Original Research Article

Theoretical Computation of Magnetic Flux Density within the Vicinity of Rukpokwu 11 KV Distribution Power Lines

Abstract

Horizontal conductors used for distribution of electrical power generate magnetic fields around the vicinity of the conductors due to the flow of current. In the absence of a well calibrated magnetometer, theoretical estimation of the magnitude of the magnetic flux density around these power lines is possible and recommendable. In this study, we calculated the magnetic field exposure from extremely low frequency magnetic field around 11 kV power distribution lines at Rukpokwu, Rivers State, Nigeria using theoretical and mathematical formulations. 32 sample points were considered at horizontal distances of between 1m and 1000m from the foot of the vertical pole subtending the electrical conductors. We used a mathematical software (Wolfram Mathematica 8.0) to generate the initial results of the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic fields and the total magnetic fields for x=1 to 1000 m (horizontal distance from the foot of the pole) for a vertical height of 1 m above the ground surface (considered to be the average height of head positions of the workers and the public within the vicinity of magnetic field). The results showed that for horizontal distances of between 1 and 10m, the magnetic field exposures ranged from 45.82 μT/hr to21.62 μT/hr and are above the occupational field exposure limit of 21.0 $\mu T/hr$ set by International Committee on Non Ionizing Radiation Protection (ICNRIP). Also, the results of field exposure for horizontal distances ranging from 1 to 20m were between 45.82 $\mu T/hr$ and 8.3 $\mu T/hr$ and are above the ICNRIP limit of 4.2 $\mu T/hr$ set for the public. It is recommended that between horizontal distances of 1 and 10 metres from the distribution lines, relevant government agencies and the populace should discourage the building of shops for businesses, and between the horizontal distances of 1 to 20 metres, they should discourage the building of residential areas, since doing business and residing within these stipulated distances may not be very safe as a result of the magnetic field exposure.

Keywords: Magnetic field, Distribution Lines, Impact, Rukpowu Residents

1. Introduction

In recent years, due to technology and massive industrialization, and consequently greater need for power generation, electric power lines crisscross our cities, urban areas and the rural areas giving rise to extremely low magnetic fields in our environment. When charges move, current flow is induced, consequently magnetic fields are created around the vicinity of the conductor where the current is flowing. Most high voltage power lines in Nigeria consist of vertically positioned brick cylindrical poles with 3 horizontally separated metallic conductors drawn on these poles which act as pathways for current. Electric and magnetic fields are present around all wires carrying current; high voltage power lines, house wiring, or wires inside domestic appliances. The strength of the electric field depends on the voltage, while the strength of the magnetic field depends on the size of the current carried by the conductor [1]. Low frequency electromagnetic field around electrical power substations is quasistatic with two component vector fields; the electric field caused by charges and eddy component of the magnetic field caused by currents. The current that flows across these horizontal conductors generate magnetic field. Generally, the impact of the magnetic field from electric transmission lines can be understudied from theoretical (computations) as well as practical point of view [2].

In the absence of a well calibrated magnetometer, theoretical estimation of the magnitude of the magnetic field intensity around these power lines is possible and recommendable. Calculation of field intensity of these fields at points away from the source (charges and currents) can be computed with thin-wired approximation [3]. Previous researchers had carried out theoretical calculations and experimental measurements of exposure of children living close to a major transmission line in Norway. The results revealed that children living close to a major transmission line had a greater exposure to magnetic fields than children living farther away. A fairly good correlation was also seen between measured and calculated exposure [4]. Exposure to magnetic fields was measured around the vicinity of 34.5 KV power distribution lines. The results were 0.2 to 2.7 µT, 0.1 to 0.5 µT and 0.1 to 0.2 µT at 0 ft, 50 ft and 100 ft respectively from the wire lines [5]. Computation of the magnetic field from the three phase 63 kV power transmission lines has been carried out by previous researchers using a new magnetic field simulation package- Marvdasht. The results of this study confirmed the environmental pollution of the magnetic field produced near transmission lines. By using the curves of magnetic field around the 63kV transmission lines obtained from software, they were able to determine the safe distance around the towers [6]. Studies on the effect of electromagnetic radiation emitted from 400KV high voltage transmission lines on human health were carried out. The results ranged between 1.8 to 7.6 µT and were in close agreement with measured values [7].

In Nigeria, many persons are living and doing businesses under the transmission lines and are constantly exposed to the ELF (Extremely Low Frequency) magnetic fields. ELF measuring meters are not always available and even the available ones may not be routinely calibrated. In this work, we have adopted a basic Physics law (Ampere's law) in calculating the magnetic field around 11 kV distribution lines to ascertain the prevailing magnetic field exposure of individuals who live and work around the power lines. We shall use the mathematical software (Wolfram Mathematica 8.0) to enable us facilitate the generation of the results of the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic so as to easily compute the magnetic flux density around the powerlines.

