

**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  $45.82 \mu T/hr$  to  $21.62 \mu T/hr$  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

50 measured around the vicinity of 34.5 KV power distribution lines. The results were 0.2 to 2.7  $\mu\text{T}$ , 0.1 to 0.5  $\mu\text{T}$   
51 and 0.1 to 0.2  $\mu\text{T}$  at 0 ft, 50 ft and 100 ft respectively from the wire lines [5].  
52 Computation of the magnetic field from the three phase 63 kV power transmission lines has been carried out by  
53 previous researchers using a new magnetic field simulation package- Marvdasht. The results of this study  
54 confirmed the environmental pollution of the magnetic field produced near transmission lines. By using the  
55 curves of magnetic field around the 63kV transmission lines obtained from software, they were able to  
56 determine the safe distance around the towers [6]. Studies on the effect of electromagnetic radiation emitted  
57 from 400KV high voltage transmission lines on human health were carried out. The results ranged between 1.8  
58 to 7.6  $\mu\text{T}$  and were in close agreement with measured values [7].

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

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## 69 2. Methodology

### 70 2.1 Study Area

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

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

### 80 2.2. Theoretical Formulations and Computations

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

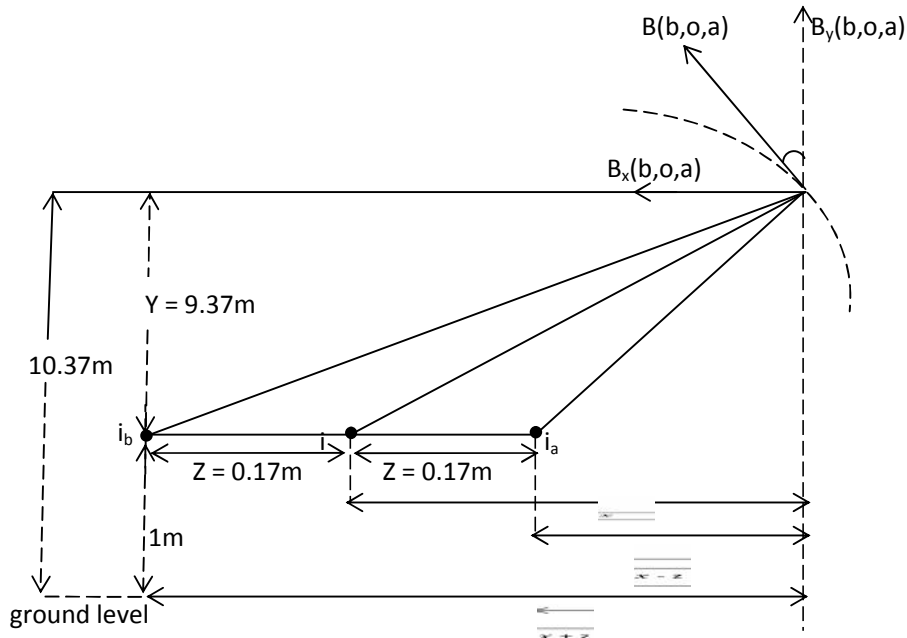
$$85 \oint Bdl = \mu_0 I \quad (1)$$

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87 Where the line integral is over any arbitrary loop, 'B' is the magnetic flux density, 'I' is the current enclosed by  
 88 the loop and ' $\mu_0$ ' is the permeability constant for free space.

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

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



128  
 129 Figure 2: Geometry of the magnetic field for the 3 phase currents ( $i_b$ ,  $i$  and  $i_a$ )

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 131 Integrating (1), we have  $\mathbf{B} = \frac{i\mu_0}{2\pi r}$  (2)

