
***Physical Science International Journal***

***15(1): 1-9, 2017; Article no.PSIJ.32022***
***ISSN: 2348-0130***

# Investigation of Field Induced Effect of High Voltage Transmission Line in Calabar South, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/PSIJ/2017/32022
Editor(s):
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Complete Peer review History: http://www.sciencedomain.org/review-history/19827

***Short Research Article***

***Received 31st October 2016***
***Accepted 30th January 2017***
***Published 3rd July 2017***

## ABSTRACT

Due to increase in energy cost of transmission, high voltage transmission becomes the most economical for the transfer of large amounts of electrical power, because the higher the transmission voltage, the more efficient and cheaper the transmission. Due to increase in population, the towns are expanding, and naturally result in the construction of buildings near high voltage power lines. This research gives an in depth analysis of fields emitted by 11 kV and 33 kV power line and also describes in details the points where the highest field emission (at distance of 50 m, 1.17 µT is recorded for magnetic field around 11 kV power line and beneath the power line a field of 0.82V/m was recorded for electric field) and compares measurements of this fields with the international standard threshold values of 5V/m and 0.1 µT for the public. The magnetic field shows field/health effect as its exceeds the threshold value at some point while the electric field at all points is still below the limit as recommended by International Commission of Non-Ionizing Radiation Protection (ICNIRP).

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*Keywords: High voltage; transmission line; electric field; health effect; magnetic field; threshold values.*

## 1. INTRODUCTION

The potential health and environmental effects of the very low frequency (VLF) electromagnetic field surrounding power lines and electrical devices is subject of ongoing research. While electrical and electromagnetic field in certain frequency bands have fully beneficial effects for medicine, radar and mobile telephony, they appear to have more or less potentially harmful, non-thermal, biological effects on plants, insects and animals, as well as human body when exposed to levels that are below the standardized threshold values. One must respect the precautionary principle and revise the current threshold values that have become inefficient and not aligned in different countries. Asbestos, leaded petrol and tobacco that are polluting and aggressive to human health are currently managed by enacting appropriate law of strict precaution after several sessions of legislative revisions. Nowadays, people are highly concern about the effects of high voltage transmission lines on their health and that of their plants and livestock. Probable risks for leukemia, breast cancer, neuropsychological disorders and reproductive outcome have been reported [1].

A noticeable source of extremely low frequency radiation is the high voltage electrical transmission lines, which in some instance produce such high losses that they bend the earth's ionosphere. Power lines are dangerous because they are constantly losing energy. If we have an extremely low frequency spectrum analyzer, we could find that extremely low frequency fields propagate very far, even at long distances, and the intensity will be quite significant from biological viewpoint for long term exposures. Both high-voltage transmission lines and also power lines vicinity constitute a radiation hazard. The size of the power line is not the issue. The strength of the electromagnetic field (especially the magnetic component) where you live is what is important. For people living at distance from power lines, long term exposure may be dangerous. Often it was found that secondary transmission lines, like in the street are much worse polluters than the huge power lines [2]. The human body is a living antenna that can absorb and re-emit power line energy, in the environment. A school full of children and teacher near power line can become a tremendous new source of electrical energy and a major polluter, not only to the children in the school, but even to people living nearby [3].

The configuration of power transmission lines greatly affects the electromagnetic field (EMF) bio-effects. It is common for high voltage, high-current carrying power transmission lines to generate a magnetic field whose strength is well above normal household ambient levels, at distances up to 400 meters. But it is also common for a neighborhood power line to create a similar EMF at a distance of 300 meters, and for the wiring inside the walls of your house to create a dangerous EMF at 1.0 meters. In each case, much depends on the configuration of the wires and the amount of current they carry. The following health outcomes have been conclusively linked with EMF exposure in some scholarly literature: a variety of cancers, leukemia, tumor growth, skin damage, abnormal cell activity, sleep and daily rhythm disturbances, perception and memory changes, genetic defects and impairment of hormone regulation and production, also gland deficiencies, nervous system disorders, fetal development problems, miscarriages, birth defects, and blood and circulatory problem [3].

