A Novel Approach for High Voltage Power Substations Design Regarding to Electric Field Dosage assessment

Mohammad Reza Vahidi, Asaad Shemshadi

***Abstract*— This investigation present a new method for reducing electrical field in power electrical substation and also it has been paid attention to health personnel who work in this place therefore the health of staff has been a priority. In this way we have measured RMS values of electrical field by a standard device for variety level of voltage and various distances in a common prototype power electrical substation. Measured values have been prepared in this manuscript. In the following paragraphs these results were compared with International Commission on Non-Ionizing Radiation Protection (ICNIRP) standards and was observed some zones are in higher than standard, so for solving this issue we have done review of basic design in substation and present a new method .we simulated this plan in comsol multi physics software and optimized design for achieving standard value of electrical field dosage is achieved and leads to more safe operating area regarding to biological considerations**

***Index Terms*— human health, electric field, high voltage, power substation, occupational exposure.**

I. INTRODUCTION

Due to developments in industrial centers like power substations, inference radiation and emitted electric field, increases and affects the passers and the operators[1]-[5]. Electric and magnetic fields are produced wherever electricity is used – they are around us all the time. Electric and magnetic fields exist wherever electric current flows - in power lines and cables, residential wiring and electrical appliances. [5], [6]. Destructive effects on mankind health especially in high voltage equipments are investigated in details. Reduced electric currents were estimated for both the pregnant woman and the fetus. The nervous system functions by virtue of electrical signals and may be thought particularly vulnerable to electric and magnetic fields [7]-[10]. A lot of malignancy diseases like blood cancer, migraine headache, Visual impairment, heart rate etc., seem to be in relation with absorbed emitted electric field dose. During the 1990s, most electromagnetic field (EMF) research focused on extremely low frequency exposures stemming from conventional power sources, such as power lines, electrical substations, or home appliances[11]-[13]. While some of these studies showed a possible link between EMF field strength and an increased risk for childhood leukemia. Furthermore people worry about high voltage sites installations especially high-voltage power lines and their Carcinogenic risks. Few relatively about static electric field effects on human body are undertaken like ICNIRP 2003 dosimeter aspect report. Some studies sponsored by The *World Health Organization /International Agency for Research on Cancer* (*IARC*), were published and mostly demonstrate the effect of extremely low frequency fields (ELF) on the Experimental Animals biology between 2001-2009. Regarding to ICNIRP reports the common level for occupational exposure to time varying electric field related to 50 Hz is 10 kV/m [14]. Afterward a recently published report by England health center represents new achievements on both the biological and therapeutic effects of Electromagnetic Fields (EMFs). The reader is guided through explanations of general problems related to the benefits and hazards of EMFs, step-by-step engineering processes, and basic results obtained from laboratory and clinical trials. Scientists use a type of research called epidemiology the study of patterns and possible causes of diseases in human populations. Epidemiologists study short-term epidemics such as outbreaks of food poisoning and long-term diseases such as cancer and heart disease. Results of these studies are reported in terms of statistical associations between various factors and disease [14]-[17].

It's important to note that the produced electric field magnitude has dominant effect on human biology comparing with magnetic field which is in the standard range limitations [16]-[24]. So in this essay only electric field effects are investigated in details.

Mohammad Reza Vahidi, Mechanical Engineering Department, Shiraz University, Shiraz, Iran
Asaad Shemshadi, Electrical Engineering Department, Arak University of Technology, Arak, Iran

II. ELECTRICAL HIGH VOLTAGE SUBSTATIONS

An electrical substation is an assemblage of electrical components including bus bars, switchgear, power transformers, auxiliaries etc. Substations are part of the electricity supply network that enables the widespread use of electricity at home, work, places for education, leisure, commerce, health care, etc. The size of substations can be very variable, depending on whether they serve mainly residential properties, or also commercial and industrial units, etc. so the substations are divided as below regarding to highest voltage level.

- Low voltage substations for U<1000 volts.
- Medium voltage substations for 1000<U<36 kV.
- High voltage substations for 36 kV<U.

Fig. 1. A typical 132/20 kV high voltage substation (outdoor switchyard).

In most cases the induced electric field is proportion with equipment voltages. So the high voltage substations EMF investigations are in great importance for investigation.

Furthermore the high voltage substation equipments are divided to:

- Outdoor Switchyard like; Bus bars, Incoming Lines, Outgoing Lines, transformers, Galvanized steel structures etc.(fig. 1)
- Indoor equipment like: Low voltage A.C. Switchgear, Control Panels, Protection Panels, Battery Room etc. (fig. 2)

Fig. 2. 20 kV metal-clad switchgear (indoor switchgear equipment). [3].

