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Assessment of the risk of occupational exposure to extremely low frequency electromagnetic fields

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Abstract

Aims: Extremely low-frequency electromagnetic fields are identical to the spectrum of human brainwaves and therefore, have more effect on function. Power substation operators are more exposed to these waves compared to other people. The purpose of this study was to assess the risk of power substation workers' occupational exposure to extremely low-frequency electromagnetic fields.

Methods: This cross-sectional descriptive study was performed on 67 power substation operators of Kerman who were selected by available sampling method in 2010. The electric field intensity and magnetic flux density were measured in different parts of the substations and the amount of occupational exposure of each operator was estimated using the mean intensity of electric field and magnetic flux density in a work shift. Data was analyzed by descriptive statistical methods and one-way variance analysis using SPSS 18 software.

Results: Occupational exposure to extremely low-frequency electromagnetic fields was mostly related to 400kV substations and the lowest exposure belonged to 132kV substations. Minimum and maximum ranges of the magnetic flux density and electric field intensity varied from 0.11 to 60.8mG and from 0.0008 to 0.13kV/m in the interior equipment and from 0.01 to 790mG and from 0.0008 to 110kV/m in the outdoor equipment.

Conclusion: The mean exposure time of operators in a work shift in various substations is lower than standard occupational permissible limits, except for some parts in the outdoor equipment which may have resulted from their proximity to transformators' earth system.

Keywords: Occupational Exposure, Extremely Low-Frequency Electromagnetic Fields, Power Substation

Introduction

Electric and magnetic fields with frequencies between 3 and 3000Hz are generally known as extremely low frequency electromagnetic fields (ELF) [1]. Exposure to the mentioned fields is probable almost everywhere [2] and they are naturally produced by production and transmission of electric power and power used in home appliances and therefore, many society members are prone to them [3]. Power substations, transmission lines, distribution lines, industrial devices, electronic appliances are some of the identified magnetic fields with extremely low frequency. As some of the substations are enclosed with residential or commercial areas, it is likely that people who live at their vicinity and those who are working in the substations are exposed to them [4]. The effects of electromagnetic fields are almost located at extremely low frequency [5] and most of the recent studies have been performed on the effects of low frequency non-ionizing radiation exposure [4]. The probable health effects of exposure to extremely low frequency fields has considerably raised general concern and has changed to a stimulation for further investigation in scientific centers. Electromagnetic fields can result in premature aging and has significant effects on metabolic systems such as raising the blood glucose, increasing the fat percentage, decreasing the testosterone amount in men and effect on central nervous system, cardiovascular system and the immunity of other tissues. It is possible that electromagnetic fields increase the risk of cancer, leukemia, brain tumors, spontaneous abortion, Alzheimer and suicide in the workers of power stations up to 200 to 600% [6]. As a result, the evaluation of exposure amount and its effects seems essential. Different kinds of organisms including human has shown sensitivity to relatively slight exposure to electric fields [4].

Several epidemiological studies have shown relationship between exposure to extremely low frequency electromagnetic fields and higher risk in children and adults who are at occupational exposure to these fields [5]. In 1979, Nancy, an epidemiologist,

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and Wertheimer and Leeper, physicians, arrived to this conclusion in their study that in the children who die from cancer the possibility to live at 40-meter distance from power transmission lines, is 2 or 3 times [6]. In 1979, Wertheimer and Leeper reported the association between leukemia in childhood and the manner of connecting wiring from power transmission lines to the homes of these children. The analysis of these studies by the National Science Academy showed that power lines near residential areas are associated with childhood leukemia (RR=1/5) but does not have any association with other cancers [7]. Medical studies conducted in 16 stations from high pressure stations including totally 286 individuals, have mentioned bad effects of exposure to electric field on nervous system. Sharify et al. in 1388 reported that long term exposures with magnetic fields despite being lower than the standard occupational allowed range of International Commission of Non-Ionizing Radiation Protection (ICNIRP) causes psychiatric disorders including sleep disorder. Yousefi also conducted his study on 103 individuals from the staff of high pressure stations in Tehran. He reported the symptoms of depression, mental and practical obsession, and sensitivity in interpersonal relations, anxiety, aggression, phobia and psychosis [10].