The U.K stakeholder advisory group on extremely low frequency EMFs (2007) cited links between EMFs and the following adverse effect; childhood and adult leukemia, adult brain cancer, Alzheimer's disease, Lou Gehrig's disease, breast cancer, childhood cancer, depression, electrical sensitivity symptoms, certain types of heart disease, miscarriage and suicide, many occupational epidemiological (population health and illness), animal and cell studies reported in the peer reviewed literature by Colchester School Parent's Association (1988) show major increase in the occurrence of many diseases and health problem in children and adult exposed to EMFs. These include: leukemia, non-Hodgkins lymphoma intestinal cancer, myeloid leukemia, brain tumors, brain cancer, immune system deficiencies, DNA uncoding retardation of fertilization, increased infant mortality, embryo abnormality and stunting of growth [4]. A comprehensive review recorded by Rubtsova, included those effects recorded elsewhere in the literature as well as the following; fatigue decrease in visual and motor reaction time, attention and memory deterioration, persistent mental disorders, headache, nausea, male sexual disfunction changes, and embryonic death [4].

Nowadays, a multi-line power system is present in our neighborhood to satisfy increasing need for electric power. To distribute power from power plant to the load centre it will be required a network starting from the transmission line until the consumer, so that in the vicinity of the transmission line and distribution network 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 are easily accelerated by a variety of mechanisms.

### 1.1 Standard Guidelines Limits

There are European and International Commission on Non-Ionizing Radiation Protection (ICNIRP) standards. In these criteria, the frequencies of different electromagnetic fields have a “reference value”. In 1990, the World Health Organization (WHO) set the limit values for the fields electric and magnetic fields shown in Table 1 (“Electromagnetic Fields and Public Health” [5].

### 1.2 Overhead Power Line

High-voltage overhead power lines conduct electricity from power generating stations to power source substations, which are located close to where the energy is actually used. These power lines produce two types of energy: electrical energy and magnetic energy which are given off in a field that expands in all directions around the wire. The U.S National cancer institute (NCI) describes electromagnetic field (EMF) as areas of energy that surround any electrical device. The NCI also explains that EMF is produce by variety of sources, including power lines, electrical working and household appliances.

However, the fields emitted from high voltage power lines are much stronger than those surrounding household appliances, which typically produce fields measuring between 0.01 to 0.02 µT, or 300 to 600 times higher than in the average home [7].

### 1.3 Power Delivery Systems

Power lines are characterized by voltages and currents; voltage is a measure of the electric potential energy that makes electric charges flow through a circuit. Current is a measure of the rate at which electrical charges flow in a power line or wire. The amount of power that a line transmits is simply the product of its voltage and current. Power systems are designed so that the voltage is held relatively constant over time while currents are permitted to rise and fall with power demand.

Electric generators in power stations produce electric power at about 20kV. Large “step-up” transformers are used to increase the voltage for efficient long distance power transfer over high voltage transmission lines to load centers. Transmission lines operate at voltages up to 785kV and carry current of up to 2000 amperes. Transmission lines terminate at substations where step-down transformers transfer power to lower-voltage distribution lines. Distribution lines deliver power locally through load centers to individual users. Residential distribution systems are comprised of two different circuits: (1) a high voltage (5-35kV) or “primary” circuit that delivers power from the substation to a local pole-mounted or underground distribution transformer and (2) a low voltage or “secondary” circuit that delivers power from the local transformers to the home. The voltage of the secondary side is low enough (115/230V) to allow appliances, lighting, and other electrical loads in the home to be operated safely. Commercial and industrial installations often have their own step-down transformers and so obtain their power directly from distribution primaries. Distribution primaries carry currents of up to 900 A. 115/230 V wall wiring in homes is typically design to carry currents of up to 30 A.

The amount of power lost in the wires during transmission and distribution can be reduced by increasing the voltage at which these lines operate. Transmission and primary distribution voltages have therefore increased over the years [8].

