Effects of magnetic fields during high voltage live-line maintenance

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Abstract. In case of transmission and distribution networks, extra low frequency (typically 50 or 60 Hz) electric and magnetic fields have to be taken into consideration separately from each other. Health effects have been documented from exposures to both types of fields. Magnetic fields are qualified as possibly carcinogenic to humans (category “2B”) by WHO’s cancer research institute, International Agency for Research on Cancer (IARC), so it is essential to protect the workers against their harmful effects. During live-line maintenance (LLM) electric fields can be shielded effectively by different kinds of conductive clothing, which are enclosed metal surfaces acting as a Faraday-cage. In practice laboratory measurements also prove their efficiency, the required shielding ratio is above 99% by the related standard. A set of measurements have proved that regular conductive clothing used against the electric fields cannot shield the magnetic fields effectively at all. This paper introduces the possible risks of LLM from the aspect of the health effects of magnetic fields. Although in this case the principle of shielding the electric fields cannot be applied, new considerations in equipment design and technology can be used as a possible solution. Calculations and simulations based on the data of the Hungarian transmission network – which represents the European grid as a part of ENTSO-E – and high-current laboratory measurement results also prove the importance of the topic.

1. Introduction
Live-line maintenance can guarantee the execution of various kinds of activities on the different equipment of the low, medium and high voltage grid while the system is energized. This way of work has numerous technical and economic benefits without any consumer disturbance. The method – often called as the “future of maintenance” – is beneficial from both the side of the consumer and the transmission system operator (TSO) or distribution system operator (DSO) [1]. Lately different methods of LLM became popular because of the advantages introduced above. Besides its well-known benefits, from the other side all risks related to the LLM personnel have to be taken into consideration. The main aim of this paper is to clarify the non-visible sources of danger from the aspect of both short and long-term effects of electric, but especially magnetic fields. With the growth of TSOs and DSOs applying different LLM methods, this mostly unclarified question become up-to-date, important, practical and more and more urgent to handle in a proper way.

2. Electric and magnetic fields (EMF)
Both extra low frequency (ELF) electric and magnetic fields (below 100 kHz) can have several short- and long term health effects which have to be taken into consideration separately from each other. There are presently two sets of International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines in use. For ELF electric fields, the guideline values from ICNIRP (2010) and ICNIRP (1998) both stipulate 5 kV/m maximum permissible exposures for the general public and 10 kV/m for occupational exposures [2], [3], [4]. The proposed maximum magnetic flux density values given in ICNIRP (2010) are twice as high as those in ICNIRP (1998), with permitted vales of 200 µT for the general public and 1 mT for occupational exposures. 19 European Union members have adopted exposure guideline values of 100 µT for power frequency exposures for the general public, sometimes with special provisions included [13].

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2.1. Effects of ELF electric fields

It is generally recognised that short-term above-the-limit exposure to electric fields values may cause discharges on the surface of the skin and generate eddy currents in the human body. This is as a result of drift currents, which have similar long-term effects to static magnetic fields. These are a major reason why electric fields also have specified limits as prescribed by ICNIRP and elsewhere.

2.2. Effects of ELF magnetic fields

Short-term effects of above-the-limit ELF magnetic fields have several effects on body organs especially with high moisture rate (e.g. human eyes). Decrease in precision of movements is also reported in various articles based on the results of different in-vitro and in-vivo experiments inspecting bio-currents [2], [3]. Numerous epidemiological inspections have been executed lately to inspect the possibly harmful long-term effects of magnetic fields. The main reason is that ELF magnetic fields are often referred to as a possible cause of childhood leukaemia [3]. As a result of the studies, WHO’s cancer research institute, International Agency for Research on Cancer has qualified ELF magnetic fields as possibly carcinogenic to humans (category “2B”) [5]. As it can be seen, proper shielding of ELF magnetic fields is important. For the proper simulation of a typical high voltage power line, a cross-border Hungarian interconnection – as a part of ENSTO-E’s European grid – has been selected. Based on the data of the Hungarian TSO, typical peak current load of this given power line is about 2 kA per phase.