Extremely low frequencies are at the range of brain waves and therefore have higher influence on brain function. Meanwhile, the International Agency for Research of Cancer (IARC) and the World Health Organization (WHO) arrive to this conclusion that magnetic fields with extremely low frequencies are presumably carcinogenic to humans. This conclusion is supported more by the International Commission on non-ionizing Radiation Protection [4]. Since the employees of high pressure substations are exposed to these waves more than the general population, it is tried to reduce the risk of exposure of the operators by measuring magnetic and electric fields of the substations of Kerman and comparing them to the standards of International Commission on non-ionizing Radiation Protection.

The aim of this study was to evaluate the risk of occupational exposure of workers exposed to electromagnetic fields with extremely low frequencies in power stations of Kerman.

Methods

This is a cross-sectional descriptive study that was conducted in 1389. The sample size was calculated using the mean comparisons. Due to low number of people employed, all substations of Kerman and suburbs (16 stations) were selected, of these 16 stations, one was 400kV, three ere 230kV stations and 12 were 132kV stations and 12 operators were working in these stations (with the age range of 24 to 57 years) (41 people in 132kV stations, 20 people in 230kV stations and 6 people in 400kV stations).

All the operators of these posts were men. The inclusion criteria were exposure to the extremely low frequency electromagnetic fields. An important factor in evaluating the effects of cumulative exposure to individuals is the amount of time taken to perform the job duties that requires contact with extremely low frequency electromagnetic fields. The term 'job duty' which is used here not only includes inspection and maintenance of equipment, but also the activities performed during leisure time, eating, resting and watching TV, etc. [11, 12].

To calculate the amount of occupational exposure, first all stations were inspected. After inspection, the measuring points were selected given to the area of each station, the presence of operators in different parts, proximity to the equipment, also in the equipment section and the areas close to the equipment where operators had the highest traffic and stations were classified and the number of samples was determined at each station. According to the Electrical and Electronics Engineers Standards Association (IEEE std 644-1994) and using Hi-3604 device (Haldy; USA) the intensity of electric field and magnetic flux density was measured [13]. This machine is designed for frequencies from 30 to 2000Hz. Sensitivity range of the device is from 0.2mG to 20 gauss and from 1V/m to 200kV/m. The measurement of magnetic flux density (in term of mG) and Electric field intensity (in term of V/m) was conducted within a meter distance from earth and after the measurement the electric field was converted to kV/m. To measure the electric field intensity, the device was installed on a tripod (when measuring the electric field intensity the operator should be twice his height far from the device and his knees should be bent) and the electric field was read using the remote control system [14, 15]. When the measurements were taken, the consuming load of each station was also measured (Table 1). Since atmospheric conditions can affect the measurement results, all measurements were conducted between the hours of 4 pm to 9 pm during summer and the weather was sunny and quite similar.

1445 was a total number of measured points of that **777** were magnetic and 668 were electric field. From **777** measured magnetic fields, 509 points in 132kV station, 215 points in 230kV stations and 38 points in 400kV stations were identified. Occupational exposure of operators of power stations to extremely low frequency electromagnetic fields in a work shift was calculated by the following formula:

$$B_c = \frac{\sum B(t)_i \times h_i}{h}$$

Where, B_c, is "the average magnetic flux density in different parts of each station", h_i, is "The average time spent by the operator for a specific duty in various parts of the station" (per hour) and h, is "the length of a work shift (12h and 24h)" [16].

Table 1- Load voltage at the time of electric and magnetic fields measurement in different stations

Station's name	Type of the Station (kw)	Load Voltage (MV)
Secondary copper industry	132	10
Baghin 2	230	184
Baghin 1	132	28
Rubber industry	132	14
Zangi Abad	132	38
Kerman 2	132	14
Shahab	230	140
Mahan	132	8
Tavakol Abad	132	33
Kerman 1	132	40
Kazem Abad	132	29
Rain	132	11.4
Sirch	132	9
Niroogah	400	1100
Niroogah	230	100
Siman	132	23.83

Finally, the results measured were compared with the standard of the International Commission on non-ionizing Radiation Protection and the ranges of Occupational exposure of pathogens of Health ministry. The amount of occupational exposure in terms of standard of International Commission on non-ionizing Radiation Protection is 500Micro-tesla for magnetic flux density (5000mG) and 10kV/m for electric field intensity. Also occupational exposure limits according to the occupational exposure standard of pathogens of Health ministry for extremely low frequencies magnetic fields is 12000mG in 50Hz frequency and 10000mG in 60Hz frequency and is 25kV/m for Electric field intensity [17, 18, 19].

