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Occupational exposure to electric and magnetic fields during tasks at ground or floor level at 110 kV substations in Finland

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The aim was to investigate occupational exposure to electric and magnetic fields during tasks at ground or floor level at 110 kV substations in Finland and to compare the measured values to Directive 2013/35/EU. Altogether, 347 electric field measurements and 100 magnetic field measurements were performed. The average value of all electric fields was 2.3 kV/m (maximum 6.4 kV/m) and that of magnetic fields was 5.8 µT (maximum 51.0 µT). It can be concluded that the electric and magnetic field exposure at ground or floor level is typically below the low action levels of Directive 2013/35/EU. The transposition of the directive will not create new needs to modify the work practice of the evaluated tasks, which can continue to be performed as before. However, for workers with medical implants, the exposure may be high enough to cause interference.

Keywords: electric fields; magnetic fields; exposure; substations

1. Introduction

Occupational exposure to extremely low frequency electric and magnetic fields of power lines, electrical devices and domestic installations are ubiquitous in modern working life. Guidelines have been published for safe occupational exposure to power-frequency electromagnetic fields (EMFs): (a) the guidelines of the International Commission on Non-ionizing Radiation Protection (ICNIRP), for limiting exposure to time-varying EMFs (1 Hz–100 kHz);[1] (b) the safety standards of the Institute of Electrical and Electronics Engineers (IEEE);[2] and (c) European Parliament and Council Directive 2013/35/EU on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (EMFs).[3] In Directive 2013/35/EU, the action levels (ALs, workers) for magnetic fields (at 50 Hz) are as follows: low ALs 1000 μT (rms), high ALs 6000 μT (rms) and ALs 18 mT (rms) for exposure of limbs to a localized magnetic field and to electric fields (at 50 Hz): low ALs 10 kV/m (rms) and high ALs 20 kV/m (rms).[3]

In an earlier study,[4] we measured occupational exposure to electric and magnetic fields during various work tasks at switching and transforming stations of 110 kV and analyzed if reference values of the ICNIRP [1] were exceeded. The average electric and magnetic field values of all measurements were 3.6 kV/m ($n = 765$) and 28.6 µT ($n = 203$). The maximum value of electric fields was 15.5 kV/m at the task 'Maintenance of operating device of circuit breaker from service platform.' The maximum magnetic field in the same task was 13.6 µT and the exposure ratio of magnetic fields was 4.6%. We measured the exposure ratios of magnetic fields, because it takes into account the harmonic components of the field. We did not carry out frequency analyses and then broadband measurements of the spectrum, because, based on the measurements performed by Fingrid, there are usually no significant harmonic contents in the currents and voltages of the 110 kV grid. Therefore, we could draw a conclusion that in the EMFs, the harmonics are not an important factor.[4] The current densities and contact currents associated with the task have also been studied. The highest maximum average current density in the neck was 1.8 mA/m^2 (calculated internal electric field 9.0–18.0 mV/m) and the highest contact current was 79.4 mA in the task 'Maintenance of an operating device of a circuit breaker from a service platform.'[5]

In the magnetic field measurements of Ozen,[6] the maximum field inside the 380/154 kV substation under normal load conditions was about 20 µT for outdoors, and the substation's outdoor magnetic field was 3.03–20 µT.[6] According to Gobba et al. [7] and based on monitoring with an EMDEX Lite for three whole work shifts (8 h × 3 days, one measurement every 10 s), in five substation workers, the arithmetical mean of an individual time-weighted average (TWA) was 0.12 µT (*SD* 1.18), while the geometric mean of TWAs was 0.152 µT.[7]

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In addition, the occupational exposure to magnetic fields in 6–400 kV substations has been studied in Poland. The results of their measurements were: in 110 kV substations, 88% were below 10 μT and only 1% of the results exceeded 100 μT; in 220 kV substations, 79.3% were below 10 μT and none exceeded 100 μT; and in 400 kV substations, 71.4% of the measurement results were up to 10 μT and none exceeded 100 μT.[8]

2. Aim of the study

The aim of the study was to investigate occupational exposure to electric and magnetic fields at 110 kV substations while performing the tasks of working at ground or floor level and compare the measured values to the ALs of Directive 2013/35/EU. Moreover, the aim is to analyze details of the tasks at ground or floor level. We published maximum values earlier.[4]

3. Methods

3.1. *Measured substations*

We measured the exposure to electric fields at task A 'Maintenance of an operating device of a circuit breaker at ground level' (at 4 substations), task B 'Walking in a 110 kV substation' (at 15 substations) and at task C 'Maintenance of an operating device of disconnector at ground or floor level' (at 6 substations). We measured magnetic fields at task B (at 15 substations) and at task C (at 2 substations). We did not carry out magnetic field measurements at task A, because we considered the field to be insignificant compared to electric fields. We performed altogether 347 electric field measurements and 100 magnetic field measurements.

