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POWER FREQUENCY ELECTROMAGNETIC FIELD EXPOSURE ASSESSMENT DURING 500-750 KV SUBSTATION MAINTENANCE

Abstract: *The increase in extreme and ultra-high voltage power grid facilities is associated with the impact on employees of harmful and dangerous occupational environment factors, such as electromagnetic fields. At the places of employment for electrical staff, power frequency electric and magnetic fields may surpass allowable limit values. The purpose of this study was to conduct a hygienic assessment of power frequency electric and magnetic fields in 500-750 kV substation workplaces and to design staff protection proposals. The study was conducted at electrotechnical staff workplaces of five open switchgear, some of which are work current or voltage transformers inspection, disconnector maintenance, reading electrical appliances at the ground, etc. The paper presents the results of power frequency electric and magnetic field measurements.*

Key words: power frequency electric and magnetic fields, open switchgear, personal protective equipment.

INTRODUCTION

The staff working in the vicinity of power transmission elements and distribution systems (extremely- and ultra-high voltage overhead transmission lines and open switch gears) are exposed to power frequency (50 Hz) electric (EF) and magnetic (MF) field high levels, often are over than permissible limit values (PLV) [1], [2]. All substation territory includes, as a rule, several different voltage classes of open switchgear and various high-voltage equipment due to the possibility of worker exposure to varying EF and MF levels.

In accordance with the Russian Federation hygienic standards, EF PLV is 5 kV/m during the working day, PLV from 5 to 20 kV/m depending on the exposure time and the maximum PLV is 25 kV/m (up to 10 minutes per shift) [3]. MF PLV of whole-body exposure is 100 μT for the entire working shift and for time exposure less than 8 hours is determined by interpolation curve within different time intervals [3]. When time MF exposure is less than 1 h, PLV is 2 mT for whole-body exposure.

Meanwhile, according to International Hygienic Requirements Directive 2013/35/EU and ICNIRP 2010 the minimum requirement for EF occupational exposure is 10 kV/m (limiting the internal EF below the exposure limit values and spark discharges) [4]. Below 20 kV/m the internal EF does not exceed the exposure limit values and annoying spark discharges are prevented, provided protection measures [4]. The magnetic flux density of occupational exposure is 1 mT related to sensory effects [4] and 6 mT related to electric stimulation of peripheral and autonomous nerve tissues in the head and trunk [4].

Hygienic standards regulate occupational electromagnetic safety by means of working time, equipment distance limitation, and collective or personal (PPE) protective equipment use [6]. In case of EF is higher than 25 kV/m the use of PPE is obligatory all working day [3].

PPE includes conductive clothing (coveralls or jackets, trousers/semi-coveralls forming a one-piece garment) and conductive component parts (head protection – hoods and helmets, gloves and boots). All PPE parts must be connected to provide electrical continuity and a reduction of EF inside PPE [9].

The goal of this study was power frequency electric and magnetic field hygienic assessment at workplaces during equipment maintenance in 500-750 kV substations and the design of staff protection proposals.

MATERIALS AND METHODS

The study was carried out in 5 open switchgears including workplaces of the electrotechnical staff while performing work tasks such as going around to the 500-750 kV open switchgears, current or voltage transformers inspection, disconnector maintenance and reading electrical appliances at the ground, etc. (Figure 1).

EF and MF levels are assessed by the methodology of Methodical Requirements 4.3.2491-09 "Hygienic assessment of power frequency (50 Hz) electric and magnetic fields at occupational conditions" at height 0.5 m, 1.5 m and 1.7 m from the ground at each point [12].

EF and MF were measured by a portable electric field analyzer EFA-300 and EHP-50F (Narda, USA) with a calibrated isotropic electric probe and optical interface for connection to the PC.

Measurement results present as maximum values, means (measured values arithmetic average), standard deviations and medians (50th %iles), and quartiles (25th, 75th, 95th %iles).

There were 1057 measurement points in three 500 kV open switchgears and 671 measured points in 750 kV open switchgears.

Figure 1. *The example of electric and magnetic field measurement in open switchgear*

RESULTS

Table 1 shows 500 kV open switchgears EF measurement results at 1.7 m. Figure 2 shows the share (%) of EF levels of different values in each 500-750 kV open switchgear territory.

EF maximum values range of all substations were from 18.70 to 22.20 kV/m, which was more than 4 times higher PLV [3]. At the same time, the mean, median and 75th %iles values of EF were over 5 kV/m (≤ 10 kV/m).

