Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 14 (19): 2380-2385, 2014
ISSN 1812-5654 / DOI: 10.3923/jas.2014.2380.2385

Evaluation of Extremely Low Frequency Electromagnetic Field Intensity in Power Station and Substations of Hamadan City and Calculating its Occupational Received Dose by Personnel

[1]Karim Ghazikhanlou-Sani, [1]Asghar Teymourian Motlagh, [2]Seyed Ali Rahimi and [1]Reza Habibipour
[1]Department of Basic Science, Islamic Azad University, Hamadan Branch, Hamadan, Iran
[2]Health Sciences Research Center, Mazandaran University of Medical Sciences, Kilometer 18, Khazarabad Road, Sari, Iran

Abstract: Public and occupational exposure to Extremely Low Frequency (ELF) electromagnetic fields induced by electrical equipment is a significant issue in the environment and at the workplace due to their potential health effects on public health. This study was conducted for evaluation of the magnetic field intensity in transmission or distribution substations of Hamadan City and calculating its occupational received dose by personnel. The intensities of the magnetic and electric fields were measured at seven high-voltage electric power substations. Measurements were done in all the points where usually personnel were present at these places using a Holaday electro-magneto meter (model HI-3604 instrument, USA). Then calculation of electromagnetic exposure received by personnel and comparison with ICNIRP recommendations was performed. The maximum value of induced magnetic field was observed at CVT, sectionner and breaker of 400-kV substation (40.06±21.69, 38.76±13.59 and 35.56±17.52 m Gauss, respectively). While, the intensity of induced magnetic fields in battery room, control room and relay room is negligible. The maximum calculated value of TWA for magnetic fields was registered at 230-kV substation (25.16±8.32 µTesla). The measurements of the low frequency magnetic field around different substations indicate that the measured values were lower than the value of 100 µTesla recommended by ICNIRP guidelines. The intensities of electric and magnetic fields in the selected stations are lower than the ICNIRP standard levels for public and occupational exposures.

Key words: Occupational hazards, electromagnetic fields, power lines, extremely low frequency, Hamadan city

INTRODUCTION

Nowadays, the use of electrical energy has become an important life necessity. It has brought prosperity and welfare to humanity. The Maxwell-Faraday equation is a generalization of Faraday's law that states that a time-varying magnetic field is always accompanied by a spatially-varying, non-conservative electric field and vice-versa. As a result, all of us are constantly affected by Electromagnetic Fields (EMFs). EMF is a form of electromagnetic energy that has a wide range of frequencies, above Direct Current (DC) to 1015 Hz of ultraviolet radiation (Korpinen *et al*., 2009; Filippopoulos and Tsanakas, 2005). EMF with a frequency of 3,000 Hz or less is defined as Extremely Low-Frequency (ELF- EMF) and majority of electronic devices that uses electric energy with a frequency of 50 or 60 Hz are in this category (Savitz *et al*., 1999; Sakurazawa *et al*., 2003; Floderus *et al*., 1999).

All people are exposed to electric and magnetic fields from many sources including power lines, electric wiring inside buildings and electric vehicles. Environmental levels of ELF fields are very low, 5-50 V m^{-1} for electric fields and 0.01-0.2 µTesla for magnetic fields (Floderus *et al*., 1999). Long-term exposure of strong EMF fields is a health hazards and may cause different disorders such as: Lack of energy or fatigue, irritability, aggression, hyperactivity, sleep disorders and emotional instability. Electric and magnetic fields can be measured in practically every environment or estimated from other parameters (Sakurazawa *et al*., 2003; Feychting *et al*., 2005; Kliukiene *et al*., 2003).

Wertheimer and Leeper (1979) first reported an increased prevalence of leukemia in children who were exposed by EMF induced by high voltage power lines. After that, many studies have shown a significant relationship between ELF-EMF and malignant diseases. Since then, several studies have been conducted to determine the biologic effects of EMF. But there is still controversy about the effects of EMFs on human health (Floderus *et al*., 1999; Feychting *et al*., 2005; Kliukiene *et al*., 2003; Feychting and Forssen, 2006; Ahlbom *et al*., 2004).

