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Electromagnetic Radiation Dose Exposure and Current Densities for Human Tissues at Dan'agundi Power Sub-Station, Kano, Nigeria

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Abstract
This paper presents an estimation of Extremely Low Frequency (ELF) exposure of Magnetic field and the associated currents density at Dan'agundi power substation. The electromagnetic field radiation dose expose to workers at the 33/11kV injection substation control room and the hawkers outside the entire power substation was calculated. Also currents densities across human Lung and Liver are determined. The readings of the electromagnetic field at the 33/11Kv injection substation control room and around the entire substation were taken in the morning, afternoon and evening using a hand held device called Electromagnetic Field Radiation (EMFR) Tester. All the result obtained were compared to the International Standard Exposure Limits (ISEL) and it was found that the workers in the control room of the Injection substation area and the immediate vicinity of substation area are within safe limits as magnetic field and the current density.

Keywords: Extreme low frequency, Magnetic field, EM field radiation and Current density.

INTRODUCTION
The electrical substations are used to step-up or step-down the generated voltage from generating stations to receiving stations as transmission of electrical power. The substations are mainly used to step down voltage and transmit electrical power. The electromagnetic fields at these substations can be harmful to living beings. The electricity is mainly generated at the remote locations of a country. The generated power is to be transmitted from remote location to the residential areas. Therefore, the generated power is transmitted through overhead lines with support of the transmission towers.(Raghu N,;Krishna Murthy,; Nagendra K,; Trupti V N., 2015)

Background radiation (which scientists call "ubiquitous" because it is everywhere) is emitted from both natural and human-made radioactive sources. Humans are continuously irradiated by sources outside and inside our bodies. Some naturally occurring radiation comes from the atmosphere as a result of radiation from outer space, some comes from the earth, and some is even in our bodies from radionuclides in the food and water we ingest and the air we breathe. Natural background radiation is the largest source of radiation exposure to humans (about 50 percent). However, medical sources of radiation exposure are almost as large (about 48 percent). The remaining 2 percent comes from consumer products, occupational exposure,

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and industrial exposure. A small fraction of this 2 percent comes from the operation of nuclear power plants.

Helheland Ozen (2008) reported that the standard EMF values given by the ICNRP is 500 μT for occupational exposure and 100 μT for the general public. Also report Operator desks at the three different substations read a lowest magnetic field of 0.3 μT at minimum loaded season and reached up to 1 μT at maximum loaded season, which means that operators are exposed to a magnetic field of ≥0.3 μT for 8 h per day. For the chosen substations, under the normal load conditions, a maximum magnetic field of 40 μT is measured at the 31.5 kV main bus and in the substation of the Free Trade Zone. The maximum values of the measured magnetic fields were below the standard level of ICNIRP, 500 μT for occupational."

Karabetsos, Skamnakis, Xenoulis, Gourzoulidis, Skourias and Axtypis (2013) reported regardless of electric and magnetic fields produced in the vicinity of high voltage substations, the measurements have shown that the equipment installed into the substation does not produce any significant values of electric and magnetic fields outside the substation and in the power lines connected to it, produces the levels of electric and magnetic fields measured in the vicinity of the substations. The measurements verified also that far from the power lines there are insignificant levels of fields, whereas close to the power lines the typical electric and magnetic field levels in the vicinity of the corresponding lines were found to be within safe level. MarinkoStojkov, DamirSljivac and Lajos Jozsa (2010) reported thatelectric and magnetic field radiate by the transformer station 35/10 kV that all values are within the permissible limits of legislation, even for unlikely case of human residential exposure during 24h per day.Safigianni, and Tsompanidou (2009) reported the measured field values are substantially within recognized guidelines and are not dangerous and, therefore, are no cause for concern among the public or working personnel.

