ELECTROMAGNETIC FIELDS NEAR TRANSMISSION LINES – PROBLEMS AND SOLUTIONS

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ABSTRACT
Nowadays, people are highly concerned about the effects of high voltage transmission lines on their health. Probable risk for leukemia, breast cancer, neuropsychological disorders and reproductive outcomes has been reported due to this exposure. In this study, several measurements around different areas such as overhead transmission lines, GIS compartments and some appliances have been conducted and compared with the standard tolerances. The emphasis of this research is on high voltage substations and publics. Field magnitudes above 10kV/m have been measured under wires. Results show that there is no serious concern for the people living near the transmission lines but for the individuals who are beneath those lines for long. Recent achievements about electric fields' effect on human health are reviewed in the present paper. In a case study, three types of 230kV structures are analyzed and the best phase arrangement for reducing the electric and magnetic fields is determined (the circular arrangement). It is concluded that the most effective solution is for the governments to use the best phase arrangement and replace outdoor substations with GIS to reduce the radiations and for the people to be near the high voltage overhead lines as rarely as possible.

Key words: Transmission lines, Electromagnetic fields, Public health

INTRODUCTION
Humans are continuously exposed to electromagnetic fields (EMF) emitted from such sources as electric transmission lines (TL), telecommunication and radio-television antennas. Thus, EMFs of various frequencies are ubiquitous in our environment. The extensive network of high voltage (HV) transmission limits (TLs), electric engines in cars, trains and trams, welding devices, and the electrical appliances are the primary sources of extremely low frequency (ELF) EMFs. All countries set their own national standards for exposure to EMFs. However, the majority of these national standards draw on the guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The effects of chronic exposure to environmental EMF have been the subject of intensive researches (Djanab, 1960) leading to no definitive answers. Possible risks for childhood and adult leukemia have been acknowledged (Portier and Wolfe, 1998), (Wartenberg, 1998), (Yang *et al.*, 2008), but many other health outcomes are reported, among them are breast cancer (Stevens, 1993; Brainard *et al.*, 1999), neuropsychological disorders (Sobel *et al.*, 1996; Verkasalo *et al.*, 1997; Liu *et al.*, 2008), decrease in blood sugar (Abbasi and Nakhjavani, 2002), and reproductive outcomes (Hatch, 1992; Roychoudhury *et al.,* 2009).

An underlying mechanism that could explain all of these potential effects is alteration of melatonin secretion as a result of EMF exposure (Reiter, 1993). Melatonin secretion is important in the regulation of circadian rhythms and sleep (Brzezinski, 1997), but could also be involved in the aging process (Poeggeler *et al.,* 1993),

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carcinogenesis (Blask, 1997; Fedrowitz and Loscher, 2008), , and reproduction (Reiter, 1998).

In crowded regions, as a result of city's expansion during the past years, TLs which were far from houses are now nearby buildings. Though previous investigations had shown no serious effects on human health from the EMFs due to TLs (California Health Department, 2001), but recent studies have taken the opposite side (Sher, 1997; Huss *et al.*, 2009). Workplaces have also been studied for finding possible risks (Akbar Khanzadeh, 1982; Zahiroddin *et al.*, 2006; Garcia *et al.*, 2008). Besides TLs, there are a lot of appliances that produce EMFs such as electric blankets, copy machines, monitors and televisions which need to be studied.

As a gap in pertinent literature, especially in Iran, this research was conducted to analyze the real situation and make clear the vague probability of danger. Reminding the responsible institutions for applicable solutions is another goal of the authors, because, informing the people about the health risks and giving them scientific advice are mandatory.

MATERIALS AND METHODS

Current study was conducted by measuring EMFs at different areas in Tehran. These measurements are meaningful when compared with the standard limits. Table 1 is a summary of the exposure guidelines for three frequency levels: ELF, mobile phone base stations and microwave ovens. These guidelines have been last updated in April 1998 by ICNIRP. Each measurement was done in increasing distance from instrument or overhead line (for TLs, every 10m away from the line and for devices like copy machines every 1m) and the measured data were recorded.

