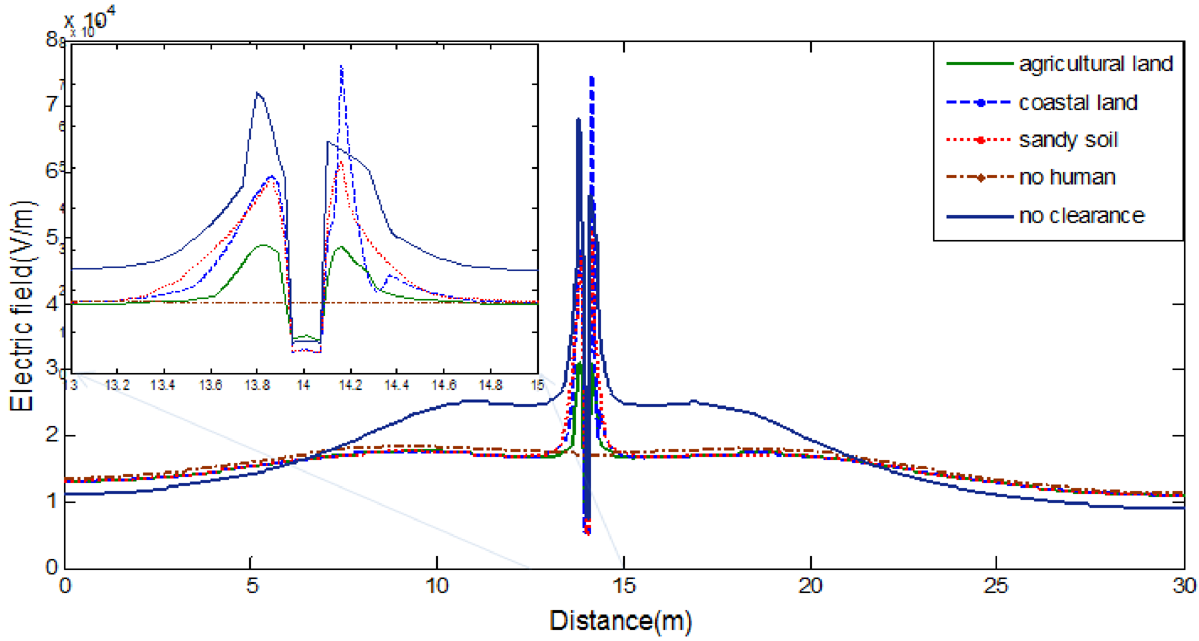


**Figure 8**: Dependence of electric filed on distance from the transmission line for different geographical areas

Fig 8 shows variation of electric field (E) with distance. E is large when a person is standing directly below the power lines, but as we move away from power lines E reduces. It is safe to stand at distance of 50m from the power line.

