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ARTICLE

Occupational exposure to extremely low-frequency magnetic fields near 20 kV, 3-phase shunt reactors at substations

H. Pirkkalainen[1], T. Heiskanen[1], M. Penttilä[1], J. Elovaara[1] and L. Korpinen[2,*]

[1] Fingrid Oyj, Helsinki, Finland.
[2] Clinical Physiology and Neurophysiology Unit, North Karelia Central Hospital, Joensuu, Finland.

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Abstract – Directive 2013/35/EU of the European Parliament and Council, among other things, sets values for the occupational exposure of workers regarding the health and safety risks arising from electromagnetic fields. In order to ensure worker safety, the Finnish national grid operator, Fingrid Oyj, conducted several measurements of electromagnetic fields at its substations. One of the goals of the measurements was to ensure that a magnetic flux density of 1000 μT (rms), set as the lower action value by the EU directive, was not reached in any location accessible to substation workers. The highest magnetic flux densities at substations can be found near shunt reactors and their cables, which is why the measurements were focused on those areas. The lower action value of 1000 μT (rms) was surpassed at two locations. This discovery led to immediate actions to prevent workers from accessing these locations.

Keywords: magnetic field / shunt reactor / occupational exposure / electrical substation

1 Introduction

In 2013, a new directive was issued by the European Parliament and Council (European Parliament, 2013), which sets the minimum health and safety requirements regarding the exposure of workers to the health and safety risks arising from electromagnetic fields. The new directive repealed the old EU directive (European Parliament, 2004). In the new directive, the action values (AV) for magnetic flux densities at 50 Hz are as follows: the low AV is 1000 μT (rms), the high AV is 6000 μT (rms), and the AV for the exposure of limbs to a localized magnetic field is 18 mT (rms). The directive also mentions that interference can occur in medical implants, *e.g.*, cochlear implants and cardiac pacemakers, at magnetic flux densities below the AVs (European Parliament, 2013). When compared to the earlier EU directive (European Parliament, 2004), the lower AV was doubled from 500 μT (rms) to 1000 μT (rms). The Finnish national legislation follows this new EU directive closely and has identical AVs.

Fingrid Oyj is the corporation that has the government-granted monopoly on overseeing the nation-wide high-voltage grid, which is the backbone of electricity transmission in Finland. It is also responsible for the cross-border connections of the grid and promotes the functioning of the electricity market. Fingrid operates over 14 000 km of transmission lines and 22 substations with a total number of 43 shunt reactor sets.

Fingrid and Tampere University of Technology (TUT) have previously studied electric and magnetic field exposures and compared the results to the old EU directive (European Parliament, 2004), where the goal was to ensure that the electricians working at substations would be safe from exposure to high electric and magnetic field strengths. In this earlier study, the highest magnetic flux density was 600 μT (measurement height 1.30 m from the fence), which was measured at the safety fence around a three-phase air-core shunt reactor set (Latva-Teikari *et al.*, 2008). In this context, a shunt reactor is a large inductive coil meant to balance out the inductive and capacitive loads of the electric grid. This discovery led to the reinstallation of some of the wooden safety fences that prevent workers from getting too close to the reactors. Additional design requirements for new shunt reactors were also made. Since then, new shunt reactors have been installed in new substations, and old reactors at the end of their lifetime have been replaced. Manufacturers have given calculations for the new reactors, which provide a minimum distance from the reactor where the magnetic flux density stays below 500 μT (rms) at maximum rated power. The fences have been placed 50 cm further away from the reactors than the minimum calculated distance would require.

When the new EU directive came into effect in 2013, Fingrid wanted to ensure that it complied with the exposure values set in it. A study was conducted in 2014 in which the

*Corresponding author: leenakorpinen@gmail.com

Fig. 1. A 3-phase, 20 kV air core shunt reactor with a protective fence.

exposure levels were measured from a single shunt reactor at a 400 kV substation in Finland (Pääkkönen *et al.*, 2015). The highest magnetic flux density measured in the study was 710 μT (rms). The measurement was taken next to the cables that connect the reactor to the transformer.