EF PLV excess for the entire working shift (5 kV/m) for the 1st substation (Table 1) was registered in 35 of 54 points (65%). The share of EF levels 5 to 10 kV/m was 48%, 10 to 15 kV/m – 13%, and from 15 to 20 kV/m – less than 4% of total measurement points (Figure 2).

On 2nd substation, EF PLV excess for all work days (5 kV/m) was registered in 351 of 413 points (85%). The share of EF levels from 5 to 10 kV/m was 59%, from 10 to 15 kV/m – 22%, from 15 to 20 kV/m – 2%, over 20 kV/m – less than 2% of total measurement points (Figure 2).

EF PLV (5 kV/m) excess was registered in 331 of 590 points (56%) for 3rd substation. The share of EF values from 5 to 10 kV/m was 47%, from 10 to 15 kV/m – 8%, from 15 to 20 kV/m – about 1% of total measurement points (Figure 2).

Table 1. *Electric field in 500 kV open switchgears (means and standard deviations; quartiles (25th, 50th, and 75th %iles and 95th %iles; height – 1.7 m*

Switchgear	1 (54 points)	2 (413 points)	3 (590 points)	all (1057 points)
Electric field (kV/m) Mean	6.56	8.26	5.38	6.57
Electric field (kV/m) Standard Deviation	4.03	3.56	3.28	3.70
Electric field (kV/m) 25th %ile	2.93	5.70	2.40	4.30
Electric field (kV/m) Median	5.90	7.80	5.50	6.40
Electric field (kV/m) 75th %ile	8.53	10.00	7.70	8.70
Electric field (kV/m) 95th %ile	13.74	14.18	10.96	12.20
Electric field (kV/m) Peak	18.70	22.20	19.40	22.20

The total trend for observed substations shows PLV exceedances in more than 55% of measurement points individually and 68% considering all measurement points (1057). The main proportion of points were from 5 to 10 kV/m EF values (at least 45% for each substation and 52% for all measurement points). The lowest number of points was from 15 to 20 kV/m (1-4%).

The measured magnetic flux density in 500 kV open switchgears did not exceed the hygienic standard for the entire work shift (100 µT) [3].

Results of 750 kV open switchgears EF measurements in 2 substations are present in Table 2. In all substations, the maximum EF was over 30.00 kV/m. EF maximum level range for all substations was from 30.80 to 34.00 kV/m, with a higher PLV was more than 6.5 times [3]. At the same time, mean and median EF values were over 5 kV/m (≤ 15 kV/m), and 75th % percentile EF values – over 10 kV/m.

In 1st substation (Table 2), EF PLV excess for the working shift (5 kV/m) was registered in 233 of 324 points (72%). EF share from 5 to 10 kV/m was 35%, from 10 to 15 kV/m – 25 %, from 15 to 20 kV/m – 7%, from 20 to 25 kV/m – 2%, from 25 to 30 kV/m – 2%, over 30 kV/m – less than 1% of total measurement points (Figure 2).

Table 2. *Electric field in 750 kV open switchgears (means and standard deviations; quartiles (25th, 50th, and 75th %iles and 95th %iles); height – 1.7 m*

Switchgear	1 (324 points)	2 (347 points)	all (671 points)
Electric field (kV/m) Mean	8.40	12.05	10.29
Electric field (kV/m) Standard Deviation	5.87	7.13	6.80
Electric field (kV/m) 25th %ile	3.90	6.85	5.80
Electric field (kV/m) Median	8.10	11.60	9.50
Electric field (kV/m) 75th %ile	11.70	15.85	13.90
Electric field (kV/m) 95th %ile	18.26	25.24	23.90
Electric field (kV/m) Peak	30.80	34.00	34.00

EF PLV (5 kV/m) excess for the 2nd substation was registered in 289 of 347 points (83%). The share of EF levels from 5 to 10 kV/m was 24%, from 10 to 15 kV/m – 30 %, from 15 to 20 kV/m – 12%, from 20 to 25 kV/m – 11%, from 25 to 30 kV/m – 4%, over 30 kV/m – above 2% of total measurement points (Figure 2).