The results of measurement were analyzed after entering data by using descriptive statistical methods and one-way analysis of variance.

Results

Results of operators' exposure in a 12-hour and 24-hour shifts are shown in Table 2 that the most occupational exposure belonged to 400kV station with 7.51mG and the lowest occupational exposure belonged to 132kV station with 2.32mG. Also the highest average electric field intensity belonged to 400kV station with 0.83kV/m and the lowest belonged to 132kV station with 0.26kV/m.

Table 2- The average magnetic flux density (mG) and electric field intensity (kV/m) Occupational exposure of operators in a work shift.

Type of the Station	No. of the station	No. of the operator	Magnetic flux in one shift	Eclectic field intensity in one shift
132 (kV)	12	41	2.32±1.32	0.26±0.31
230 (kV)	3	20	7.49±3.61	0.68±0.50
400 (kV)	1	6	7.51±0	0.83±0

Table 3- The average magnetic flux density (mG) and electric field intensity (kV/m) in a 400kV station

Substation	Magnetic flux	Electric field intensity
Control room	6.95	0.007
Resting place	6.6	0.004
Kitchen	6.38	0.05
Outer equipment	16.61	9.90

Discussion

Results from this study showed that the highest amount of occupational exposure of operators in a 12-hour (power substations) and a 24-hour work shift in 132, 230 and 400kV stations of Kerman is related to 400kV station with 7.51mG and 0.83kV/m and the lowest is related to 132kV station with 2.32mG and 0.26kV/m.

Table 4- The average of magnetic flux density (mG) and the intensity of electric field (kV/m) in 230kV stations

Substation→ Precinct↓	Shahab Post		Baghin 2 Post		Niroogah Post	
	Magnetic flux	Eclectic field intensity	Magnetic flux	Eclectic field intensity	Magnetic flux	Eclectic field intensity
Substation	5.67	0.005	8.74	0.01	1.18	0.007
Control room	7.19	0.02	6.6	0.001	0.96	0.005
Resting place	0.26	0.006	5.28	0.02	1.12	0.02
Kitchen	34.24	8.02	32.16	12.72	26.33	9.81

Table 5- The average magnetic flux density (mG) and the intensity of electric field (kV/m) in 132kV stations

Station		Control room	Resting place	Kitchen	Outer equipment
Tavakol Abad	Magnetic	2.81	0.77	0.73	79.14
	Electric	0.01	0.01	0.03	3.63
Kerman 1	Magnetic	2.59	1.06	-	36.6
	Electric	0.01	0.009	-	3.51
Kazem Abad	Magnetic	2.02	1.04	3.3	6.03
	Electric	0.02	0.05	0.04	2
Kerman 2	Magnetic	4.26	5.09	5.88	2.05
	Electric	0.01	0.009	0.02	3.92
Secondary copper industry	Magnetic	2.86	0.52	0.11	18.76
	Electric	0.02	0.06	0.02	5.8
Baghin 1	Magnetic	2.93	0.95	0.76	25.15
	Electric	0.006	0.007	0.001	2.05
Rubber industry	Magnetic	0.81	0.29	0.48	4.32
	Electric	0.002	0.008	0.009	10.87
Mahan	Magnetic	4.56	0.69	0.57	12.56
	Electric	0.006	0.005	0.006	5.61
Sirch	Magnetic	0.63	0.24	0.32	5.45
	Electric	0.008	0.009	0.03	2.75
Rain	Magnetic	0.9	0.58	0.54	9.82
	Electric	0.001	0.06	0.002	5.21
Zangi Abad	Magnetic	1.3	0.82	0.47	46.27
	Electric	0.002	0.008	0.002	4.55
Siman	Magnetic	14.61	2.41	0.43	50.13
	Electric	0.002	0.05	0.02	2.01