Corresponding Author: Karim Ghazikhanlou-Sani, Department of Basic Science, Islamic Azad University, Hamadan Branch, Hamadan, Iran

In 1974, a working group on non-ionizing radiation was formed by the International Radiation Protection Association (IPRA) which examined the complications arising in the field of non ionizing radiation. At the eighth International Congress of the IRPA, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) was established as an independent scientific organization. The main objective of this commission are to investigate the hazards that may be associated with the different forms of non ionizing radiation, developing international guidelines about exposure limits and non ionizing radiation protection (ICNIRP, 2010; Korpinen and Paakkonen, 2010). Particularly, ICNIRP develops guidelines for the safe exposure of workers and the general public of non ionizing radiation, including EMFs. EMFs exposure limits recommended in many countries are generally similar to the ICNIRP guidelines. According to ICNIRP guidelines the limits of the exposure from low frequency magnetic fields was defined as 100 μTesla for general public and 500 μTesla for occupational exposure (Ahlbom *et al.*, 2004; ICNIRP, 2010; Korpinen and Paakkonen, 2010; Safigianni and Tsompanidou, 2009).

Power stations and transmission or distribution substations are expected to produce very high-magnetic fields, since they transfer very high-electric current densities that leads an accumulating exposure to electromagnetic fields. If the used electrical devices have not proper design or are designed without reference to standards, the level of exposure to electromagnetic field could be raised over recommended standards (Ozen, 2008).

The electromagnetic fields exposure around power stations and substations has been subjected by some studies which investigate the occupational exposure, received by personnel and its health effects on the human body (Ozen, 2008; Helhel and Ozen, 2008). Although, many researches address the problems of induced electric fields and current densities inside human bodies due to exposure to magnetic fields, very few studies have investigated electric field and current induction due to proximity to actual electromagnetic field at the power stations and transmission or distribution substations (Ozen, 2008).

This study aims to assess the occupational exposure to electric and magnetic fields in high-voltage substations and compare the resulted amounts with the recommended values by the ICNIRP.

MATERIALS AND METHODS

At this cross-sectional study the intensity of electric and magnetic fields were measured by using a calibrated magnetic field meter (HI-3603) that is commercially available for measurement of environmental electromagnetic fields. Electric and magnetic field measurements were carried out at 7 different transmission or distribution substations (five 63-kV substations, two 230-kV substations and one 400-kV substation) in Hamadan city (Hamadan, Iran). Electromagnetic field measurements were made using a three-axis magnetic field meter. This meter is capable of recording magnetic field in the x, y and z axes as well as the resultant magnetic field.

All measurements were performed during the summer of 2012 between 19:00-21:00, when the energy's consumption is at its peak. During this time the substations had reached near their nominal powers.

During the measurements the instrument was adjusted for registration of the magnetic field that was created mainly by the fundamental power frequency of 50 Hz.

The measurements were conducted according to IEEE Std 644-1994 (1995) in three different heights from the ground, 1.0, 1.5 and 1.7 m which simulates the height of critical organs (including, the gonads, the heart and the brain). An available holder was used to obtain the magnetic field measurements in the above mentioned heights as shown in Fig. 1.

For data gathering, the intensities of EMF in different places of all above mentioned substations (including control room, relay room, bus bar, breaker, sectionner, CVT (Capacitor Voltage Transformer),

Fig. 1: A view of the holaday magnetic field meter (HI-3603) used in this study

Table 1: No. of measurement points at each substation separately

Substations	No. of measurement points
1st 63-kV	134
2nd 63-kV	117
3rd 63-kV	154
4th 63-kV	141
1st 320-kV	129
2nd 320-kV	181
400-kV	172

lightning elimination devices and battery Room) were measured. The number of measurement points in each substation is shown in Table 1. Each data gathering repeated 3 times and the final data calculated as the mean value. Determination of measurement points was based on possibility of personnel presence at each area.

This study was approved by the research deputy of Islamic Azad University, Hamadan branch (Iran). In each substation working places, the workers were exposed to the electromagnetic fields during all working hours. As the mean working hours of personnel is about 8 h, the occupational non ionizing radiation doses were calculated by 8 h Time-Weighted Average (TWA) (Sakurazawa *et al*., 2003). The time weighted average of an 8 h workday is calculated with the following Equation:

$$V_{(TWA)} = \frac{VaTa + VhTh... + ViTi + ...}{8}$$

where, V_i is a value within a certain time during a period T_i when the value is constant.