Alzyoud, Abuzalata and Al-Mofleh (2011) reported that electromagnetic field strength values under HV line depends mainly on cross-arm height of conductors. Dependence on other parameters such as distance between conductors and conductor radius is small even over wide range of parameters. Conductor arrangement and phase sequence in multiple-circuit lines have considerable effect, especially on spatial distribution of field strength. Field strength variations can reach 10-20 or even tens of percent. Field distribution under the line is almost uniform to the height 2.5-3.5 m above the ground. Ozen (2007) reported that Operators' rooms including operators' tables read magnetic fields between 0.5 and 0.8 μT. The maximum global magnetic field measured inside the 380/154 kV substation under normal load condition is 20 μT for outdoors and 65 μT for 34.5 kV for the control room. The substation's outdoor magnetic field varies between 3.03 and 20 μT, whereas the control rooms read a magnetic field of 1.3–60 μT. Measurement of the magnetic field made around the power transformers show that the secondary transformer reads higher magnetic fields as expected, and the magnetic field level can reach the higher levels depending on load demand. Around the power lines passing through the residential area, the maximum magnetic field value to which the human is exposed increases by 50% (from 3 to 4.5μT for 154 kV) when changing the position from tower to flux region. That variation is 83% for 380 kV from 3.4 to 6.2 μT. These data show that occupants are exposed to rather high-magnetic fields, especially in 31.6– 33.6 kV control rooms, as compared with than other places in the substations. However, all the cases in this research related to occupational and public exposure at a 380/154 kV substation and its power transmission lines. Raghu, Krishna Murthy, Nagendra, and Trupti (2015) reported that, the measurements show that in the immediate vicinity of substation where people are habituated the levels of radiation show that the area is within safe limits as far electric field is considered

but the magnetic field is beyond safe level. FalahNoori Ahmed (2015) reported that both workers and residents are within the safe limit.
The paper is aimed at reporting the amount of electromagnetic radiation exposure by the workers and hawkers under 33/11KVA Dan'agundi power station using Electromagnetic field radiation tester (PCE-EMF823). The current densities across human body were also calculated.

Mathematical Calculations
Magnetic field intensity can be evaluated using image and shadow method. So, the quasi-static magnetic field of a line source in free space above earth is equivalent to the magnetic field of the line source plus a "complex image" in free space. The magnetic field intensity at the point P is obtained by considering the contribution of all conductors, assuming parallel lines over a flat earth A line conductor is located at $(x_i; y_i)$ with electric current of I_i. The intensity of the magnetic field due to a very long conductor can be calculated according to Savart law as;

$$H = \frac{I}{2\pi r}\ (\mathrm{A/m}) \qquad (1)$$

Where H is the magnetic field intensity (A/m), I is current flowing through the conductor (A) and ris the radial distance to the destination point (m).

Calculations
Exposure to external electric and magnetic fields at extremely low frequencies induces electric fields and currents inside the body. Dosimetry describes the relationship between the external fields and the induced electric field and current density in the body, or other parameters associated with exposure to these fields. The locally induced electric field and current density are of particular interest because they relate to the stimulation of excitable tissue. The bodies of humans and animals significantly perturb the spatial distribution of an ELF electric field. At low frequencies the body is a good conductor and the perturbed field lines outside the body are nearly perpendicular to the body surface. Oscillating charges are induced on the surface of the exposed body and these induce currents inside the body.
For magnetic fields, the permeability of tissue is the same as that of air, so the field in tissue is the same as the external field. The bodies of humans and animals do not significantly perturb the field. The main interaction of magnetic fields is the Faraday induction of electric fields and associated current densities in the conductive tissues.
The internal electric field and current are related by Ohms Law

$$J = \sigma E \ldots\ldots\ldots\ldots\ldots (1)$$

Where is the tissue conductivity (s/m).
The induced electric field of an equivalent circular loop corresponding to a given human counter is given as

$$E = \pi \mathrm{fRB} \ldots\ldots\ldots\ldots\ldots (2)$$

Equation (2) is frequently employed in estimating induced electric field in animal bodies and cell cultured but will give only approximation results because biological tissue is neither cylindrical nor electrically homogeneous. (NIEHS, 1998)
∴Equation (1) becomes

$$J = \sigma \pi \mathrm{fRB} \ldots\ldots\ldots\ldots\ldots (3)$$

Where
J is the current density (A/m^2), E is the induced electric field strength, R is the radius of the loop for induction of the current (m), f is the ELF magnetic field (f=50-60Hz) and B is the magnetic flux density (T)

MATERIALS AND METHODS

Location

The Substation is located at Kofar Dan Agundi in Kano State (Kano Municipal), along BUK road at the right hand side while Sharada Road in front and lies within coordinates 11° 35' 42" N and 8° 35' 42" E in the tropical savanna belt of Nigeria sitting approximately 534m above sea level.

Figure 1. Satellite view of Dan'agundi power substation. (Google Earth)

Materials

The materials used to measure the magnetic field are EMF tester (PCE-EMF 823), Tape rule and a wooden peg.