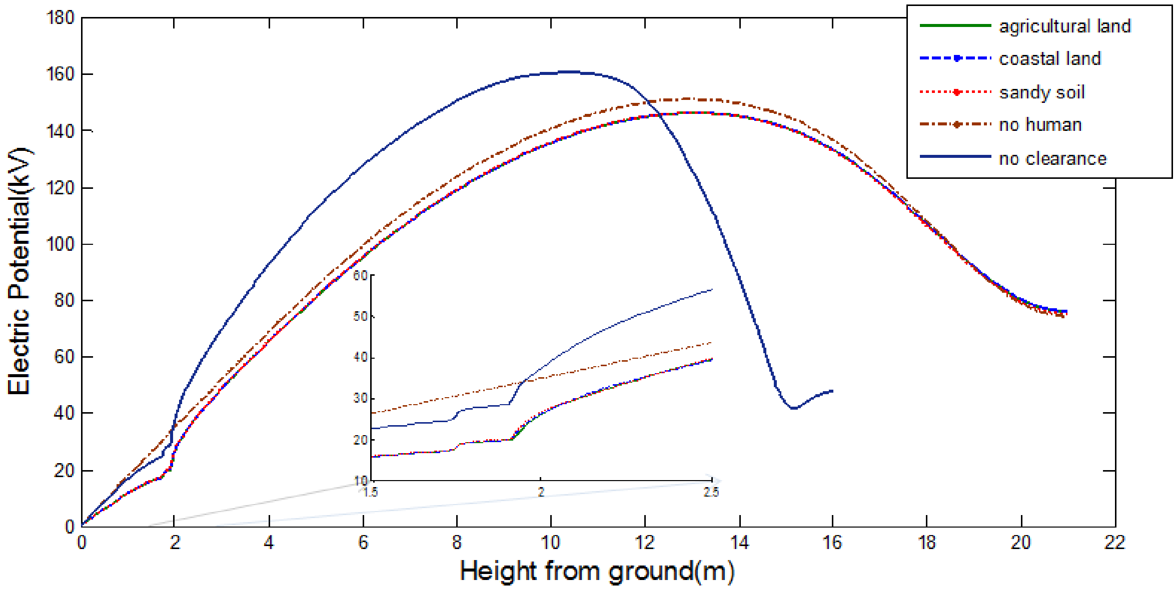


**Figure 9**: Variation of electric potential on different geographical area for 220 kV line

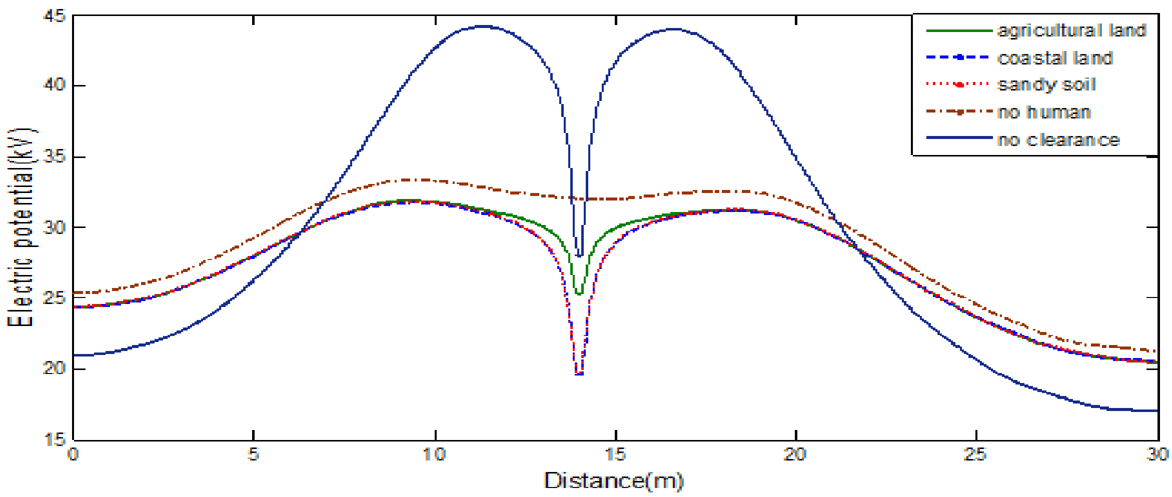


**Figure 10**: Dependence of electric potential on distance from the transmission line for different geographical area

In Fig 9 electric potential (V) versus height from ground is plotted. Potential increases up to the middle of the tower height and then decreases. When there is a discrepancy like no clearance is given then V is very high. It is almost same for agricultural land, coastal land and sandy soil. Proximity effect also changes the value of V, it is high when no human is present and low if human is present. Fig 10 shows variation of electric potential on distance.