**Table 1. Recommendation limits of the strength of electric and magnetic fields [6]**

| Organization | Public area | | Occupational area | |
|---|---|---|---|---|
| | E (V/m) | B (μT) | E (V/m) | B (μT) |
| ICNIRP | 5 | 0.1 | 10 | 0.5 |
| European Union | 5 | 0.1 | 10 | 0.5 |

### 1.4 Extremely Low Frequency (ELF) Radiation

Extremely low frequency (ELF) radiation is at the low-energy end of the electromagnetic spectrum and is a type of non-ionizing radiation. Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to remove charged particles such as electrons (ionize) and directly damage DNA. ELF radiation has even lower energy than other types of non-ionizing radiation like radio frequency radiation, visible light, and infrared. Extremely low frequency radiation has very large wavelengths-one wave can be 500 km across. This means that people and other living things are in only a small fraction of a wavelength. A magnetic field will only exists if the charges are in motion, such as with the flow of electric current. Direct current that is going in one direction and permanent magnets produce static (unchanging) magnetic fields. This is not a form of ELF radiation. Time-varying magnetic fields (including those in the extremely low frequency range) are produced by alternating current. The electric fields come from unbalanced electric charges on conductors. The electric field acts on charged particles – like electrons or protons. It can cause these particles to move leading to the flow of electric current. Magnetic fields can produce electric fields, and electric fields can produce magnetic fields. With most types of radiation, the electric and magnetic fields are coupled. Because they act as one, they are considered together as an electromagnetic field (EMF). But with ELF radiation, the magnetic field and electrical field can exist (and act) individually, and so they are often studied separately.

The possible link between electromagnetic fields and cancer has been a subject of controversy for several decades. It's not exactly clear how electromagnetic fields, a form of low-energy, non-ionizing radiation, could increase cancer risk. It should however be noted that, we are all exposed to different amounts of these fields at different times.

## 2. MAGNETIC FIELD DENSITY AND ELECTRIC FIELD STRENGTH FROM MAXWELL'S EQUATION

Generally, the electric and magnetic fields are coupled and it is necessary to solve Maxwell's equations to determine them. But in the case of overhead power lines, at the supplied voltage frequency 50 Hz, where electromagnetic field has a wave length of 6000 km, the quasistatic methods could be used. These methods use the static Maxwell's equations.

$$\nabla \times E = 0 \quad (1)$$

$$\nabla \cdot D = \rho \quad (2)$$

$$\nabla \times H = J \quad (3)$$

$$\nabla \cdot B = 0 \quad (4)$$

$$B = \mu H = \mu_o \mu_r H \quad (5)$$

$$D = \varepsilon \epsilon = \varepsilon_o \varepsilon_r \epsilon \quad (6)$$

Where

E is the electric field strength vector (V/m), B is the magnetic field density vector (T).

D is the electric field density vector (C/m$^2$), ϵ is the charge density (C/m), H is the magnetic field strength vector (A/m), J is the current density vector (A/m$^2$), ε is the permittivity of free space (F/m), μ is the permeability of free space (H/m) [9].

The static electric field and magnetic field could be calculated separately. The electric field emissions are caused by the charge q placed on the conductor element dI. The electric field strength vector D in any point in vicinity of the overhead power line can be calculated by the equation below.

$$dE = \frac{qdLR}{4\pi\varepsilon_0 R^3} \quad (7)$$

Where

dE is electric field strength vector in any point in vicinity of the overhead power line.

q is charge placed on the conductor element dI, dL is length of the conductor element dI.

$\varepsilon_o$ is the permittivity of the free space, R is the vector pointing from the conductor element.

dI to an arbitrary point of observation. Its length is denoted by R.

The magnetic field density vector dB caused by the current flowing through the straight conductor element dI, with the length dL, can be calculated by Biot-Savart's law.

$$dB = \frac{\mu_0 i(dI \text{x} \mathrm{R})}{4\pi R^3} \quad (8)$$

Where, dB is magnetic field density vector, $\mu_o$ is the permeability of the free space dI is the straight conductor element R is the vector from the element dI point to an arbitrary point of observation.

$$dE = dE_x\hat{a}_x + dE_y\hat{a}_y + dE_z\hat{a}_z \quad (9)$$

$$dB = dB_x\hat{a}_x + dB_y\hat{a}_y + dB_z\hat{a}_z \quad (10)$$

With derivation proposed in the equation for the electric field strength vector dE and magnetic field density vector dB caused by the charge q and current I of the straight conductor element dI are obtained, the calculated dE and dB are composed of components in the axis x, y and z in equation (9) and (10). The axis are defined with the unit vectors $\hat{a}_x$, $\hat{a}_y$ in $\hat{a}_z$ as shown in Fig. 1 while $dB_x$, $dE_x$, $dB_y$, $dE_y$, $dB_z$, $dE_z$ are the contributions of the magnetic field density and electric field strength in all three axis.