Methods

The readings of the electromagnetic field at the 33/11kV injection substation were taken in the morning (Peak load period),at the afternoon and in the evening (off-peak period). A hand held device Electromagnetic Field Radiation (EMF) Tester was used. The EMF tester is a hand held instrument designed and calibrated to measure electromagnetic field radiation at different bandwidths down to 50Hz/60Hz and also, used to take electromagnetic radiation levels around transformers, power lines, home appliances and industrial devices. It has three measuring ranges of 20 μT Tesla/200 μT/2000 $\mu T$and 200 mG/2000 mG/20000 mG It also records maximum and minimum readings with recall.

Four measurements were taken at a distance of 2.5m from the two transformers, two measurements were taken from the outdoor line breaker of the TR2 at a distance of 2m which is only 4.5m at the back of the TR2 and also, the outdoor line breaker of the TR1 is situated at Transmission area, therefore measurements were not taken at it. And three measurements were taken inside the substation from the injection substation control room at a distance of 4m.

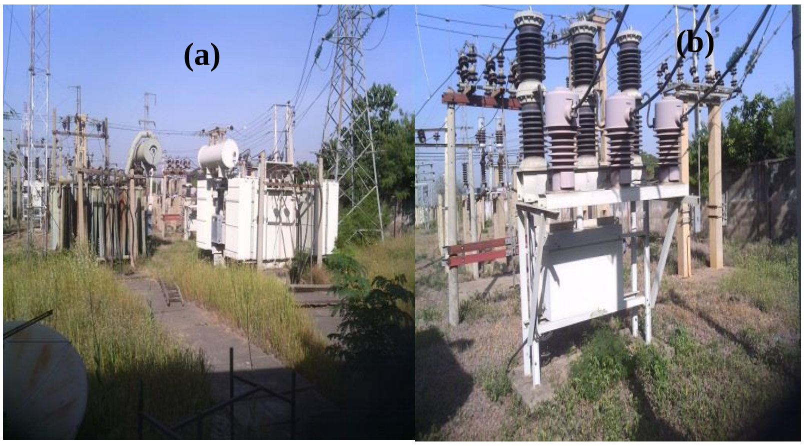


Figure 2. (a) Left TR1 and Right TR2 (b) TR2 Out-door Line Breaker

The control room is divided into two parts, the first part is where the two transformers control panels and the operators table is situated and the second part is where the Indoor line breaker which is having only 4m gap between the door and it. Four measurements were taken from the indoor line breaker at a distance of 1m, also measurements were taken at the operators table, in front of the control panels of the two transformers and the corridor of the control room which comprises of the toilet and operators resting room.

Figure3. (a) Injection Substation Control Room (b) TR1 and TR2 Control Panels

(a)

(b)

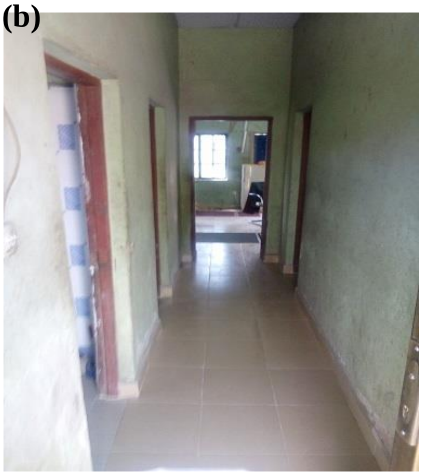


Figure 4. (a)Control Room Corridors Figure (b) Indoor Line Breaker

Outside the entire substation, measurements were taken in front of the substation, right hand side of the substation and at the back of the substation where people such as Mechanics, Hawkers etc. are situated.

Figure 5. (a) Right hand side of the substation (b) Front of the substation

RESULTS

In the morning, the measurements were taken when the transformer TR1 was at 330Amps (ie. The mean load was 330Amp which is equivalent to 5.5MW) and Transformer TR2 was off-load.

Table 1. Measurements Taken at the Injection Substation Area in the Morning (M), Afternoon (A) and Evening (E)

S/N	POSITIONS	DISTANCE (m)	MAX. VALUE (µT)			MIN. VALUE (µT)		
			M	A	E	M	A	E
1	TR1	**2.5**	**278.00**	**145.00**	**231.20**	**67.40**	**116.20**	**210.80**
		5.0	114.82	128.80	166.00	58.80	59.20	88.60
		7.5	47.20	93.60	65.40	15.60	53.80	29.00
		10.0	23.60	90.20	56.20	2.20	45.0	5.80
2	TR2	2.5	81.80	190.80	308.80	31.4	97.80	152.00
		5.0	49.40	62.60	154.40	22.60	22.60	96.20
		7.5	30.40	35.80	38.60	20.00	22.60	22.60
		10.0	14.20	31.60	31.60	8.80	1.20	2.00
3	From the control room	4.0	29.60	49.00	30.80	0.40	6.80	10.00
		8.0	33.60	38.40	33.60	0.60	12.60	5.00
		12.0	28.00	38.00	26.20	4.80	11.60	2.00
4	TR2 Outdoor Line-Breaker	2.0	28.80	80.0	51.80	12.40	46.40	37.40
		4.0	22.60	49.00	50.40	11.20	41.00	32.40