The employed device for EMF measurement was "Extech 480826 Triple Axis EMF Tester." By the aid of this device, frequencies ranged from 30Hz to 300Hz were measurable in RMS value.

Three substations in Tehran were selected including Kan, Azadegan and Ghourkhaneh, each one with a distinct feature. Kan has an income 400kV line, Azadegan is in neighborhood of inhabited houses and Ghourkhaneh is a GIS. A public park was also suspicious of being a hazardous place, as shown in Fig. 1.

Fig. 1: 230kV overhead transmission line near a public park, Azadegan Substation

The outgoing 230kV line from Azadegan to Firouzbahram, a 63kV feeder inside Azadegan SS and the incoming 400kV line from Vardavard to Kan were the outdoor test places.

The mentioned problem only affects the people who are continuously exposed to emitted radiations such as workers in HV substations (SS), copy machines' operators and people who are under TLs for a long time.

Different arrangements of phase conductors were analyzed to find the best solution for field reduction. A powerful program for reaching this purpose was employed known as COMSOL, MULTIPHYSICS MODELING AND SIMULATION, copyright 2008. It is a finite element analyzer and a solver software package for various physics and engineering applications, especially coupled phenomena.

Results are reported in two categories. The simulated fields are alternative and thus the simulation is time dependent. Therefore, first group includes figures which are only for specific time. In the second group, each plot pertains to 1/20 of a period. Hence, the maximum and minimum values are apparent which are more important than other values. It should be considered that in the second type, the simulation was done at a height of 2m above the ground.

RESULTS

Measurements of electric and magnetic fields

TLs are ubiquitous even in publics, as shown in Fig.1.The measurements were done in most probable areas of high intensity fields. Wires' weight brings them closer to the ground in the middle point of the span. The downward displacement for a 230kV line with a span of 300m is about 11-11.5m (the wire's sag). Tables 2 to 4 show the results of measurements near some TLs and inside SSs.

Information about the current and voltage of TLs was collected for the time of measurement which is reported in the table captions. There was no big difference in current magnitude during the working hours in SSs and the voltage was constant.

Table 1: Summary of ICNIRP (1998) and Council of European Union (1999) exposure guidelines

	Power lines		Mobile phone base stations		Microwave oven
Frequency	50 Hz	50 Hz	900 MHz	1.8 GHz	2.45 GHz
	Electric field (V/m)	Magnetic field (μT)	Power density (W/m^2)	Power density (W/m^2)	Power density (W/m^2)
Public exposure limits	5 000	100	4.5	9	10
Occupational exposure limits	10 000	500	22.5	45	-

These outcomes show that in about 40m far from the TLs, the field intensity is lower than the standard thresholds. But for palaces that are beneath the lines, especially the public areas such as parks in which people spend much time, there is a possible danger.

Table 2: Measured EMFs near 230kV overhead line, Azadegan-Firouzbahram (SB808 SB800), I=650A

Distance (m)	E (V/m)	B (uT)
Beneath	8000	6
10	4000	3
20	1500	2
30	800	10
40	600	6
50	400	3

Table 3: Measured EMFs near 63kV output-busbar feeder of T4(230-63), Azadegan Substation, I=640A

Distance (m)	E (V/m)	B (uT)
Beneath	5000	10
10	3000	5
20	600	3
30	200	1
40	80	8
50	20	6

Besides TLs, other appliances produce relatively high intensity EMFs about which people are probably not aware. Table 5 exhibits the measurement results for common devices. As it is obvious, these results indicate that these instruments produce high levels of electric and magnetic fields which are actually lower than the standard thresholds.