2. Methodology

2.1 Study Area

This study was carried out in Rukpokwu, Rivers State, Nigeria. This area is one of the emerging cities within the New Greater Port Harcourt Area of Rivers State with a very high population density and has become a be-hive of business and commercial activities. The area has a network of power distribution and transmission cables of power lines from both the national grid and the state power supplies. Many business activities and living houses are within the vicinity of 11 kV power lines. Figure 1 shows the picture of people doing businesses under the power lines.

Figure 1. People doing business under 11 kV power lines along Rukpokwu, Nigeria

2.2. Theoretical Formulations and Computations

Our theory is based on the Ampere's law. This law states that the line integral of the magnetic flux density around a closed path is directly proportional to the current enclosed by the path [8]. It relates the tangential component of the magnetic flux density, 'B' summed over a closed path to the current enclosed by the path. It is mathematically expressed as;

$$\oint Bdl = \mu_o \imath \qquad (1)$$

Where the line integral is over any arbitrary loop, ‘B’ is the magnetic flux density, ‘I’ is the current enclosed by the loop and ‘μ_o’ is the permeability constant for free space.

Ampere’s law can be applied in computing the magnetic flux density around a long straight conductor as is obtainable in the case of the 11 kVA power lines under investigation. The magnetic field generated by 11 kV distribution lines was calculated at 1m above the ground. The wires were assumed to be perfectly arranged horizontally.

Let the average conductor height (from the ground level) be 10.37 m but this computation will be carried out based on a height of 1 m above the ground level [9] (presumed to be the average height of an individual living or doing business within the magnetic field vicinity) and based on this, the vertical height that will be used in this computation will be 9.37 m (10.37 m – 1 m). The distance of separation between the two external wires (conductors) from the central wire will be designated z (0.17m). Let the magnetic flux density (B) for one conductor be perpendicular to the radius of its circular magnetic field lines. Let this magnetic field vector be resolved into the horizontal components, and vertical components. The positions of the observation point and that of the wire are described using XY coordinates. This is illustrated in Figure 2.

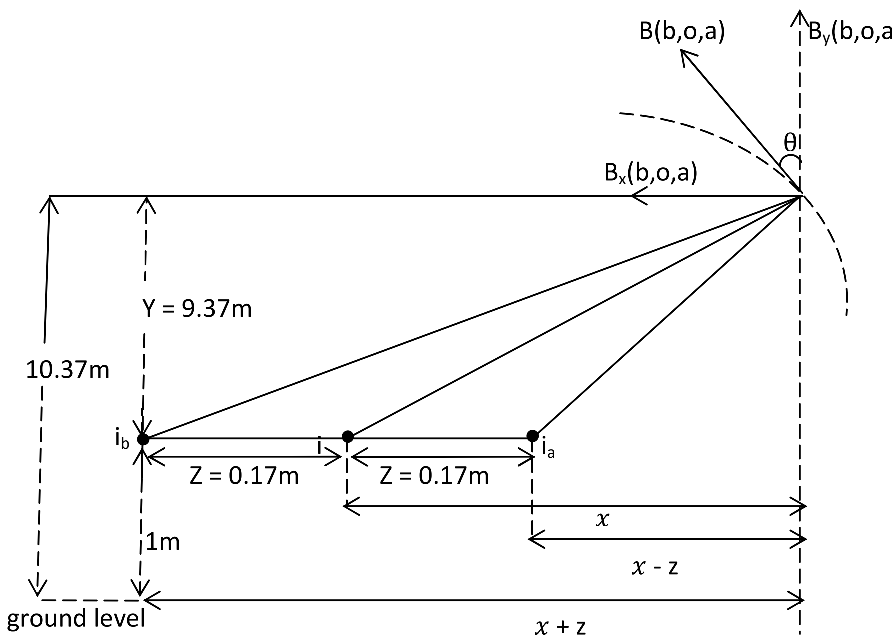

Figure 2: Geometry of the magnetic field for the 3 phase currents (i_b, i and i_a)

Integrating (1), we have $\mathbf{B} = \frac{i\mu_o}{2\pi r}$ (2)

$$\mathbf{B} = \frac{i\mu_o}{2\pi(\ x^2+y^2\ )^{\ 1/2}} \quad (3)$$

Considering Figure 1, let the horizontal and vertical components of **B** be represented by (4) and (5);

$\mathbf{B_x} = -\mathbf{B}\sin\theta$ (4)

$\mathbf{B_y} = \mathbf{B}\cos\theta$ (5)

From (3) and (4), we have, $\mathbf{B_x} = -\frac{i\mu_o}{2\pi(\ x^2+y^2\ )^{\ 1/2}}\frac{y}{(\ x^2+y^2\ )^{\ 1/2}} = -\frac{i\mu_o y}{2\pi(x^2+y^2)}$ (6)

Combining (3) and (5) gives $\mathbf{B_y} = \frac{i\mu_o x}{2\pi(x^2+y^2)}$ (7)

For our distribution line under consideration with 3 phase conductors as shown in Figure 2, the two external wires are horizontally separated from the central wire (carrying current i) by z = 0.17 m. Where i, i_a and i_b are the three-phase circuit current.

