Journal of Applied Sciences

ISSN 1812-5654

OPEN ACCESS Journal of Applied Sciences

ISSN 1812-5654
DOI: 10.3923/jas.2022.187.195

Research Article

Assessing the Health Risk Due to Exposure to Non-Ionizing Radiation in the Form of Magnetic Field from Electrical Power Substations

Ifeanyi J. Njoku, Chikwendu E. Orji, Emmanuel C. Mbamala, Udoka M. Ukewuihe, Chibueze P. Onyenegecha and Obinwa Orji

School of Physical Sciences, Federal University of Technology, P.M.B. 1526, Owerri, Imo State, Nigeria

Abstract

Background and Objective: The mechanism of how extremely low-frequency magnetic fields (ELF-EMF) affect biological systems is still not known. In this paper, the possible health risk due to exposure to magnetic fields from electrical power substations within Southeastern Nigeria is reported. **Materials and Methods:** Magnetic flux density readings are taken from five power substation switchyards. Using the prolate spheroid model, the induced current density in the body and selected tissues due to the magnetic fields. **Results:** The maximum values of the magnetic field and in the body were 15.04 μT and 0.13 mA m^{-2} as obtained from the 330 kV switchyard of substation 1. The results also show that the stomach tissue is the most affected as it showed the highest value of current density for all the tissues sampled. **Conclusion:** The results of the study are far lower than the ICNIRP reference levels for exposure to magnetic fields and induced current density.

Key words: Non-ionizing radiation, magnetic field, prolate spheroid model, ELF electromagnetic field, substations, ICNIRP

Citation: Njoku, I.J., C.E. Orji, E.C. Mbamala, U.M. Ukewuihe, C.P. Onyenegecha and O. Orji, 2022. Assessing the health risk due to exposure to non-ionizing radiation in the form of magnetic field from electrical power substations. J. Appl. Sci., 22: 187-195.

Corresponding Author: Ifeanyi J. Njoku, School of Physical Sciences, Federal University of Technology, P.M.B. 1526, Owerri, Imo, Nigeria

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Many researchers investigated the association between exposure to extremely low-frequency magnetic fields (ELF-MF) in the workplace and risk due to this exposure to certain diseases and disorders like brain tumours, infertility, congenital defects, abortion and diseases to the central nervous system[1-9]. The International Agency for Research on Cancer (IARC) classified ELF magnetic fields as potentially carcinogenic (class 2B) to humans[10], thus, further highlighting the growing danger of exposure to ELF magnetic fields especially occupationally. Furthermore, the World Health Organization (WHO), has reported that the exposure rate of most studied subjects to the ELF magnetic field was less than 0.1 μT and a small percentage was higher than 0.3 μT[10].

The mechanism of how extremely low-frequency magnetic fields (ELF-EMF) affect biological systems is still not known. Although, the formation of free radicals and oxidative stress has been reported as one of the possible mechanisms[11]. It has been reported that rats exposed to 10 mT ELF-EMF for 24 hrs/day for 7 days showed induced anxiety-like behaviour through oxidative stress and increasing NO concentration in the hypothalamus[12]. Occupational exposure to ELF-EMF has been reported to have a direct relationship with poor sleep quality[13]. Recently, research studies have reported that long-term exposure to magnetic fields can lead to increased negative psychological effects among which are sleep disorders, depression, paranoia, anxiety and psychosis in employees that work at high voltage substations[11,14,15].

The ever increasing evidence of the risk of occupational exposure to ELF magnetic fields have led to various regulatory bodies setting up standard reference levels for exposure to ELF-EMF. The most widely used of these standards is that of the International Commission for Non-Ionizing Radiation Protection (ICNIRP)[10,16]. The reference level for occupational exposure to the magnetic field is 1 mT, while the induced current density has a reference value of 10 mA m^{-2} for 50 Hz fields. These guidelines have been set up to help protect from the adverse effects of exposure to ELF MFs especially occupationally. So many countries still set up their regulations concerning ELF MF exposure, although, unfortunately, none exists in Nigeria.

When exposed to magnetic fields from substations, currents are induced in the body which can cause various effects on the nervous system[16]. To the best of the author's knowledge, no study has been reported with regards to induced current density due to occupational exposure to ELF magnetic fields in Nigeria using the prolate spheroid model, hence, the motivation for this study. This study aimed to assess the possible health risk due to exposure to magnetic fields from electrical power substations located in southeastern Nigeria and to consequently deduce the resulting induced current densities due to this exposure.

MATERIALS AND METHODS

Study area: The study area is the south-eastern part of Nigeria. The study was carried out in three power substations in the two states of Abia and Imo. The study was carried out for a period of four months, between September to December, 2020.