Table 4: Measured EMFs near 400kV, two-circuited overhead line, Vardavard-Kan, I1=500A, I2=300A

Distance (m)	E (V/m)	B (uT)
Beneath	>10000	3
10	8000	2
20	4000	1
30	1500	0.8
40	1000	0.6
50	800	0.4

Table 6 and 7 indicate the measurement results for two places inside Ghourkhaneh GIS. More data had been collected, but there was no weighty difference between them. It's apparent that GISs are significantly safer than the outdoor ones with respect to electric field intensity. Cables have a conductive shield under their insulator and so the electric field cannot reach outside the cable.

In outdoor SSs, wires were near the ground and the intensity of the electric field was too high that in the whole area, it was more than 10kV/m.

Table 5: Measured EMFs near some commonly-used appliances

Appliance	Near the Appliance		1 meter far from the Appliance	
	Magnetic field(uT)	Electric field(V/m)	Magnetic field(uT)	Electric field(V/m)
Monitor	1	1500	0.1	300
Water Cooler	4	500	0.1	40
Refrigerator	0.4	1000	0.1	150
Laptop Charger	6	800	0.04	50
Laptop	0.08	1500	-	80
Photo Copy Device	0.8	1500	0.2	350
Hair Dryer	70	40	-	-
Electric Blanket	33	2000	-	-

Simulation results of various configurations for 230kV TLs

There are several types of towers for TLs with different designs. Spans between the towers are different depending on the geographical properties of area. Wires' sag in a 300m span may exceed 11m.We set up the worst case in current study - under maximum sag of the wires. Characteristics of four usual arrangements for 230kV conductors are shown in Fig. 2. Simulation results, using COMSOL, for EMF intensity are shown in Figs. 3 to 5. Electric potential of ground was assumed to be zero.

Table 6: Measured EMFs near XLP cables, Ghourkhaneh GIS (Ghorkhane-Mosalla feeder), I=400A

Distance (m)	E (V/m)	B (uT)
0.1	0	>100
1	0	50
2	0	30
3	0	10

Table 7: Measured EMFs near GIS compartments. Ghourkhaneh Substation, I=400A

Distance (m)	E (V/m)	B (uT)
0.1	0	30
1	0	15
2	0	8
3	0	4

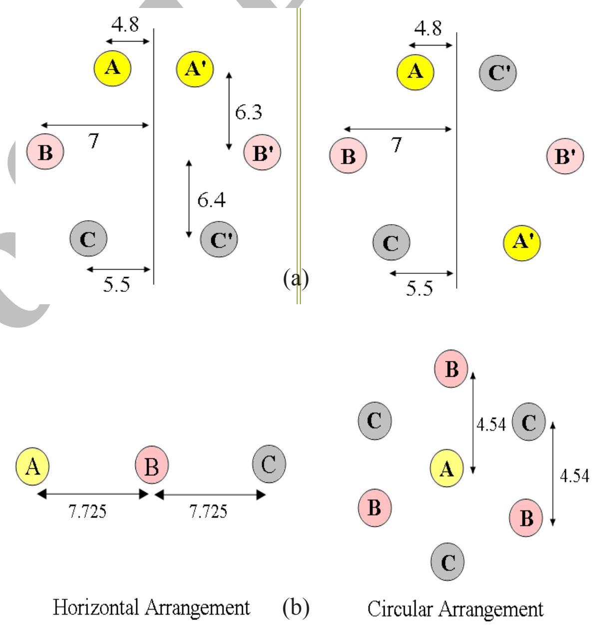

Fig. 2: Phase arrangement of DC type (a) and horizontal and circular types (b), 230kV overhead lines (all values are in meter)

In this simulation, the wires in X-Y plane were considered because of the symmetrical situation that exist toward the Z-axis; this is a time dependent simulation. All results were obtained during one period at 50Hz. The electric field produced by the current flowing through the wires was not remarkable because of the ELF of the current. Thus, only the effect of electric potential was considered.