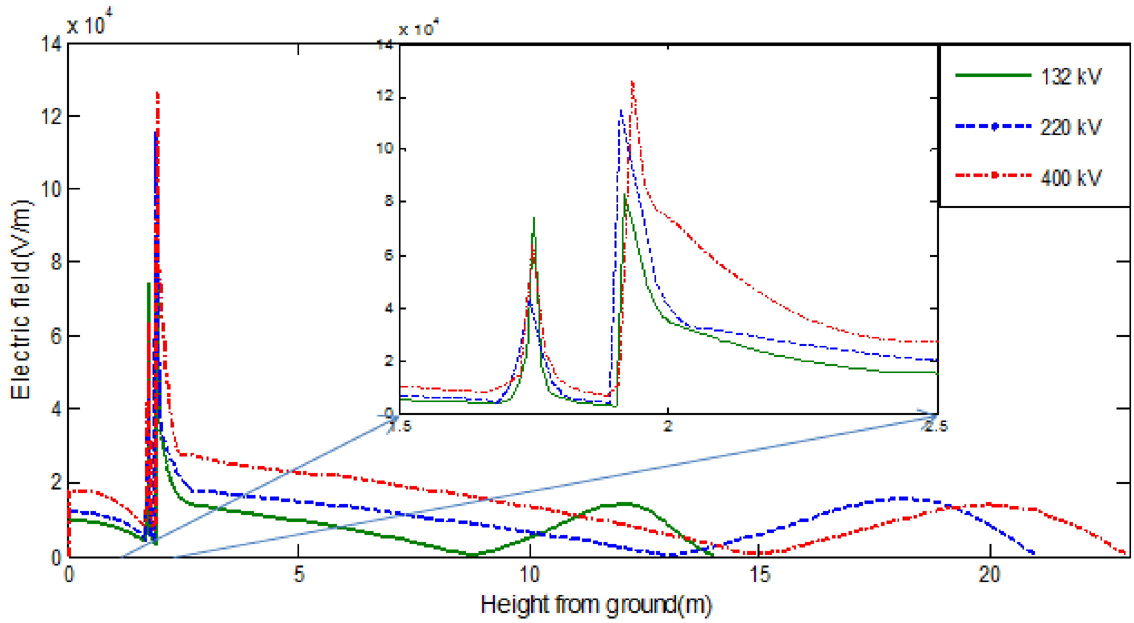


**Figure 11**: Variation of electric field on height from ground for different type of transmission line

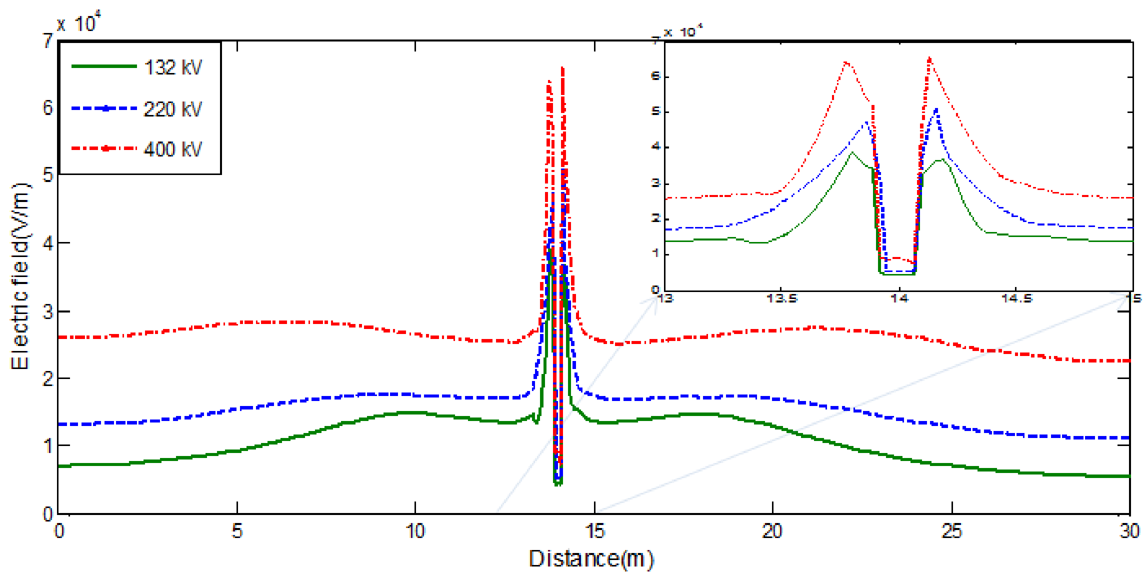


**Figure 12:** Dependence of electric field on distance for different type of transmission line

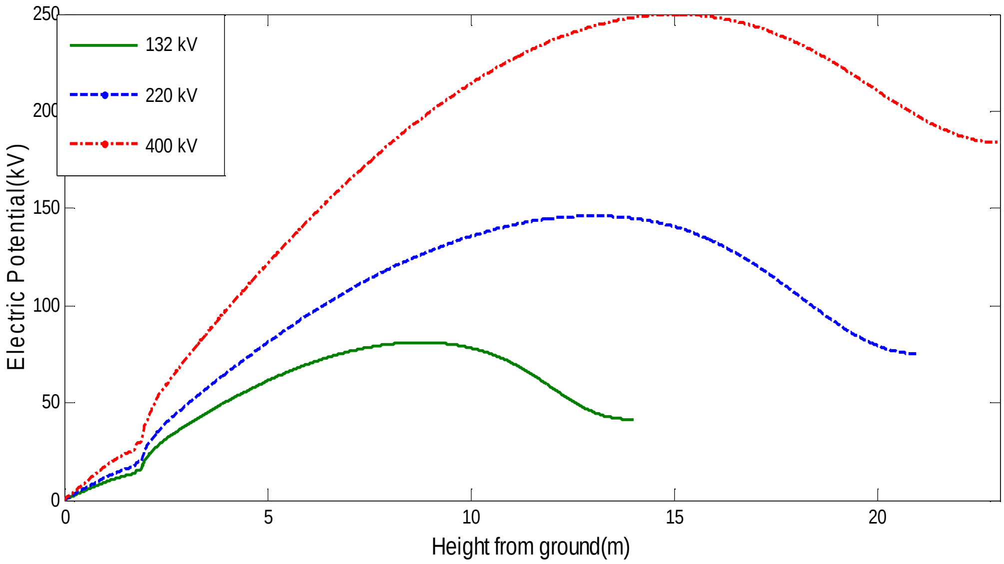


**Figure 13**: Variation of electric potential on height from ground for