Measurement of magnetic field: To measure the magnetic fields from the lines, The TENMARS magnetic field meter, model number TM-191, made in Taiwan by TENMARS Electronics Co., Ltd., was used for the measurement of magnetic flux density. It is an easy-to-carry device of 130×56×38 mm dimensions and 170 g weight which is designed to be used to measure safely magnetic flux density. It is a 3-liquid crystal display (LCD) equipped with a single axis sensor for measurement in one direction with a maximum reading of 1999. It measures magnetic field in units of μT or mG with a measuring range of 20/200 μT with a resolution of 0.01/0.1μT and a sampling rate of 2.5 per second. It is powered by a 9V alkaline battery with an approximate life of 100 hrs.

Each measurement was taken over a short period. All readings of magnetic flux density were taken by placing the meter at 1 m above the ground, positioned facing the source of field and held steady during the measurement to avoid the display of excess field value that does not reflect the actual field condition, which is caused by electrostatic charges. Readings of magnetic flux density were taken at specific points within the switchyard of the substations at the base (directly underneath) the point where the reading is to be taken and facing the meter sensor upward. Readings within the switchyard were taken from breakers, bus bars, feeders and at a point approximately at the middle of the yard. An average of these values is then evaluated. All readings were taken between the hours of 12-3 pm and at a time when the substations are functioning at their full capacity to capture peak loads. All the B values are compared to ICNIRP reference levels.

Electric power substations: Three substations were studied, comprising a total of five switchyards of varying capacity. The transmission company of Nigeria (TCN) transmission substation located at Egbu, Owerri North LGA of Imo state was

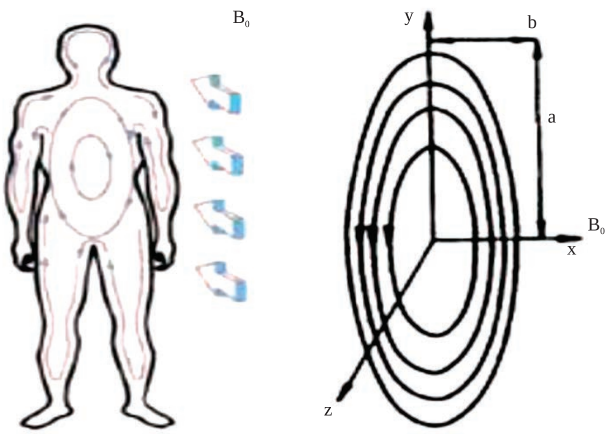

Fig. 1: A human and its prolate spheroid model in an external magnetic field. The major axis of the prolate spheroid is 2a and the minor axis is 2b[17]

studied (GPS coordinates 5.481065, 7.061016). The station comprises two switchyards-132 kV and 33 kV and eight 33 kV feeders that supply to various parts of the state. The TCN substation located at Alaoji, Aba, Abia state (GPS coordinates 5.067291, 7.321270) is the largest power substation in the South-Eastern part of Nigeria. Measurements were taken from the 132 kV and 330 kV switchyards within the station comprising of four and three operational feeders, respectively. One 11 kV Enugu Electricity Distribution Company (EEDC) injection substation (GPS coordinates 5.478107, 7.043938) was studied and located at Egbu road, Owerri, Imo state.

Induced current density: To obtain the induced current density, the prolate spheroid model was used. The prolate spheroid model is a model used to investigate the biological effects of electric and magnetic fields on humans. This model is used in approximating the interaction of the human body with electric and magnetic fields. A prolate spheroid model of a human in a magnetic field is presented in Fig. 1[17].

The current density induced by the magnetic field is dependent on the larger loop, so it is maximum at the prolate spheroid surface (the largest loop) corresponding to "r = b" (max radius of the spheroid). In another study[18], the author derived an equation for the current density induced by a magnetic field on a prolate spheroid. The equation for obtaining the highest value for the current density, J, at the surface of the prolate spheroid in a horizontal magnetic field of magnitude, B, is given by Eq. 1:

$$J = -j2\pi f\sigma bB_0 \tag{1}$$

where, f, b, B_0, σ are respective frequency, the minor axis of the spheroid, external magnetic field and tissue conductivity. Tissue conductivity of 0.2 S m^{-1} was used in calculations in this study. The appropriate value for the minor axis of the spheroid, b, when modelling the human body is 0.14 m.

RESULTS

Magnetic flux density and induced currents from the substations: The results of the study are summarized in Table 2-6 showing the values of the magnetic field (flux density) from the substations sampled in this study and the corresponding calculated values of the induced current density in the body due to these fields. The magnetic flux density is the amount of magnetic flux through a unit area of the body or an organ taken perpendicular to the direction of magnetic flux. Its unit is micro Tesla (μT). The induced current density gives a value of the electrical current induced by the magnetic field exposure within the body or an organ per unit area. Its unit is milli Ampere per square meter (mA m^{-2}).