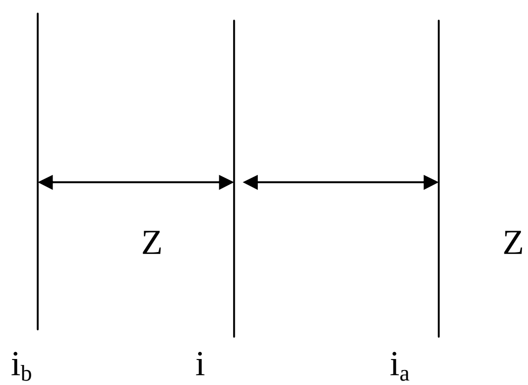

Figure 3. The three horizontally arranged conductors separated by a distance z= 0.17m.

In computing the magnetic field components produced by the current i_a and i_b for the two external wires, the geometry is the same as the magnetic field components produced by i with x component replaced by (x – z) and (x + z) for i_a and i_b respectively. Thus, for external wire carrying i_a, the two field components are;

$$\mathbf{B}_{\mathbf{xa}} = -\frac{i_a \mu_o y}{2\pi\{(\mathrm{x}-\mathrm{z})^2+\mathrm{y}^2\}} \quad (8)$$

$$\mathbf{B}_{\mathbf{ya}} = \frac{i_a \mu_o (\mathrm{x}-\mathrm{z})}{2\pi\{(\mathrm{x}-\mathrm{z})^2+\mathrm{y}^2\}} \quad (9)$$

Similarly, for external wire carrying i_b, the two field components are;

$$\mathbf{B}_{\mathbf{xb}} = -\frac{i_b \mu_o y}{2\pi\{(\mathrm{x}+\mathrm{z})^2+\mathrm{y}^2\}} \quad (10)$$

$$\mathbf{B}_{\mathbf{yb}} = \frac{i_a \mu_o (\mathrm{x}+\mathrm{z})}{2\pi\{(\mathrm{x}+\mathrm{z})^2+\mathrm{y}^2\}} \quad (11)$$

Note that we shall be referring to the coefficients of the current terms in equations (6) to (11) as current coefficient terms for the respective magnetic field components.

In order to transform the 3 phase currents (i, i_a and i_b) into a single RMS current I, we took cognizance of the fact that the 3 phase systems produce magnetic fields that rotate in specified directions. These 3 phase wires carrying alternating current of same frequency reach their instantaneous peak values such that i_a leads i by 120^o and i_b lags i by 120^o [5]. These are represented in the phase diagram of Figure 4.

Therefore, $i = I \sin wt$ (12)

$i_a = I \sin(wt + 120^o)$ (13)

$i_b = I \sin(wt - 120^o)$ (14)

Considering Figure 3 and resolving the currents in phase and out of phase in terms of current I, we have the results in Table 1.

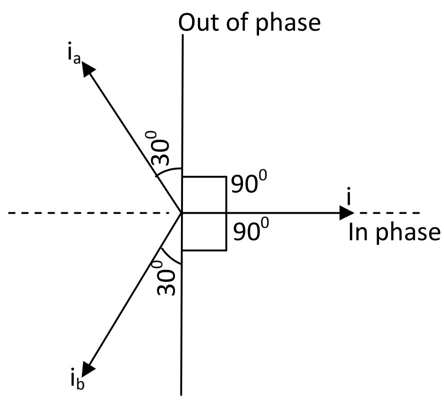

Figure 4: Resolution of the 3- phase currents into a single RMS current, I

Table 1. In-phase and out of phase current in terms of RMS current, I = 19.13 A (the values of current in Table 1 are referred to as current factors).

Phase currents	I_b	i	I_a
I-in	- ½I = -9.57 A	I = 19.13	- ½I = -9.57 A
I-out	$-\frac{\sqrt{3}}{2}$I = -9.57 A	0	$\frac{\sqrt{3}}{2}$I = 16.57 A

From Table 1 above, we can determine for each current, the in-phase vertical, out of phase vertical, in-phase horizontal and the out of phase horizontal components of magnetic field by multiplying magnetic field current coefficients by the appropriate current factors.