The results were expressed by descriptive statistics as the Mean±SD. All statistical analyses were done using SPSS Statistical Software Package, version 13.0 (SPSS Inc, Chicago, IL).

As the ICNIRP guidelines advise the limits of the exposure from low frequency magnetic fields about 100 μTesla for general public and 500 μTesla for occupational exposure, so, a comparison between of calculated TWA and ICNIRP limits were done.

RESULTS

In this cross-sectional study, the electric and magnetic fields in seven substations of Hamadan City (including five high voltage 63-kV substations, Two 230-kV substations and a 400-kV substation) were measured at different areas of each substation.

The mean intensity of electric field measured at different locations of each substation has been summarized in Table 2.

As shown in Table 2, the CVT (3814.79±1469.38 V m^{-1}), the sectionner (3337.44±1176.48 V m^{-1}) and the breaker (3030.93±1398.62 V m^{-1}) areas display the highest intensity of the electric field. While, the intensity of the electric field at some points of battery room, control room and relay room have been reported as negligible (approximately 195-421 V m^{-1}).

The mean value of magnetic field intensity measured at different locations of each substation has been summarized in Table 3.

As displayed in Table 3, the mean amount of induced magnetic field in CVT, sectionner and breaker of 400-kV substation were higher than in other cases (40.06±21.69, 38.76±13.59 and 35.56±17.52 m Gauss, respectively). While, the intensity of induced magnetic fields in battery room, control room and relay room is too small (between 2 and 4). The highest amount of the induced magnetic field was 71 m Gauss and was recorded in the CVT part of 400-kV substation in horizontal distance 1 m from the substation and in height 1 m above the ground.

Statistical analysis by ANOVA statistical test and Tukey's *post-hoc* test showed significant differences in the mean values of electric and magnetic field intensity at different stations. The difference between electric and magnetic fields induced in the different substations could be related to the structural differences in each station's equipments ($p<0.05$).

After mesurement of the mean magnetic field intensity in all workplaces and calculation of the time spent in each area by personnel (with continuous monitoring of personnel moves in every work shift), the average magnetic field received by personnel over a period of 8 h was calculated as 8 h Time-Weighted Average (TWA) magnetic field.

The calculated eight-hour time-weighted average (TWA) magnetic field for each substation is shown in Table 4.

The maximum calculated value of TWA for magnetic fields was registered at 2 and 230-kV substation (25.16±8.32 μTesla and is very lower than permissible dose limit for occupation advised by ICNIRP.

A comparison of the calculated mean values of TWA for each substation with public permissible dose limits (has been recommended by the ICNIRP) is shown in Fig. 2.

The measurements of the low frequency magnetic field around different substations led to the conclusion that the measured values were lower in comparison to the value of 100 μTesla recommended by ICNIRP.

Table 2: Mean±SD of electric field intensity at studied stations

	Substations						
Area	1st 63-kV	2nd 63-kV	3rd 63-kV	4th 63-kV	1st 320-kV	2nd 320-kV	400-kV
Control room	217.07±69.21	196.97±76.13	272.34±81.30	315.55±72.31	195.97±123.11	237.17±104.22	270.33±95.63
Relay room	243.20±136.53	315.55±124.23	297.47±96.86	212.04±165.21	421.07±198.31	288.42±113.21	244.20±96.34
Bus bar	2223.96±865.32	2166.67±1365.77	2656.08±986.85	1977.74±1169.65	2651.06±1389.21	2444.04±976.32	2883.20±1421.32
Sectionner	1965.68±765.32	1544.61±799.86	1822.98±839.23	1412.96±947.79	1905.39±698.69	2279.23±1286.59	3337.44±1176.48
Breaker	2480.22±1359.55	2388.77±1189.32	2001.86±996.67	3030.93±1398.62	2949.53±1477.83	2448.06±1469.22	3007.82±1088.46
CVT	2711.36±1698.21	2895.26±1469.86	2367.66±1976.38	3060.07±148.28	3012.84±1586.79	3530.39±2139.86	3814.79±1469.38
Lightning elimination devices	2543.53±1296.39	2156.62±1638.39	2448.06±1496.032	2163.66±975.21	2744.52±1139.86	2178.73±1876.25	2349.57±1598.67
Battery room	303.50±128.65	292.44±89.61	386.91±77.68	234.15±115.76	313.54±99.47	266.31±126.86	258.27±86.36