Substation 1: In Table 1, the values of magnetic flux, B and induced current densities, J for substation 1 are presented. The values of B range between 0.22-15.04 μT and the range of J is between 0.002-0.132 mA m^{-2}. The highest recorded values in the 330 kV switchyard of the station are 15.04 μT and 0.13 mA m^{-2}, respectively for B and J, in the middle of the switchyard, representing 32% of the exposure, while the lowest values are 0.23 μT and 0.002 mA m^{-2}, from the busbar 1. The average values recorded are 5.804 μT and 0.051 mA m^{-2}. For the 132 kV switchyard, the highest values are 4.62 μT and 0.041 mA m^{-2} for B and J on busbar 1, representing 32% of the exposure. The lowest recorded values of B and Jare in the 132 kV switchyardare0.22 μT and 0.002 mA m^{-2}, representing a negligible percentage of the exposure. The average recorded values are 1.825 μT and 0.016 mA m^{-2} for B and J, respectively.

Figure 2 and 3 show, respectively the percentage of magnetic flux, B and induced current density, J concerning each component/position within the 330 and 132 kV switchyards of substation 1. It can be seen that exposure is greatest at the middle of the switchyard (15.04 μT and 0.13 mA m^{-2}) for workers working within the station, representing 32% of the exposure for the 330 kV switchyard. For the 132 kV switchyard, the highest exposure percentage is 32% on the busbar 1.

Substation 2: Table 2 gives the readings of the magnetic field, B in μT as taken from substation 2 located at Egbu, Owerri,

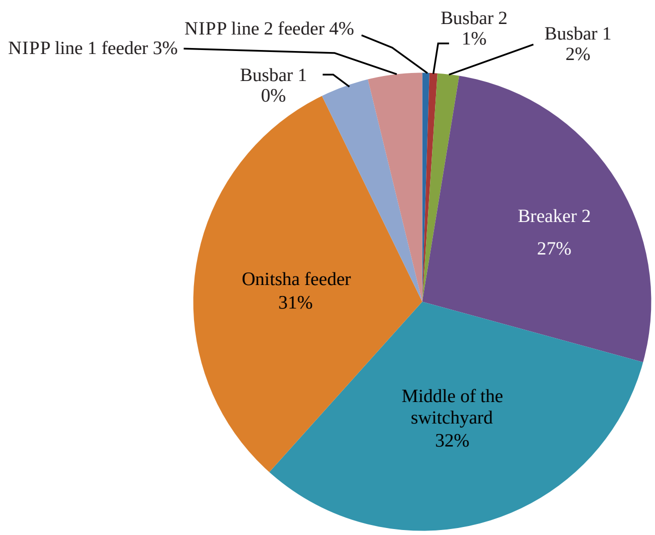

Fig. 2: Percentage of B and J values for each component/position of the 330 kV switchyard of substation

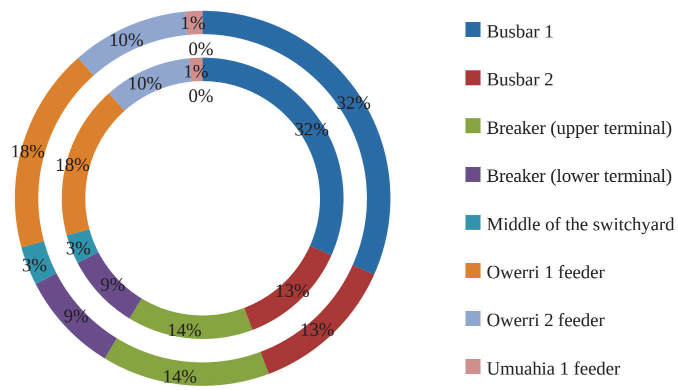

Fig. 3: Percentage of B and J values for each component/position of the 132 kV switchyard of substation 1

Table 1: Values of B (Average±SD) and J from substation 1 (Alaoji substation)

Position/Components	B (μT)	J (mA m^{-2})
330 kV Switchyard		
Busbar 1	0.23	0.002
Busbar 2	0.26	0.002
Breaker 1	0.71	0.006
Breaker 2	12.38	0.109
Middle of the switchyard	15.04	0.132
Onitsha feeder	14.46	0.127
NIPP line 1 feeder	1.58	0.013
NIPP line 2 feeder	1.77	0.015
Average	5.804±6.817	0.051
132 kV Switchyard		
Busbar 1	4.62	0.041
Busbar 2	1.84	0.016
Breaker (upper terminal)	2.11	0.019
Breaker (lower terminal)	1.27	0.011
Middle of the switchyard	0.49	0.004
Owerri 1 feeder	2.58	0.023
Owerri 2 feeder	1.47	0.013
Umuahia 1 feeder	0.22	0.002
Average	1.825±1.376	0.016