Regarding to IEEE 80/2000 standard, all cubicles should be well earthed so it seems that affecting induced electric field influenced by medium voltage bus bars on human body is negligible. But for outdoor switchyard no shielding is installed so regarding to figure 3, the electric field directly affects human body.

III. Electric Field

The electric field is an electrical quantity which is produced by the system of charges. These charges can be located on conductors when inserting external electric potential source.

To derive electric field pattern, the electrostatic Laplace's equation (eq.1) should be solved including proper boundary conditions.

$$\nabla^2 V = 0 \qquad (1)$$

$$E = -\nabla V$$

AC fields create weak electric currents in the bodies of faced people and animals regarding to capacitive effects. As shown in figure 3, currents from electric are distributed differently within the body.

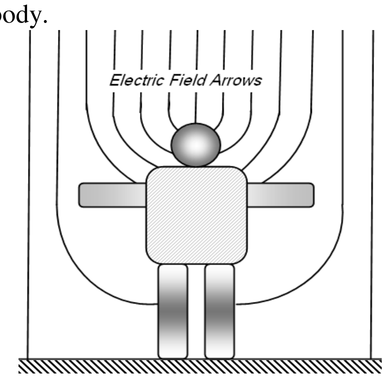

Fig. 3. Electric field arrows affects human and crosses the body.

Although the amount of this current, even if you are directly beneath a large transmission line, is extremely small but can affect the operator body if the exposure duration is long enough. But in general this current is too weak to penetrate cell membranes. It is important to note the most effective biological destructive influence is related to electric field intensity value; this is one reason why there is a potential for EMFs to cause biological effects. In the other hand the magnetic field value is generally below biological allowed values as is illustrated in the next chapter, table 1. It is clear that electric field rms value should be calculated and decreased specially in the switchyard and roads of the high voltage substations to reduce absorbed dose by human, operator, body which directly leads to improved operation.

IV. Exposure Allowed Values

Guidelines for limiting exposure to time-varying electric magnetic, and electromagnetic fields (up to 300 GHz) were issued by International Commission on Non-Ionizing Radiation Protection (ICNIRP). The main objective of this publication is to establish guidelines for limiting EMF exposure that will provide protection against known adverse health effects. Studies on both direct and indirect effects of EMF are described; direct effects result from direct interaction of fields with the body, indirect effects involve interactions with an object at a different electric potential from the body. Results of laboratory and epidemiological studies, basic exposure criteria, and reference levels for practical hazard assessment are discussed, and the guidelines presented apply to occupational and public exposure .in this reference you can see Reference levels for occupational exposure to time-varying electric and magnetic fields (unperturbed rms values) in table 1. Where appropriate, the reference levels are obtained from the basic restrictions by mathematical modeling and by extrapolation from the results of laboratory investigations at specific frequencies. For low-frequency fields, several computational and measurement methods have been developed for deriving field-strength reference levels from the basic restrictions. The reference levels for 50/60 E-field strength is 10 kV/m.

4.1 Exposure Allowed Intervals

Regarding to table 1, only maximum allowed electric field is specified. In continue the maximum allowed time interval should be obtained from eq. 2.

$$T \le \frac{E_{\max}}{E} \times 8 \qquad (2)$$

For example if $E = 2E_{\max}$, so the maximum interval of allowed dose decreases to 4 hours.

V. Proposed Procedure Statement

The proposed algorithm for systematic field value reduction of a high voltage device is to consider an earthed metallic shield under high voltage devices like bus bar or above substation roads. Of course it is important to consider suitable clearance distance based on VDE0111-1 standard for high voltage parts and the proposed metallic shield.

VI. Measurment and Methodes

To investigate real operating condition a typical 400/63/20 kV high voltage substation is considered to measure real electric field values in 230 kV section. The utilized measuring instrument is named HI3616 with, Electric Fields Sensitivity: 1 V/m - 200 kV/m and Frequency Response (nominal): 30 - 2000 Hertz.

Table 1. Reference levels for general public exposure to time-varying electric and magnetic fields (unperturbed rms values) [3].