Values are Mean±SD of electric field intensity (V m^{-1})

Table 3: Mean±SD of magnetic field intensity at studied stations

	Substations						
Area	1st 63-kV	2nd 63-kV	3rd 63-kV	4th 63-kV	1st 320-kV	2nd 320-kV	400-kV
Control room	2.53±1.36	2.45±0.98	3.12±1.29	3.71±0.83	2.18±0.86	2.67±1.35	2.99±1.08
Relay room	2.75±1.37	3.82±0.86	3.29±0.92	2.37±1.39	4.88±1.63	3.12±1.87	2.91±1.53
Bus bar	26.44±12.38	25.98±14.85	32.91±9.74	24.06±11.28	32.12±13.61	28.96±16.13	34.59±12.79
Sectionner	24.15±8.21	18.27±11.13	22.19±7.68	19.88±6.98	20.81±11.31	28.20±9.97	38.76±13.59
Breaker	29.15±16.42	27.90±11.96	26.75±18.72	34.72±16.40	31.87±14.23	28.00±11.09	35.56±17.52
CVT	33.10±9.62	34.87±12.38	28.42±11.86	37.14±18.95	35.01±17.21	38.27±11.30	40.06±21.69
Lightning elimination devices	30.49±10.21	26.14±18.38	29.88±9071	24.23±14.29	31.69±11.08	25.49±16.98	26.98±8.29
Battery room	3.13±2.11	2.88±1.68	3.65±1.02	2.74±0.86	3.61±1.53	2.76±1.39	3.15±1.08

Values are Mean± SD of magnetic field intensity (m Gauss)

Table 4: Mean±SD of TWa magnetic field calculated for each substation

Substations	TWA (m Gauss)	TWA (µTesla)	ICNIRP recommendation
1st 63-kV	56.90±37.99	5.69±3.80	100 µTesla (for public)
2nd 63-kV	123.82±59.62	12.38±5.96	
3rd 63-kV	91.22±49.99	9.12±5.00	
4th 63-kV	112.76±95.29	11.277±9.53	500 µTesla (for occupation)
1st 230-kV	121.66±52.34	12.17±5.23	
2nd 230-kV	251.61±83.22	25.16±8.32	
400-kV	149.70±102.54	14.97±10.25	

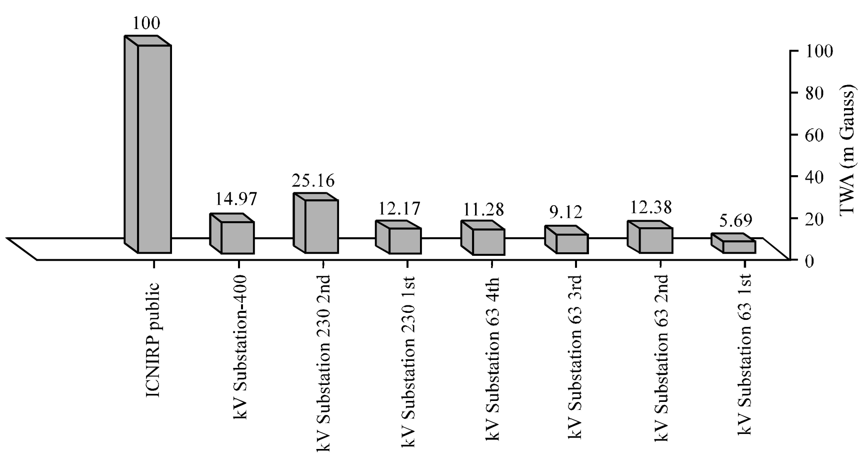

Fig. 2: A comparison of the calculated mean values of TWA with ICNIRP recommendations

DISCUSSION

Every electrical device produces EMF and all people are constantly exposed to EMF of various strengths. There are many researches about the complications of exposure to EMF on human health such as increasing the risk of cancer and nonmalignant diseases. A few studies have proposed that that EMF is associated with cardiovascular and neurodegenerative diseases (Feychting *et al*., 2005; Kliukiene *et al*., 2003).