Therefore the three-out-of phase vertical components of magnetic field for each of the three currents (i, i_a and i_b) will be computed using the current factors in Table 1; For i,

$$B_y \text{ out} = \frac{0\mu_o x}{2\pi(x^2+y^2)} = 0 \quad (15)$$

Doing the same for I_a and I_b;

$$\mathbf{B_{ya}}\text{ out} = \frac{16.57\,\mu_o(\mathrm{x-z})}{2\pi\{(\mathrm{x-z})^2+\mathrm{y}^2\}} \quad (16)$$

$$\mathbf{B_{yb}}\text{ out} = \frac{-16.57\mu_o(\mathrm{x+z})}{2\pi\{(\mathrm{x+z})^2+\mathrm{y}^2\}} \quad (17)$$

Therefore total B_y-out will be given as;

$$B_y\text{ out-T} = \frac{16.57\,\mu_o}{2\pi}\left\{\frac{(\mathrm{x-z})}{\{(\mathrm{x-z})^2+\mathrm{y}^2\}} - \frac{(\mathrm{x+z})}{\{(\mathrm{x+z})^2+\mathrm{y}^2\}}\right\} \quad (18)$$

The three in- phase vertical components for each of the three current (i, i_a and i_b) were computed using similar procedure and adopting the current factors in Table 1;

Therefore total B_y in- phase will be given as;

$$B_y\text{ in-T} = \frac{-9.57\,\mu_o}{2\pi}\left\{\frac{(\mathrm{x-z})}{\{(\mathrm{x-z})^2+\mathrm{y}^2\}} + \frac{(\mathrm{x+z})}{\{(\mathrm{x+z})^2+\mathrm{y}^2\}}\right\} + \frac{19.3\,\mu_o x}{2\pi(\mathrm{x}^2+\mathrm{y}^2)} \quad (19)$$

Similarly, total B_x out of phase will be given as;

$$B_x\text{ out-T} = -\frac{16.57\mu_o y}{2\pi\{(\mathrm{x-z})^2+\mathrm{y}^2\}} + \frac{16.57\mu_o y}{2\pi\{(\mathrm{x+z})^2+\mathrm{y}^2\}} \quad (20)$$

Also, total B_x in- phase will be given as;

$$B_x\text{ in-T} = \frac{9.57\,\mu_o}{2\pi}\left\{\frac{\mathrm{y}}{\{(\mathrm{x-z})^2+\mathrm{y}^2\}} + \frac{\mathrm{y}}{\{(\mathrm{x+z})^2+\mathrm{y}^2\}}\right\} - \frac{19.13\,\mu_o x}{2\pi(\mathrm{x}^2+\mathrm{y}^2)} \quad (21)$$

The square of the grand sum of all the component magnetic fields both in- phase and out of phase is the sum of the squares of equations (18) to (21);

$$\mathbf{B}^2_{\mathbf{T}} = B_y^2\text{ out-T} + B_y^2\text{ in-T} + B_x^2\text{ out-T} + B_x^2\text{ in-T} \quad (22)$$

Hence, $\mathbf{B_T} = (\mathrm{B_y^2out - T} + \mathrm{B_y^2in - T} + \mathrm{B_x^2out - T} + \mathrm{B_x^2in - T})^{1/2}$ (23)

We went further to adopt a mathematical software (Wolfram Mathematica 8.0) which enabled us facilitate the generation of the results of the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic fields (both in-phase an out of phase) for x=1m to 1000 m (horizontal distance from the foot of the pole) for a vertical height of 1 m above the ground surface (presumed to be the average height of head positions of those who live and do business within the study area). This software also enabled us to calculate the total magnetic field for x=1m to 1000 m**.** In carrying out these computations, we used the parameters collected from Power Holdings Company of Nigeria (PHCN). These parameters include; Power = 11 kVA, Line voltage = 415V, Height of pole = 10.37m, Distance between central horizontal conductor and the two external horizontal conductors 'z' = 0.17m. The current in the horizontal conductor 'I', was calculated using the Expression;

$$\mathrm{I} = \frac{Power}{v\cos\theta\sqrt{3}} = 19.13\text{ A} \quad (24)$$

(Where Power = $VI\cos\theta \times \sqrt{3}$ and $\cos\theta$ (power factor) = 0.8)

3. Results

The results of the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic fields (both in-phase an out of phase) for x=1m (horizontal distance from the foot of the pole) for a vertical height of 1 m above the ground surface are presented in Table 2. Summary of the results of the component magnetic fields for the various phases and their corresponding total magnetic fields are presented in Table 3. The results of the computed total magnetic field exposure are presented in Table 4. We have assumed that the computed magnetic fields are generated per second, therefore all the results are expressed as magnetic field exposure in Tesla per second (T/s). In order to convert from µT/sec to µT/hr we have used;

$$1\ \mu T/hr = \mu T/sec \times 3600 \quad (25)$$

We presented the relationship between log of magnetic field exposures in µT/hr against the corresponding horizontal distances in meters in Figure 5. A comparison between the results of the calculated magnetic field exposure in µT/hr and the standard limits established by International Committee on Non Ionizing Radiation Protection (ICNIRP) has been presented in Table 5 and correspondingly in the bar charts of Figures 6 and 7. We considered occupational and public exposure limits of 500 µT/day and 100 µT/day respectively as set by ICNIRP 1998 guidelines [10] which we computed to be approximately equal to 21 µT/hr and 4.2 µT/hr for occupational and public exposure limits respectively.