different type of transmission line

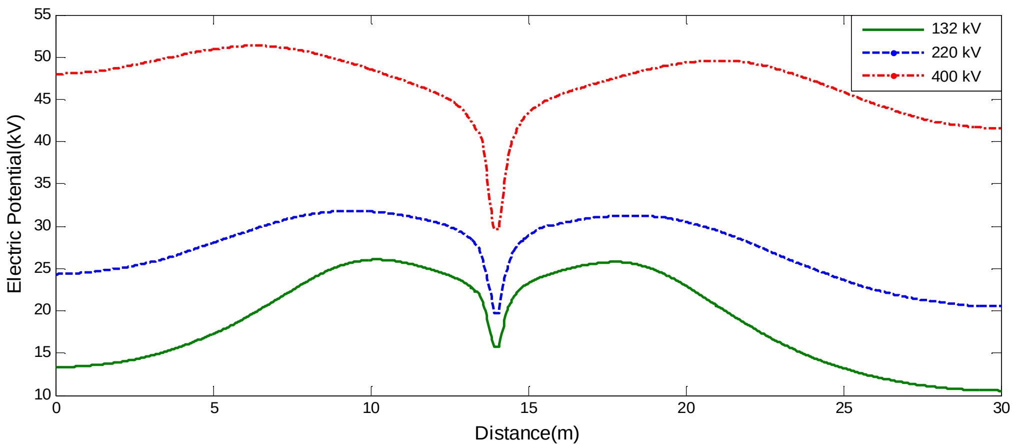


**Figure 14:** Dependence of electric potential on distance for different type of transmission line

From Fig 11-14 variation of electric field and electric potential for different voltages is shown. Here E & V are high for 400 kV and low for 132 kV so one can say electric field is affected by voltage of transmission line.