Imo state and calculated values of induced current density, Jin mA m^{-2} for both the 132 and 33 kV switchyards of the station. The values of B for this substation ranges from 0.06-6.45 μT and the values for J ranges between 0.001-0.057 mA m^{-2}. As observed in Table 2, for the 132 kV switchyard, the maximum values of B and J are, respectively 6.45 μT and 0.057 mA m^{-2} as recorded at the middle of the switchyard, representing 41% of the exposure as can be seen in Fig. 4. The lowest recorded values are 0.94 μT and 0.008 mA m^{-2} from the busbar 1, representing 6% of the exposure. The average values of B and J are 3.144 μT and 0.028 mA m^{-2}, respectively for the 132 kV switchyard. For the 33 kV switchyard, the highest values of B and J recorded are2.85 μT and 0.025 mA m^{-2} from the Okigwe feeder, representing 27% of the exposure as can be observed in Fig. 5. The lowest values recorded are 0.06 μT and 0.001 mA m^{-2} for B and J, respectively from the busbar 1,

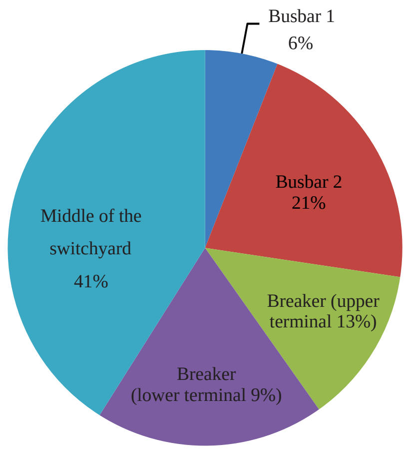

Fig. 4: Percentage of B and J for each component/position of the 132 kV switchyard of substation 2

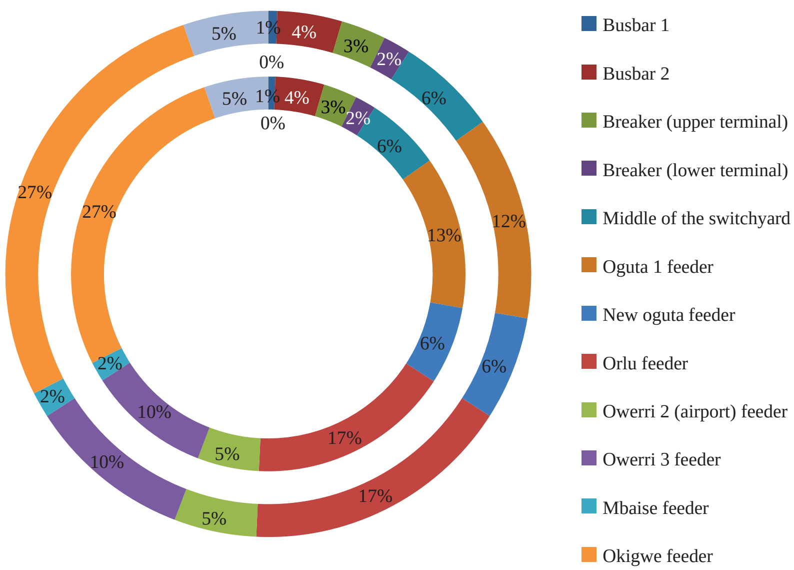

Fig. 5: Percentage of B and J for each component/position of the 33 kV switchyard of substation 2

representing a negligible percentage of the exposure as seen from Fig. 5. The average values of the B and J are respectively given as 0.806 μT and 0.007 mA m^{-2} for the 33 kV switchyard.

Substation 3: Table 3 gives the readings of magnetic field, B as taken from 11 kV, Enugu eElectricity Distribution Company injection substation 3 located at Egbu road, Owerri, Imo state and calculated values of induced current density, J. It can be seen that the values of B range between 0.57-3.24 μT, while the values of J range from 0.005-0.029 μT. The highest values of B and J were recorded on the outgoing 33 kV breaker as 2.56 μT and 0.023 mA m^{-2}, respectively, representing 13% of the exposure as is observed from Fig. 6, while the lowest values were located at the middle of the switchyards 0.57 μT and 0.005 mA m^{-2}, representing 2% of the exposure. The average values of B and J are recorded as 1.783 μT and 0.016 mA m^{-2}, respectively.

