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Analysis of Magnetic Field Exposure at Extremely Low Frequency (ELF) in 330kV Transmission Switchyards

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ABSTRACT

The present study assessed the exposure levels of extremely low frequency (ELF) magnetic fields in five 330 kV transmission switchyard of generation stations located in north-central, Nigeria. In conformity with IEEE standards of measurement procedures, ELF magnetic field levels were detected in the switchyards using Extech 480826 triple-axis EMF metre via spot technique at three different observation heights of 1.0, 1.5 and 1.8 m. The data obtained were subjected to analysis using the One-way ANOVA SPSS package. The results demonstrated occupational significant differences of ($p < .001$) between 330 kV switchyards of Shiroro Hydro-plant and Geregu Phase II Gas-plant, significant differences of ($p = .045$) between switchyards of Geregu Phase I Gas-plant and Geregu Phase II Gas-plant, and also significant differences of ($p < .001$) in occupational exposure was demonstrated between switchyards of Jebba Hydro-plant, Kainji Hydro-plant when separately compared to Geregu Phase I and Geregu Phase II Gas-plants. However, non-significant differences occurred between switchyards of Shiroro Hydro-plant and Jebba Hydro-plant, Kainji Hydro-plant and Geregu Phase I Gas-plant, and Jebba Hydro-plant with Kainji Hydro-plant. This study has revealed the occurrence of field pollution within the switchyard and the variation of ELF magnetic field magnitude from between switchyards.

1. Introduction

Electrical infrastructure, like the transmission lines, substations and its facilities are the main sources of extremely low frequency (ELF) magnetic fields which are widespread in the environment [1]. These radiated ELF magnetic fields are referred to as electropollution [2] and have contributed to the level of environmental pollution in the atmosphere in which modern society exists and develops [3]. In Nigeria, the operational frequency of generated electricity is 50 Hz, which falls within the frequency range of 3 to 300 Hz, therefore considered extremely low frequency [4]. The results from epidemiological surveys have established that the intensity of ELF magnetic field from manmade sources is manifold higher when compared to the intensity of naturally occurring sources [5].

The strongest occupational exposure to extremely low-frequency magnetic fields that form the fundamental part of the operating mechanism can be found in work environments where electricity is generated, transmitted or distributed [6]. The systems unexpectedly emit very high ELF magnetic fields, because of the very high electric current densities that result in an accumulating exposure to electromagnetic field [7]. These form part of the reasons why the average magnetic field exposures in the workplace are higher in utility than other occupations [8]. And since a limited number of people are exposed to these fields due to professionalism [9] and the field limits in occupational environments stipulated safety regulations [10]. Pieces of evidence from epidemiological studies of workforces who operate electric power stations [11] have revealed that prolonged and excessive exposure to ELF magnetic field induces an electric field within the human body and if there exist potential differences within, it causes current to flow due to its conductive nature [8]. The biological effects appear to cause or promote certain forms of leukaemia and brain tumours [12]. Because of these, the wide usage of electricity and its associated appliances have raised the question of electropollution and health risks associated with excessive exposure.

The International Agency for Research on Cancer (IARC) relying on the international published literature [13], has classified ELF magnetic fields into category 2B, "possibly carcinogenic to humans" [14], that might transform normal cells into cancerous cells [15]. And to support the claim World Health Organisation (WHO) through the International EMF Project has established the International Commission on Non-Ionising Radiation Protection (ICNIRP) which releases periodically recommendations and the present occupational reference level is set at 1 mT [6]. However, scientists of the International Electromagnetic Fields Alliance (IEMFA), recommend that global governments should adopt lower exposure guidelines of 0.1 μT to protect current public health and that of future generations by reducing exposure limits for radiated electromagnetic fields from electrical power and associated devices [16].