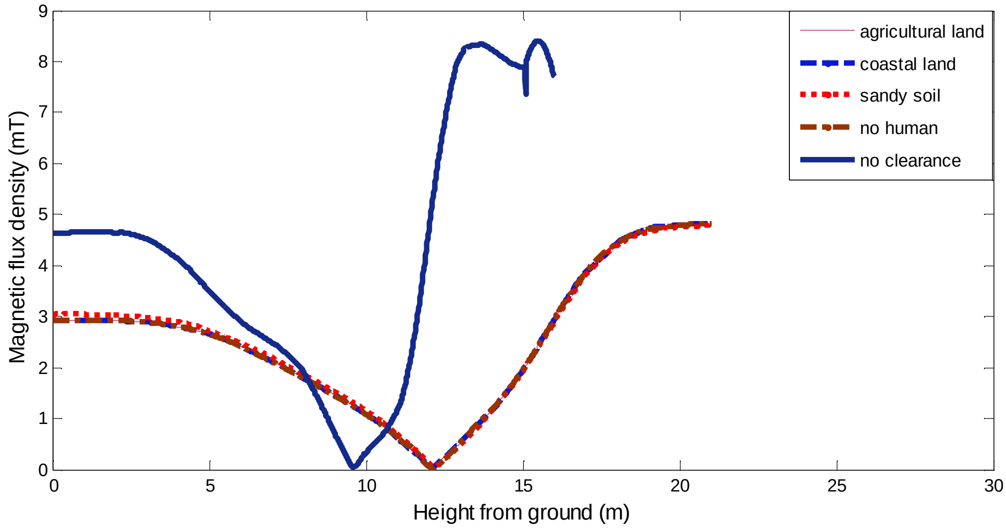


**Figure 15:** Comparison of magnetic flux density with height from ground for different geographical region

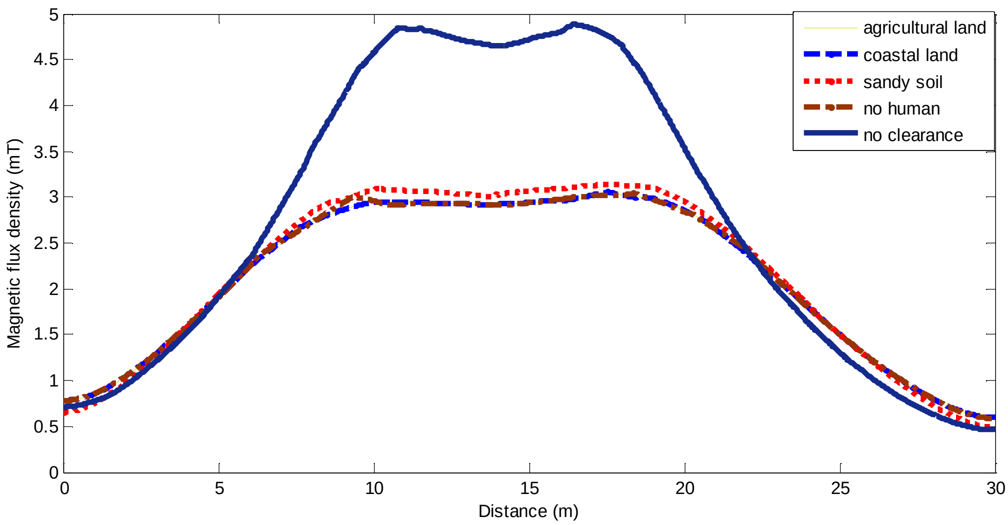


**Figure 16:** Dependence of magnetic flux density on different geographical region for a 220KV transmission line

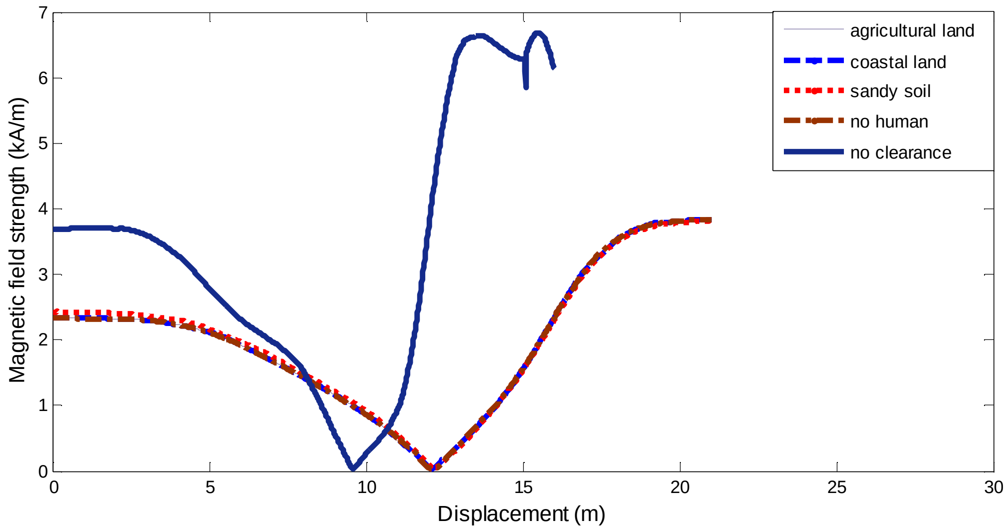


**Figure 17:** Dependence of magnetic field strength on geography of region for 220 kV transmission line

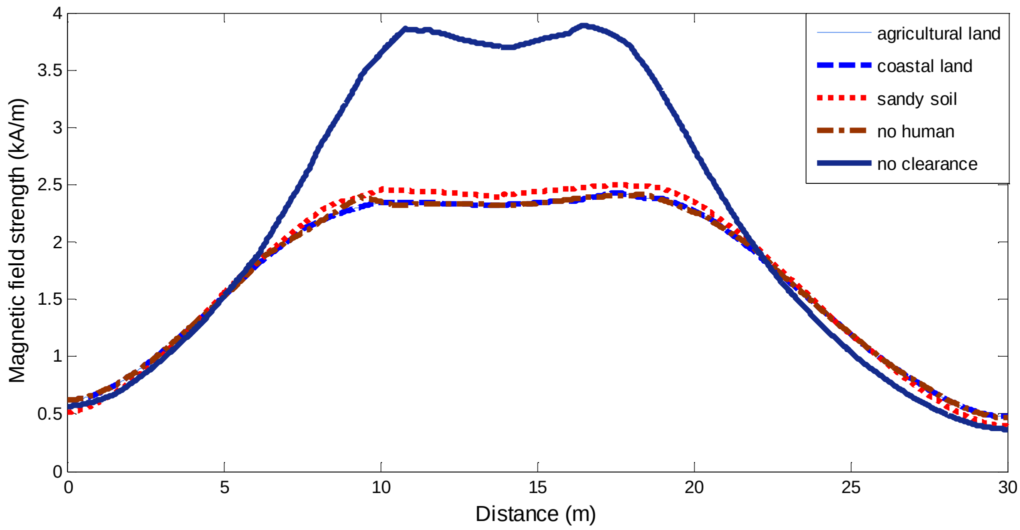


**Figure 18:** Dependence of magnetic field strength on distance from 220 kV transmission line

From Fig.15 to Fig.18 dependence of magnetic flux density (B) and magnetic field (H) on 220 kV transmission line is shown. When the height increases from ground both B and H decreases up to mid height of highest point of power line but it increases from there onwards. When there is no clearance, values of B and H are at very dangerous level. It is also notice that as one move away from the power line B and H decreases. From the simulation it is seen that at a distance of 15 m from power line B is in the acceptable range of exposure as given in table 4.