Induced current density in various human tissues due to exposure to the magnetic field within power stations: Table 4 presents the tissue conductivities of the brain, heart, stomach, bones and lungs. Table 5, 6 and 7 show calculations using the prolate spheroid model are made of the induced current density in the brain, heart, stomach, bones and lung tissues due to exposure to the magnetic field for different substations using the average magnetic field values measured within the station switchyards.

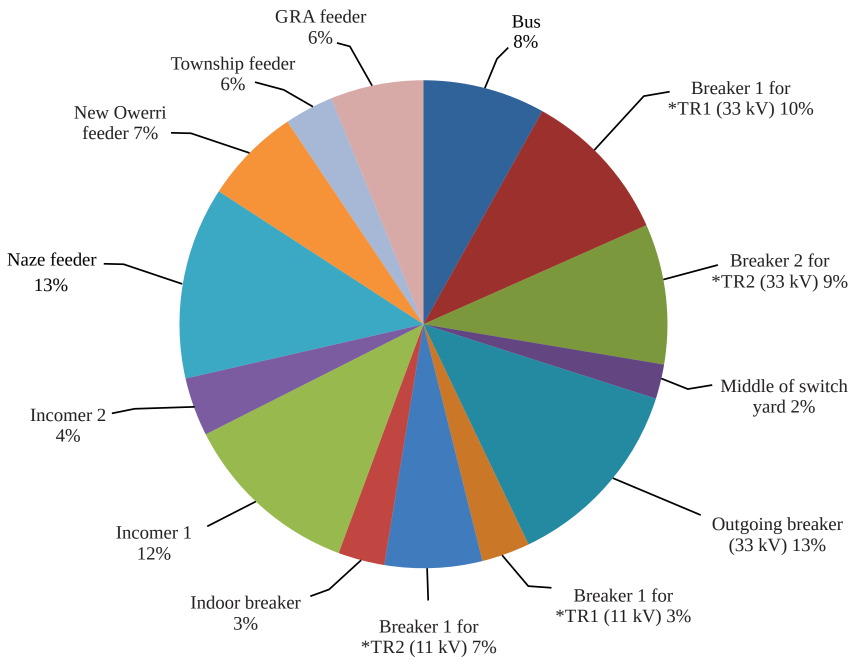

Fig. 6: Percentage of B and J for each component/position of the 11 kV injection power substation 3

Table 2: Values of B (Average±SD) and J from substation 2 (Egbu substation)

Position/Components	B (μT)	J (mA m^{-2})
132 kV switchyard		
Busbar 1	0.94	0.028
Busbar 2	3.36	0.029
Breaker (upper terminal)	2.02	0.017
Breaker (lower terminal)	2.95	0.026
Middle of the switchyard	6.45	0.057
Average	3.144±2.069	0.028
33 kV switchyard		
Busbar 1	0.06	0.001
Busbar 2	0.42	0.004
Breaker (upper terminal)	0.29	0.003
Breaker (lower terminal)	0.18	0.002
Middle of the switchyard	0.65	0.006
Oguta 1 feeder	1.31	0.012
New Oguta feeder	0.67	0.006
Orlu feeder	1.74	0.015
Owerri 2 (airport) feeder	0.53	0.005
Owerri 3 feeder	1.06	0.009
Mbaise feeder	0.17	0.002
Okigwe feeder	2.85	0.025
Alex feeder	0.55	0.005
Average	0.806±0.781	0.007

Substation 1: Table 5, the results of the induced current density for the selected tissues from substation 1 are given. The values range from 0.004-0.133 mA m^{-2}. In the 330 kV switchyard, the stomach tissue has the highest induced current density of 1.133 mA m^{-2}, while the bone tissues have the lowest value at 0.013 mA m^{-2}. Similarly, in the 132 kV switchyard, the stomach tissues show the highest current density values at 0.042 mA m^{-2}, while the lowest value was observed for the bone and brain tissues at 0.004 mA m^{-2}.

Substation 2: Table 6, the results of the computed values of the induced current density for selected tissues for substation 2. The values obtained ranged from 0.002-0.072 mA m^{-2}. In the 132 kV substation, the induced is highest in the stomach tissues at 0.072 mA m^{-2}, while the lowest value was recorded in the bone and brain tissues at 0.007 mA m^{-2}. In the 33 kV switchyard, the stomach also recorded the highest value of 0.018 mA m^{-2} and the lowest value is from the brain, bone and lung tissues at 0.02 mA m^{-2}.