Table1 shows the maximum and minimum values of magnetic field measured in the morning, afternoon and Evening at the various positions and distances. It was observed that there is higher emission of EMF from TR1 at 2.5 m distance in the morning, afternoon and evening and decreases as the distance increases.

Table 2. Indoor Line-Breaker Area in the Morning (M), Afternoon (A) and Evening (E)

DISTANCE (m)	MAX. VALUE (µT)			MIN. VALUE (µT)			AVE. VALUE (µT)		
	M	A	E	M	A	E	M	A	E
1	50.40	116.80	108.80	7.00	7.40	8.60	28.70	62.10	58.70
2	35.60	70.80	59.20	6.00	9.40	6.40	20.80	40.10	32.8
3	14.40	49.20	35.80	0.00	0.00	6.80	7.02	24.60	21.3
4	5.80	43.8	33.40	0.00	0.00	2.00	2.90	21.90	17.7

Figure 6. Plot of Magnetic field versus Distance of the Indoor line breaker (a) in the morning (b) in the Afternoon (c) in the Evening

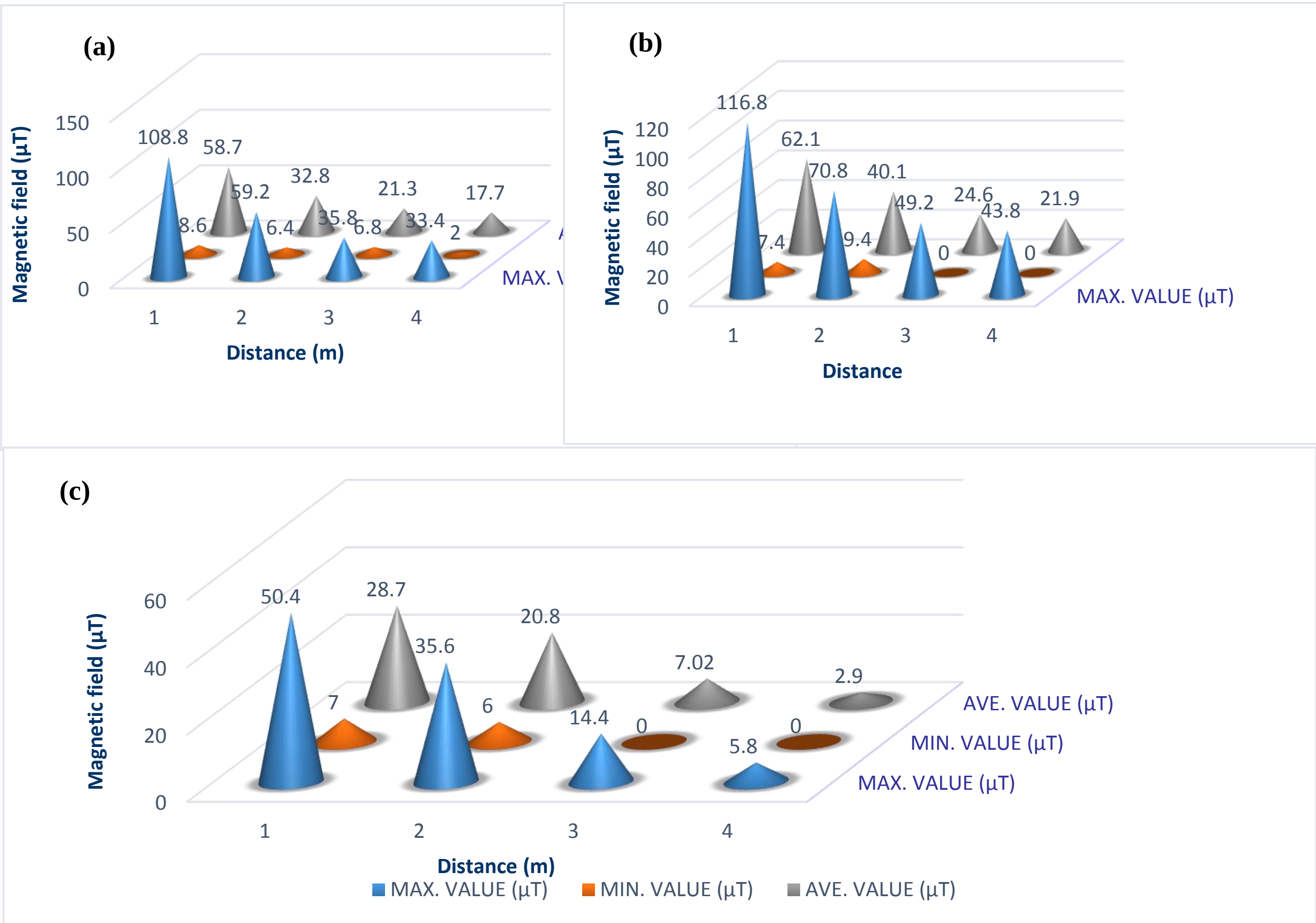


Table 2 shows the distances from the Indoor-line breaker and maximum, minimum and the average measured values of the magnetic field in the morning, afternoon and evening and figure 6 shows the graph for the corresponding values.

Table 3. Measurements Taken Within the Control Room Area in the Morning (M), Afternoon (A) and Evening (E)

S/N	POSITION	MAX. VALUE (μT)			MIN. VALUE (μT)			AVE. VALUE (μT)		
		M	A	E	M	A	E	M	A	E
1	In front of the TR1 and TR2 control panels	12.20	8.80	2.80	0.20	0.00	0.00	6.20	4.40	1.40
2	Operators table	12.60	9.60	5.40	3.80	3.00	0.00	8.20	6.3	2.70
3	Corridor	9.80	21.60	18.20	1.60	1.40	0.40	5.70	11.5	9.45

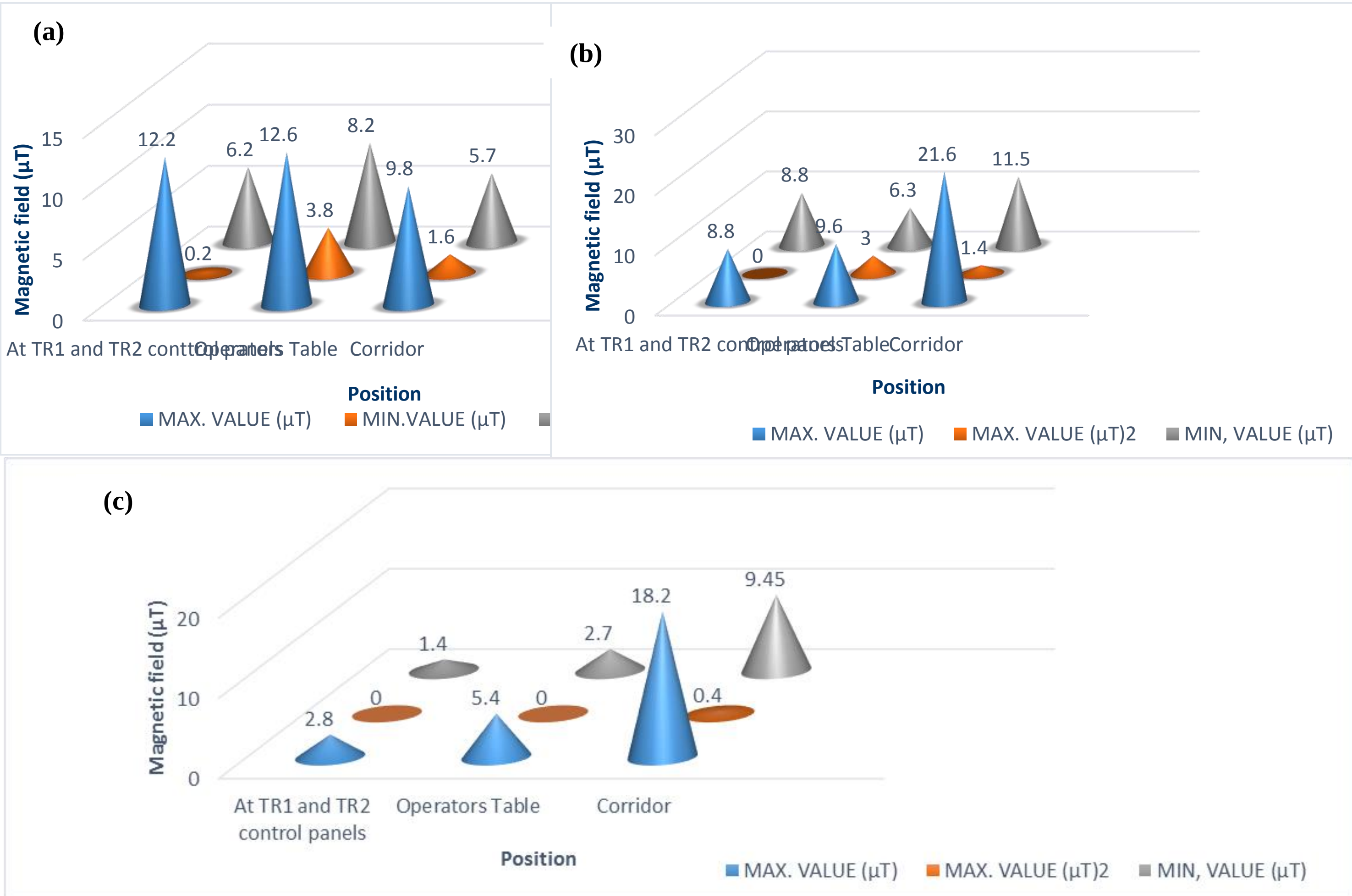
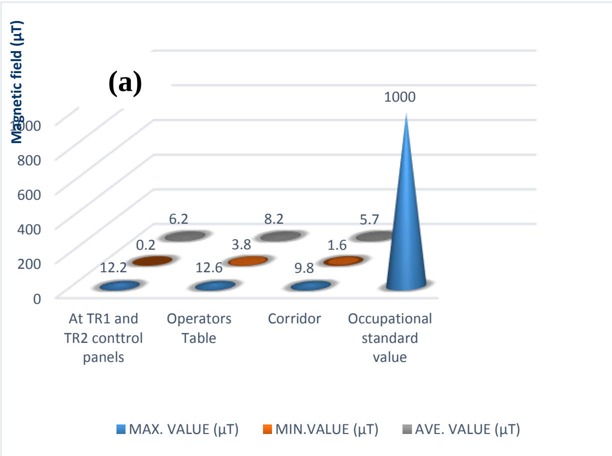