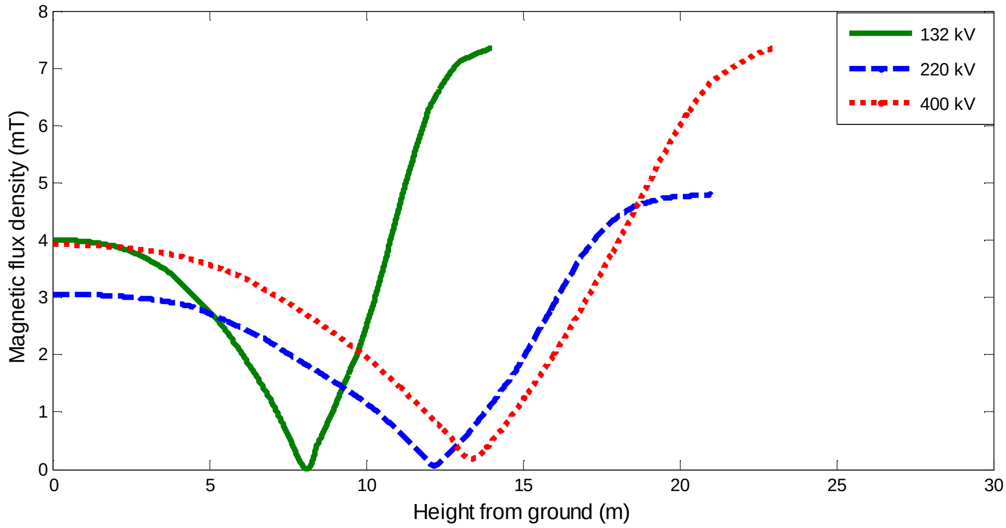


**Figure 19:** Dependence of magnetic flux density on height from ground for different type of transmission line

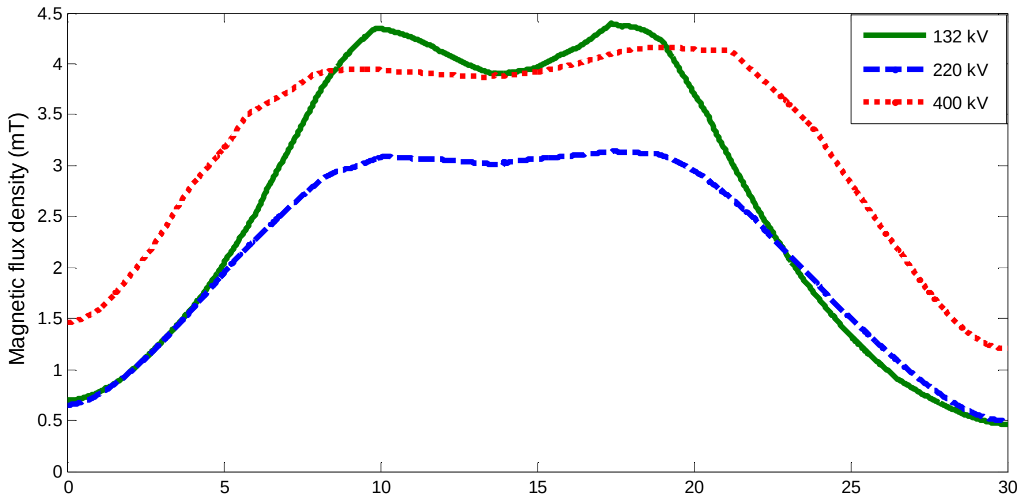


**Figure 20:** Variation of magnetic flux density on distance from transmission line

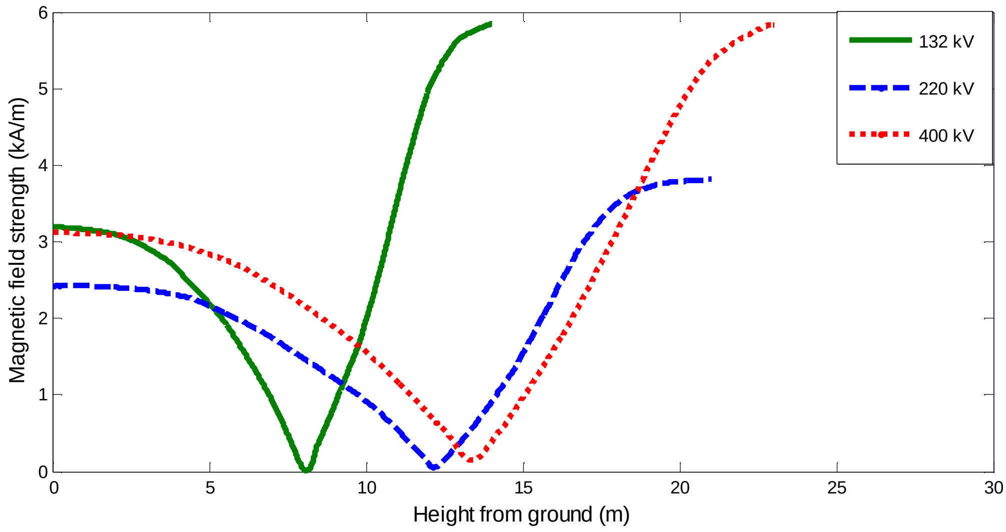


**Figure 21:** Dependence of magnetic field strength on height from ground for type of different transmission line

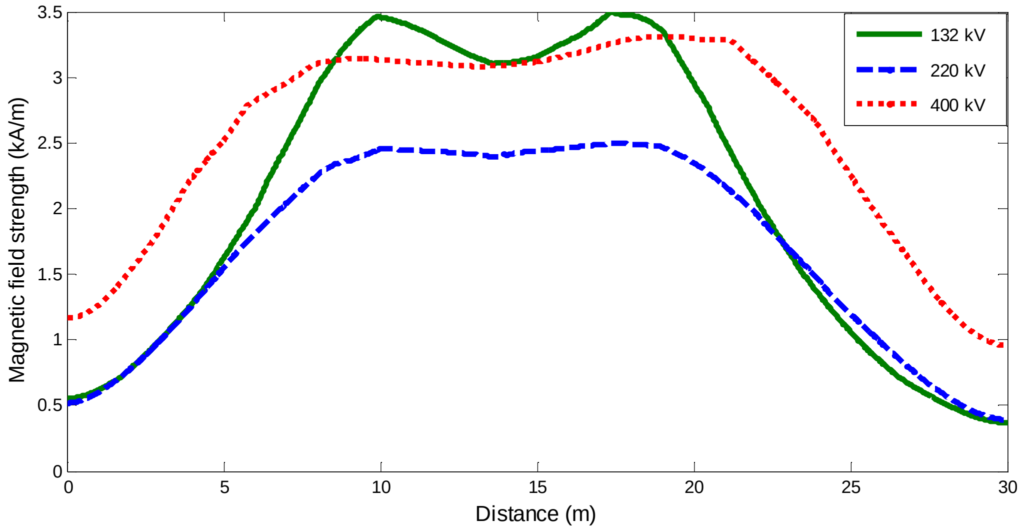


**Figure 22:** Variation of magnetic field strength on distance from transmission line for different type of transmission line voltage

From Fig 19 to Fig 22, it is seen that Magnetic flux density and Magnetic field are dependent on transmission line voltage. Here 132 kV and 400 kV lines are considered for a region containing sandy soil and 220 kV line is selected for agricultural region. So at the position where person is standing below transmission line, data for 132kV and 400 kV are nearly same where as it is less for 220 kV agricultural regions. This is because of presence of moisture in the agricultural land.

**Table7.1:** Simulation result summary for human being of height 1.83 m and standing under the power line

| Test condition | Electric field (E) in V/m | Electric potential (V) in kV | Magnetic flux density (B) in mT | Magnetic field (H) in kA/m |
|---|---|---|---|---|
| Agricultural land (220 kV) | 5810 | 19.5 | 2.92 | 2.32 |
| Coastal land (220 kV) | 6000 | 19.54 | 2.92 | 2.32 |
| Sandy soil (220 kV) | 5506 | 19.7 | 3.02 | 2.40 |
| No human (220 kV) | 17220 | 32 | 2.92 | 2.32 |