Table 3: Values of B (Average±SD) and J from 11 kV injection substation 3

Position/Components	B (μT)	J (mA m^{-2})
Busbar	2.02	0.018
Outdoor breakers (incoming)		
Breaker 1 for *TR1 (33 kV)	2.56	0.023
Breaker 2 for *TR2 (33 kV)	2.32	0.020
Middle of switchyard	0.57	0.005
Outgoing breaker (33 kV)	3.24	0.029
Indoor breakers (outgoing)		
Breaker 1 for *TR1 (11 kV)	0.8	0.007
Breaker 1 for *TR2 (11 kV)	1.61	0.014
Indoor breaker	0.77	0.007
Incomer 1	2.97	0.026
Incomer 2	0.97	0.009
Naze feeder	3.18	0.028
New Owerri feeder	1.6	0.014
Township feeder	0.81	0.007
GRA feeder	1.54	0.014
Average	1.783±0.946	0.016

*TR: Transformer

Table 4: Tissue conductivities of selected human tissues at 50 Hz for a 1.75 m tall human[17]

Tissues	Conductivity (S m^{-1})
Brain	0.0533
Heart	0.0827
Stomach	0.5210
Bones	0.0504
Lungs	0.0684

Table 5: Induced current densities to selected tissues of the human body for substation 1

Switchyard	Tissues	J (mA m^{-2})
330 kV	Brain	0.014
	Heart	0.021
	Stomach	0.133
	Bones	0.013
	Lungs	0.017
132 kV	Brain	0.004
	Heart	0.007
	Stomach	0.042
	Bones	0.004
	Lungs	0.005

Table 6: Induced current densities to selected tissues of the human body for substation 2

Switchyard	Tissues	J (mA m^{-2})
132 kV	Brain	0.007
	Heart	0.011
	Stomach	0.072
	Bones	0.007
	Lungs	0.009
33 kV	Brain	0.002
	Heart	0.003
	Stomach	0.018
	Bones	0.002
	Lungs	0.002

Substation 3: The computed values of the induced current densities of the stomach, heart, lung, brain and bone tissues are given in Table 7 for substation 3. The values range from 0.004-0.041 mA m^{-2}. The highest value was recorded for the stomach tissue at 0.041 mA m^{-2} and the lowest value is recorded by the bones and brain tissues at 0.004 mA m^{-2}.

Table 7: Induced current densities to selected tissues of the human body for substation 3

Switchyard	Tissues	J (mA m^{-2})
11 kV	Brain	0.004
	Heart	0.006
	Stomach	0.041
	Bones	0.004
	Lungs	0.005

DISCUSSION

The measurement of the magnetic flux density and the corresponding calculated induced current density for the study using the prolate spheroid model has given significant insight into the level of exposure that electricity workers at substations within the southeast of Nigeria are exposed to. The results have shown that the exposure and corresponding health risks due to these exposures increase significantly as the substation capacity increases. That is to say, higher voltage substation workers are more at risk from the exposure than lower voltage substation workers as demonstrated by the results since substation 1 has the highest values of both the magnetic field and induced current density, followed by the substation 2 and then substation 3. This trend also follows the trend of their sizes as substation 1 is the largest, followed by 2 and then 3. The highest values of the magnetic flux and induced current density for the whole study were recorded in the middle of the 330 kV switchyard of substation 1, which is the largest. The values recorded were significantly lower than the ICNIRP reference levels of 1 mT for B[16] and 10 mA m^{-2} for J[10]. In comparison with the literature, this value for the magnetic field in this study is lower than the maximum value of 18 μT reported by Ozen[19], even though they are in the same range. Also, Rahman *et al.*[20], reported a much higher value of 55.84 μT for the 11/0.4 kV substation. Also, a maximum value of 70 μT has been reported for the 154/34.5 kV power substation[21]. For the 220 kV substation, significantly higher values of the magnetic flux have been reported (356.8 μT)[22]. It should be noted that in all of these studies, none reported the induced current density values and thus, no comparisons are made. This result implies that the workers in substation 1 are at greater risk due to exposure to non-ionizing radiation from magnetic fields.

In substation 2, the health risk due to exposure to magnetic fields is much less as the values of B and J are lower and with a lower average value than substation 1. However, the part of the switchyard with the most risk of exposure and damage to health is the middle of the switchyard as in substation 1. Thus, workers are advised to spend less time in the middle of the switchyard and other high voltage areas within the station. It should be noted that the recorded for this station are very well below the ICNIRP reference[10,16]. The highest value recorded for this substation is much lower than the values reported in the literature[19-22] as previously pointed out.