In case of localized sources (in a distance of less than 20 cm) limits cannot be applied directly [2], [3], [6]; dosimetric calculations have to be executed case by case instead. For this case the reference current density value is 10 mA/m² inside the human body. Model of IEC 62233 [7] is shown in Figure 1 with the results of the finite element calculations for current densities. The distance from the phase conductor was 10 cm (3.94") which is typical in case of barehand method – widely applied as a technology of high voltage live-line maintenance worldwide. As it can be seen form the results, current density in the head – which is one of the most critical part of the human body – may exceed the limit during normal operational conditions. The main question about the topic is whether ELF magnetic fields can be shielded by the conductive clothing similarly to ELF electric fields or not. To clarify this question different types of conductive clothing have been inspected in the High Voltage Laboratory of Budapest University of Technology and Economics (BUTE). As results show none of the conventional clothing is effective from the shielding of ELF magnetic fields at all [8]. Because of the exposure values (induced currents) above the limits and the ineffective way of current shielding it is especially urgent and important to find a solution to prevent the workers from the possibly carcinogenic effects of these kind of fields.

![Figure 1. 3D human body model and calculated induced current densities in the head.](image)

3. Ways of EMF shielding EMF

Although generation of both ELF electric and magnetic fields are regardless from voltage level or current load, in case of most low and medium voltage overhead lines, relatively low voltage and current (or relatively high distances) can guarantee the safety of the worker without any additional need of any kind of shielding. In case of high voltage LLM, both electric and magnetic fields might be above their valid limits [9], [10], [11]. Electric fields can be shielded effectively by a conductive clothing acting as a Faraday cage. Inside an ideal Faraday cage (an enclosed conductive surface)
electric field is zero from outer source. However ideal Faraday cages cannot been applied practically during any kind of live-line work, conductive clothing – with a face screen [12] – usually act as an effective way of shielding, with screening efficiencies above 99%. However shielding of ELF electric fields is solved practically during LLM, in the current practice magnetic fields cannot be reduced significantly at all during any kind of live-line work. The main aim of this paper is to present a possible (currently mainly theoretical) way of shielding ELF magnetic fields during high voltage live-line maintenance. Development of practical way of application is under development in the High Voltage Laboratory of Budapest University of Technology and Economics as a part of an international research and development project in co-operation with European TSOs.

4. Principle of shielding ELF magnetic fields

It is possible to “shield” ELF magnetic fields by the application of basic physical laws. If an additional current path is ensured in parallel with the original current-carrying conductor, two effects of the distributed currents will decrease magnetic flux density simultaneously. Original magnetic field of phase conductors is generated by the phase current flowing through them. In case of parallel current path(s) ensured at the site of the work, summarized current is divided by a ratio depending on the number of branches; current of each branch – so the magnetic flux density generated by them – will be lower than the original value. If there are two or more conductors with a current in the same direction a given area between the conductors will be “shielded” by the cancellation of the magnetic field between the conductors. The size and the shape of this area depends on the currents of each branch and the geometry of the arrangement. As a result of the reasons above a so-called “protected area” is being generated between the conductors. If the worker remains inside this area, this kind of shielding can guarantee the safety of the work at any time. An example for the shielding in case of 2 conductors (1 original phase conductor and 1 additional conductor installed at the working site) is shown in Figure 2. Protected area marked with “P” is also shown both in the magnetic flux density distribution map and the magnetic flux density strength curve as a function of distance.

![Figure 2. Principle of shielding ELF magnetic fields.](image)

5. Conclusion
Based on the latest research of WHO IARC and others, it is recognised that extra-low frequency magnetic field exposure can cause several long-term health effects. During high voltage live-line maintenance magnetic field might be higher than current limits defined by ICNIRP (there are a number of countries within the European Union that apply limits different from those given in ICNIRP guidelines [13], [14]. None of conventional conductive clothing have significant shielding effect on ELF magnetic fields. ELF magnetic fields can be shielded effectively by a parallel conductor as a summarized result of two basic physical laws. In case of conductive live-line equipment with more than one potential clamps, an undefined amount of current may flow through the structure of the equipment itself. The risks related to these currents have to be handled during any kind of live-line work. In case of proper design guidelines the conductive structure itself can be used as an alternate current path for ELF magnetic field shielding. Principle of a possible way to shield ELF magnetic
fields has been introduced in this paper. Practical application is under development in the High Voltage Laboratory of Budapest University of Technology and Economics.

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