| No clearance (220 kV) | 8400 | 28 | 4.65 | 3.7 |
| 132 kV | 4500 | 15.5 | 3.9 | 3.11 |
| 400 kV | 8520 | 29.5 | 3.88 | 3.1 |

Above Table 8.1 gives the summary of simulation results at a position where the human being is standing below the transmission line i.e. 14m in x axis and at an elevation of 1.83m which is also the height of human being.

# Chapter 8

## Conclusion and future scope of work

Electromagnetic effect of transmission lines on human being is represented in a simulation set up by use of finite element method. One such FEM software is ANSYS Maxwell 3D. Simulations are carried out for various conditions as presence of human being in different geographical areas like agricultural land, coastal land and sandy region. Different transmission line voltages are also studied. Harsh conditions are also taken into account like not giving permissible clearance for transmission lines. Electric fields and magnetic fields which are generated in ANSYS are further analyzed in MATLAB. All the results obtained are compared with standard safe limits of electromagnetic radiation given by International Radiation Protection Association.

In future field study around a transmission line should be carried out. There are different equipments which can be used to measure electromagnetic fields like MAGNUM **310** of Dexsil Corporation, Trifield 100XE EMF Meter which is a task for future batches to take over and complete the project.

# Reference


[1] Grandolfo M, Michaelson S M, Rindi A eds. *Biological effects and dosimetry of static and ELF electromagnetic fields.* New York and London: Plenum Press, 1985.