Table 6- The results of measurements of electric fields (kV/m) and magnetic flux density (mG) in all electric substations of Kerman

Type of station	Equipment	Number of measurements	Density	Magnetic flux	The number of measurements	Electric field intensity
132 (kV)	Internal	378	Min	0.11	323	0.0008
			Max	60.8		0.13
			Average	3.23±5.75		0.1±0.1
	External	560	Min	0.28	560	0.001
			Max	790		110
			Average	22.8±75.6		4.79±9.15
230 (kV)	Internal	159	Min	0.13	112	0.0008
			Max	44.8		0.11
			Average	4.02±4.73		0.006±0.01
	External	168	Min	7.63	168	0.14
			Max	75.3		48.5
			Average	32.28±22.72		7.97±7.04
400 (kV)	Internal	22	Min	0.66	21	0.0009
			Max	13.54		0.09
			Average	6.45±3.16		0.0009±0.09
	External	56	Min	3.13	56	0.46
			Max	66.2		50.3
			Average	16.61±18.94		9.90±11.56

The average of operators' occupational exposure of mentioned stations is lower than the allowed limits of standard of International Commission on non-ionizing Radiation Protection and the ranges of Occupational exposure of pathogens of Health ministry. These results are consistent with Korpinen et al. study in 2010 that reported the occupational exposure to electric and magnetic fields in various occupational duties in 110kV high pressure stations in Tampori Finland region none of the occupational duties passed beyond the allowed occupational limits of standard of International Commission on non-ionizing Radiation [20]. The results of Helhel et al. study 2007, in 154 and 34.5 stations showed that the average of operators' exposure with magnetic fields higher than 0.3micro-Tesla is for 8 working hours a day [21]. Although this amount is different from the amount of exposure in the present study, this amount of exposure and the maximum measured amount of magnetic field in mentioned stations is lower than the limits of standard of International Commission on Non-ionizing Radiation. Meanwhile, the results of Lina et al. study at 400kV station [22] and Joseph and colleagues, 2008, at Belgium power distribution stations [23] confirm the results of the present study.

According to the conducted investigations in all stations, the operators spend most of their time in a work shift in the fallowing places respectively: control room, resting place, kitchen, outside equipment and rarely at other parts. In 230kV stations, the highest amount of the average of magnetic flux density and the intensity of electric field in control room belongs to the Baghin 2 station with 8.74mG and 0.01kV/m and the lowest amount belongs to the Niroogah station with 1.18mG and Shahab station with 0.005kV/m.

One of the reasons for the high average of magnetic flux density and the intensity of electric field is high in the control room of Baghin 2 station is that its distance with the outside equipment is very low. In Niroogah and Shahab 230kV station, the control room is adjacent to the transformators and transformation lines. Therefore, in this part of the electric field and magnetic flux density is lower. In the resting place, the average magnetic flux density and electric field intensity is related to Shahab station with 7.19mG and 0.02kV/m and the lowest amount is related to Niroogah station with 0.96mG and Baghin 2 station with 0.001kV/m. The power lines pass under the Shahab station's resting place. Therefore, this part has the highest amount of average magnetic flux density and electric field intensity. In the kitchen, the highest amount of average magnetic flux density and electric field intensity belongs to Baghin 2 and Niroogah with 5.28mG and Baghin 2 station and Niroogah station with 0.02kV/m respectively and its lowest amount belongs to Shahab station with 0.26mG and 0.006V/m. The reason of increase in the magnetic flux density and electric field intensity in the kitchen of Baghin 2 station is its proximity to the internal electrical equipment and the high consumption load of this station. In outside equipment, the highest amount of average magnetic flux density and electric field intensity belongs to Shahab station with 34.24mG and Baghin 2 station with 12.72kV/m respectively and the lowest is related to Niroogah station with 26.33mG and Shahab station with 8.02kV/m (Table 4).

The reason if increasing the magnetic flux density and electric field intensity in these two stations, is their high consuming load. In Niroogah station, it is located far from power lines and transformators and in Shahab station, the garden area is more than other 230kV stations therefore, the lowest intensity electric field is related to this station.