3.2. *Measurements of the fields*

The instantaneous rms values of EMFs were measured in places where workers generally do their tasks. The electric field strength was measured with two three-axis commercial electric meters: EFA-300 meter (Narda Safety Test Solutions, Germany) (accuracy ±3%, rms), where the frequency range was 5 Hz–30 kHz and the magnetic flux density was measured with a Narda ELT-400 meter (L-3 Communications, Narda Safety Test Solutions, USA) (accuracy ±4% rms), which has a frequency range of 1 Hz–400 kHz. Figure 1 shows an example of the electric field measurement with a three-axis commercial EFA-3 meter and Figure 2 illustrates the magnetic field measurement with a Narda ELT-400 meter. Both rms measurements involved the use of measurement probes of flat frequency response. The measurement height from the ground was 1.7 m. In addition, we sometimes used 1.8, 2.0 and 2.1 m.

Figure 1. Example of electric field measurement at a 110 kV substation.

Figure 2. Example of magnetic field measurement at a 110 kV substation.

4. Results

Figure 3 shows the histogram of the electric field values at tasks A, B and C, and Figure 4 shows the histogram of the magnetic field values at tasks B and C. The average value (arithmetic mean) of all electric field measurements was 2.3 kV/m and $SD = 1.3$ kV/m. The average value (arithmetic mean) of all magnetic field measurements was 5.8 μT and $SD = 8.6$ μT. Table 1 gives the electric field measurement results of tasks A, B and C (in different substations), and Table 2 reveals the magnetic field results (in different

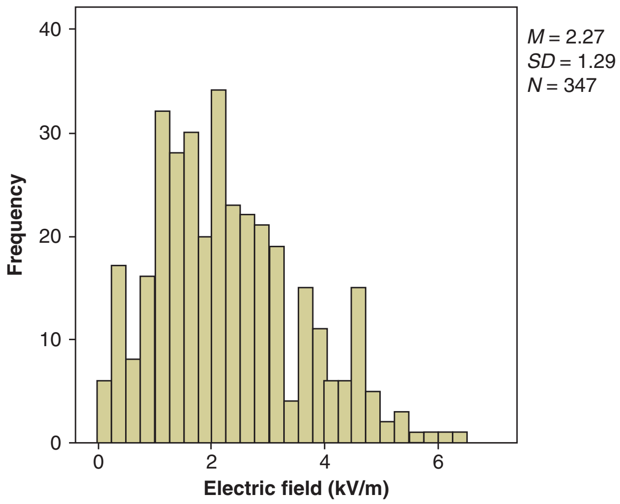

Figure 3. Histogram of measured electric field values at tasks A, B and C.
Note: Task A = maintenance of an operating device of a circuit breaker at ground level; task B = walking in a 110 kV substation; task C = maintenance of an operating device of disconnector at ground or floor level.

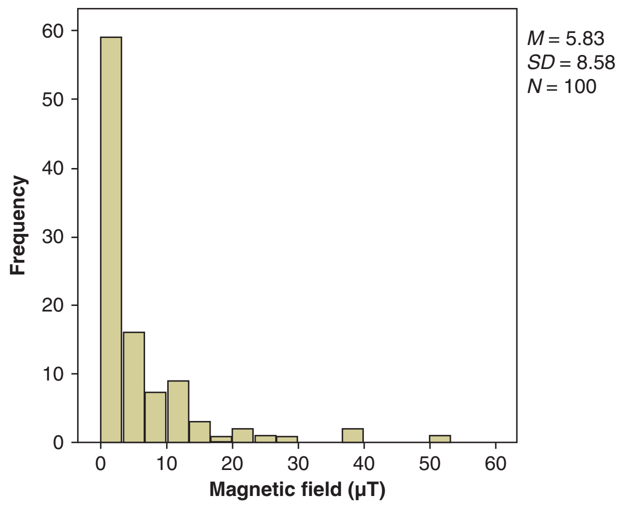

Figure 4. Histogram of measured magnetic field values at tasks B and C.
Note: Task B = walking in a 110 kV substation; task C = maintenance of an operating device of disconnector at ground or floor level.

substations). Because Figures 3 and 4 show that the data are not normally distributed, the geometric means were also calculated in Tables 1 and 2.