In Nigeria, several studies on ELF magnetic field transmission lines environment have been carried out in recent times, thus, emphasizing the presence of an extremely low-frequency magnetic field. However, from published literature, it was observed that there is scarce research on comparative analysis of the magnitude of ELF magnetic fields in switchyards of generating plants in the study areas. Therefore, it is noteworthy to embark on an exposure assessment of the magnitude of ELF magnetic field in the transmission switchyards using spot measurements technique to fill the existing gap in knowledge. The study was aimed at determining whether the intensity of emitted field lies within the occupational reference thresholds set by ICNIRP. Therefore, there is a need to embark on an exposure assessment of the ELF magnetic field in the switchyard's vicinity to compare the strength and determine the extent of field workforces encountered during duties. Most important since ELF magnetic field cannot be easily screened by the human body because of the resemblance of permeability in both air and skin. Figure 1 indicate the study areas on map of Kogi and Niger State, Nigeria.

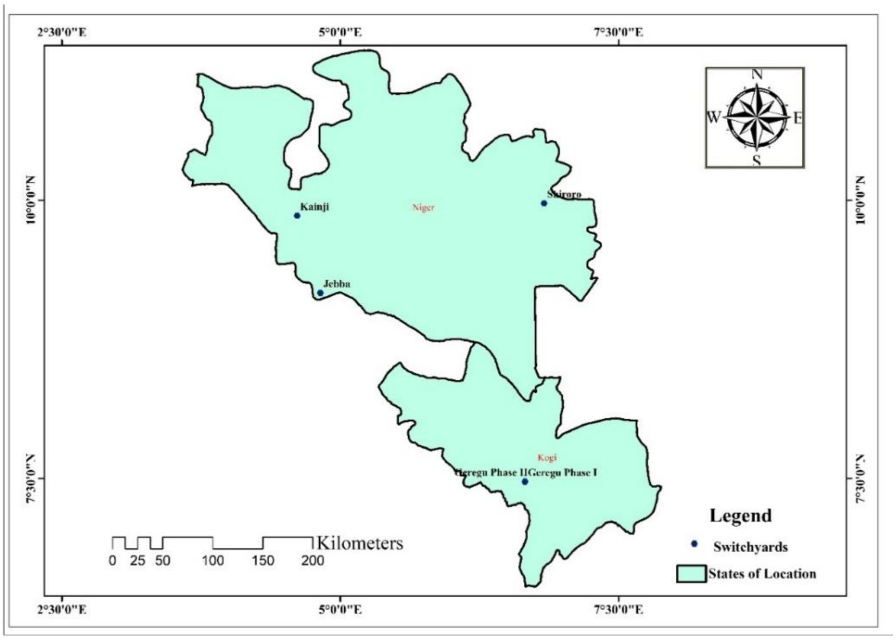

Figure 1. Map of the Study Areas

The study was carried out in switchyards of five 330 kV transmission stations. The stations are 330 kV switchyards of Geregu phase I (7.470116ºN, 6.658052ºE) and Geregu phase II (7.472133ºN, 6.659133ºE) located in Kogi state whose sources of generation are gas plants, and 330 kV switchyards of Kainji (9.861044ºN, 4.613103ºE), Jebba (9.168045ºN, 4.821214ºE) and Shiroro (9.972474ºN, 6.830333ºE) located in Niger state whose sources of generation are hydro plants.

1.2 Governing laws of magnetostatic fields emission

Electric and magnetic fields generated by power systems are usually decoupled because the ELF field varies so slowly in time that Maxwell's equations are generally converted into the electrostatic and magnetostatic equations [17], and their effects on the human body can be studied and computed independently of one another [18]. Magnetostatic is a magnetic field phenomenon produced by steady currents [19]. There are two laws governing the phenomena of magnetostatic field emission in space close to sources: Biot-Savart law and Ampere's circuit law.

Biot-Savart's law: This law is also referred to as the point source model. The current-carrying conductors are modelled as point sources if the length of conductors or conductor spacing is much smaller than the observation distance [11]. The magnetic field of a steady current is expressed by Biot-Savart law as [19]:

$$\vec{B} = \frac{\mu_o}{4\pi}\int\frac{Id\vec{l}\times\hat{r}}{r^2} \quad (1)$$

where is the permeability of free space, is the line current, is a differential element of the conductor in the direction of current, is the distance between an observation point and a source point and is a distance vector. The law specifies the direction and strength of the magnetic field in the vicinity of a current-carrying conductor [20].

