ELECTRIC AND MAGNETIC FIELD GUIDELINE EVALUATION AND MAGNETIC FIELD EXPOSURES FOR LIVE-LINE WORKERS

Prepared for

Saudi Electricity Company (SEC)
Riyadh, Saudi Arabia

Dhu al-Qa'dah 1426 H
December 2005 G

SECTION 1 INTRODUCTION

This is the executive summary of the final report of the project entitled electric and magnetic field guideline evaluation and magnetic field exposures for live-line workers. The project was funded by Saudi Electricity Company (SEC), Riyadh and was initiated on March 1, 2003. The major objective of the study was to assess the safety of electric line worker exposed to HV transmission line electromagnetic field.

Existing scientific studies and literature which are concerned with the effect of extremely low frequency electric field on live line workers has been reviewed. Possible precautions and standard protective techniques to improve safety levels are surveyed and summarized. The existing international standards which deal with safety assessment are thoroughly reviewed, and discussed. Based on this review, the maximum allowable limits for exposure to power line frequency electromagnetic field were extracted.

To conduct a safety assessment study for SEC live line workers, a double circuit transmission line was selected in consultation with SEC. The selected line spans from substation 8114 (Qortoba Area) to substation 8079 (Alhamra Area-Khorais) in Riyadh region. Its nominal voltage and power ratings are 132 kV and 293 MVA respectively. Eleven practical exposure scenarios which represent actual working conditions for live-line workers were identified in consultation with SEC.

The charge simulation method was adopted to compute the external electric field around the selected 132 KV transmission line; a method based on Biot-Savart law was chosen to compute the external magnetic field around the transmission line. Electric EMF WORKSTATION software, which is based on charge simulation method and Biot-Savart law, was adopted to calculate the external electric and magnetic field due to 132 KV High Voltage transmission line. Comparison of the values of external electric and magnetic field, with the allowable limits set by the international standards and guidelines reveals that the levels of workers exposures to extremely low frequency electromagnetic field are below the recommended international standards and guidelines limits for the eleven exposure scenarios representing actual working conditions.

After a thorough literature investigation, it was found that the Finite Difference Time Difference computational algorithm is the most suitable candidate to calculate the induced electric field and induced current densities inside the human body. EMPIRE software, along with a 3 mm and 6 mm resolutions model for the human body in standing position and 5 mm resolution model for sitting position, were utilized to calculate the internal electric field and induced current densities inside the human body model generated by the external electric and magnetic fields for the eleven exposure scenarios.

Finally, a through comparison was conducted between the induced current densities and electric field inside human body model with the allowable limits set by the international standards and guidelines. The comparison indicated that the induced current densities and the electric fields inside a human body model are well below the allowable limits as recommended by the international standards and guidelines for the eleven scenarios representing actual working conditions.

SECTION 2 OBJECTIVES

The general objective of this study was to assess the effects of electric and magnetic fields on humans. The specific objectives were:

1. To summarize and evaluate the proposed IEEE Standard C 95.6 – 2002 for electric and magnetic field exposures in the 0 to 3000 Hz range.

2. To extract the threshold values and Electric and Magnetic Field (EMF) exposures from the International Commission on Non-Ionizing Radiation Protection (ICNIRP) Guideline and the American Conference of Governmental Industrial Hygienists (ACGIH) for electric and magnetic field exposures in the Extremely Low Frequency (ELF) range.

3. To compute electric fields and current densities induced in a realistic, anatomically derived human body model for ten exposure scenarios.

4. To examine the induced field in tissues often considered critical (brain, cerebrospinal fluid, pineal gland, retina, and spinal cord) in light of existing regulations.

5. To develop strategies for evaluating compliance with electric and magnetic field exposure guidelines

6. To validate the computations by comparison with previously published data where possible.

SECTION 3 SUMMARY OF RESULTS AND FINDINGS

3.1 EXPOSURE SCENARIOS

In this study the electric and magnetic fields produced by the transmission line was modeled using the subroutine Expocalc of the EPRI software EMF WORKSTATION, Version 2.51. The study was conducted for eleven different exposure scenarios which represents actual working conditions selected in consultation with SEC; these scenarios are illustrated in Figure 3.1. The computation of the external and internal electric and magnetic fields as well as the maximum current densities at selected sensitive body organs has been conducted for all the eleven scenarios. These scenarios cover the most probable locations of a live-line worker under a transmission line and were selected after consultation and discussion with SEC.