$$132 \quad \mathbf{B} = \frac{i\mu_0}{2\pi(x^2+y^2)^{1/2}} \quad (3)$$

133 Considering Figure 1, let the horizontal and vertical components of  $\mathbf{B}$  be represented by (4) and (5);

$$134 \quad \mathbf{B}_x = -\mathbf{B}\sin \theta \quad (4)$$

$$135 \quad \mathbf{B}_y = \mathbf{B}\cos \theta \quad (5)$$

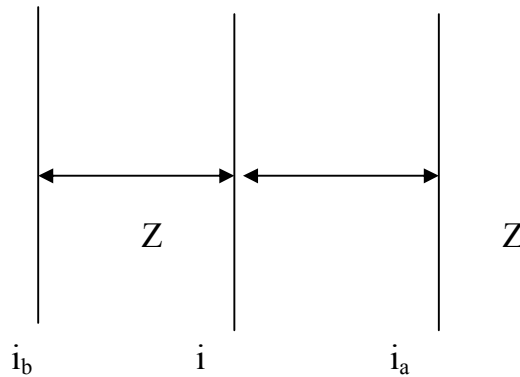
$$136 \quad \text{From (3) and (4), we have, } \mathbf{B}_x = -\frac{i\mu_0}{2\pi(x^2+y^2)^{1/2}} \frac{y}{(x^2+y^2)^{1/2}} = -\frac{i\mu_0 y}{2\pi(x^2+y^2)} \quad (6)$$

$$137 \quad \text{Combining (3) and (5) gives } \mathbf{B}_y = \frac{i\mu_0 x}{2\pi(x^2+y^2)} \quad (7)$$

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

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

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

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

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

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

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

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

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

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169 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  
 170 fact that the 3 phase systems produce magnetic fields that rotate in specified directions. These 3 phase wires  
 171 carrying alternating current of same frequency reach their instantaneous peak values such that  $i_a$  leads  $i$  by  $120^\circ$   
 172 and  $i_b$  lags  $i$  by  $120^\circ$  [5]. These are represented in the phase diagram of Figure 4.

173 Therefore,  $i = I \sin \omega t$  (12)

174  $i_a = I \sin(\omega t + 120^\circ)$  (13)

175  $i_b = I \sin(\omega t - 120^\circ)$  (14)

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

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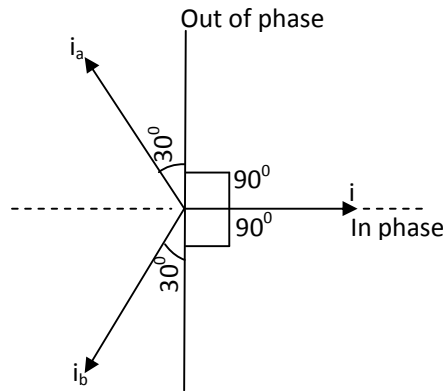
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Figure 4: Resolution of the 3- phase currents into a single RMS current, I

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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).

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Phase currents	$I_b$	$i$	$I_a$
I-in	$-\frac{1}{2}I = -9.57 \text{ A}$	$I = 19.13$	$-\frac{1}{2}I = -9.57 \text{ A}$
I-out	$-\frac{\sqrt{3}}{2}I = -9.57 \text{ A}$	0	$\frac{\sqrt{3}}{2}I = 16.57 \text{ A}$

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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  $i$ ,

$B_y \text{ out} = \frac{0\mu_0 x}{2\pi(x^2+y^2)} = 0$  (15)

211 Doing the same for  $I_a$  and  $I_b$ ;

$$212 \quad \mathbf{B}_{ya} \text{ out} = \frac{16.57 \mu_o(x-z)}{2\pi\{(x-z)^2+y^2\}} \quad (16)$$

$$213 \quad \mathbf{B}_{yb} \text{ out} = \frac{-16.57 \mu_o(x+z)}{2\pi\{(x+z)^2+y^2\}} \quad (17)$$

214 Therefore total  $B_y$ -out will be given as;

$$215 \quad B_y \text{ out-T} = \frac{16.57 \mu_o}{2\pi} \left\{ \frac{(x-z)}{\{(x-z)^2+y^2\}} - \frac{(x+z)}{\{(x+z)^2+y^2\}} \right\} \quad (18)$$

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

219 Therefore total  $B_y$  in- phase will be given as;

$$220 \quad B_y \text{ in-T} = \frac{-9.57 \mu_o}{2\pi} \left\{ \frac{(x-z)}{\{(x-z)^2+y^2\}} + \frac{(x+z)}{\{(x+z)^2+y^2\}} \right\} + \frac{19.13 \mu_o x}{2\pi(x^2+y^2)} \quad (19)$$

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

$$223 \quad B_x \text{ out-T} = -\frac{15.57 \mu_o y}{2\pi\{(x-z)^2+y^2\}} + \frac{15.57 \mu_o y}{2\pi\{(x+z)^2+y^2\}} \quad (20)$$

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

$$226 \quad B_x \text{ in-T} = \frac{9.57 \mu_o}{2\pi} \left\{ \frac{y}{\{(x-z)^2+y^2\}} + \frac{y}{\{(x+z)^2+y^2\}} \right\} - \frac{19.13 \mu_o x}{2\pi(x^2+y^2)} \quad (21)$$