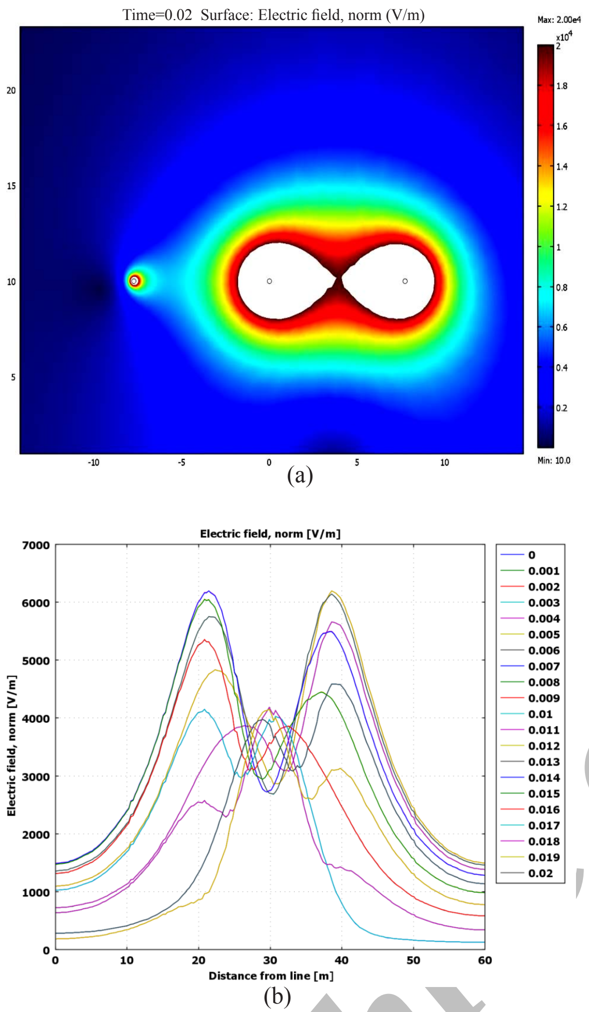

Fig. 3: Electric field for 230kV, SC-type towers at t=2ms (a) and for 20 time partitions in a period at 2m above the ground (b). (Intensity of electric field in the white areas of (a) is higher than the maximum determined threshold)

DISCUSSION

Previous studies have shown controversial outcomes about adverse impacts of continuous exposure to ELF-EMFs, especially for workers in HV SSs (Yousefi Rizi, 1997).

Results reported by Yousefi Rizi follows the results of this research. According to the standard limits, intensity of electric field in SSs is in danger zone. Moreover, staying a long time beneath the HV TLs, as the reported data has confirmed, is also a risky region which was not exactly addressed in earlier researches. Children play in such places and other people may sit for hours on the benches provided there. Considering these as environmental health risks, people should be informed about potential hazards.