Figure 7. Plot of Magnetic field versus Position within control room (a) in the Morning (b) in the Afternoon (c) in the Evening

Table 3 shows the measured values taken within the control room of the substation and their positions and figure 7 shows the result.



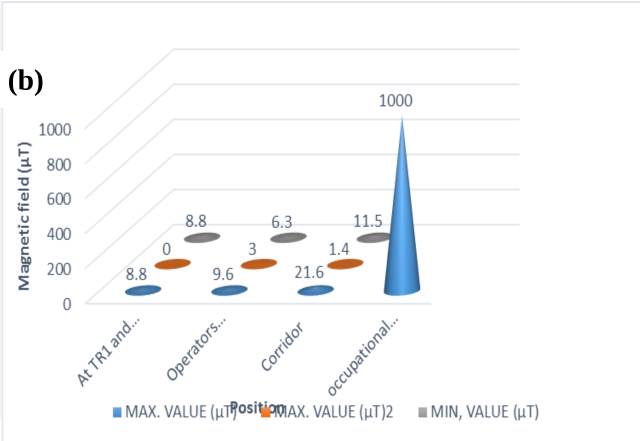


Figure 8.Comparison of the EMF absorbed with International standard for the values obtained (a) in the Morning (b) in the Afternoon (c) in the Evening

(c)