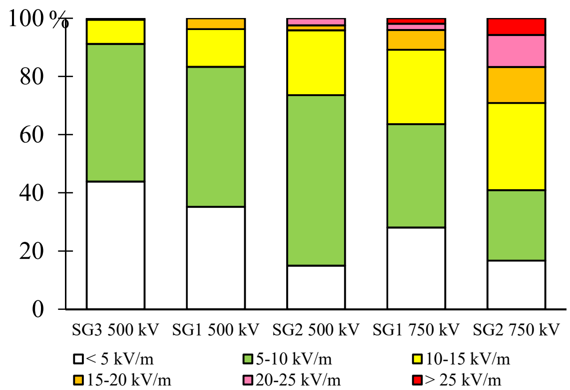

Figure 2. *The share (%) of EF levels of different values on each open switchgear territory*

Equal dependency of PLV excess shows for more than 70% of measurement points separately and 78% considering all measurement points (671) in 750 kV substations.

EF levels from 5 to 10 kV/m were the main fraction of points (at least 20% for each substation and 30% for all measurement points), which is less than in 500 kV substation. Least number of points was over 30 kV/m (1-2%).

Measured MF in 750 kV open switchgears also did not exceed the hygienic standard for the entire work shift [3].

CONCLUSION

The results of the present research are similar to other studies, for example, EF occupational exposure measurement in 400 kV substation during main transformer inspection, maintenance of operating device of disconnector or maintenance of operating device of circuit breaker showed the average levels 0.2–24.5 kV/m in Finland [1].

Other research evaluated extremely low-frequency electromagnetic field occupational exposure by performing tour inspection close to transformers and distribution power lines [10]. In 500 kV areas, EF levels at 71.98 % of the total measured 590 spots were above 5 kV/m (national occupational standard of China) and the maximum level was 14 kV/m [13].

EF and MF were evaluated in 8 electrical transformation stations in the North-East counties of Romania showing 4.0-26.0 kV/m at 380-kV Installation [14].

Differences between the present results and other literature data may be due to the different dimensions of the equipment for different voltages and open switchgears area sizes.

In this way, the allowable time for the staff to stay in a 500 kV substation is no more than 10 minutes per shift, and in a 750 kV substation the use of PPE is obligatory all working day [3]. In accordance with MF measurements, in 500-750 kV substations no work time limits for personnel are required [3].

Electrical staff protection from EF hazard effects is organizational and technical measures, time limits including as mentioned above.

Maintaining electromagnetic safety requires keeping employees safely away from conductive areas and organizing the workplace. The purpose of these measures is to install warning barriers at workplaces with EF exceeding 25 kV/m because the main proportion of points in all open switchgears was from 5 to 10 kV/m EF levels (working time is not more than 3 hours).

However, the most optimal way to protect the staff against EF's negative effects is PPE use. The staff using PPE can be in open switchgears for the duration of the work shift without time limits.

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BIOGRAPHY of the first author

Sergey Perov was born in Moscow, USSR, in 1980. He received a diploma in biomedical engineering from Bauman Moscow State Technical University, a Ph.D. degree in Radiobiology from the Lomonosov State University, Faculty of Biology and Doctor of Science from Research Institute of Occupational Health. His main areas of research include EMF occupational and general public exposure evaluation, assessment of personal protective equipment from EMF, biological effects of EMF different frequency ranges, and human health EMF effects. He is currently working as a head of the electromagnetic fields laboratory at the Izmerov Research Institute of Occupational Health.

PROCENA IZLOŽENOSTI ELEKTROMAGNETNOM POLJU TOKOM ODRŽAVANJA OPREME NA TRAFOSTANICAMA 500-750 KV

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Rezime: *Intenziteti električnog i magnetnog polja na radnim mestima elektrotehničkog osoblja mogu premašiti dozvoljene granične vrednosti koje zahtevaju poštovanje propisanih vrednosti elektromagnetne bezbednosti za profesionalnu izloženost na radu. Cilj ove studije bio je procena intenziteta električnih i magnetnih polja industrijske učestanosti na radnim mestima u elektroenergetskim postrojenjima i definisanje predloga za zaštitu osoblja. Studija je rađena na 5 otvorenih elektro energetskih rasklopnih postrojenja koja su obuhvatala radna mesta elektrotehničkog osoblja pri obavljanju radnih zadataka kao što su obilazak otvorenih uklopnih uređaja 500-750 kV, pregled strujnih ili naponskih transformatora, održavanje rastavljača i fiksiranje električnih uređaja u zemlji i dr. U radu su prikazani rezultati merenja intenziteta električnog i magnetnog polja.*

Ključne reči: postrojenja industrijske učestanosti, električna i magnetna polja, otvoreni rasklopni uređaji, lična zaštitna oprema.