Table 2. Results of the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic fields (both in-phase and out of phase) for x=1m

B- Phase	**Current**	**A**	**B**	**C**	**Icoef.**	**I**	**Magnetic Field (Icoef. * I)**
	Ib	x+y	x+y	Y	2.00E-10	-16.57	-3.31E-09
By. Out	**i**	X	x	Y	2.00E-10	0	0
	Ia	x-z	x-z	Y	2.00E-10	16.57	3.31 E-09
	Ib	x+y	x+y	Y	2.00E-10	-9.57	-1.91E-09
By. In	**i**	X	x	Y	2.00E-10	19.13	3.83E-09
	Ia	x-z	x-z	Y	2.00E-10	-9.57	-1.91E-09
	Ib	Y	x+z	Y	1.87E-12	-16.57	-3.10E-11
Bx. Out	**i**	Y	x	Y	1.87E-12	0	0
	Ia	Y	x-z	Y	1.87E-12	16.57	3.11E-11
	Ib	Y	x+z	Y	1.87E-12	-9.57	-1.79E-11
Bx. In	**i**	Y	x	Y	1.87E-12	19.13	3.58E-11
	Ia	Y	x-z	Y	1.87E-12	-9.57	-1.79E-11

Table 3. Summary of the total magnetic field for the different phases and the total magnetic fields for X =1 m to 1000 m

S/n	X (m)	**By Out_T**	**By In_T**	**$BxOut_T$**	**$Bxin_T$**	**B^2_T**	**B_T (Tesla)**
1	**1**	-1.20E-08	1.00E-09	4.00E-09	1.00E-09	1.62E-16	1.26853E-08
2	**2**	-1.12E-08	-2.74E-11	4.32E-09	-6.35E-10	1.45E-16	1.20218E-08
3	**5**	-5.60E-09	5.00E-10	8.30E-09	-1.56E-09	1.03E-16	1.01456E-08
4	**10**	3.89E-10	-7.90E-11	5.99E-09	-1.33E-10	3.61E-17	6.00461E-09
5	**15**	1.58E-09	-9.35E-11	3.24E-09	-7.97E-11	1.30E-17	3.60681E-09
6	**20**	1.48E-09	-8.42E-11	1.775E-09	-4.84E-11	5.35E-18	2.31311E-09
7	**30**	9.38E-10	-6.29E-11	6.492E-10	-2.23E-11	1.31E-18	1.1427E-09
8	**40**	5.982E-10	-4.87E-11	2.965E-10	-1.21E-11	4.48E-19	6.69532E-10
9	**50**	4.059E-10	-3.93E-11	1.577E-10	-8.02E-12	1.91E-19	4.37302E-10
10	**60**	2.909E-10	-3.30E-11	9.316E-11	-5.3E-12	9.44E-20	3.07276E-10