The highest amount of average magnetic flux density and electric field intensity in control room of 132kV stations is respectively related to Siman station with 14.61mG and Kazem Abad and Secondary copper industry stations with 0.02kV/m and the lowest amount is respectively related to Sirch station with 0.63mG and Rain station with 0.001kV/m. the reason of high magnetic flux density in Siman station is its placement at the distance lower than 2m from switchgear equipment of this station and in Kazem Abad and in Secondary copper industry is for proximity to transformators. In the resting place, the highest amount of average magnetic flux density and electric field intensity was related respectively to Kerman 2 station with 5.09mG and secondary copper industry station and Rain station with 0.06kV/m and the lowest belonged to Sirch station with 0.24mG and Mahnattion with 0.005kV/m respectively. In the kitchen the highest amount of average magnetic flux density and electric field intensity was related respectively to Kerman 2 with 0.11milli-gauss and Kazem Abad station with 0.04kV/m and the lowest average was related respectively to Secondary copper industry station with 0.11mG and Baghin 1 station with 0.001kV/m. its reason is the proximity of the kitchen of these two stations to outer equipment. In the section of outer equipment the highest amount of average magnetic flux density and electric field intensity was related respectively to Tavakol Abad station with 79.14mG and Rubber industry station with 10.87kV/m and the lowest average is related to Kerman 2 station with 2.05mG and Kazem Abad station with 2kV/m (Table 5). Considering the results shown in Tables 3, 4 and 5, the highest amount of average magnetic flux density and electric field intensity in different parts of the stations is related to the low distance from outside equipment , being in the power transition lines, proximity to transformators and passing power cables under these rooms. Being located far from producers of electromagnetic fields decreases these fields. Martin et al. reported in their study that with increase of distance from the source, the magnetic flux density and electric field intensity decrease sharply [24]. The study of Said et al. has also confirmed these results [25].

According to the results presented in Table 6, in all substations the minimum, maximum and average magnetic flux density is lower than the standard limit (5000mG) of occupational exposure of international Commission of non-ionizing radiation protection. This result is consistent with the data obtained by Sharifi et al. study in 2010 from 230kV high voltage substations in tehran, the study of Habibolah et al. in 2003 at 230kV high voltage substations, Malfit et al. study, Said et al. study in 2004 of 132kV High Voltage substation in Malaysia, the study of Ozone in 2007 on the 154.380kV high voltage substations [9, 14, 25, 26]. But some of the values measured at the maximum electric field intensity and the average electric field intensity in two stations of Rubber industry station (132kV) and Baghin 2 station (230kV) is higher than above standard limit. Given that these two averages like maximum amounts are among results measured at 1 meter distance far from transformators, perhaps the increased electric field intensity in this distance was due to the Earth system of devices particularly transformator units. Given that earth system is installed one meter far from transformators and in this section and passing of intense flow from the grounding electrode cause the voltage to ground at this point to reach a significant value and in areas adjacent to the place where flow crossing to the earth, the voltage gradually decreases due to spreading of the flow in the larger section of the land and in far distance it appears almost to zero [27]. Also this can be caused due to inappropriate material of the earth.

Similar studies have been conducted in other countries. For example, in Victor Angelo and Margalo's study which was conducted in two stations of 100 Megavolt-Ampere in Philippine, it is reported that the maximum value of the measured magnetic and electrical fields is in the vicinity of the transformators. And all values of the magnetic field, is lower than the allowed limits [4]. Also the results of Christian et al.in 2006 in some power stations of Romania which show that in some measured parts intensity of the electric field is higher than standard limits, is also consistent with the results of this study [28].

Since there is no practical and economical method for protection against magnetic fields, the only practical method for field control is limiting exposure [7] and for decreasing the intensity of electrical field, main sources which are usually transformators can be enclosed by a metal cage connected to the earth. Due to lack of dosimeter systems, environmental measurements were performed in this study. Therefore, the accurate assessment of occupational exposure of substation operators, using dosimeter can provide more accurate results.

Conclusion

The average magnetic flux density in all substations is lower than allowed standard limit recommended by International Commission of Non-Ionizing Radiation Protection. But the average electric field intensity at some points is more than the above standard limit. Occupational exposure of operators is lower than allowed limit according to this standard.

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