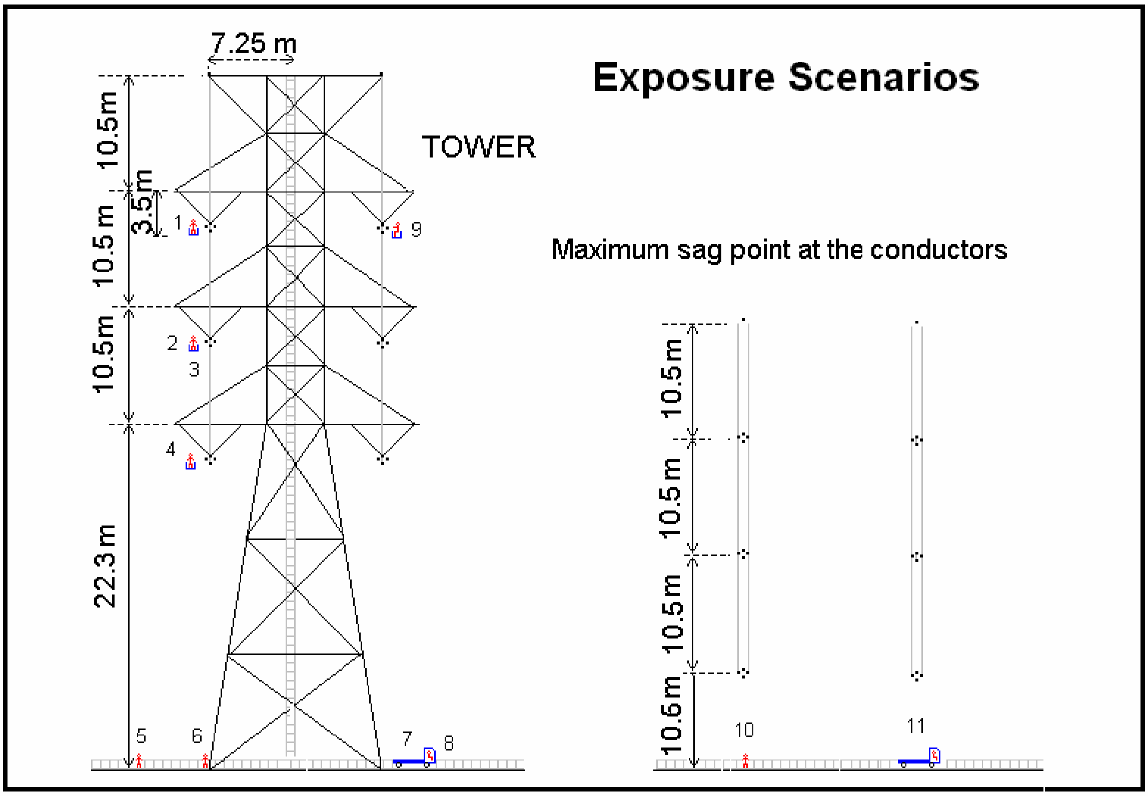

Figure 3.1. Eleven selected scenarios for simulation studies.

3.2 COMPLIANCE WITH MAXIMUM PERMISSIBLE EXPOSURE

EMF WORKSTATION software was utilized to calculate the external electric and magnetic field for scenarios under consideration in this study. The accuracy of EMF WORKSTATION software was verified by comparing the simulation result of EMF WORKSTATION software with available results in the literature. The comparison shows a good agreement between EMF WORKSTATION results and the literature. Six EMF WORKSTATION simulations were conducted for each scenario, along the human body model. The maximum value (electric and magnetic fields) of these six computed values for each scenario was selected as the exposure level for that scenario and is presented in Table 3.1. In this table, the Magnetic Flux Density (B) in milli-gauss (mG) and the Electric Field (E) in kilo-volt per meter (kV/m) are shown for all the eleven exposure scenarios. The highest exposure level for both B (663.58 mG) and E (6.485 kV/m) is at scenario no. 4, which corresponds to a worker standing in the bucket close to conductor phase C and about 2 m away from the conductor. While the minimum exposure level for both B (21.38 mG) and E (0.165 kV/m) is at scenario no. 5 that corresponds to a worker standing on the ground and at the edge of the right-of-way of the transmission line.