Frequency range	E-field strength (Vm^{-1})	H-field strength (Am^{-1})	B-field (µT)	Equivalent plane wave power density $S_{eq}(Wm^{-2})$
up to 1 Hz	——	$1.63*10^5$	$2*10^5$	——
1-8 Hz	*20,000*	$1.63*10^5/f^2$	$2*10^5/f^2$	——
8-25 Hz	*20,000*	$2*10^4$/f	$2.5*10^4$/f	——
25-82 Hz	*500000/f*	20/f	25/f	——
0.82-65 KHz	*610*	24.4	30.7	——
.065-1 MHz	*610*	1.6/f	2/f	——
1-10 MHz	*610/f*	1.6/f	2/f	——
10-400 MHz	*61*	0.16	.2	10
400-2000 MHz	$3f^{1/2}$	$.008f^{1/2}$	$.01f^{1/2}$	f/40
2-300 GHz	*137*	0.36	0.45	50

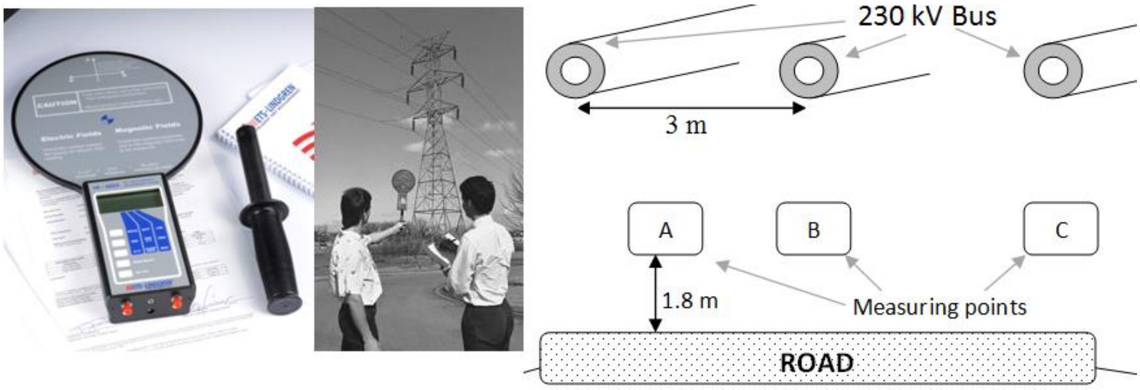

Fig. 4. Measuring instrument and the regions under 230 kV busbare for measurement.

Measured electric field values are as given in table 2. Over dosage is also given in this table. Concerning eq. 2 regarding to table 1 formula, considering ICNIRP standard limit: 10Kv in 50 Hz, the daily dose time is limited to maximum 2.4 hours which is not enough for operator's activities in switchyard area.

Table 2. Measured values using HI3616 instrument.

Measurement No.	Point A	Point B	Point C	Over Dosage Percent
1	*33400*	34200	32700	334% - Dangerous
2	*33100*	33800	32200	330%- Dangerous
3	*34100*	34900	33400	341%- Dangerous

VII. Editorial Policy

The submitting author is responsible for obtaining agreement of all coauthors and any consent required from sponsors before submitting a paper. It is the obligation of the authors to cite relevant prior work.

Authors of rejected papers may revise and resubmit them to the journal again.

VIII. Simulation Results

Regarding to a typical specified high voltage 230kV substation parameters and a recursive computation process using *COMSOL Multi physics* program the desired model is simulated (Fig. 5-6) using finite element method. Comparing with real measured values the simulated results have good similarity regarding to finite element simulation results which demonstrates that simulation modeling is correctly performed.

IX. Discussions

Serious problems related to high intensity of electrical field value, occurred in conventional high voltage substations and their influencing biological effects on operators' body, is faced nowadays. This destructive phenomenon is investigated in details in this article and in section 4 a solution is suggested for improvement of electrical fields in power electrical substation with utilization of an metallic shield grid specially in above area of transportation road of the station. Also we simulated this proposed procedure which illuminated that electric field is highly decreased by this proposed solution. In continue the derived electrical field value illuminated very low values comparing the primary model and in the acceptable range according to ICNIRP standards level for occupational exposure. The derived level in a cross sectional horizontal sheet located in 1.85 m above earth level (height of a normal man), was achieved less than 9 kV/m by simulation regarding to proposed model under the high voltage 230kV bus bar and on a 6 m width transportation road, which usually has one of most affected regions in a high voltage substation. It is important to note that in common installation, the electric field value regarding to figure 5, exceeds 33.7 kV in same investigation region which shows that utilization of proposed shielding method reduces electric field stress value by 72.5%.