Ampere's circuit law: This law is also referred to as the long-conductor source model. The current-carrying conductors are modelled as long-conductor sources if conductors are much larger than the observation distance, as well as if conductor spacing is much smaller than the observation distance [11]. In power systems, magnetic fields occur around the current-carrying conductor [21]. This symmetrical magnetic field generated by current distribution around the conductor can be determined by application of Ampere's law [22]:

$$B = \frac{\mu_o I}{2\pi r} \quad (2)$$

where B is the magnetic field, is the current flow through the long conductor is the permeability of free space and is the circumference of the magnetic field generated by current through a long conductor.

2. Methodology

Measurement of ELF magnetic fields was conducted in the switchyard's vicinity where electrical power infrastructures are installed and magnetic fields are emitted in the process of transmission of electricity.

The instrument used for the measurement of the ELF magnetic field was Extech 480826 triple-axis EMF metre manufactured by Extech Instrument. It was calibrated to a flat frequency response, with a frequency bandwidth of 30 to 300 Hz and a sampling time of approximately 0.4 s. The three modes of selection with corresponding basic accuracy are 20 µT (4 %), 200 µT (5 %) and 2000 µT (10 %), and measured field isotropically with a detachable external magnetic field probe.

The field probe of the Extech 480826 Triple-Axis EMF metre during the measurement of ELF magnetic field was set to 200 µT (5 %) mode of selection and then mounted on a specially designed "field probe stand" constructed to correspond to three observation heights of 1.0, 1.5 and 1.8 metres of interest. The field probe stands along with the mounted sensor were then placed at a successive position in a segmented manner in the switchyard vicinity for the measurement of field intensity and the sensor moved between the various heights for detection before subsequent changes in position were made. The resultant rms vector magnitude of unperturbed extremely low-frequency magnetic field in three orthogonal directions was computed according to Institute of Electrical and Electronics Engineers (IEEE) 644-1994 standards for measurement procedure [23].

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2} \quad (3)$$

After obtaining the field data, the estimated standard for occupational exposure at each position was computed by finding the mean from the three observation heights at each spot of measurement.
The whole data were subjected to One-way analysis of variance (ANOVA) to analyse the significant differences in the strength of ELF magnetic field level in 330 kV switchyards to determine whether the person performing their day-to-day task in each switchyard is exposed to the same level of environmental hazard within the vicinity.
What informed the construction of the field probe stand was to have corresponding uniformity in height for measurement of the field levels throughout the survey, to guarantee the degree of accuracy and stability of field reading.

3. Results and Discussion

After the exclusion of erroneous data that failed to meet the criteria for evaluation, a total of 767 data fields were assessed and analysed for the five 330 kV switchyards of Hydro-plants and Gas-plants. The statistical analysis of the field data was performed using the IBM SPSS Statistics package (IBM version 21.0, USA). The ANOVA with a significant level set at (P - value $\leq .05$) was performed to compare the mean strength of the ELF magnetic field generated between the switchyards with similar infrastructures, which operate at the same highest national voltage level of 330 kV. The essence of using ANOVA for analysis was to determine whether the switchyard influences the level of ELF magnetic field generated within the vicinity.
The assessed results revealed that Shiroro hydro-plant station has the highest standard deviation and the least was obtained in the Geregu phase II gas-plant station for the measured ELF magnetic field, while the highest mean ELF magnetic field appear to occur in the Kainji hydro-plant and the least was in Geregu phase II gas-plant station.

The one-way ANOVA between switchyards was performed with occupational ELF magnetic field as the dependent variable and generation switchyards as the independent variable. The results revealed significant differences between switchyards with Levene's statistic of $F(4,762) = 16.842$, $p < .001$ and, Kainji Hydro-plant switchyard ($N = 170$, $M = 6.18$, $SD = 3.19$) was observed to have the highest mean occupational exposure to ELF magnetic fields, while Geregu Phase II Gas-plant switchyard ($N = 125$, $M = 2.94$, $SD = 2.43$) was observed to have the least occupational exposure to ELF magnetic field. Since Levene's statistical test was significantly different at ($p < .001$), therefore, the assumption for homogeneity of variance has been violated. So, the Null Hypothesis "there was no significant difference in occupational ELF magnetic field exposure level in 330 kV switchyards of both hydro-plants and gas-plants" stand rejected. The Welch robust test of equality of mean was then employed for the analysis because it is robust to violation of homogeneity of variances. The Welch robust test of equality of mean demonstrated that the switchyard's occupational exposure to ELF magnetic field level had statistically significant differences of ($p < .001$) between them.