Table 3.1. External exposure values of magnetic flux density and electric field for all the eleven exposure scenarios.

Scenario #	**Magnetic Flux Density B (mG)**	**Electric Field E (kV/m)**
1	521.47	4.949
2	621.51	6.065
3	621.51	6.065
4	663.58	6.485
5	21.38	0.165
6	37.29	0.745
7	40.78	0.766
8	40.78	0.766
9	521.47	4.949
10	91.41	1.689
11	104.8	1.806

The exposure levels computed are compared to the IEEE Standard C95.6 - 2002. The IEEE Standard C95.6 recommends limits on exposures to magnetic fields, electric fields, and contact currents in the frequency range of 0 to 3000 hertz (Hz). Exposure limits are derived for both controlled (occupational, live-line workers) and uncontrolled (publicly accessible) environments, for uniform and non-uniform fields, for whole-body and extremity exposures.

The highest electric field exposure level computed is 6.485 kV/m for scenario no. 4; however, the Maximum Permissible Exposure (MPE) for the power frequency electric fields and for exposure to whole body as per the IEEE Standards C95.6 is 20 kV/m for a controlled (occupational) environment. Thus, the highest electric fields exposure level for the SEC 132 kV transmission line is much less than the limit set by the standard. Similarly the MPE level for the power frequency magnetic fields (magnetic flux density) and for exposure to head and torso as per the IEEE Standards C95.6 is 2.71 mT (2.71 $x10^4$ mG) for a controlled (occupational) environment. However, the highest magnetic flux density computed is 663.58 mG for scenario no. 4. Again the highest magnetic field exposure level for the transmission line under study is much lower that the limit set by the IEEE Standard C95.6.

3.3 COMPLIANCE WITH THE BASIC RESTRICTIONS FOR INTERNAL VALUES

EMPIRE software combined with in house MATLAB software code has been utilized to calculate the internal electric and magnetic field inside the human body for the study scenarios. The accuracy of the software has been verified by comparing simulation results with the available results in the literature. The comparison shows good agreement between EMPIRE simulation and the published results. The in house MATLAB code were utilized to process the raw data results obtained from EMPIRE software to calculate

- Average current density Javg, maximum current density $\mathbf{J}_{max}$ (mA/m^2), organ-averaged electric field $\mathbf{E}_{avg}$ (mV/m) and maximum induced electric field $\mathbf{E}_{max}$ (mV/m) for selected tissues.

- Average current density Javg, maximum current density $\mathbf{J}_{max}$ (mA/m^2), organ-averaged electric field $\mathbf{E}_{avg}$ (mV/m) and maximum induced electric field $\mathbf{E}_{max}$ (mV/m) for all human body layers.

- The location of maximum current density J_{max} in selected tissue

The calculated maximum induced electric field and current density induced the selected body tissues are extracted for all exposure scenarios and then compared with the basic restriction limits identified by IEEE C95.6-2002 standard. Table 3.2 shows the maximum induced currents for all scenarios. All the induced current densities are below the limit of 10 mA/m^2.

Table 3.2. The maximum induced current density for the all the scenarios.

Exposure Tissue	**Current Density Limit Jmax (mA/m^2)**	**Scenario 1**	**Scenario 2**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 9**	**Scenario 10**	**Scenario 11**
Brain	**10.00**	1.16	1.39	1.49	0.24	1.04	0.75	0.94	2.37	1.78
Heart	**10.00**	0.87	1.04	1.11	0.07	0.24	0.11	0.64	0.54	0.26
Hands, wrists, feet and ankles	**10.00**	2.07	2.51	2.68	0.32	1.40	2.61	6.74	3.18	6.17
Other tissues (excluding skin)	**10.00**	2.07	2.51	2.68	0.37	1.57	2.61	6.74	3.57	6.17

Table 3.3 shows the maximum induced electric field for all scenarios. All the induced electric fields are below the IEEE limit for workers.

Table 3.3. The maximum induced electric field for all scenarios.