On the other hand the conductor of overhead power line inside the span is not straight. In fact, the shape of the conductor between the two towers can be described by the centenary curve, which depends on the environmental conditions and characteristics of the conductor. To obtain even more exact results of the electric and magnetic field emissions, the conductor sagging should be included in the calculations in equation (9) and (10) Fig. 1 shows the section dI of the overhead power line conductor with length dL. In Fig. 1; the dy and dz are the components of dL in the axis z and y, p is the conductor weight, while $\sigma^1$ and $\sigma^1 + d\sigma^1$ are the conductor tensile stress components in the vertical $\sigma^{11}$, $\sigma^{11} + db^{11}$ and horizontal σ, σ, + dσ directions.

In order to determine the line charges q required in equation (8), the conductors between two discrete points are approximated with the straight conductor to ground. Since the matrix of the transmission line capacities C depends only on the line geometry between the two discrete points, the matrix of charges q on individual conductor elements can be determined from known matrix of line voltage U. the elements of U = $(U_1, U_2, U_3)t$ are given in the following equations.

$$U_1 = U_m\text{Cos}\ (2\pi ft) \quad (11)$$

$$U_2 = U_m\text{Cos}\ (2\pi ft - 2\pi/3) \quad (12)$$

$$U_3 = U_m\text{Cos}\ (2\pi ft - 4\pi/3) \quad (13)$$

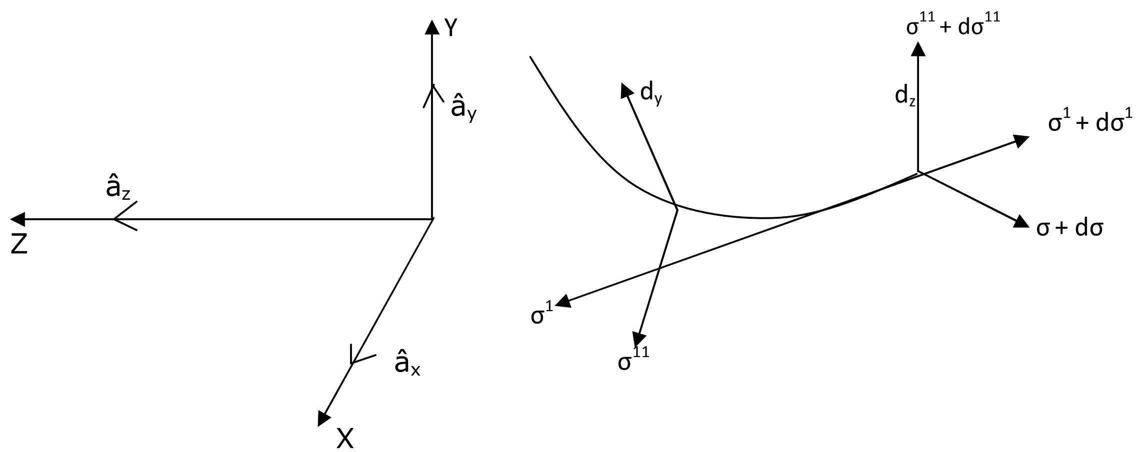


**Fig. 1. The section dI of the overhead power line inside the span**

In case of the overhead power line there exist several conductors. Their number depends on the number of overhead power line circuits, number of conductors in the bundle, manner of energy transmission and the number of the overhead earth wires. In the case of the electromagnetic fields calculations, each conductor contributing to the electromagnetic fields emissions is composed of straight conductor elements defined with the position discritization of all conductors over the whole span, the number total of all straight conductors sections equals N.

The lengths of the electric field strength vector E and magnetic field density vector B are calculated using the following equations.

$$E = \sqrt{E^2_x + E^2_y + E^2_z} \quad (14)$$

$$B = \sqrt{B^2_x + B^2_y + B^2_z} \quad (15)$$

In case of the overhead power line, the current and voltage, respectively charge, change periodically. In order to determine the root mean square (r.m.s) values of E and B, the time discretization is introduced. The three phase overhead power line is normally fed by the three phase sinusoidal voltage $U_1$, $U_2$, and $U_3$ (Joseph, 1995).

$$U_1 = U_m \mathrm{Cos}\ (2\pi ft) \quad (16)$$

$$U_2 = U_m \mathrm{Cos}\ (2\pi ft - 2\pi/3) \quad (17)$$

$$U_3 = U_m \mathrm{Cos}\ (2\pi ft - 4\pi/3) \quad (18)$$

They are displaced for 2π/3, where

$U_m$ is the amplitude and F = 50 Hz is the frequency.