The aim of this study was, therefore, to investigate the occupational exposure to extremely low-frequency magnetic fields near the shunt reactors at all 400 kV Fingrid substations in Finland. Since most of the currently existing substations were already measured in an earlier study (Latva-Teikari *et al.*, 2008), this study investigated the substations in which the shunt reactors had been altered or renewed after the completion of the earlier measurements.

2 Materials and methods

Substation shunt reactors, seen in Figure 1, are used to compensate for the reactive power produced by the charging current of long high voltage lines. All of the shunt reactors measured in this study are 3-phase air core reactors that operate at a voltage of 20 kV with a power rating of 63 Mvar. The shunt reactors are connected to a transformer *via* insulated cables, seen in Figure 2.

The selected substations, located across Finland, had either 220 kV or 400 kV operating voltages. Some were quite old with renewed reactors, and others were very new with modern reactor designs to minimize the occupational exposure to workers.

A Hioki 3470 Magnetic Field HiTester, with a frequency bandwidth from 10 Hz to 400 kHz and an accuracy of ±3.5% at 50 Hz, was utilized to measure the magnetic flux density. The measurement results were grouped by the geographical location of the substations within Finland. The same two measurement methods from the earlier studies (Latva-Teikari *et al.*, 2008; Pääkkönen *et al.*, 2015) were used in this study as well. In the first method, measurements were taken next to the protective fence, which prevents workers from going too close to the reactors. For every measurement, the Hioki meter was placed 30 cm from the fence and 170 cm from the ground. The geometry of the reactor fences varied between having 6 to 8 sides. Measurements were taken from every corner and from the center of each side. In the second method, a worker held the Hioki meter 170 cm from the ground and walked alongside the cables that connect the reactor to the substation transformer. Measurements were taken at every location a worker could reasonably fit into, and the largest value measured was recorded.

3 Results and discussion

Measurements were taken at 15 substations, a total of 31 reactors, and their cables were measured. One hundred and eighty-nine measurements were taken next to the reactor fences. The highest measured magnetic flux density was 676 μT (rms), and the average magnetic flux density was 214 μT (rms). Thirty-two measurements were taken next to the