Exposure Tissue	**IEEE Limit Emax (mV/m)**	**Scenario 1**	**Scenario 2**	**Scenario 4**	**Scenario 5**	**Scenario 6**	**Scenario 7**	**Scenario 9**	**Scenario 10**	**Scenario 11**
Brain	**53.1**	17.7	21.5	22.9	3.0	13.0	35.9	42.0	29.5	21.2
Heart	**943**	10.1	12.0	12.9	0.8	2.7	1.3	7.5	6.3	3.1
Hands, wrists, feet and ankles	**2100**	847.0	1037.0	1112.0	171.4	760.9	104.8	261.9	1726.4	247.8
Other tissues (excluding skin)	**2100**	103.3	125.6	134.2	17.1	72.7	104.8	261.9	165.4	247.8

SECTION 4 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

A thorough literature survey for exposure to extremely low frequency electro-magnetic field has been conducted and occupational exposure limits have been extracted from relevant standards and guidelines which include IEEE Std.C 95.6, International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines, the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Radiological Protection Board (NRPB).

A 132 kV double circuit transmission line is selected in consultation with SEC. The selected line spans from substation 8114 (Qortoba Area) to substation 8079 (Alhamra Area-Khorais) in Riyadh region. Its nominal voltage and power ratings are 132 kV and 293 MVA respectively. Eleven practical exposure scenarios which represent actual working conditions for live-line worker were identified in consultation with SEC.

The charge simulation method was adopted to compute the external electric field around the selected 132 kV transmission line; a method based on Biot-Savart law was chosen to compute the external magnetic field around the transmission line. Electric EMF WORKSTATION software, which is based on charge simulation method and Biot-Savart law, was adopted to calculate the external electric and magnetic field due to 132 kV High Voltage transmission line for the eleven exposure scenarios.

After a careful literature investigation, it was found that the Finite Difference Time Difference computational algorithm is the most suitable candidate to calculate the induced electric field and induced current densities inside the human body. EMPIRE software, along with a 3 mm and 6 mm resolutions model for the human body in standing position and 5 mm resolution model for sitting position, have been utilized to calculate the internal electric field and induced current densities inside the human body model generated by the external electric and magnetic fields for the eleven exposure scenarios representing actual working conditions.

Comparison of the values of external electric and magnetic field, induced current densities and electric field inside human body model with the allowable limits set by the international standards and guidelines reveals that the levels of workers exposures to extremely low frequency electromagnetic field are below the recommended international standards and guidelines limits for the eleven scenarios. More specifically, the worst case condition in external electric field is less than 75% from ICNIRP occupational limits and less than 30% from IEEE occupational limits. The worst case condition in external magnetic field is less than 15 % from ICNIRP limits and less than 5% from IEEE occupational limits, and The worst case studied scenario has maximum current density for whole body exposure is less than 68% from the maximum allowable limit.

According to the calculated external electric and magnetic field values for the scenarios studied and accordingly the calculated induced electric fields and current densities in the human body model subjected to these fields, there is no need for any mitigation or management techniques for the actual work exposure scenarios considered in this study. This is because the calculated external and internal induced fields and electric current densities are considerably below the permissible limits provided by the international standards and guidelines.

4.2 RECOMMENDATIONS

Saudi Arabia is witnessing a rapid increase in demand for electricity and fast movement toward industrialization has resulted in fast expansion of Saudi electric power transmission network and accompanied generation facilities. This expansion has led to increase of electromagnetic pollution, which stimulates a steady increase in public concern about the possible health effects of exposure to electromagnetic fields (EMFs). Launching of public awareness campaign to communicate the study findings for interested parties and educate general public to reveal the true size and risk of the exposure to EMF problem in Saudi Arabia should be of prime importance. At a starting point, King Fahd University of Petroleum and Minerals can share in this effort by jointly arranging with Saudi Electricity Company workshops for representatives of interested parties in the Kingdom.

Saudi Standards Organization (SASO) can be approached to help in developing and/or adopting limits for extremely low frequency exposure electromagnetic field. As a starting point, the IEEE standard and limits along with other international standards, should be taken into consideration during preparation of Saudi Standards for exposure to extremely low frequency electromagnetic field.

It is highly desirable that the research work conducted in this study be extended to assess exposure of EMF for HV 380 kV transmission lines and substations through measurements and simulation. The development of standardized measurement and survey techniques and retain survey reports that include details of the exposure conditions is highly recommended.

Although there has been significant research into the possible long term effects of EMFs on health, no definitive conclusions have been reached to date on the risks to living organisms. Therefore, continuous monitoring of the scientific progress of the proposed long term mechanism of interaction between power line EMF and human is very essential to adopt the long term effects limits when long term exposure becomes an established mechanism.