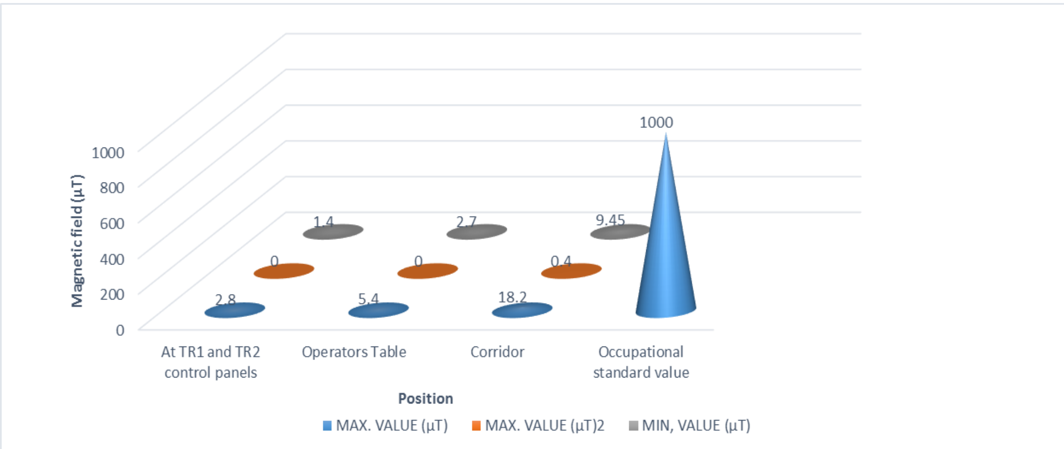


Table 4. Measurements Taken Outside the Entire Substation

S/N	POSITIONS	MAX. VALUE (µT)			MIN.VALUE (µT)			AVE. VALUE (µT)		
		M	A	E	M	A	E	M	A	E
1	In front of the substation	70.80	33.40	27.60	0.00	0.00	0.00	35.40	16.70	13.8
2	Right hand side of the substation	37.00	46.40	49.00	0.00	0.00	0.00	18.50	23.2	24.5
3	Back of the substation	31.60	46.60	86.40	0.00	0.00	0.00	15.80	23.3	43.2

Table 4 shows the measured values of the magnetic field and their respective positions taken outside the substation in the morning, afternoon and evening.

In the afternoon, the measurements were taken when the mean load of TR1 was 630Amp (which is equivalent to 10.5MW) and Transformer TR2 was 330Amp (5.5MW).In the evening, the measurements were taken when the mean load of TR1 was 610Amp and Transformer TR2 was 360Amp.

There were fluctuations encountered when taking the measurements of the magnetic field due to the incoming 132kV overhead lines to the part of the Transmission substation area and the outgoing 33kV overhead lines to some of the other Injection substations across the state (from fig.3 (a) as some of the overhead lines over the injection substation control room can be seen).

Table 5. Data of Some Human Organs

Organ	Vol.(cm^3)	Conductivity (s/m)	Equivalent radius (cm)	Mass density (kg/m^3)
Lung	3900	0.10	9.76	170
Liver	3200	0.10	9.14	470
Brain	810	0.70	5.78	1700
Heart	280	0.70	4.06	1000
Kidney	175	0.10	3.47	860
Spleen	294	0.03	4.12	680

(Abd-Allah, 2006)

Table 6. Indoor line breaker Conductivity (σ) = 0.10, Equivalent radius (R) = 9.76(cm)= 0.0976m ($J = \sigma\pi fRB$)and $f = 50\ Hz$

Time	Distance	Max.Value (μA/m^2)	Min.Value (μA/m^2)	Ave.Value (μA/m^2)
Morning	1m	77.30	10.70	44.0
	2m	54.58	9.19	31.89
Afternoon	1m	179.00	11.34	95.17
	2m	108.54	14.41	61.47
Evening	1m	166.80	13.20	90.00
	2m	90.80	9.81	50.31

Table 7. Within and Outside the Substation

Time	Position	Max.Value ($\mu A/m^2$)	Min.Value ($\mu A/m^2$)	Ave. Value ($\mu A/m^2$)
Morning	Infront of the control panels	18.70	0.31	9.51
	Operators Table	19.32	5.83	12.58
	Corridor	15.02	2.45	8.74
	Infront of the substation	108.54	0.00	54.27
	Right hand side of the substation	56.70	0.00	28.35
	Back of the substation	48.50	0.00	24.25
Afternoon	Infront of the control panels	13.50	0.00	6.75
	Operators Table	14.70	5.60	10.15
	Corridor	33.10	2.15	17.63
	Infront of the substation	51.20	0.00	25.6
	Right hand side of the substation	71.10	0.00	35.55
	Back of the substation	71.40	0.00	35.70
Evening	Infront of the control panels	2.29	0.00	1.15
	Operators Table	8.26	0.00	4.13
	Corridor	27.90	0.62	14 26
	Infront of the substation	42.30	0.00	21.15
	Right hand side of the substation	75.12	0.00	37.56
	Back of the substation	132.46	0.00	66.23

Table 6 shows the result of the calculated induced current density across the Lung of a person at the indoor line breaker from morning to evening and it has a max. of 179$\mu A/m^2$ and min. of 9.19 $\mu A/m^2$, and Table 15 shows the values within the control room and outside of the substation.