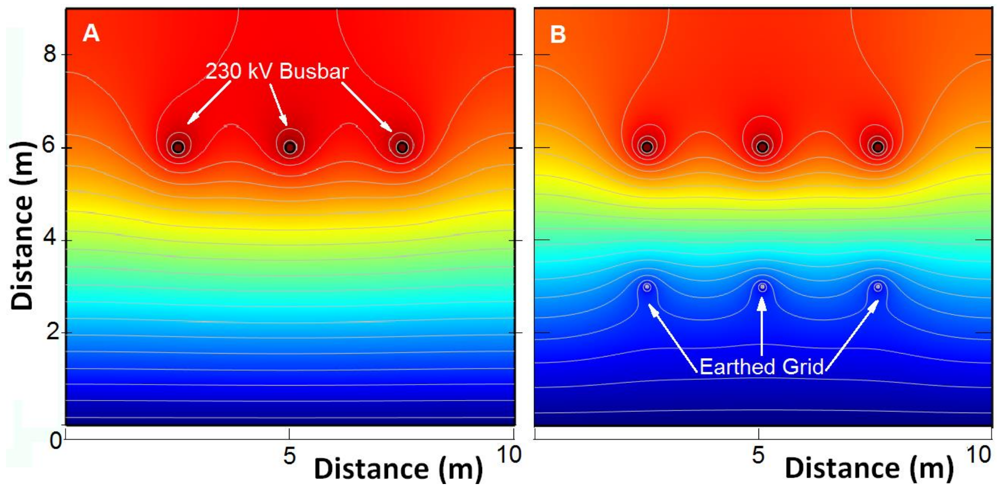

Fig. 5. Potential distribution pattern under a 230 kV bus bar using finite element. A: for regular arrangement, B: for proposed shielding arrangement. The low electric dosage region expands vertically with utilization of a proposed earthed grid.

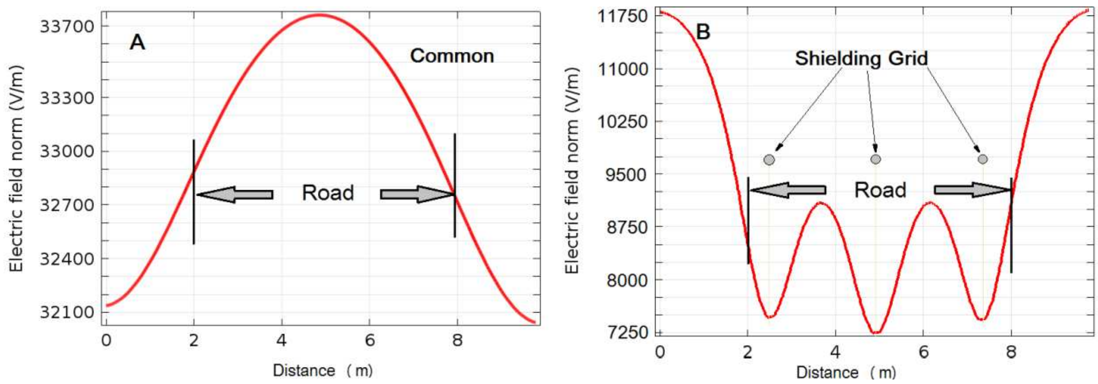

Fig. 6. Electric field profile at height 1.85 m above earth level and on transportation road, A: common installation, B: with proposed shielding grid installation.

X. CONCLUSION

This paper presents a new method for reduction of electric field value and controlling the absorbed electrical dose by a human body like; operators personnel in a typical high voltage substations.

By investigating the AC voltage distribution pattern on the switchyard of the high voltage equipments which commonly has higher voltage comparing with indoor equipments; One can observe illegal electric field level above standard values in this obtained pattern. for example in a 230kV substation under 3-phase bus bar region the investigated value is 32.7 kV (ICNIRP standard limit: 10Kv in 50 Hz), of course the electric field level can exceeds the specified high limit if and only if dosage time reduces inversely. The criterion is to design a metallic earthed grid under high voltage installations especially in the high transported regions like the roads. The simulations demonstrate that installation such a low cost shielding grid can reduce induced electric field by 72.5%. It is important to note that this shielding grid should be installed such that:

- No disturbance for commuting personnel and vehicles should occur (minimum installation height).
- Clearance distance from high voltage energized parts should be considered (maximum installation height).
- For durable installation it is recommended that this grid be painted using galvanized color.