The lowest values of magnetic flux density and induced current density have been recorded in substation 3 which is the smallest substation in terms of voltage and capacity. However, the middle of the switchyard is not the most prone to exposure as reported in stations 1 and 2. The place with the most health risk due to exposure is the area near the breakers as indicated by the highest values of B and J in these areas for the substation. The difference between substation 3 and substations 1 and 2 is a difference in configuration and capacity since 1 and 2 have similar configuration and capacity. These values recorded in this substation are very well below the ICNIRP reference[10,16] and also significantly below the literature values[19-22].

Using the average values of magnetic flux density from the switchyards of the various stations, the induced current density due to exposure of the heart, brain, lung, stomach and bone tissues are computed from the values of their tissue conductivities using the prolate spheroid model. As would be expected, the values obtained for these tissues are highest in substation 1, followed by substation 2 and substation 3. The implication of this is that the heart, lung, stomach, brain and bone tissues of people who work at higher voltage substations is more exposed to the adverse health risk from non-ionizing radiation in the form of magnetic fields than those working in low voltage substations. For all the substations, it is seen from the values of the induced current density that the stomach is the most affected tissue, i.e., it is the most exposed to the effect of the magnetic field. Thus, of all the selected tissues, the stomach should be the most protected by electricity workers. These results are in line with the results presented by Manel[17] which is the only recent study in the literature where these tissues have been used in the context of non-ionizing radiation from magnetic fields.

It is important to state that even though the results of this study are below the reference level of the ICNIRP, the health risk to humans becomes more significant, particularly for long term exposure mostly for those living near these power lines and substations[17,21,23]. In comparison to the values reported for transmission power line[24,25], the maximum value of the induced magnetic flux density for this study are much higher. This implies that the health risk due to exposure from power lines is less compared to the exposure in a substation. Thus, occupational exposure is higher than general public exposure, thus, confirming the accretion by Orji *et al.*[10]. The values of induced current density due to the magnetic fields in this study are lower than the levels that could cause significant biological effects in humans. People living near the 11 kV and 33 kV lines are at the least risk health-wise. It should be noted that the maximum values reported for this study for the 330, 132 and 33 kV lines are higher than 1 μT, which should be a source for concern as it has been reported that there is an association between long-term exposure to ELF magnetic fields (1 μT) and risk of Leukemia in children[26]. Thus, measures must be taken to mitigate the level of exposure to these fields even though they are low.

CONCLUSION

The occupational exposure to the magnetic field from power substations and the resulting induced currents in the human body and selected tissues have been assessed in this study. The study has shown that workers in very high voltage power substations are more exposed to the magnetic fields and their health effects than those in lower voltage power substations. It has also been shown that the tissue most susceptible to the adverse effect of this exposure is the stomach which showed higher values of the induced current than other users in the study tissues. The results of the study have shown that the level of exposure to magnetic fields and induced current density in the substations studied is far lower than the ICNIRP reference levels for exposure to magnetic fields and induced current density. This should not be however overlooked as long-term exposure could prove dangerous to those exposed. Thus, more has to be done to protect electricity workers, especially those who do most of their work within the switchyards of power stations from the adverse effect of exposure to magnetic fields from transformers and other electrical components within the switchyard by providing them with better insulating equipment and personal protective equipment, specifically those that can attenuate magnetic flux.

SIGNIFICANCE STATEMENT

This study discovered that occupational exposure to magnetic fields within the selected power substations in south-eastern Nigeria is reasonably lower than the world standard but still of serious concern due to the potential health risks from long term exposure as a result of induced current densities from these fields. It will be beneficial for more such studies to be carried out within the country so that a national baseline can be set for occupational exposure to these fields. This study will serve as a springboard to further research in this area, especially within Nigeria and will equally serve as a tool for policymakers to assist them in making policies that safeguard the electricity workers and general public mitigate the potential dangers to health due to exposure to magnetic fields from electrical power installations. Furthermore, it will serve as a useful template for other researchers to carry out research in this area.