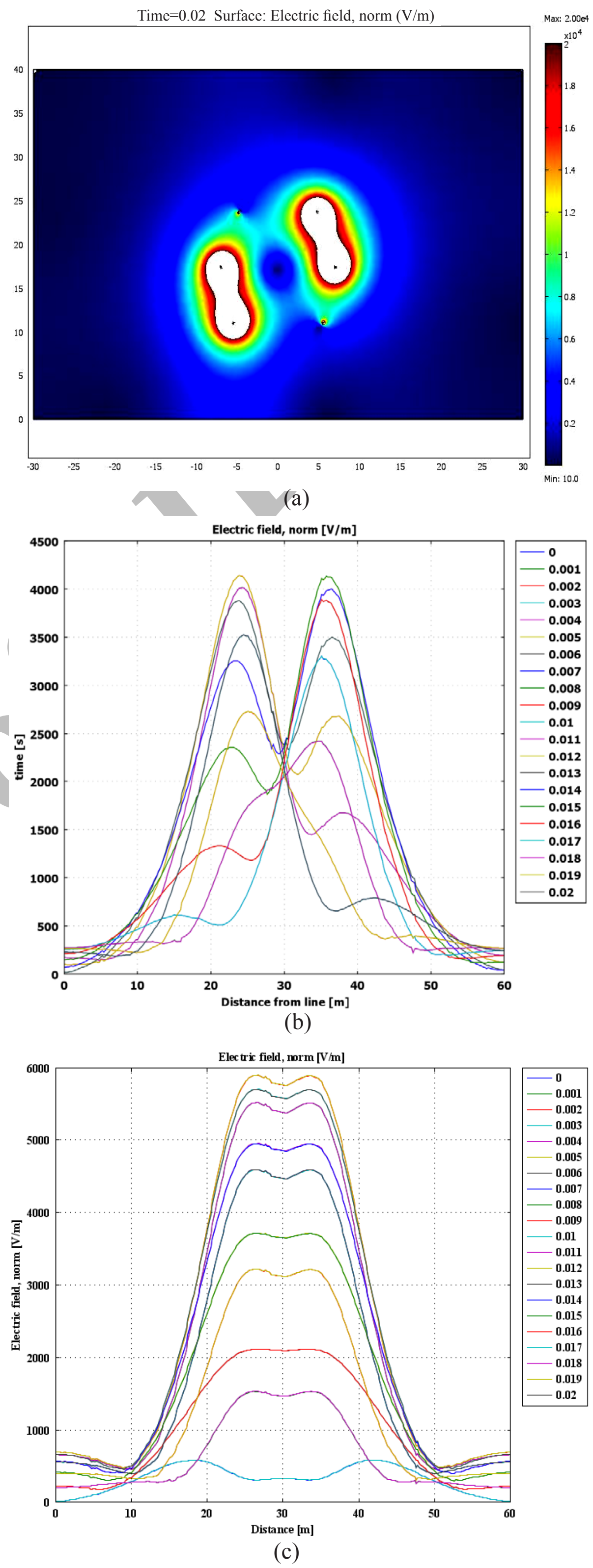

Fig. 4: Electric field intensity for 230kV, 2-circuited DC-type towers according to Fig. 2a right arrangement (a) at t=2ms and at 20 time partitions in a period at 2m above the ground according to Fig. 2a right (b) and left (c) arrangements.

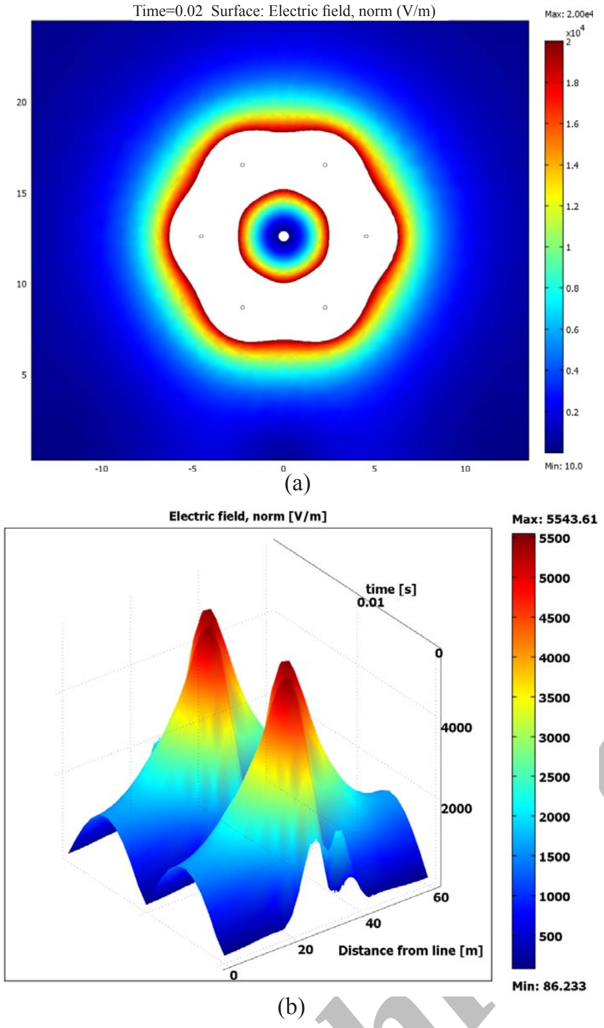

Fig. 5: Electric field intensity for circular-type 230kV 3-circuited according to Fig. 2b right side arrangement at t= 2ms (a) and for time versus distance from the TL (b)

High voltage power lines produce clouds of electrically charged ions as a consequence of corona discharge. It is suggested that they may increase the deposition of airborne pollutants on the skin and on airways inside the body, possibly adversely affecting health. However, it seems unlikely that corona ions will have more than a small effect, if any, on long-term health risks, even in the individuals who are most exposed (Allen *et al.*, 1996).