Similarly, in the case of symmetrically loaded overhead power line, the line currents $i_1$, $i_2$ and $i_3$ are described by the following equations

$$i_1 = I_m \mathrm{Cos}\ (2\pi ft) \quad (19)$$

$$i_2 = I_m \mathrm{Cos}\ (2\pi ft - 2\pi/3) \quad (20)$$

$$i_3 = I_m \mathrm{Cos}\ (2\pi ft - 4\pi/3) \quad (21)$$

Where $I_m$ is the amplitude

In this way, the instantaneous values of the currents in equations (19) – (21), voltages (16) – (18), as well as E in equation (14) and B equation (15), are determined in each time discrete point. The r.m.s values of the electric field strength $E_r$.m.s and magnetic field density $B_r$.m.s are defined by the following

$$E_{r.m.s} = \sqrt{1/L \ \underline{\Sigma} \ E^2 (j)} \quad \text{for} \quad J=1 \quad (22)$$

$$E_{r.m.s} = \sqrt{1/L \ \underline{\Sigma} \ B^2 (j)} \quad \text{for} \quad J=1 \quad (23)$$

where L is the number of samples per one cycle of fundamental frequency, while j denotes sample.

## 3. MATERIALS AND METHODS

In this article, the following materials were used; meter rule to measure distances (10 m, 20 m, 30 m, 40 m …..100 m). A sensor ED78S electrosmog meter was used; It detects low frequency (LF) magnetic field in units of tesla or gauss, electric field in unit of V/m and high frequency RF electromagnetic field strength signal as well as cell phone radiation. Also measured LF magnetic field strength is shown on the digital LCD display (with µT and mG). Two LF modes can be selected; (a) LF30 mode (0.1 mG-30 mG) and (b) LF 600 mode (1 mG – 600G). It runs on one 9v alkaline battery.

Study areas were selected based on the local high voltage transmission (HVT) line distribution. We took measurements (10 m, 20 m, 30 m, 40 m ……100 m) of electric and magnetic fields at selected locations along preferred route. Both electric fields and magnetic fields were measured. Each measurement was acquired over a short period. Upon stabilization of a reading, the maximum value was recorded. Continuous measurements were performed at different distances at each measuring points. The measurements were taken at a height of 1meter above sea level, in accordance with the industry standard protocol for taking measurements of EMF near power lines.

The electric field was measured in units of V/m with an electrosmog sensor and meter. The magnetic field was measured in units of µT using electrosmog meter and sensor. This instrument meets the Institute of Electrical and Electronic Engineering (IEEE) instrumentation standard for obtaining valid and accurate field measurements at power lines frequencies (IEEE Std. 1308 – 1994, R2001, R2010). Measurements of electric field and magnetic fields were taken horizontally on the preferred Route on Palm Street and Okodi/Atakpa. Measurements of electric fields and magnetic fields was carried out on a 33 kV transmission line that runs through Cross River

University of Technology and 11 kV transmission line along Palm Street and Okodi/Atakpa measurement of both electric field and magnetic fields was carried out when the lines were charged.

## 4. RESULTS AND DISCUSSION

Tabulated results of the measurements are presented in Tables 2 and 3, also in Figs. 2 and 3. Nearby sources of electric fields include not only the existing overhead transmission lines, but also other sources like cell phone tower along Palm Street.

**Table 2. Measured electric and magnetic fields around 11 kV power line**

| Distance (m) | Mean E(V/m) | Mean B(μT) |
|---|---|---|
| 0.00 | 0.82 | 0.38 |
| 10 | 0.71 | 0.75 |
| 20 | 0.61 | 1.08 |
| 30 | 0.50 | 0.73 |
| 40 | 0.34 | 0.65 |
| 50 | 0.36 | 1.14 |
| 60 | 0.31 | 0.29 |
| 70 | 0.49 | 0.64 |
| 80 | 0.59 | 1.17 |
| 90 | 0.47 | 0.86 |
| 100 | 0.035 | 0.48 |