The maximum electric field was 5.3 kV/m and the geometric mean (at the same substation) was 2.9 kV/m in task A 'Maintenance of an operating device of a circuit breaker at ground level', 6.1 and 3.8 kV/m in task B 'Walking in a 110 kV substation', and 6.4 and 4.9 kV/m in task C 'Maintenance of an operating device of disconnector at ground or floor level.' Table 2 reveals that in task B, the maximum magnetic field was 51.0 and 42.1 μT for the geometric mean (at the same substation). In task C, the values were 7.1 and 1.6 μT.

5. Discussion

Generally, at 110 kV substations, the exposure of workers to electric fields was below 10 kV/m in tasks A, B and C, and the exposure to magnetic fields was below 500 μT in tasks A and B. The average values were 0.004–5.2 kV/m. The magnetic fields were 1.3–42.5 μT. Electric fields were less than 65% of low ALs, which are set within Directive 2013/35/EU,[3] and magnetic fields were less than 10% of low ALs. We also found this in our other measurement projects.[4] When we analyzed the mean values, we noted that the geometric mean was very often lower than the arithmetic mean. Typically, it was possible to measure many low values and find only some special places where the exposure was higher.

When we are interested in comparing measured values to Directive 2013/35/EU, the maximum values are important because we need to compare the maximum value to ALs, which are instantaneous values. This paper gives also more information regarding the general exposure level during the tasks at ground or floor level at 110 kV substations. When we compare the results of different substations, tables show that there can be a significant discrepancy between maximum values, but the average values can be more similar.

As we mentioned earlier, in the magnetic field measurements of Ozen,[6] the maximum field inside the 380/154 kV substation under normal load conditions was about 20 μT for the outdoors. It is the same level as our magnetic field results. According to Gobba et al.,[7] in five substation workers, the arithmetical mean of an individual TWA was 0.12 μT (*SD* 1.18), while the geometric mean of TWAs was 0.152 μT.[7] Those values are quite low. However, in our data, we also had many low values.

Table 2 shows that in task B, there is one substation (S19) where exposure is higher than in other substations (maximum value 51.0 μT and geometric mean 42.1 μT). In this case, the results are based on only three measurements, which is quite a low amount. At other substations, values are less than 55% of the maximum values at this one substation.

It is also always possible that a worker at a 110 kV substation starts to use medical implants, such as a cardiac pacemaker (PM) or implantable cardioverter defibrillator (ICD). According to Directive 2013/35/EU, it is possible that interference problems, especially with PMs, may occur at levels below the ALs (European Parliament and Council, 2013). According to the directive, when carrying out the risk assessment pursuant to Article 6(3) of Directive 89/391/EEC, the employer shall pay particular attention to the following: e.g., interference with medical electronic equipment and devices, including PMs and other implants

Table 1. Maximum values, *M* and *SD* of measured electric fields at work tasks A, B and C at 110 kV substations.

Task (*n*)	Code of substation	Electric field (kV/m), max	Electric field (kV/m), *M*	Electric field (kV/m), *SD*	Electric field (kV/m), geometric mean	Height of sensor above ground (m)
A (4)	S8	0.8	0.8	0.1	0.7	1.7
A (1)	S12	2.1	2.1	0.0	2.1	1.7
A (4)	S17	1.5	1.1	0.4	1.0	1.7
A (23)	S19	5.3	3.1	0.9	2.9	1.7 or 1.8
B (32)	S1	6.1	4.0	1.1	3.8	1.7 or 1.8 or 2.0
B (8)	S2	2.1	1.5	0.4	1.4	1.0 or 1.7
B (12)	S3	3.7	1.1	0.9	0.7	1.7
B (2)	S4	2.2	1.4	1.1	1.1	1.7
B (1)	S5	1.7	1.7	–	1.7	1.7
B (1)	S6	0.004	0.004	–	0.004	1.7
B (38)	S7	4.8	2.6	0.9	2.5	1.7 or 1.8 or 2.0
B (13)	S8	4.8	2.5	1.1	2.3	1.7
B (2)	S9	1.1	0.9	0.4	0.8	1.7
B (11)	S11	5.6	4.1	0.9	4.0	1.7
B (1)	S13	2.8	2.8	–	2.8	1.7
B (1)	S14	4.7	4.7	–	4.7	1.7
B (6)	S16	4.6	3.6	0.7	3.5	1.7 or 1.8
B (2)	S17	1.4	0.9	0.8	0.6	1.7
B (45)	S19	4.0	3.0	0.6	2.9	1.7
C (9)	S7	1.8	1.5	0.3	1.5	1.7
C (3)	S11	6.4	5.2	1.7	4.9	1.7 or 1.8
C (2)	S15	3.2	2.7	0.8	2.6	1.7 or 2.1
C (12)	S16	2.8	1.8	0.7	1.7	1.7
C (54)	S17	3.0	1.6	0.6	1.4	1.7 or 2.0
C (60)	S19	2.4	1.1	0.6	0.9	1.7