ELF-EMFs induce currents in the human body. But various biochemical reactions within the body itself generate currents as well. The cells or tissues will not be able to detect any induced currents below this background level. Therefore, at low frequencies, exposure guidelines ensure that the level of currents induced by EMFs is below that of natural body currents.

The conclusion that ELF magnetic fields are possibly carcinogenic is still valid. This was concluded based on studies indicating that children exposed to relatively strong magnetic fields from power lines were more likely to develop leukemia (Draper *et al.*, 2005). In European countries, the proportion of children exposed to such levels is less than 1% (Annual Report of WHO, 2007). Whether recommended exposure limits ought to be changed is a risk management decision.

Nevertheless, the lack of identified plausible mechanisms does not rule out the possibility of health effects existing even at very low field levels providing the basic scientific principles are adhered to.

Of the numerous suggested mechanisms proposed for the direct interaction of fields with the human body, three stands out as potentially operating at lower field levels than the others: induced electric fields in neural networks, radical pairs, and magnetite.

Electric fields induced in tissue by exposure to ELF-EMFs will directly stimulate myelinated nerve fibers in a biophysically plausible manner when the internal electric field strength exceeds a few volts per meter. Much weaker fields can affect synaptic transmission in neural networks as opposed to single cells. Such signal processing by nervous systems is commonly used by multi-cellular organisms to discriminate weak environmental signals. A lower bound of 1mV/m on neural network discrimination was suggested, but based on current evidence threshold values around 10-100mV/m seem more likely.

The radical pair mechanism is an accepted way in which magnetic fields can affect specific types of chemical reactions, generally increasing reactive free radical concentration in low fields and decreasing them in high fields. These increases have been seen at less than 1mT.

Magnetite crystals, small ferromagnetic crystals of various forms of iron oxide, are found in animal and human tissues. Calculations based on extreme assumptions suggest a lower bound for the effects on magnetite crystals of ELF fields of 5μT.

Other direct biophysical interactions of fields, such as the breaking of chemical bonds, forces on charged particles and the various narrow band width "resonance" mechanisms, are not considered to provide plausible explanations for the interactions at field levels encountered in public and occupational environments.

With regard to indirect effects, the surface electric charge induced by exposure to ELF electric fields can be perceived and it can result in painful micro shocks when touching a conductive object. This produces small electric fields, possibly above background noise levels, in bone marrow. However, whether these present a risk to health is unknown.

ELF-EMFs can affect the nervous systems of people exposed to them, resulting in adverse health consequences such as nerve stimulation, at very high exposure levels (Huss *et al.*, 2009). Exposure at lower levels induces changes in the excitability of nervous tissue in the central nervous system which may affect memory, cognition and other brain functions. These acute effects on the nervous system form the basis of international guidelines. However, they are unlikely to occur at the low exposure levels in the general environment and most working environments (Clements-Croome, 2004).

Influences of EMFs on the human health were studied and deduced that there is no concern for the inhabitants living outside the Right of Way (ROW) of TLs. The warning is for individuals who are under the HV lines for long times like workers in HV SSs (Zahiroddin *et al.*, 2006): there may be harmful effects for them.