Occupational EMF exposure has also been found to increase the risk of genital system cancers by affecting the immune systems. It has also been reported that exposure to high levels of non ionizing radiation is associated with breast cancer (Floderus *et al*., 1999; Feychting *et al*., 2005; Kliukiene *et al*., 2003; Feychting and Forssen, 2006; Ahlbom *et al*., 2004).

However, majority of studies are in agreement on the harmful effects of radiation on human health. In 1998, the National Institute of Environmental Health Sciences reported that, after review of literatures, they found limited evidences about relevance of occupational exposure to ELF-EMF and chronic lymphocytic leukemia and increasing the risk for other cancers including brain, breast and lung cancer (Sakurazawa *et al*., 2003; Feychting and Forssen, 2006; Korpinen *et al*., 2011). Also they reported that there was inadequate evidence for relationship between exposure to ELF-EMF and other complications (such as birth outcomes, reproductive effects, immune system diseases, Alzheimer disease, cardiovascular diseases and depression (Sakurazawa *et al*., 2003).

So far, no evidence has been obtained about dose-response relationship with workers in jobs with higher exposure to magnetic fields and malignant diseases (Sakurazawa *et al*., 2003).

Power stations and transmission or distribution substations are expected to produce very high magnetic fields and occupational non ionizing accumulative dose could be over the standard levels for personnel (Ozen, 2008; Atudori and Rotariu, 2012).

The maximum calculated value of TWa for magnetic fields at present study was registered at a 230-kV substation (25.16±8.32 μTesla that is very lower than permissible dose limit for occupation advised by ICNIRP. This result is good agreement with the findings of Gobba *et al*. (2004). They showed that for three whole work shifts (8 h 3 days, 1 measure each 10 sec), in seven electrical cabin maintenance workers, the arithmetical mean of individual Time-Weighted Average (TWA) was 0.35±0.25 μTesla. Ahmadi *et al*. (2010) also indicated that the exposure received by public near the transmission power lines is lower than ICNIRP recommendations.

At this study minimum induced magnetic field was measured at control room and battery room (0.25-0.4 μTesla. According to the Ozen (2008) study at 2008 in the intensity of magnetic field measured at control room of a 380-kV substation at turkey estimated in the range of 0.5-0.85 μTesla. Helhel and Ozen (2008) also showed that the magnetic field intensity at different areas of Kemer Substation at Turkey is measured between 0.35-40 μTesla.

According to our gathered data the mean amount of induced magnetic field in CVT of 400-kV substation was 4.00±2.17 μTesla). While, the intensity of induced magnetic fields in battery room, control room and relay room was about 0.2-0.4 μTesla. Said *et al*. (2004) following the electromagnetic field measurement at a 132-kV substation at Malaysia reported that the maximum and minimum registered value for magnetic fields was 34 for the transformer room and 0.33 for the official rooms, respectively.

Sakurazawa *et al*. (2003) also found that the magnetic field intensity around distributing board is in the range of 1-2.5 μTesla. Atudori and Rotariu (2012) study on the impact of the electromagnetic map generated by a three phase power line on the electrical equipment showed that the magnetic field intensity around the three phase power line is generally lower than 0.67 μTesla.

As shown in present study, the intensity of the electric field at different points of abovementioned substations was in the range of 195-5000 V m^{-1}. The gathered data confirms Korpinen *et al*. (2011) study in Finland. They achieved the range of 40-6300 V m^{-1} for the mean electric field at different work tasks on a 110-kV substation.

For future studies, improving the exposure assessment and accounting for various confounders it is recommended. Residential exposure by the electromagnetic fields did not considered at present study but it is recommended to be measured and included in the final results of subsequent studies.

CONCLUSION

After the analysis of the descriptive data, it could be claimed that all measured values and all calculated values for TWA magnetic field were lower in comparison to the value of 100 μTesla for public exposure introduced by ICNIRP. The values of TWA magnetic field exposure that were calculated were between 4-33 μTesla, that is very lower than upper permissible dose of non ionizing radiation recommended by ICNIRP (500 μTesla).

However, the harmful effects of electromagnetic radiation on human health is undeniable and further studies on the hazards of high-voltage power line electromagnetic fields (specially on the values obtained in this study and other similar studies) is highly recommended.

ACKNOWLEDGMENTS

This study was supported by a Grant of Research Deputy of Islamic Azad University, Hamadan Branch (Hamadan, Iran).

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