11	**70**	2.179E-10	-2.84E-11	5.941E-11	-3.88E-12	5.18E-20	2.27665E-10
12	**80**	1.69E-10	-2.48E-11	4.013E-11	-2.96E-12	3.08E-20	1.75486E-10
13	**90**	1.346E-10	-2.21E-11	2.835E-11	-2.33E-12	1.94E-20	1.39337E-10
14	**100**	1.097E-10	-2E-11	2.075E-11	-1.89E-12	1.29E-20	1.13438E-10
15	**110**	9.11E-11	-1.81E-11	1.56E-11	1.55E-12	8.87E-21	9.41944E-11
16	**120**	7.69E-11	-1.67E-11	1.20E-11	-1.31E-12	6.34E-21	7.96114E-11
17	**130**	6.52E-11	-1.54E-11	9.52E-12	-1.11E-12	4.58E-21	6.76762E-11
18	**140**	5.68E-11	-1.43E-11	7.63E-12	-9.55E-13	3.49E-21	5.9075E-11
19	**150**	4.95E-11	-1.33E-11	6.21E-12	-8.39E-13	2.67E-21	5.16373E-11
20	**160**	4.36E-11	-1.24E-11	5.03E-12	-7.33E-13	2.08E-21	4.56131E-11
21	**170**	3.86E-11	-1.18E-11	4.27E-12	-6.55E-11	5.94E-21	7.70564E-11
22	**180**	3.45E-11	-1.12E-11	3.60E-12	-5.80E-13	1.33E-21	3.64554E-11
23	**190**	3.10E-11	-1.58E-11	3.06E-12	-5.25E-13	1.22E-21	3.49321E-11
24	**200**	2.80E-11	-1.01E-11	2.63E-12	-4.69E-13	8.93E-22	2.98854E-11
25	**300**	4.10E-12	-2.22E-12	7.72E-13	-2.09E-13	2.24E-23	4.73055E-12
26	**400**	6.06E-12	-5.76E-12	2.95E-13	-1.54E-13	7.00E-23	8.36731E-12
27	**500**	3.58E-12	-4.02E-12	1.19E-13	-1.23E-13	2.90E-23	5.38573E-12
28	**600**	3.08E-12	-1.11E-12	9.79E-14	-9.96E-11	9.93E-21	9.96638E-11
29	**700**	2.30E-12	-2.85E-12	6.15E-14	-3.82E-14	1.34E-23	3.66302E-12
30	**800**	5.87E-13	-2.50E-12	4.12E-14	-2.93E-14	6.60E-24	2.56849E-12
31	**900**	1.37E-12	-2.27E-12	2.90E-14	-2.31E-14	7.03E-24	2.65164E-12
32	**1000**	1.12E-12	-2.01E-12	2.11E-14	-1.87E-14	5.30E-24	2.30115E-12

Table 4: The Rate of Magnetic Field Exposures for Specified Horizontal Distances from the Central Conductor

S/n	HORIZONTAL DISTANCE (X, m)	Field Exposure T/sec	Field Exposure μT/sec	Field Exposure μT/hr
1	1	1.27E-08	1.27E-02	45.82
2	2	1.20218E-08	1.20E-02	43.28
3	5	1.01456E-08	1.01E-02	36.52
4	10	6.00461E-09	6.00E-03	21.62
5	15	3.60681E-09	3.61E-03	12.98
6	20	2.31311E-09	2.31E-03	8.33
7	30	1.1427E-09	1.14E-03	4.11
8	40	6.69532E-10	6.70E-04	2.41
9	50	4.37302E-10	4.37E-04	1.57
10	60	3.07E-10	3.07E-04	1.11
11	70	2.28E-10	2.28E-04	0.82
12	80	1.75486E-10	1.75E-04	0.63
13	90	1.39337E-10	1.39E-04	0.50

14	100	1.13438E-10	1.13E-04	0.41
15	110	9.41944E-11	9.42E-05	0.34
16	120	7.96114E-11	7.96E-05	0.29
17	130	6.76762E-11	6.77E-05	0.24
18	140	5.9075E-11	5.91E-05	0.21
19	150	5.16373E-11	5.16E-05	0.19
20	160	4.56131E-11	4.56E-05	0.16
21	170	7.70564E-11	7.71E-05	0.28
22	180	3.64554E-11	3.65E-05	0.13
23	190	3.49321E-11	3.49E-05	0.13
24	200	2.98854E-11	2.99E-05	0.11
25	300	4.73055E-12	4.73E-06	0.02
26	400	8.36731E-12	8.37E-06	0.03
27	500	5.38573E-12	5.39E-06	0.02
28	600	9.96638E-11	9.97E-05	0.36
29	700	3.66302E-12	3.66E-06	0.01
30	800	2.56849E-12	2.57E-06	0.01
31	900	2.65164E-12	2.65E-06	0.01
32	1000	2.30115E-12	2.30E-06	0.01