REFERENCES

1. Calvente, I., M.F. Fernandez, J. Villalba, N. Olea and M.I. Nuñez, 2010. Exposure to electromagnetic fields (non-ionizing radiation) and its relationship with childhood leukemia: A systematic review. Sci. Total Environ., 408: 3062-3069.
2. Carpenter, D.O., 2013. Human disease resulting from exposure to electromagnetic fields1). Rev. Environ. Health, 28: 159-172.
3. Duan, W., C. Liu, H. Wu, C. Chen and T. Zhang *et al*., 2014. Effects of exposure to extremely low frequency magnetic fields on spermatogenesis in adult rats. Bioelectromagnetics, 35: 58-69.
4. Kheifets, L., J. Monroe, X. Vergara, G. Mezei and A.A. Afifi, 2008. Occupational electromagnetic fields and leukemia and brain cancer: An update to two meta-analyses. J. Occup. Environ. Med., 50: 677-688.
5. Hardell, L. and C. Sage, 2008. Biological effects from electromagnetic field exposure and public exposure standards ☆,1. Biomed. Pharmacother., 62: 104-109.
6. Feychting, M., F. Jonsson, N.L. Pedersen and A. Ahlbom, 2003. Occupational magnetic field exposure and neurodegenerative disease. Epidemiology, 14: 413-419.
7. Johansen, C., 2000. Exposure to electromagnetic fields and risk of central nervous system disease in utility workers. Epidemiology, 11: 539-543.
8. Kheifets, L., J.D. Bowman, H. Checkoway, M. Feychting and J.M. Harrington *et al*., 2009. Future needs of occupational epidemiology of extremely low frequency electric and magnetic fields: Review and recommendations. Occup. Environ. Med., 66: 72-80.
9. Vergara, X., L. Kheifets, S. Greenland, S. Oksuzyan, Y.S. Cho and G. Mezei, 2013. Occupational exposure to extremely low-frequency magnetic fields and neurodegenerative disease: A meta-analysis. J. Occup. Environ. Med., 55: 135-146.
10. Orji, C.E., I.J. Njoku, E.C. Mbamala, K.B. Okeoma and O. Orji, 2021. Assessing the health risk due to exposure to non-ionizing radiation in the form of magnetic field from electrical power lines. Sci. Lett., 9: 72-77.
11. Hosseinabadi, M.B., N. Khanjani, M.H. Ebrahimi, B. Haji and M. Abdolahfard, 2019. The effect of chronic exposure to extremely low-frequency electromagnetic fields on sleep quality, stress, depression and anxiety. Electromagn. Biol. Med., 38: 96-101.
12. Djordjevic, N.Z., M.G. Paunović and A.S. Peulić, 2017. Anxiety-like behavioural effects of extremely low-frequency electromagnetic field in rats. Environ. Sci. Pollut. Res., 24: 21693-21699.
13. Liu, H., G. Chen, Y. Pan, Z. Chen and W. Jin *et al*., 2014. Occupational electromagnetic field exposures associated with sleep quality: A cross-sectional study. PLOS ONE, Vol. 9. 10.1371/journal.pone.0110825.
14. Sharifi, M., P. Nasiri and M.R. Monazzam, 2010. Measurement of the magnetic fields from high-voltage (230 kV) substations in Tehran and assessment of their effects. Iran. J. Med. Phys., 7: 49-56.
15. Yousefi, H. and P. Nasiri, 2006. Psychological effects of occupational exposure to electromagnetic fields. J. Res. Health Sci., 6: 18-21.
16. ICNIRP, 2010. Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz). Health Phys., 99: 818-836.
17. Manel, B., 2020. Biological risk assessment of high-voltage transmission lines on worker's health of electric society. Arch. Elect. Eng., 69: 57-68.
18. Spiegel, R.J., 1977. Magnetic coupling to a prolate spheroid model of man. IEEE Trans. Power Apparatus Syst. 96: 208-212.
19. Ozen, S., 2008. Evaluation and measurement of magnetic field exposure at a typical high-voltage substation and its power lines. Radiat. Prot. Dosimetry, 128: 198-205.
20. Rahman, N.A., N.A. Rashid, W.N. Mahadi and Z. Rasol, 2011. Magnetic field exposure assessment of electric power substation in high rise building. J. Appl. Sci., 11: 953-961.
21. Helhel, S. and S. Ozen, 2008. Assessment of occupational exposure to magnetic fields in high-voltage substations (154/34.5 kV). Radiat. Prot. Dosim., 128: 464-470.
22. Ellithy, K.A., 2010. Measurement of magnetic fields in a 220kV Gas insulated substation. EEE PES T&D, 2010: 1-6.
23. Ozen, S., 2008. Low-frequency transient electric and magnetic fields coupling to child body. Radiat. Prot. Dosim., 128: 62-67.
24. Ukhurebor K.E., E.E. Aigbe and S.M. Maor, 2019. Evaluation of electromagnetic fields from power lines in Irrua, Edo State, Nigeria. J. Sci. Res. Rep., 22: 1-7.
25. Djalel, D.I.B. and M. Mourad, 2014. Study of influence high-voltage power lines on environment and human health (case study: The electromagnetic pollution in Tebessa city, Algeria). J. Elect. Elect. Eng., 2: 1-8.
26. Ahlbom, A., N. Day, M. Feychting, E. Roman and J. Skinner *et al*., 2000. A pooled analysis of magnetic fields and childhood leukaemia. Br. J. Cancer, 83: 692-698.