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

$$230 \quad \mathbf{B}_T^2 = B_y^2 \text{ out-T} + B_y^2 \text{ in-T} + B_x^2 \text{ out-T} + B_x^2 \text{ in-T} \quad (22)$$

$$231 \quad \text{Hence, } \mathbf{B}_T = (B_y^2 \text{ out-T} + B_y^2 \text{ in-T} + B_x^2 \text{ out-T} + B_x^2 \text{ in-T})^{1/2} \quad (23)$$

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233 We went further to adopt a mathematical software (Wolfram Mathematica 8.0) which enabled us facilitate the  
234 generation of the results of the magnetic field current coefficients ( $I_{coef}$ ) for the vertical and horizontal  
235 components of the magnetic fields (both in-phase and out of phase) for  $x=1m$  to 1000 m (horizontal distance  
236 from the foot of the pole) for a vertical height of 1 m above the ground surface (presumed to be the average  
237 height of head positions of those who live and do business **within the study area**). This software also enabled us  
238 to calculate the total magnetic field for  $x=1m$  to 1000 m. In carrying out these computations, we used the  
239 parameters collected from Power Holdings Company of Nigeria (PHCN). These parameters include; Power =  
240 11 kVA, Line voltage = 415V, Height of pole = 10.37m, Distance between central horizontal conductor and the  
241 two external horizontal conductors ' $z$ ' = 0.17m. The current in the horizontal conductor ' $I$ ', was calculated using  
242 the Expression;

$$243 \quad I = \frac{Power}{v \cos \theta \sqrt{3}} = 19.13 \text{ A} \quad (24)$$

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

245

246 **3. Results**

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

254  $1 \mu T/hr = \mu T/sec \times 3600$  (25)

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

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

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

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268 Table 3. Summary of the total magnetic field for the different phases and the total magnetic fields for  $X = 1 m$  to  
 269 1000 m

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

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**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 $\mu$ T/sec	Field Exposure $\mu$ T/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

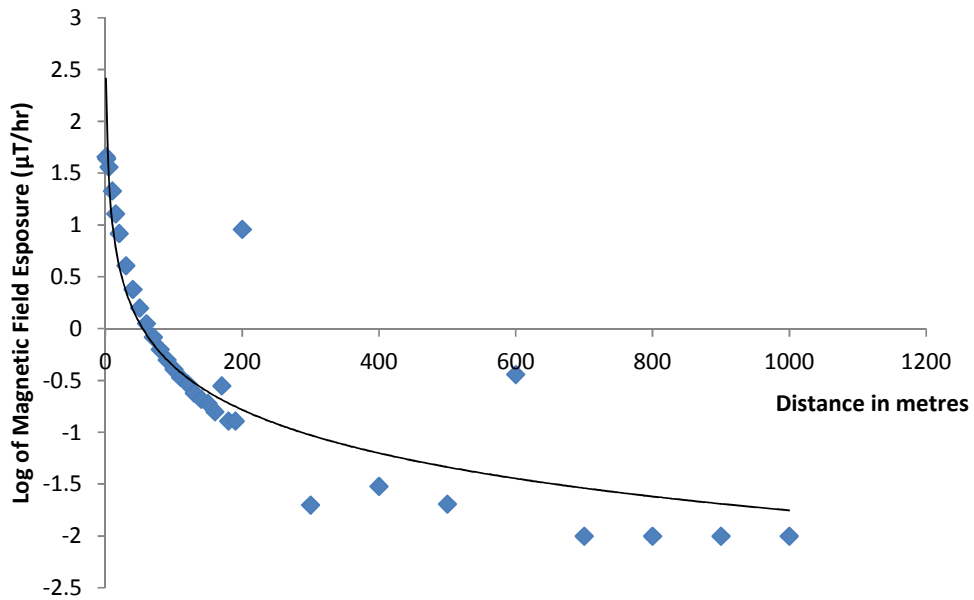
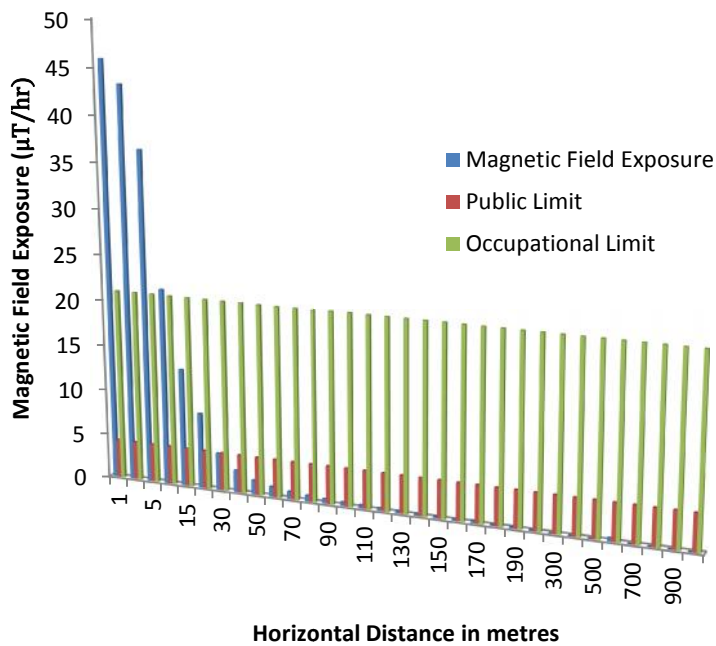