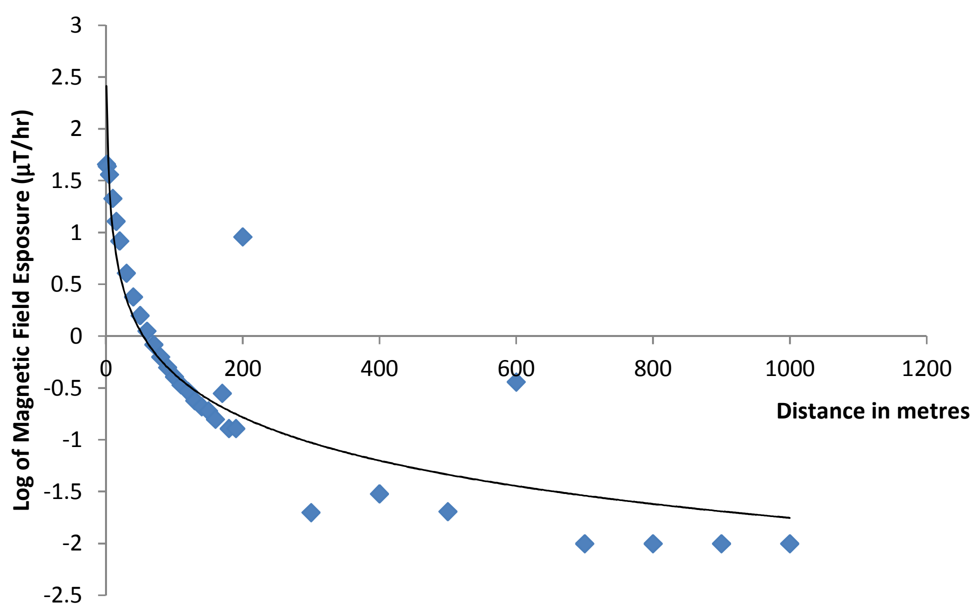

Figure 5: Relationship between Log of magnetic field exposure and the horizontal distance away from the conductor

Table 5: Comparison of Magnetic field exposure in micro Tesla per hour (μT/hr) with the international standard limits.

s/n	HORIZONTAL DISTANCE X (m)	Magnetic Field Exposure	ICNIRP LIMIT PUBLIC	ICNIRP LIMIT Occupational
		μT/hr	μT/hr	μT/hr
1	1	45.82	4.2	21
2	2	43.28	4.2	21
3	5	36.52	4.2	21
4	10	21.62	4.2	21
5	15	12.98	4.2	21
6	20	8.33	4.2	21
7	30	4.11	4.2	21
8	40	2.41	4.2	21
9	50	1.57	4.2	21
10	60	1.11	4.2	21
11	70	0.82	4.2	21
12	80	0.63	4.2	21
13	90	0.50	4.2	21
14	100	0.41	4.2	21
15	110	0.34	4.2	21
16	120	0.29	4.2	21
17	130	0.24	4.2	21
18	140	0.21	4.2	21
19	150	0.19	4.2	21
20	160	0.16	4.2	21
21	170	0.28	4.2	21
22	180	0.13	4.2	21
23	190	0.13	4.2	21
24	200	0.11	4.2	21
25	300	0.02	4.2	21
26	400	0.03	4.2	21
27	500	0.02	4.2	21
28	600	0.36	4.2	21
29	700	0.01	4.2	21
30	800	0.01	4.2	21
31	900	0.01	4.2	21
32	1000	0.01	4.2	21

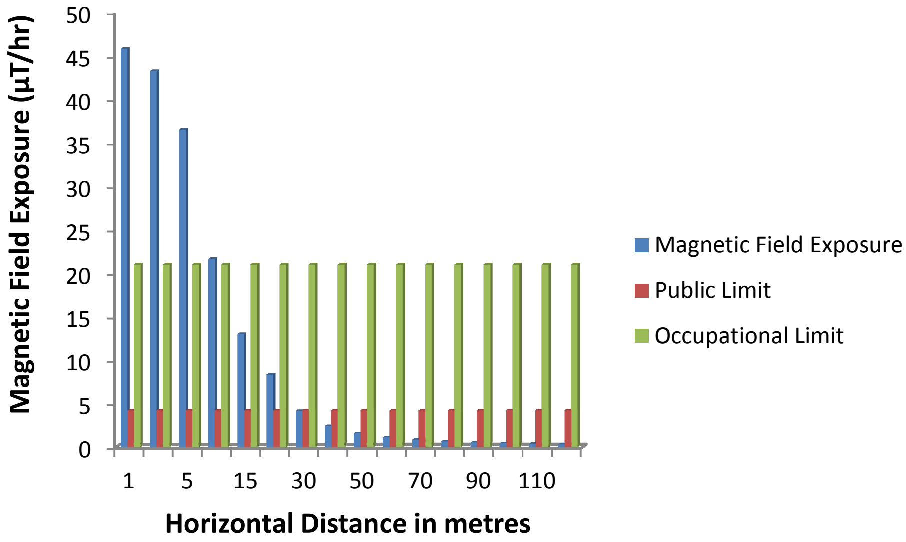

Figure 6. Bar chart comparing computed magnetic field exposure in µT/hr (at distance of between 1 and 120 m) with the international standard limits.