Furthermore this proposed grid can be so designed that if any repair operation is needed, the repair group can uninstall a part of this shielded grid. It is clear that this effective structure should be well earthed and the earthing risers should be connected to main underground earth of the substation.

REFERENCES

[1] Markov, Marko S., ed. Electromagnetic Fields in Biology and Medicine. CRC Press, 2015, pp. 96-154.

[2] A. Shemshadi, et al., A Novel Approach for Reduction of Electric Field Stress in Vacuum Interrupter Chamber using Advanced Soft Computing Algorithms, *IEEE Transactions on Dielectrics and Electrical Insulation,* Vol. 20, No. 5 , 2013, pp. 1951-1958.

[3] H. Riadh, applications of electromagnetic energy, CRC press, 2007. pp. 15-86.

[4] Barnes, Frank S., and Ben Greenebaum, eds. Biological and medical aspects of electromagnetic fields. CRC press, 2006. pp.12-71.

[5] Cleveland, Robert F., et al. Questions and answers about biological effects and potential hazards of radiofrequency electromagnetic fields, 1999. pp. 30-78.

[6] Lin, James C., ed. Electromagnetic fields in biological systems. CRC press, 2011, pp. 5-56.

[7] Habash, Riadh WY. Electromagnetic fields and radiation, human bio effects and safety. CRC Press, 2001.pp. 2-90.

[8] Adams, Casey. Electromagnetic Health: Making Sense of the Research and Practical Solutions for Electromagnetic Fields (EMF) and Radio Frequencies (RF). Sacred Earth Publishers, 2010. pp. 14-50.

[9] Roosli, Martin, ed. Epidemiology of electromagnetic fields. CRC press, 2014. pp.18-130.

[10] McLean, Lyn. The Force: living safely in a world of electromagnetic pollution. Melbourne, *Scribe journal*, 2011.
[11] Shellock, Frank G., ed. Magnetic resonance procedures: health effects and safety. CRC Press, 2000. pp. 1-42.
[12] Hitchcock, R. Timothy, and Robert M. Patterson. Radio-frequency and ELF electromagnetic energies: A handbook for health professionals. John Wiley & Sons, 1995. pp. 5-142.
[13] Pullar, Christine E., Ed. The physiology of bioelectricity in development, tissue regeneration and cancer. CRC Press, 2016. pp. 38-172.
[14] Scientific research, Exposure to Static and Low Frequency Electromagnetic Fields, Biological Effects and Health Consequences (0-100 kHz) - Review of the Scientific Evidence and Health Consequences", International Commission on Non-Ionizing Radiation Protection, Munich, Germany, 2003.
[15] Goldberg, Gerald. Would you put your head in a Microwave Oven, Author House, 2006, pp. 11-85.
[16] Eichholz, Geoffrey G. Non-ionizing Radiation, Part 1: Static and Extremely Low-Frequency (ELF) Electric and Magnetic Fields, *electromagnetic magazine*, 2002, pp.915- 920.
[17] World Health Organization, Extremely Low Frequency Fields Environmental Health Criteria Monograph 238, 2007, pp. 32-38.
[18] Lin, James C., ed. Advances in electromagnetic fields in living systems, Health effects of cell phone radiation. Vol. 5. *Springer Science & Business Media*, 2009. pp. 23-29.
[19] Franceschetti, Giorgio, mechanisms, safety standards, protection guides. Electromagnetic biointeraction, Springer *Science & Business Media*, 2012. pp. 5-9.
[20] IEEE standard for safety levels with respect to human exposure to electromagnetic fields in the frequency range 0-3 kHz, C95.6, *International Committee on Electromagnetic Safety (ICES)*, 2004.
[21] Belyaev I, Markova E, Malmgren L. , Microwaves from Mobile Phones Inhibit 53BP1 Focus Formation in Human Stem Cells Stronger than in Differentiated Cells: Possible Mechanistic Link to Cancer Risk, *Environmental Health Perspective*, volume 118, 2010, pp. 394–399
[22] Carpenter DO, Sage C., Setting prudent public health policy for electromagnetic field exposures, *Rev. Environ Health* volume 23, 2008, pp. 91-117.
[23] Comba P, Fazzo L. Health effects of magnetic fields generated from power lines: new clues for an old puzzle", *Ann Ist Super Sanità*, volume 45, 2003. pp. 233-237
[24] Cooper D, Hemming K, Saunders P. ,Cancer incidence near radio and television transmitters in Great Britain, Sutton Cold field transmitter, *Am J Epidemiol*, volume 145, 2009,pp. 1–9.