Note: Task A = maintenance of an operating device of a circuit breaker at ground level; task B = walking in a 110 kV substation; task C = maintenance of an operating device of disconnector at ground or floor level; – denotes a single measurement where standard deviation cannot be calculated.

Table 2. Maximum values, *M* and *SD* of measured magnetic fields at different work tasks B and C at 110 kV substations.

Tasks (*n*)	Code of substation	Magnetic field (μT), max	Magnetic field (μT), *M*	Magnetic field (μT), *SD*	Magnetic field (μT), geometric mean	Height of sensor above ground (m)
B (5)	S1	12.9	10.2	3.6	9.5	1.7
B (6)	S2	4.1	2.6	0.9	2.4	1.7
B (6)	S3	2.2	1.3	0.8	1.0	1.7
B (1)	S4	16.0	16.0	–	16.0	1.7
B (2)	S5	12.2	11.6	0.7	11.5	1.7
B (2)	S6	4.4	3.1	1.9	2.7	1.7
B (3)	S7	23.5	19.5	4.3	19.2	1.7
B (2)	S8	28.0	25.0	4.2	24.8	1.7
B (2)	S10	18.5	12.8	8.1	11.4	1.7
B (2)	S11	5.4	3.7	2.4	3.3	1.7
B (1)	S14	4.5	4.5	–	4.5	1.7
B (3)	S15	3.5	2.3	1.3	2.0	1.7
B (2)	S16	13.7	12.4	1.9	12.3	1.7
B (5)	S18	11.0	7.5	3.5	6.7	1.7
B (3)	S19	51.0	42.5	7.4	42.1	1.7
C (1)	S4	1.8	1.8	–	1.8	1.7
C (54)	S17	7.1	2.2	1.7	1.6	1.7

Note: Task B = walking in a 110 kV substation; task C = maintenance of an operating device of disconnector at ground or floor level; – denotes a single measurement where standard deviation cannot be calculated.

or medical devices worn on his or her body (European Parliament and Council, 2013).

EMF interference with PMs and ICDs has been studied, e.g., in Finland and France.[9–13] The PM tests (in Finland) found that the electric field under a 400 kV power line (6.7–7.5 kV/m) may disturb a PM in unipolar mode. This electric field level can occur at tasks under 400 kV power lines or at 110 kV (or higher) substations.

However, the risk of interference is not considered to be high because only one of the several PMs tested showed a major disturbance.[9] During the tasks at ground or floor level at 110 kV substations, the maximum electric field exposure was 6.4 kV/m, which is almost the same as the exposure in the PM experiments near 400 kV power lines. Therefore, the risk of interference is also a reality for workers performing ground or floor level tasks.

For the 50-Hz magnetic field, PM tests (in France) show no interference under 50 µT in unipolar mode and under 100 µT in bipolar mode.[12] In France, *in vitro* tests for ICDs showed no interference until 3000 µT, but they only tested four devices.[13] At 110 kV substations, the magnetic field exposures were below 2% of the no-interference level (3000 µT) [13] during tasks at ground or floor level. However, the no-interference level (50 µT) [12] of unipolar PMs can be exceeded.

6. Conclusion

In conclusion, it is possible to say that in the work tasks of 110 kV substations at ground or floor level, the electric and magnetic field exposure is typically so low that it is below the ALs of Directive 2013/35/EU. In the future, when the directive will be transposed to labor legislation, it is possible to perform those tasks in the same manner as before in Finland. However, for a worker with a PM or an ICD, the exposure can be so high that it is important to take into account the risk of interference.

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Disclosure statement

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