Fig. 2 shows that the magnetic field in 11kV power line in Palm Street was close to environmental background levels. However, nearly half of all measurements at Atakpa/Okodi were in the range of 0.25-0.36 µT. At a distance of 80 m the maximum emission of 1.17 µT is recorded; this is the point of lowest conductor sag. At distances of 50 m, 90 m and 100 m at Atakpa**/**Okodi is the points where the magnetic field is high compared to the reference limit of 0.1 µT. In order to define explicitly different levels of exposure to magnetic field from transmission lines of the two points in this work. Atakpa**/**Okodi was defined to locate in a higher power frequency EMF exposure area compared with Palm Street. The maximum measurements obtained in Palm Street and Atakpa**/**Okodi is 0.9 µT and 0.71 µT at distances of 80 m and 90 m respectively. The minimum measurement for Palm Street and Atakpa**/**Okodi is 0.4 and 0.25 at distances of 0.00, 100 m and 30 m respectively for magnetic field in 11 kV power line. This exceeds the threshold values of 0.1 µT as recommended by ICNIRP for the public. Also, measurements of electric field in Atakpa/Okodi were taken and the mean of the two points taken. The maximum field measurement was measured at Palm Street underneath the power line (1.021V/m). The strength of the electric fields decreases with distance. At a distance of 70m and 80m the field increases again. This is caused by radiation from mobile phone base station and lowest conductor sag. The field reduces at a distance of 90m and 100 m. This could be caused by shielding of the fields by houses and trees. The minimum field measurement was recorded at a distance of 100 m (0.035v/m). In Atakpa the electric field beneath the power line is much higher than the field recorded in Okodi but do not exceed the reference level (0.021V/m). At a distance of 10m the electric field in Okodi reduces to normal environmental background level. At a distance of 20 m to 100 m the electric field in Okodi Street is at normal reference level. The points with highest electric fields are points of lowest conductor sag. At distance of 30 m to 80 m and 100 m the electric fields here are at normal reference level. The point of highest field emission is recorded beneath the power line in Atakpa Street though none of these points exceeds the threshold value as recommended by ICNIRP for the public.