[2] Grandolfo M, Vecchia P. *Existing safety standards for high voltage transmission lines.* In: Franceschetti G, Gandhi 0 P, Grandolfo M eds. Electromagnetic biointeraction: mechanisms, safety standards, protection guides. New York and London: Plenum Press, 1989.

[3] Ahlbom A et al. *Biological Effects of Power Line Fields.* In: New York State Power Lines Project, Scientific Advisory Panel Final Report. New York, 1987. 67-87.

[4] United Nations Environment Programme/World Health Organization/International Radiation Protection Association. Environmental Health Criteria 35. *Extremely Low Frequency (ELF) Fields.* Geneva: World Health Organization, 1984. Washington, DC: NBS, 1964, pp. 32-33.

[5] United Nations Environment Programme/World Health Organization/International Radiation Protection Association. Environmental Health Criteria 69. *Magnetic Fields.* Geneva: World Health Organization, 1987.

[6] International Radiation Protection Association/International Non-Ionizing Radiation Committee. *Review of concepts, quantities, units and terminology for non-ionizing radiation protection.* Health Physics 49: 1329-1362, 1985.

[7] Kaune W.T, Forsythe W C. *Current densities measured in human models exposed to 60 Hz electric fields.* Bioelectromagnetics 6:13-22, 1985.

[8] Kaune W T, Forsythe W C. *Current densities induced in swine and rat models by power-frequency electric fields.* Bioelectromagnetics 9:1-24, 1988.

[9] Cabanes J, Gary C. *Direct perception of the electric field.* In: International Conference on Large High Voltage Electric Systems, CIGRE, Stockholm, 1981.

[10] Institute of Electrical and Electronics Engineers. Working Group on Electrostatic and Electromagnetic Effects. *Electric and magnetic field coupling from high voltage AC power transmission lines-classification of short-term effects on people.* IEEE Trans. Power Appar. Syst. 97:2243-2252, 1978.

[11] Hauf R, Wiesinger J, *Biological effects of technical electric and electromagnetic VLF fields*. Int. J. Biometeorol. 17:213-215, 1973.

[12] Hauf R. *Effects of 50 Hz alternating fields on man*. Electrotechn. Z.B. 26:319-320, 1974 (in German).

[13] Rupilius J P. *Investigations on the effects on man of an electrical and magnetic 50 Hz alternating field.* Freiburg, Germany: Albert Ludwig University 1976. (Dissertation) (In German).

[14] Wertheimer N. Leeper E. *Electrical wiring configurations and childhood cancer.* Am. J. Epiderniol. 109:273-284, 1979.

[15] Savitz D A et al. *Case-control study of childhood cancer and exposure to 60 Hz magnetic fields*. Am. J. Epidemiol. 128:21-38, 1988.

[16] Institute of Electrical and Electronics Engineers. Power Engineering Society Transmission and Distribution Committee. *Corona and field effects of AC overhead transmission lines.* 1984. Available from: IEEE, 445 Hoes Lane, Piscataway, NJ.

[17] Guy A W. *Hazards of VLF electromagnetic fields.* In: The impact of proposed radiofrequency radiation standards on military operations, Proceedings of a NATO Workshop, Neuilly-sur-Seine: AGARD, 1985; AGARD-LS-138; 9.1-9.20.

[18] Chari, M.V.K., and Salon, S.J., *Numerical Methods in Electromagnetism*, Academic Press, USA, 2000.

[19] Preston, T.W., Reece, A.B.J., and Sangha, P.S., Induction Motor Analysis by Time-Stepping Techniques, *IEEE Transactions on Magnetics*, Vol.24, No.1, 1988, pp. 471-474.

[20] Weiner, M., *Electromagnetic Analysis Using Transmission Line Variables*, World Scientific Publishing, Singapore, 2001.

[21] Pao-la-or, P., Kulworawanichpong, T., Sujitjorn, S., and Peaiyoung, S., Distributions of Flux and Electromagnetic Force in Induction Motors: A Finite Element Approach, *WSEAS Transactions on Systems*, Vol.5, No.3, 2006, pp. 617-624.

[22] Hayt, Jr.W.H. and Buck, J.A., *Engineering Electromagnetics (7th edition)*, McGraw-Hill, Singapore, 2006.

[23] C. Gabriel, “The dielectric properties of tissues,” in Radiofrequency Radiation Dosimetry and Its Relationship To the Biological Effects of Electromagnetic Fields, B. J. Klauengerg and D.Miklavic, Eds., vol. 82 of Nato Science Series, pp. 75–84, High Technology, London, UK, 2000.

[24] Davis, J.L. and Annan, A.P. 1989. Ground-penetrating radar for high resolution mapping of soil and rock stratigraphy. Geophysical Prospecting 37, 1989. pp. 531-551.