Table 1 presents a summary of descriptive statistics, the Test for Homogeneity of Variance, the Robust test of Equality of Means and the Games-Howell Post Hoc test of Multiple Comparisons of occupational exposure to ELF magnetic field level in the 330 kV

Table 1.Statistical Descriptive Data and Games-Howell Post Hoc Test in 330 kV Switchyards for ELF Magnetic Field Measurements

Descriptive Statistics				**Test of Homogeneity of Variance**		**Robust Tests of Equality of Means**	
330 kV Switchyard	**N**	**Mean μT**	**Std. Deviation**	**Levene Statistics**	**Sig.**	**Welch**	**Sig.**
Shiroro Hydro-plant	183	5.0555	4.76172	16.842	.000	31.885	.000
Jebba Hydro-plant	164	5.7843	3.28311				
Kainji Hydro-plant	170	6.1780	3.18878				
Geregu Phase I Gas-plant	124	3.9473	3.21017				
Geregu Phase II Gas-plant	126	2.9426	2.42697				

330 kV Switchyards of Generation Stations		**Mean Difference**	**Sig.**	**95% Confidence Interval**	
				Lower Bound	**Upper Bound**
Shiroro Hydro-plant	Geregu Phase II Gas-plant	2.11285	.000	.9788	3.2469
Jebba Hydro-plant	Geregu Phase I Gas-plant	1.83699	.000	.7775	2.8965
	Geregu Phase II Gas-plant	2.84171	.000	1.9211	3.7624
Kainji Hydro-plant	Geregu Phase I Gas-plant	2.23066	.000	1.1923	3.2690
	Geregu Phase II Gas-plant	3.23538	.000	2.3394	4.1314
Geregu Phase I Gas-plant	Geregu Phase II Gas-plant	1.00472	.045	.0139	1.9956

* The mean difference is significant at the 0.05 level

To determine the specific groups that differed in exposure levels, a Multiple comparison of Game-Howell Post Hoc tests was performed by assuming nonequality of variances for the five switchyards to identify which switchyard are significantly different from the other. As revealed in Table 1, the mean and 95% confidence intervals for emission level demonstrated Jebba hydro-plant and Kainji hydro-plant switchyards to have statistically significant differences of ($p < .001$) when independently compared to both Geregu phase (I & II) gas-plant switchyards, while Shiroro hydro-plant revealed a significant difference of ($p < .001$) with Geregu phase II gas-plant and, a significant difference of ($p = .045$) was observed between switchyards of Geregu phase I and Geregu phase II gas-plant. However, no significant differences were observed between the switchyards of the Shiroro, Jebba and Kainji hydro plants when compared with each other and between the switchyards of the Shiroro hydro plant and Geregu Phase I gas plant. The means occupational exposure to ELF magnetic field in 330 kV switchyards of Kainji hydro-plant (6.18 μT), Jebba hydro-plant (5.78 μT) and Shiroro hydro-plant (5.06 μT) were found to be significantly high when compared to 330 kV switchyards of Geregu phase I (3.95 μT) and Geregu phase II (2.94 μT). However, these exposure levels are still far below the expected set limit of 1 mT for occupational exposure stipulated by ICNIRP. These results have revealed that the workforces operating in switchyards at a voltage level of 330 kV are not exposed to the same level of ELF magnetic field. Medical research has shown that exposure to ELF magnetic fields above safe limits can have a significant detrimental effect on health. Short-term exposure might cause nervous system disorder, abnormal cell activity, muscle pain and other effects while long-term exposure might cause a risk of neurodegenerative diseases [24]. Further studies revealed that it causes physiological changes in human tissues [25], like neurological, and cardiovascular disorders and low sperm count in workers [26] because the nervous system has bioelectric properties that make it more susceptible to the effects of electromagnetic fields [27]. Suri *et al*. carried out a cross-sectional study among male employees of different units of the selected power plant, the time-weighted average exposure to ELF magnetic field revealed that there was no significant statistical correlation between ELF exposure and reproductive hormone level [28]. However, it was reported that the possible effects on health are supported by the suggestion by WHO and IARC that exposure to time-weighted average (TWA) of ELF magnetic field levels above 0.3 μT increases the probability of leukaemia [29].