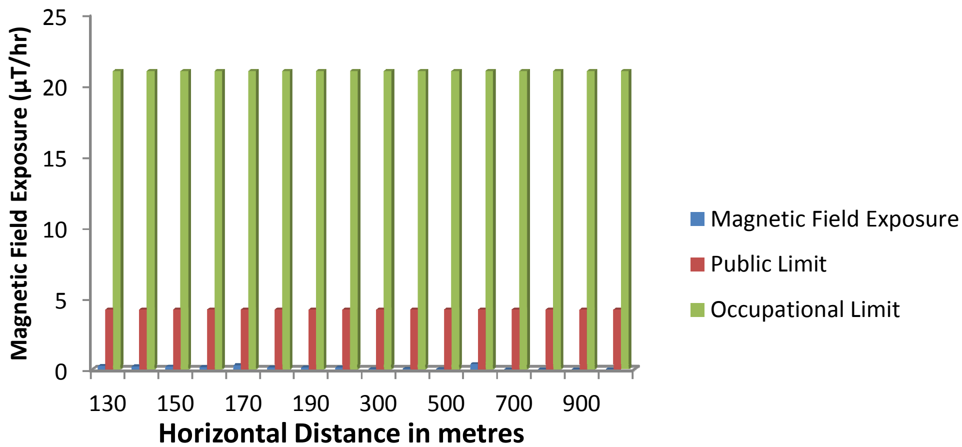

Figure 7. Bar chart comparing computed magnetic field exposure in µT/hr (at distance of between 130 and 1000 m) with the international standard limits.

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4. Discussions

The results of the the magnetic field current coefficients (I_{coef}) for the vertical and horizontal components of the magnetic fields (both in-phase and out of phase) for x=1m have been successfully computed using Wolfram Mathematica 8.0 software and have been presented in Table 2. The product of I_{coef} and I for each of the phases enabled us to compute the magnetic fields in Tesla. On application of Wolfram Mathematica 8.0 software, inputting x = 1m to 1000 m, the equivalent magnetic flux densities in Tesla were generated automatically. This application software helped us to overcome the rigours of computing each of the magnetic fields manually for the numerous horizontal distances (x = 1m to 1000 m) from the conductors considered in this work.

Table 3 presents the summary of the total magnetic field for the different phases and the total magnetic fields for X =1 m to 1000 m as computed using Wolfram Mathematica 8.0 software. The results ranged from 1.26853E-08 to 2.30115E-12 Tesla for x = 1m to x = 1000 m respectively, implying a decline in the magnitude of total magnetic flux densities with respect to increase in horizontal distances away from the foot of the pole.

In Table 4, the results of the rate of magnetic field exposures presented for the various horizontal distances from the central conductor (x = 1m to x = 1000 m) ranged from 45.8µT/hr to 0.01µT/hr. For x = 1 to 20 m, the magnetic field exposure exceeded the standard limits of 4.2 µT/hr and 21 µT/hr set by ICNIRP (1998) for both public and occupational areas respectively as can be seen from the bar chart of Figure 6 [10]. These values suggest that within the horizontal distances of between 1 to 20 m, people should not build residential houses. Within the range of 1 to 10 m, we have values above the standard limit of 21.0µT/hr set by ICNIRP (1998) for the occupational area [10]. Also, these values suggest that people should not do business close to the power lines to avoid undue exposure to magnetic fields.
From the results, the horizontal distances of x=30m to x=1000m have magnetic field exposures below the standard limits set by ICNIRP. It follows that within these horizontal distances, it is safe for people to reside and also do their businesses.

Figure 5 shows a decrease in the magnetic field exposure as the horizontal distances from the conductor increase. This fact is demonstrated in the exponential decay curve of the log of magnetic field exposure against the horizontal distances. It shows that at horizontal distances well above x = 200m, the magnetic field exposure remains relatively uniform as the horizontal distances increased. This indicates that the magnetic field exposures within these horizontal distances are too small to have any significant impact or changes on the public and occupationally exposed persons. In a similar work done by Adnan using 400 kV high voltage power lines, he computed a range of magnetic field exposure values of between 7.6µT/hr and 1.8µT/hr while the measured values ranged from 7.36µT/hr to 1.7µT/hr respectively. He showed from his results that the calculated values agreed with the measured values. The results of the present research fall within this range [6].

5. Conclusion

In this research, we have calculated the magnetic field exposure from extremely low frequency magnetic field around 11 kV power distribution lines at Rukpokwu, Rivers State, Nigeria using theoretical and mathematical formulations. The results showed that for horizontal distances of between 1 and 10m, the magnetic field exposures ranged from 45.82 μT/hr to21.62 μT/hr and are above the occupational field exposure limit of 21.0 $\mu T/hr$ set by International Committee on Non Ionizing Radiation Protection (ICNIRP). We could refer to this horizontal region as the exceedance Zone, that is the zone with magnetic field exposure beyond the prescribed limit [11]. Also, the results of field exposure for horizontal distances ranging from 1 to 20m were between 45.82 $\mu T/hr$ and 8.3 $\mu T/hr$ and are above the ICNIRP limit of 4.2 $\mu T/hr$ set for the public. It is suggested that between horizontal distances of 1 and 10m from the distribution lines, it is unsafe to build shops and do businesses and between the horizontal distances of 1 to 20m it is unsafe to build residential areas.

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