Induced Currents across Liver; Conductivity (σ)= 0.10, Equivalent radius (R)= 9.14(cm)=0.0914m and f = 50Hz

Table 8. Induced Currents across Liver in Indoor line breaker with Conductivity (σ) = 0.10, Equivalent radius (R) = 9.14(cm)=0.0914m ($J = \sigma \pi f R B$) and $f = 50\ Hz$

Time	Distance	Max.Value ($\mu A/m^2$)	Min.Value ($\mu A/m^2$)	Ave.Value ($\mu A/m^2$)
Morning	1m	72.40	10.00	41.20
	2m	51.10	8.61	29.86
Afternoon	1m	168.00	10.60	89.30
	2m	102.00	13.50	57.75
Evening	1m	156.00	9.19	82.60
	2m	85.00	9.19	47.10

Table 9. Within and Outside the Substation

Time	Position	Max.Value ($\mu A/m^2$)	Min.Value ($\mu A/m^2$)	Ave. Value ($\mu A/m^2$)
Morning	Infront of the control panels	17.50	0.29	8.90
	Operators Table	18.10	5.46	11.78
	Corridor	14.10	2.29	8.20
	Infront of the substation	102.00	0.00	51.00
	Right hand side of the substation	53.10	0.00	26.50
	Back of the substation	45.4	0.00	22.70
Afternoon	Infront of the control panels	12.60	0.00	6.30
	Operators Table	13.80	4.31	15.96
	Corridor	31.00	2.01	16.51
	Infront of the substation	48.00	0.00	24.00
	Right hand side of the substation	66.60	0.00	33.30
	Back of the substation	66.90	0.00	33.45
Evening	Infront of the control panels	4.02	0.00	2.01
	Operators Table	7.75	0.00	3.88
	Corridor	21.10	0.57	21.49
	Infront of the substation	39.60	0.00	21.20
	Right hand side of the substation	70.40	0.00	35.20
	Back of the substation	124.00	0.00	62.00

Table 8 shows the result of the calculated induced current density across the Liver of a person at the indoor line breaker from morning to evening and it has a max. of 179μA/m^2 and min. of 9.19 μA/m^2, and Table17 shows the values within the control room and outside of the substation.

The magnetic field measured within the control room where the occupant spend 24 hrs of working were found out to vary from minimum of 0μT to maximum of 116.8μT at the indoor line breaker, at the control panels of the two transformers, it ranges from 0μT to 12.2 μT, from 0μT - 12.6 μT at the operators table, and also at the corridor where the operators resting room and toilet is ranges from 0.1μT -21.6μT.

Also, around the entire substation where hawkers, mechanics and others are making business, the magnetic field ranges from 0μT-70.8μT at the front of the substation, from 0μT-49μT at the right hand side of the substation, and from 0μT-86.4μT at left hand side of the substation.

The estimated induced current densities J in the human lung using ohm's law is as presented in Table 8 of 1m and 2m for the Indoor line breaker and it has a max. of 179μA/m^2 and min. of 9.19μA/m^2, and Table 15 presents the values within the control room and has a max. of 33.10μA/m^2at the corridor and min. of 0.00 μA/m^2 and outside the substation area which has a max. of 132.46 μA/m^2at the back of the substation and a min. of 0.00 μA/m^2.

Also, the estimated induced current densities J in the human Liver which has an equivalent radius of 9.14cm using ohm's law is as presented in Table 9 of 1m and 2m for the Indoor line breaker and it has a max. of 168μA/m^2 and min. of 8.61μA/m^2, and Table 17 presents the values within the control room and has a max. of 31μA/m^2at the corridor and min. of 0.00 μA/m^2 and outside the substation area which has a max. of 124 μA/m^2at the back of the substation and a min. of 0.00 μA/m^2.

CONCLUSION

The measurement of the magnetic field and implementation of new techniques that enhance the reduction of the exposure to electromagnetic field which include by the power lines have been the concern of many engineers for the past years, this led to the publication of many studies and development researches in this subject.

Long-term effects of chronic exposure have been excluded from the ICNIRP guidelines because of insufficient consistent scientific evidence to set a threshold for such possible adverse effects. According to the International Commission on Non - Ionizing Radiation Protection (ICNIRP) guidelines for low-frequency magnetic field (1 Hz-100kHz), the safety levels at short term exposure are 1mT for occupational exposure and 200μT for the general public. Until now, safety levels are for long term exposure is not determined. The maximum induced current density for safety levels set by ICNIRP (4Hz-1kHz) was set out to be 10mA/$m^2$for occupational and 2mA/$m^2$for general public.

Thus, it may be concluded that the measurements from all the above related works show that in the control room of the Injection substation area and the immediate vicinity of substation where people are habituated, the levels of radiation show that the area is within safe limits as magnetic field and the current density is considered. Even some researchers predicted that 2.75m should be minimum distance from HV equipment ground clearance in a substation.

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