Figure 5: Relationship between Log of magnetic field exposure and the horizontal distance away from the conductor

**Table 5: Comparison of Magnetic field exposure in micro Tesla per hour ( $\mu\text{T/hr}$ ) with the international standard limits.**

s/n	HORIZONTAL DISTANCE X (m)	Magnetic Field Exposure $\mu\text{T/hr}$	ICNIRP LIMIT	
			PUBLIC	Occupational
			$\mu\text{T/hr}$	$\mu\text{T/hr}$
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 ( $\mu\text{T/hr}$ ) with the international standard limits.**

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276 4. Discussions

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

284

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

289 In Table 4, the results of the rate of magnetic field exposures presented for the various horizontal distances from  
290 the central conductor ( $x = 1\text{ m}$  to  $x = 1000\text{ m}$ ) ranged from  $45.8\mu\text{T/hr}$  to  $0.01\mu\text{T/hr}$ . For  $x = 1$  to  $20\text{ m}$ , the  
291 magnetic field exposure exceeded the standard limits of  $4.2\mu\text{T/hr}$  and  $21\mu\text{T/hr}$  set by ICNIRP for both public  
292 and occupational areas respectively [8]. These values suggest that within the horizontal distances of between  $1$   
293 to  $20\text{ m}$ , people should not build residential houses. Within the range of  $1$  to  $10\text{ m}$ , we have values above the  
294 standard limit of  $21.0\mu\text{T/hr}$  set by ICNIRP (1998) for the occupational area [9]. Also, these values suggest that  
295 people should not do business close to the power lines to avoid undue exposure to magnetic fields.  
296 From the results, the horizontal distances of  $x=30\text{m}$  to  $x=1000\text{m}$  have magnetic field exposures below the  
297 standard limits set by ICNIRP. It follows that within these horizontal distances, it is safe for people to reside and  
298 also do their businesses.

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

## 308 5. Conclusion

309 In this research, we have calculated the magnetic field exposure from extremely low frequency magnetic field  
310 around  $11\text{ kV}$  power distribution lines at Rukpokwu, Rivers State, Nigeria using theoretical and mathematical  
311 formulations. The results showed that for horizontal distances of between  $1$  and  $10\text{m}$ , the magnetic field  
312 exposures ranged from  $45.82\mu\text{T/hr}$  to  $21.62\mu\text{T/hr}$  and are above the occupational field exposure limit of  
313  $21.0\mu\text{T/hr}$  set by International Committee on Non Ionizing Radiation Protection (ICNIRP). We could refer to  
314 this horizontal region as the exceedance Zone, that is the zone with magnetic field exposure beyond the  
315 prescribed limit [11]. Also, the results of field exposure for horizontal distances ranging from  $1$  to  $20\text{m}$  were  
316 between  $45.82\mu\text{T/hr}$  and  $8.3\mu\text{T/hr}$  and are above the ICNIRP limit of  $4.2\mu\text{T/hr}$  set for the public. It is  
317 suggested that between horizontal distances of  $1$  and  $10\text{m}$  from the distribution lines, it is unsafe to build shops  
318 and do businesses and between the horizontal distances of  $1$  to  $20\text{m}$  it is unsafe to build residential areas.

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