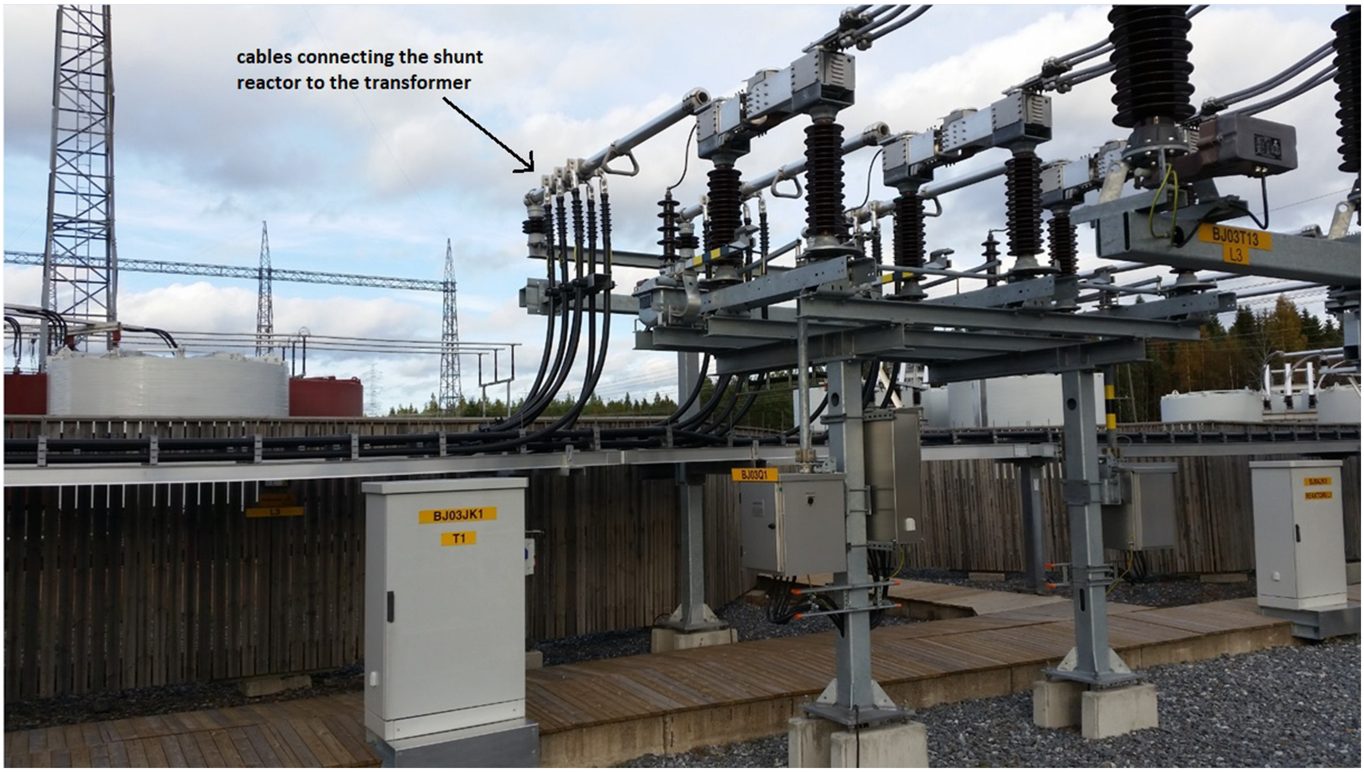

Fig. 2. Insulated cables connecting a 20 kV shunt reactor to the substation transformer. The highest magnetic flux densities were measured next to these cables.

Table 1. The magnetic flux density measurement data. The data presented for every substation includes: the number of measurements, the minimum magnetic flux density measured, the arithmetic mean of the measurements, the maximum magnetic flux density measured, and finally the standard deviation of the measurements.

Substation	*n*	Minimun (μT)	Average (μT)	Maximum (μT)	Standard deviation
1	14	237	374	676	108
2	10	41	152	290	97
3	10	40	139	245	75
4	8	270	316	370	37
5	7	223	256	285	22
6	14	225	266	307	23
7	14	120	147	170	15
8	14	72	135	231	53
9	6	183	199	223	13
10	27	85	178	481	73
11	19	81	200	389	87
12	20	93	220	365	74
13	6	32	109	320	97
14	7	72	241	405	111
15	12	216	300	380	47

n = amount of measurements

cables connecting the reactor to the transformer. The highest measured magnetic flux density was 1450 μT (rms) with a cable current of 1601 A (rms), and the average magnetic flux density was 326 μT (rms). The reactor fence measurement data from all substations are shown in Table 1.

The results were in tune with the earlier studies conducted at substations (Latva-Teikari *et al.*, 2008; Pääkkönen *et al.*, 2015). They show that the exposure to magnetic fields near shunt reactors at substations is, in general, significantly lower than the value set by the new EU directive (European Parliament, 2013). However, the lower AV of 1000 μT (rms) was exceeded twice at one substation near the cables leading from the shunt reactor to the transformer, even though the cable currents were quite reasonable (1450 μT/1601 A (rms) and 1060 μT/1606 A (rms)). In these locations, a worker could get very close (20 cm distance) to the cables while taking a shortcut between maintenance locations. This prohibited working near the shunt reactor in question, while a physical barrier that prevents workers from getting too close to the cables was being built.

The study also shows that the new shunt rectors have been successfully designed and fenced, minimizing the exposure to high magnetic flux densities around them. The calculations of the reactor manufacturers were found to mostly correlate with the measurements of this study (the majority of the results fell under the 500 μT (rms) threshold as expected, with a few exceptions). Moreover, it was shown that the cables leading from the shunt reactors to the transformers create the largest risk of exposure, which should be kept in mind when designing new substations and purchasing new shunt reactors.

The conclusion of this note is that at Fingrid substations, worker exposure to extremely low-frequency magnetic fields near 20 kV 3-phase shunt reactors is within the values set by the new EU directive (European Parliament, 2013). In instances where the exposure values might be reached, physical barriers can be set up to ensure worker safety.

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