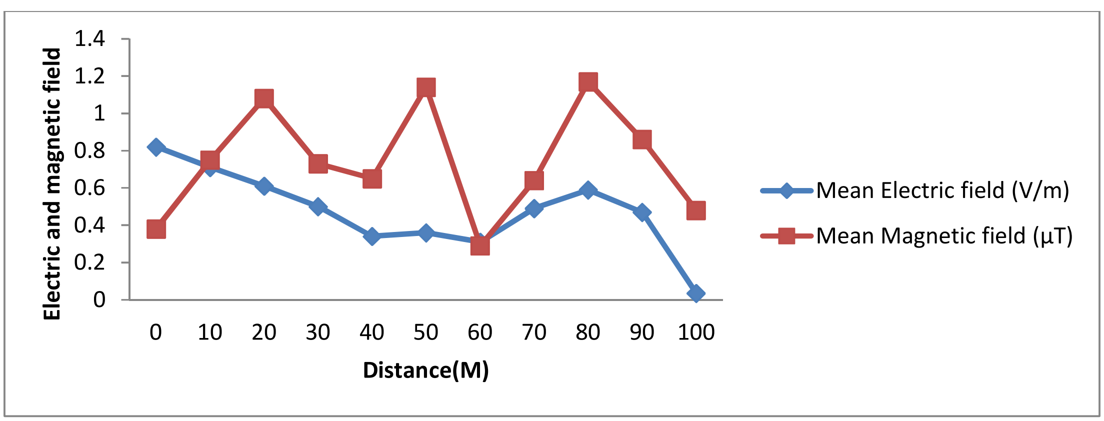


**Fig. 2. Plot of electric and magnetic field strength around 11 kVA line**

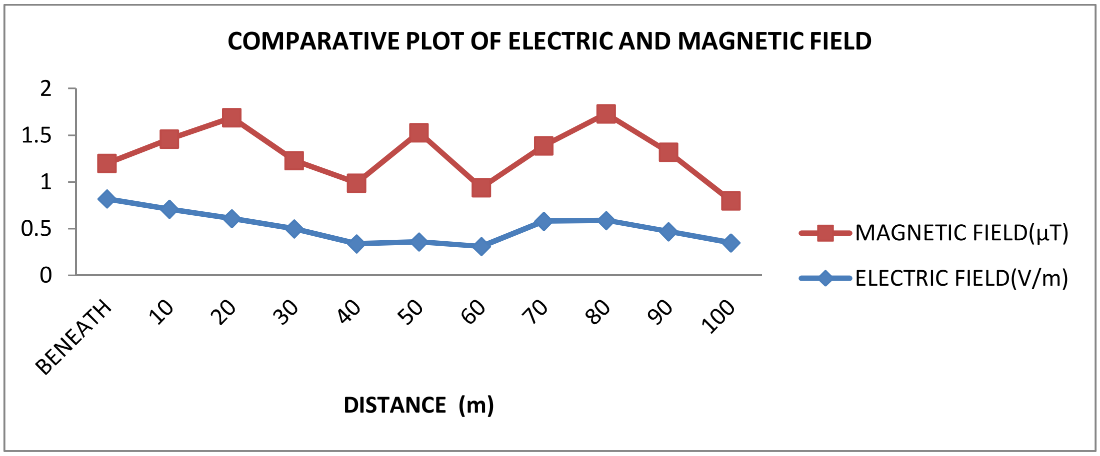


**Fig. 3. Plot of electric and magnetic fields strength around 33 kVA power line**

Fig. 3 above shows that the electric field measurement from 33 kV power line, beneath the line and at distance of 10 m to 100 m around Cross River University of Technology Gate, the fields are at normal reference level. The field is lowest at distance of 30 m (0.27 V/m). Around Cross River University of Technology Model Primary School, the field is at normal reference level beneath the power line. At this point i.e beneath the power line there was no conductor sagging and there is no transformer or mobile phone base station in this area. At a distance of 10 m where there is lowest conductor sag, the radiation increased slightly above normal reference level. At a distance of 20 m to 50 m the level of radiation decreases again to normal reference level. As the metre was gradually moved away from this point, the radiations begin to decrease gradually to normal reference level. The highest radiation from the 33 kV line is recorded at a distance of 60 m (0.43 V/m) from the power line.

**Table 3. Measured values of electric and magnetic fields around 33 kVA power line**

| Distance(m) | Electric field E(V/m) | Magnetic field B(µT) |
|---|---|---|
| Beneath | 0.82 | 0.38 |
| 10 | 0.71 | 0.75 |
| 20 | 0.61 | 1.08 |
| 30 | 0.5 | 0.73 |
| 40 | 0.34 | 0.65 |
| 50 | 0.36 | 1.17 |
| 60 | 0.31 | 0.63 |
| 70 | 0.58 | 0.81 |
| 80 | 0.59 | 1.14 |
| 90 | 0.47 | 0.85 |
| 100 | 0.35 | 0.45 |

## 5. CONCLUSION

Measurements of electric and magnetic fields in Atakpa/Okodi Street and Palm Street are carried out by in-situ measurement using electrosmog meter. The results are considered and studied. The comparison of this result with the standard exposure limits which is set by the international commission on non-ionizing radiation protection of 5 V/m for electric field and 0.1 µT for magnetic field shows they don't pose any risk to human health if the exposure is for short period (ICNIRP, 1998). However, a risk does exist if the human exposure is for a long and continuous period. The minimum field measurement is recorded at a distance 60 m from the transmission line. It was discovered that, the maximum field measurement is recorded at points of lowest conductor sag and from Fig. 3 it shows that where there is drop in electric field a simultaneous drop in magnetic field was observed as a result there is good correlation between electric field and magnetic field. Fig. 2 also shows that at a distance of 80 m the maximum emission of 1.17 µT is recorded; this is the point of lowest conductor sag.

Base on the results and theoretical analysis, we recommend that people should keep away as much as possible from the source that causes electromagnetic pollution. Avoid prolong exposure to higher levels of fields. Buildings should not be erected beneath the transmission line. We also recommend increase in the height of the central phase of the conductor above the current level of 11 m for 33 kV and 11 kV power line. Correcting point of low conductor sag will equally reduce the rate of exposure to electromagnetic field around power lines. This will leads to the reduction of the peak value of the magnetic field. Limiting the possibility of induce current from objects like buildings, mobile objects such as vehicles to person's can be accomplished by maintaining proper clearances for above ground conductor.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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   ISBN: 0-07-018993-5




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