Alignment of the wires affects the resulted electric field of TL. To decrease the field intensity, many designs have been proposed (Stewart and Oppel, 1996). One method is to compact the former towers which also has been discussed in other literatures (Amman *et al.*, 1998; Tsanakas *et al.*, 2000). Conductor bundling will mitigate the electric field by 25% to 30%. Placing the wires close to each other will decrease the electric field, but the safety of system would decline. The second method is to change the conductors' arrangement (Tsanakas *et al.*, 1997; Feng *et al.*, 2008). As suggested by Tsanakas, changing symmetrical arrangement into mirrored one lowers the EMFs. Anyhow, the mentioned circular design in this paper will be more effective in this aspect, although it is more expensive. The third method is to plant trees along TLs in order to reduce the electric field and subsequently the ROW for TLs (Ismail and Al-Kandari, 2003). Besides the indicated impact, there is no doubt about the other favorable environmental effects of cultivating trees. These methods are helpful, but considering the conditions and available instruments, the configuration which is showed in right side of Fig. 2, may be the optimum choice. However, the reduction in magnetic field intensity according to the circular arrangement is remarkable.

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REFERENCES

Abbasi, M., Nakhjavani, M., (2002). Biological effects of magnetic fields: Field effect on reducing blood sugar in mice. Iran. Mag. Diabetes and Lipid, **2(1)**: 59-63.

Akbar Khanzadeh, F., (1982). Biological effects of magnetic fields and assessing the magnetic field intensity in aluminum workshop, Iran. J. Pub. Health, **3**: 59-73.

Allen, J.O., Dookeran, N. M., Smith, K. A., Sarofim, A. F., (1996). Measurement of polycyclic aromatic hydrocarbons associated with size-segregated atmospherix aerosols in Massachusetts. Environ. Sci. Technol, **30**: 1023-1031.

Amman, M., Dalleves, P., Papailiou, K. O., Leva, M., Villa, S., (1998). A new 400kV line with compact towers and composite insulated cross arms, CIGRE Report.

Annual Report of World Health Organization (WHO) about the Extremely Low Frequency Electromagnetic Fields, (2007).

Blask, D. E., (1997). Systemic, Cellular, and molecular aspects of melatonin action on experimental breast Carcinogenis. In: Stevens, R.G., Wilson, B.W., Anderson LE, the Melatonin Hypothesis: Breast Cancer and Use of Electric Power, Columbus, OH: Battelle Press, 189–230.

Brainard, G.C., Kavet, R., Kheifets, L. I. , (1999). The relationship between electromagnetic field and light exposures to melatonin and breast cancer risk: a review of relevant literature, J Pineal Res, **26(2)**: 65–100.

Brzezinski, A., (1997). Melatonin in humans, N Engl J Med, **336(**3): 186–195.

California Health Department, (2001). An evaluation of the possible risks from electric and magnetic fields (EMFs) from power lines, internal wiring, electrical occupations and appliances (California EMF program, 1515 Clay Street, 17th Floor, Oakland, CA94612).

Clements-Croome, D., (2004). Electromagnetic environments and health in buildings. 1st Ed, Spon Press.

Djanab, K., (1960). Report on some biological responses to high electric fields and indirect action of ultraviolet rays. Acta Medica Iranica, **3(**2**)**: 1-9.

Draper, G., Vincent, T., Kroll, M. E., Swanson, J., (2005). Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ, **330**:1290-1294.

Fedrowitz , M., Löscher, W., (2008). Exposure of Fischer 344 rats to a weak power frequency magnetic field facilitates mammary tumorigenesis in the DMBA model of breast cancer. Carcinogenesis **29**:186-193.

Feng, G., Wang, Y., Zhang, B., (2008). Study on electromagnetic environment of multi-circuit transmission lines on same tower, IEEE Power India Con., **1**: 1-5.

García, A. M., Sisternas, A., Hoyos, S. P., (2008). Occupational exposure to extremely low frequency electric and magnetic fields and Alzheimer disease: a meta-analysis. Int. J. Epidemiol. **37(2)**: 329-340.

Hatch, M., (1992). The Epidemiology of electric and magnetic field exposure in the power frequency range and reproductive outcomes, Paediatr Perinat Epidemiol, **6(**2**)**: 198-214.