4. Conclusion

The One-way ANOVA performed for the five 330 kV switchyards of Hydro-plants and Gas-plants to analyse the density of ELF magnetic fields in the studied locations revealed that there exists a significant difference in occupational exposure levels between switchyards. Though the level of ELF magnetic field magnitude in the study areas is lower than the ICNIRP recommended permissible set limits of 1 mT for occupational exposure, there still exists variation in exposure between the switchyard field levels encountered by the workforce. With government efforts for stability in power supply, the ELF magnetic field in the switchyards is expected to rise in future with increased load demand. Therefore, it is advisable that priority to constant monitoring of field levels to detect high-risk zone for possible avoidance of prolonged exposure for a safe working environment.

Nomenclature

F	F-Statistics
M	Milli
M	Mean
N	Number
P	Probability
SD	Standard deviation
T	Tesla

Greek letters

μ	Micro
μ_o	Permeability of free space

References

[1] D. Urban, L. Tjong and K. Karipidis (2014). Measurement of extremely low frequency electric and magnetic fields associated with electricity supply and distribution infrastructure. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), 619 Lower Plenty Road, Yallambie, Melbourne.

[2] I. J. Al-Faqeeh, M. Abu-Jafar and I. R. Abdelraziq (2015). The effect of the electromagnetic radiation from high voltage transformers on students health in Hebron district. International Journal of Geology, Agriculture and Environmental Sciences. Vol. 3(1), pp. 75–81.

[3] H. Jalilian, K. Najafi, M. R. Monazzam, Y. Khosravi and Z. Zamanian (2017). Assessment of static and extremely low-frequency magnetic fields in the electric-powered trains. International Journal of Occupational Hygiene. Vol. 9(2), pp. 105–112.

[4] P. Rathebe, C. Weyers and F. Raphela (2018). Exposure levels of ELF magnetic fields in the residential areas of Mangaung metropolitan municipality," Environ Monit Assess. Vol. 190(544), pp. 1–9.

[5] Sudarti, L. Nuraini, T. A. Saleh and T. Prihandono (2014). The analysis of extremely low frequency (ELF) electric and magnetic field exposure biological effects around medical equipments. International Journal of Advanced Engineering Research and Science (IJAERS). Vol. 5(7), pp. 289–296.

[6] R. Stam (2014). The Revised Electromagnetic Fields Directive and Worker Exposure in Environments with High Magnetic Flux Densities. Annal of Occupational Hygiene. Vol. 58(5), pp. 529–541.

[7] S. Özen (2008). Evaluation and measurement of magnetic field exposure at a typical high-voltage substation and its power lines. Radiation Protection Dosimetry. Vol. 128(2), pp. 198–205.

[8] G. Kulkarni and W. Z. Gandhare (2012). Proximity effect of high voltage transmission lines on humans. ACEEE Int. J. on Electrical and Power Engineering, Vol. 3(1), pp. 28–32.

[9] M. Kokoruš, S. Delić, A. Mujezinović, M. Muratović and A. Čaršimamović (2014). Analysis of the possible solutions for the reduction of electric and magnetic fields near 400 kV overhead transmission lines. Environmental Impact II. Vol. 181, pp. 225–236.

[10] R. W. Habash (2001). Electromagnetic fields and radiation: Human bioeffects and safety. CRC Press, Ottawa, Ontario, Canada.

[11] I. O. Habiballah, M. M. Dawoud, K. Al-Balawi and A. S. Farag (2003). Magnetic field measurement & simulation of A 230 kV substation. Proceedings of the International Conference on Non-Ionising Radiation at UNITEN (ICNIR 2003) Electromagnetic Fields and Our Health, Kuala Lumpur, Malaysia.

[12] L. Battistelli, A. Geri and G. Veca (2005). Magnetic field shielding of underground power cables in urban areas: A real-life example. Boundary Elements, Vol. XXVII(39), pp. 527–540.