Huss, A., Spoerri, A., Egger, M., Röösli, M., (2009). For the Swiss national cohort study. Residence near power lines and mortality from neurodegenerative diseases: longitudinal study of the Swiss population. Am. J. Epidemiol., **169(**2**)**: 167-175.

Ismail, H.M., Al-Kandari, A.M., (2003). Electric field reduction of Kuwait transmission systems using natural trees, European Power and Energy Systems, ACTA press, **409**: 5-12.

Liu, T., Wang, S., He, L., Ye, K., (2008). Anxiogenic effect of chronic exposure to extremely low frequency magnetic field in adult rats. Neurosci. Lett **434(**1**)**: 12-17.

Poeggeler, B., Reiter, R. J., Tan, D. X., (1993). Melatonin Hydroxyl radical-mediated oxidative damage and Aging: A Hypothesis, J Pineal Re, **14**: 151–168.

Portier, C.J., Wolfe, M.S., (1998). Assessment of health effects from exposure to power-line frequency electric and magnetic fields (working group report), Research Triangle Park, NC: National Institute of Environmental Health Sciences of the National Institutes of Health, (NIH publication 98-3981).

Reiter, R. J., (1993). Electromagnetic fields and melatonin production, Biomed Pharmacother, **47**: 439–444.

Reiter, R. J., (1998). Melatonin and human reproduction, Ann Med, **30(1)**: 103–108.

Roychoudhury, S., Jedlicka, J., Parkanyi, V., Rafa, J., Ondruska, L., Massanyi, P., Bulla, J., (2009). Influence of a 50 Hz extra low frequency electromagnetic field on spermatozoa motility and fertilization rates in rabbits, J Environ. Sci. and Health, Part A, **44**: 1041–1047

Sher, L., (1997). Effects of natural and man-made electric/electromagnetic fields on human health: a possible mechanism, Journal of Medical hypotheses, **49**: 31-34.

Sobel, E., Dunn, M., Davanipour, Z., (1996). Elevated risk of Alzheimer's disease among workers with likely electromagnetic field exposure, Neurology, **47**: 1477–1481.

Stevens, R.G., (1993). Breast cancer and electric power, Biomed Pharmacother, **47**:435–438.

Stewart, J. R., Oppel, L. J., (1996). Electric and magnetic fields from overhead transmission lines. IEEE/PES Transmission and Distribution Con., 1-9.

Tsanakas, D., Filippopoulos, G., Voyatzakis, J., Kouvarakis, G., (2000). Compact and optimum phase conductor arrangement for the reduction of electric and magnetic fields of overhead lines, CIGRE Report, 36-103.

Tsanakas, D., Tsalemis, D., Agoris, D., Voyatzakis, J., (1997). Optimum arrangements of the phase conductors of overhead transmission lines for the electric field minimization, ISH 97, **6**: 97-100, Montreal.

Verkasalo, P. k., Kaprio, J., Varjonen, K., (1997). Magnetic fields of transmission lines and depression, Am J Epidemiol, **146**: 1037–1045.

Wartenberg, D., (1998). Residential magnetic fields and childhood leukemia: a meta-analysis, Am J Public Health, **88(**12**)**: 1787–1794.

Yang, Y., Jin, X., Yan, C., Tian, Y., Tang, J., Shen, X., (2008). Case-only study of interactions between DNA repair genes (hMLH1, APEX1, MGMT, XRCC1 and XPD) and low-frequency electromagnetic fields in childhood acute leukemia. Leuk. Lymphoma, **49**:2344-2350.

Yousefi Rizi, H., (1997). Evaluation of the electromagnetic fields at ELF and their effects on high voltage substation workers. MS thesis in occupational health. Medical school of Tarbiat Modarres University.

Zahiroddin, A. R., Shafiee Kandijani, A. R., Mahdavi Hezaveh, N., (2006). Mental health status of employees in substations of electromagnetic fields at extremely low frequency in Tehran. Iran. J. Environ. Health. Sci. Eng., **3(**3**)**: 217-221.