[13] C. Roldán-Blay and C. Roldán-Porta (2020). Quick calculation of magnetic flux density in electrical facilities. Applied Sciences, Vol. 10(891).

[14] International Agency for Research on Cancer [IARC] (2012). IARC monographs on the evaluation of carcinogenic risks to humans: Non-ionising radiation, part 1, static and extremely low frequency (ELF) electric and magnetic fields. IARCPRESS, Lyon, France.

[15] H. Liu, G. Chen, Y. Pan, Z. Chen, W. Jin, C. Sun, C. Chen, X. Dong, K. Chen, Z. Xu, S. Zhang and Y. Yu (2014). Occupational electromagnetic field exposures associated with sleep quality: A cross-sectional study. PLOS ONE, Vol. 9(10), pp. e110825.

[16] O. Johansson, A. Fragopoulou, Y. Grigoriev, L. Margaritas, L. Morgan, E. Richter and C. Sage (2011). The Seletun Scientific Statement. The International Electromagnetic Fields Alliance [IEMFA], Oslo, Norway.

[17] W. Tourab and A. Babouri (2015). Measurement and modelling of personal exposure to the electric and magnetic fields in the vicinity of high voltage power lines. Safety and Health at Work (SH@W), vol. 7(2016), pp. 102–110.

[18] A. Laissaoui, B. Nekhoul, K. Kerroum, K. K. Drissi and D. Poljak (2013). On the rotationally-cylindrical model of the human body exposed to ELF electric field. Progress in Electromagnetics Research M, Vol. 29, pp. 165–179.

[19] D. J. Griffiths [1999]. Introduction to Electrodynamics, 3rd ed., R. Alison and D. Kim, Eds., New Jersey: Prentice Hall, Upper Saddle River, New Jersey 07458.

[20] I. N. Ztoupis, I. F. Gonos and I. A. Stathopulos (2013). Calculation of power frequency fields from high voltage overhead lines in residential areas. Paper presented at the 18th International Symposium on High Voltage Engineering, Seoul, Korea.

[21] C. Kocatepe, C. F. Kumru and E. Taslak (2014). Analysis of magnetic field effects of underground power cables on human health. Paper presented at the 5th International Symposium on Sustainable Development (ISSD 2014), Sarajevo, Bosnia and Herzegovina.

[22] N. O. M. Sadiku (1989). Elements of Electromagnetics, 3rd ed., Philadelphia, US: Saunders.

[23] Institute of Electrical and Electronics Engineers [IEEE] Standards Coordinating Committee 39 (2010). IEEE recommended practice for measurements and computations of electric, magnetic and electromagnetic fields with respect to human exposure to such fields 0 Hz to 100 kHz. IEEE 3 Park Avenue, New York, NY 10016–5997, USA.

[24] N. Raghu, M. N. Krishna, K. Nagendra and V. N. Trupti (2017). Survey of electromagnetic field near EVH lines and their health hazards. Paper presented at the International Conference on Smart Grids, Power and Advanced Control Engineering (ICSPACE2017), Bangalor, India.

[25] S. Bhattacharjee (2014). Protective Measures to Minimize the Electromagnetic Radiation. Advance in Electronic and Electric Engineering, Vol. 4(4), pp. 375–380.

[26] O. Aliyu, I. Maina and H. Ali (2012). Analysis of electromagnetic pollution due to high voltage transmission lines. Journal of Energy Technologies and Policy, Vol. 2(7), pp. 1–10.

[27] J. Huang, T. Tang, G. Hu, J. Zheng, Y. Wang, Q. Wang, J. Su, Y. Zou and X. Peng (2013). Association between exposure to electromagnetic fields from high voltage transmission lines and neurobehavioral function in children. PLoS ONE, Vol. 8(7), pp. 1–10.

[28] S. Suri, S. F. Dehghan, A. S. Sahlabadi, S. K. Ardakani, N. Moradi, M. Rahmati and F. R. Tehrani (2020). Relationship between exposure to extremely low-frequency (ELF) magnetic field and the level of some reproductive hormones among power plant workers. *Journal of Occupational Health*, *V*ol. 62(e12173).

[29] World Health Organisation [WHO] (2007). Exposure to Extremely Low Frequency Fields. WHO|Electromagnetic fields and public health.